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The future of food and agriculture

Drivers and triggers for transformation

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Foreword

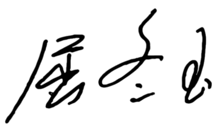
This corporate report *The future of food and agriculture – Drivers and triggers for transformation* is the culmination of efforts that mobilized hundreds of technical experts in domains related to agrifood systems, both within and outside the Food and Agriculture Organization of the United Nations (FAO). All of them contributed to the Corporate Strategic Foresight Exercise (CSFE), a forward-looking effort aimed at identifying possible transformative patterns for agrifood systems towards sustainability and resilience. It is a foresight exercise whose ambition is to enable all readers to gain a vision that encompasses potential alternative futures and inform decision-making processes. It does so knowing that shedding light on the complexities of agrifood systems and their interrelations with broader socioeconomic and environmental systems is a tall order.

All these experts engaged in identifying key "triggers" for transformation and their impacts on socioeconomic and environmental outcomes, including food security, nutrition, natural resources, ecosystems restoration and climate change. They were conscious of the crucial role that agrifood systems play in achieving the "four betters" to which the Organization aspires: better production, better nutrition, a better environment and a better life. The findings of these efforts contributed to elaborate FAO *Strategic Framework 2022–31*. The logical next step of this endeavour was to share them with all stakeholders that have common values and aspirations. As such, this report presents the richness of the discussions, analyses and findings that emerged during the entire CSFE to all those who are concerned with the future of agrifood systems.

As pointed out by the United Nations Secretary-General, many Sustainable Development Goals (SDGs) are off-track, including those to which agrifood systems are expected to contribute. The COVID-19 pandemic, economic downturns and ongoing conflicts all add to the creation of even greater challenges in achieving such SDGs. The previous FAO reports on the future of food and agriculture had already clearly stated that a "business as usual" approach would lead to a worrying future, characterized by increasing uncertainties and exacerbated inequalities. There is an urgent need to accelerate transformative processes in which agrifood systems interact with broader socioeconomic and environmental systems.

Consequently, this report highlights four key triggers for the transformation of agrifood systems: improved governance; increased consumer awareness; better income and wealth distribution; widespread technological, social and institutional innovations. All of them will have to be activated by means of suitable public strategies and policies, and through the participation of all stakeholders. Along this transformative pathway, choices will have to be made to trade off contrasting objectives, such as increasing immediate consumption and well-being versus investing to ensure a better future, or deciding how to charge the costs of unsustainable development to wealthier societies to assist poorer ones. This implies overcoming vested interests and reconciling different visions.

The key message of this report is that it is still possible to move agrifood systems along a pattern of sustainability and resilience. The broader socioeconomic and environmental systems could move in the same direction – which means short-term unsustainable achievements will have to be traded off for longer-term sustainability and resilience. Along this pattern, one can always find recourse by recalling the words of the Italian philosopher Antonio Gramsci: "…my mind is pessimistic, but my will is optimistic. Whatever the situation, I imagine the worst that could happen in order to summon up all my reserves and will power to overcome every obstacle." I hope this corporate report is a positive contribution in this direction.



QU Dongyu
FAO Director-General

Acknowledgements

This report, *The future of food and agriculture – Drivers and triggers for transformation*, is the ultimate output of the Corporate Strategic Foresight Exercise (CFSE), a long-term, forward-looking effort carried out by the Food and Agriculture Organization of the United Nations (FAO) over the last two years, aimed at strengthening the strategic thinking of the Organization and the whole development community, so as to move agrifood systems towards sustainability and resilience.

Overall process. Contributions to the CFSE were provided by several hundreds of FAO staff during meetings, workshops, discussions and interviews, under the overall guidance of Máximo Torero, FAO Chief Economist; with the support of Beth Crawford, Director of the Office of Strategy, Programme and Budget (OSP), FAO; and the technical and organizational leadership of Lorenzo Giovanni Bellù, Senior Economist, Agrifood Economics Division (ESA), FAO. This allowed for the identification of 18 drivers of future agrifood systems and key triggers of transformation that fed into the preparation of the FAO *Strategic Framework 2022–31*. Drivers and triggers identified during the CFSE constitute the conceptual backbone of this corporate report. Based on these findings, most technical divisions of FAO provided technical background papers, and the contents of these enabled the preparation of the first chapter of this report, as specified in more detail below. All these inputs are gratefully acknowledged. The second and third chapters of this report are based on the next steps outlined by the CFSE.

The preparation of this report, as much as the whole CFSE, was coordinated by the Foresight Management Team, comprising: Tomoyuki Uno, Senior Strategy and Planning Officer; Helene Sow and Ahmed Jilani, Strategy and Planning Officers, Office of Strategy, Programme and Budget (OSP); Ayca Donmez, former Statistician, Office of the Chief Statistician (OCS); Vittorio Fattori, Cornelia Boesch and Kosuke Shiraishi, Food Safety Officers, Food Systems and Food Safety Division (ESF); Pedro Morais de Sousa, Political Economist (ESA); and Lan Huong Nguyen, Economist (ESA).

Drafting of the report. This report was written by a drafting team comprising: Lorenzo Giovanni Bellù, Lead Author; Materne Maetz, Senior Editorial advisor and former FAO Senior Policy Officer; and Pedro Morais de Sousa. Lorenzo Giovanni Bellù conceived and outlined the structure of the whole report, wrote the introduction and the introductory parts of all the sections in Chapter 1, provided substantive inputs to Sections 1.2 and 1.3, drafted Chapters 2 and 3, and revised the final draft of the whole report by providing additional text and boxes, while incorporating subsequent comments received from reviewers. Materne Maetz, in addition to advising on the structure and logical sequence of the whole report, harmonized, complemented and integrated the contributions received from technical divisions on drivers of agrifood systems, drafted substantial parts of Sections 1.8, 1.12, 1.14 and 1.16, and organized the whole set of references for Chapter 1. Pedro Morais de Sousa, in addition to coordinating the inputs from the technical divisions during the various phases of revisions, supported Materne Maetz in revising selected sections in Chapter 1, provided important inputs in Sections 1.5, 1.7 and 1.10, preliminary drafts for the introduction, parts of Chapters 2 and 3, and drafted parts of the concluding remarks.

Data gathering and analysis. Graphs and numerical tables have been prepared by the data analysis team, coordinated by Lorenzo Giovanni Bellù. The team comprises Lan Huong Nguyen; Isabel Parras, Data and Policy Analyst; Jacopo Di Iorio, Chiara Ghiringhelli and Anja Peebles-Brown, Data Analysts; as well as the former FAO Consultant Dominik Wisser, now FAO Livestock Policy Officer in the Animal Production and Health Division (NSA). The data analysis team has also prepared the web-based dashboard that renders all the data used in this report available in an interactive way.

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Publication process. Daniela Verona, Publishing Coordinator (ESA), supported the whole publication process by preparing preliminary master documents, laying out the entire document, and coordinating the editing and graphical services provided by Anna Farkas, Copy-Editor, Martha Bonilla, Publishing Coordinator (OCC), Dianne Berest, Copy-Editor; and Gabriele Zanolli, graphic designer. The support from Yongdong Fu, Editorial Project Officer, Office of Communications (OCC), in smoothing the Organization of the editorial work is also acknowledged.

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Internal expert consultation. The 18 drivers and the key triggers of transformation, which constitute the conceptual backbone of this report, were identified through Internal Expert Consultation (IEC) held at the early stages of the CFSE process. The IEC and the subsequent phases of the CFSE gathered an contributions from the following FAO Senior Experts: Maya Takagi, Regional Programme Leader of the FAO Regional Office for Latin America and the Caribbean (RLC); Ignacio Moncayo, Expert in Rural Development (RLC); Pablo Rasmussen, Advisor to the Regional and Subregional coordination (RLC); Raimund Jehle, FAO Regional Programme Leader for the FAO Regional Office for Europe and Central Asia (REU); Erzsebet Illes, National Professional Officer (REU); Jean Marc Faures, Regional Programme Leader in the FAO Regional Office for Near East and North Africa (RNE); Rachid Serraj, Senior Agricultural Officer (RNE); David Dawe, Senior Economist in the FAO Regional Office for Asia and the Pacific (RAP); Ade Freeman, Regional Programme Leader in the FAO Regional Office for Africa (RAF); Pablo Rabczuk, Agrifood Systems Officer in the Subregional Office for Mesoamerica (SLM); Ruben Flores Agreda, FAO Representative in Uruguay; Roberto Sandoval, Emergency Focal Point and Disaster Risk Management Specialist in the Subregional Office for the Caribbean (SLC); Xiangjun Yao, Representative in the Subregional Office for the Pacific Islands (SAP); Madankumar Janakiraman, Programme Officer (SAP); Sumiter Broca, Senior Policy Officer in the Subregional Office for Central Asia (SEC); Suffyan Koroma, Senior Policy Officer in the Subregional Office for Eastern Africa (SFE); Adama Taoko, Policy Officer (SFE); Lewis Hove, Resilience Team Leader in the Subregional Office for Southern Africa (SFS); Eugene Rurangwa, Land and Water Officer in the Subregional Office for West Africa (SFW); Mohamed Amrani, Senior Policy Officer in the Subregional Office for North Africa (SNE); Armen Sedrakyan, Economist in the Subregional Office for the Gulf Cooperation Council States and Yemen (SNG); Dunja Dujanovic, Senior Emergency and Rehabilitation Officer in the Office of Emergencies and Resilience (OER); Sasha Koo-Oshima, Deputy Director of the Land and Water Division (NSL); Erdgin Mane, Policy Officer in the Inclusive Rural Transformation and Gender Equality Division (ESP); Farid El Haffar, Technical Officer, Joint FAO/WHO Centre (CODEX Food Standards and Zoonotic Diseases, CJW); Driss Haboudane, Joint FAO/IAEA Centre (Nuclear Techniques in Food and Agriculture, CJN); Jose Valls Bedeau, Policy Officer (ESF); Holger Matthey, Senior Economist in the Markets and Trade Division (EST); Shukri Ahmed, Deputy Director (OER); James Tefft, Senior Economist in the FAO Investment Centre (CFI); Manuel Barange, Director of Fisheries and Aquaculture Division (NFI), Chikelu Mba, Senior Officer in Plant Production and Protection Division (NSP); Mona Chaya, Senior Advisor in the Office of the Chief Scientist (DDCC); Eduardo Mansur, Director of Office of Climate Change, Biodiversity and Environment (OCB); Daniela Kalikoski, Fishery Industry Officer (NFI); Guenter Hemrich, Senior Strategy and Planning Officer (OSP); Henning Steinfeld, Coordinator (NSA); Selvaraju Ramasamy, Senior Agricultural Officer in the Office of Innovation (OIN); Karel Callens, Senior Adviser in the Governance Unit (DDCG); Mette Wilkie, former Director of Forestry Division (NFO); Arni Mathiesen, former Assistant Director-General; Frederic Castell, Senior Natural Resources Officer (OCB); Nancy Aburto, Deputy Director of Food and Nutrition Division (ESN); Margret Vidar, Legal Officer in the Legal Office (LEG); Blaise Kuemlangan, Chief (LEG); Jose Rosero Moncayo; Ewald Rametsteiner, Deputy Director (NFO); Elena Aguayo, Indigenous Women Coordination and Monitoring Support Consultant in the Partnership and UN collaboration Division (PSU); Anne Brunel, Coordinator,

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- *Population dynamics and urbanization (Driver 1).* Main contributors: Kostas Stamoulis, Senior Advisor (ESP). Other contributors: Cecilia Marocchino, Urban Food Agenda Coordinator (ESF); Ahmed Raza, Nutrition and Food Systems Officer (ESN); Pilar Santacoloma, Agrifood Systems Officer (ESN); Libor Stloukal, Policy Officer (ESP); and Lourdes Marie Orlando, Territorial development and food systems consultant (ESP).
- *Economic growth, structural transformation and macroeconomic stability (Driver 2).* Main contributors: Eric Kemp-Benedict, Equitable Transitions Program Director at the Stockholm Environment Institute (SEI).
- *Cross-country interdependencies (Driver 3).* Main contributors: Eric Kemp-Benedict (SEI).
- *Big data (Driver 4).* Main contributors: Nikola Trendov, Digital Agriculture and Innovation Specialist (OIN); Erik Van Ingen, Digital Agriculture and Innovation Specialist (OIN). Other contributors: Paul Whimpenny, Senior Information Technology Officer (CSI), Thembani Malapela, Information Manager Officer (OIN); and Sergio Bogazzi, Information Technology Officer (CSI).
- *Geopolitical instability and increasing impact of conflicts (Driver 5).* Main contributors: Julius Jackson, Technical Officer (OER).
- *Risks and uncertainties (Driver 6).* Main contributors: Sylvie Wabbes Candotti, Emergency and Rehabilitation Officer (OER); Antoine Libert, Climate Resilience Expert (OER); Rebeca Koloffon, Operations Specialist (OER); Roman Malec, Climate Resilience Consultant (OER). Other contributors: Rein Paulsen, Director (OER); Shukri Ahmed; and Dervla Cleary, Emergency and Rehabilitation Officer (OER).
- *Rural and urban poverty and inequalities (Drivers 7 and 8).* Main contributors: Ana Paula de la O Campos, Economist (ESA), and Lorenzo Moncada, Economist (ESA). Other contributors: Gala Dahlet, Senior Policy Officer (ESP); Leopoldo Tornarolli, former Economist (ESA); Erdgin Mane. Technical inputs in this section on future projections of global inequality were also provided by Dominique van Der Mensbrugghe, Director, Center for Global Trade Analysis, Purdue University, United States of America.
- *Innovation and science (Driver 10).* Main contributors: Preetmoninder Lidder, Technical Adviser (DDCC) and Mona Chaya.
- *Investment in agrifood systems (Driver 11).* Main contributors: James Tefft; Meeta Punjabi, Economist (CFI); and Atisha Kumar, Economist (CFI).
- *Capital and information intensity of production (Driver 12).* Main contributors: Eric Kemp-Benedict and Kevin M. Adams, Research Fellow (SEI).
- *Consumption and nutrition patterns (Driver 14).* Main contributors: Fatima Hachem, Senior Nutrition Officer (ESN); Melissa Vargas, Technical Adviser (ESN); and Yenory Hernandez, Nutrition Specialist (ESN).

- *Epidemics and degradation of ecosystems (Driver 16).* Main contributors: Claudia Pittiglio, Disease Ecology and Risk Modelling expert (NSA); Sheila Wertz, Senior Forestry Officer (RAP); Jeffrey Lejeune, Food Safety Officer (ESF); Madhur Dhingra, Senior Animal Health Officer (NSA); and Keith Sumption, Chief (CJW). Other contributors: Buyung Hadi, Agricultural Officer (NSP); Baogen Gu, Senior Agricultural Officer (NSP); Shoki Al Dobai, Senior Agricultural Officer (NSP); Alejandro Dorado García, Animal Health Officer (CJW); Shiroma Sathyapala, Forestry Officer (NFO); Kristina Rodina, Forestry Officer (NFO); Vittorio Fattori; Cornelia Boesch; Martin Heilmann, Veterinary Public Health Specialist (NSA); Sophie Von Dobschuetz, Animal Health Officer (NSA); Timothy Robinson, Senior Livestock Policy Officer (NSA); and Badi Besbes, Senior Animal Production Officer (NSA).
- *Climate change (Driver 17).* Main contributors: Zitouni Ould-Dada, Deputy Director (OCB), and Liva Kaugure, Natural Resources Officer (OCB).
- *Sustainable ocean economies (Driver 18).* Main contributors: Carlos Fuentevilla, Fishery Officer (NFI); Anders Brudevoll, Associate Professional Officer (NFI); Other contributors: Manuel Barange; Vera Agostini, Deputy Director (NFI); and Stefania Vannuccini.

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Narrative for alternative future scenarios. The narratives of alternative scenarios for the future of agrifood systems and related strategic policy options, presented in Chapters 2 and 3, respectively, benefited from the findings of an External Expert Consultation run in November 2021, in collaboration with the UN Foresight Network and the United Nations Educational, Scientific and Cultural Organization (UNESCO) Futures Literacy team. The commitment and contributions of Riel Miller, former coordinator of the UN network and Head of the Futures Literacy Team; Irianna Lianaki-Dedouli, UNESCO Futures Literacy team; and Roumiana Gotseva, futures literacy expert and ESA consultant, are very much appreciated and acknowledged. Materials to develop alternative futures were also provided by Merle Remy, working on the project SHAPE (Sustainable development pathways achieving Human well-being while safeguarding the climate And Planet Earth) at the Institute for Advanced Sustainability Studies, Potsdam (Germany).

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Acronyms and abbreviations

AFOLU	Agriculture, Forestry and Other Land Use
AFU	adjusted future (scenario)
AI	artificial intelligence
AOI	FAO Agriculture Orientation Index
BAU	business as usual (scenario)
CFSE	Corporate Strategic Foresight Exercise
DES	dietary energy supply
EAP	East Asia and the Pacific
ECA	Europe and Central Asia
EIDs	emerging infectious diseases
EIU	Economist Intelligence Unit
FAO	Food and Agriculture Organization of the United Nations
FDI	foreign direct investment
GDP	gross domestic product
GEA	government expenditure on agriculture
GFI	Global Financial Integrity
GHG	greenhouse gas
GM	genetically modified
GWP	Gross World Product
HICs	high-income countries
ICT	information and communication technology
IEC	Internal Expert Consultation
IFFs	illicit financial flows
IoT	Internet of Things
IPCC	Intergovernmental Panel on Climate Change
IT	information technology
LAC	Latin America and the Caribbean
LICs	low-income countries
LMICs	low- and middle-income countries
LULUC	land use and land-use changes
MOS	more of the same (scenario)
NGOs	non-government organizations
NNA	Near East and North Africa
ODA	Official Development Assistance
OECD	Organisation for Economic Co-operation and Development
PaaS	platform as a service
PPP	purchasing power parity
PPPs	public-private partnerships
R&D	research and development
RAB	race to the bottom (scenario)

SAS	South Asia
SDGs	Sustainable Development Goals
SIDS	Small Island Developing States
SSA	sub-Saharan Africa
SSB	sugar-sweetened beverages
SSPs	Shared Socioeconomic Pathways
SSS	stratified societies (scenario)
TFP	total factor productivity
TOS	trading off for sustainability (scenario)
TSS	towards sustainability (scenario)
UNSC	United Nations Security Council
WEF	World Economic Forum
WTO	World Trade Organization

Executive summary

Overarching concerns

- Will global agrifood systems sustainably nourish humanity in the future, while also meeting the non-food demand for agricultural products and the demand for required environmental services?
- Will socioeconomic systems evolve in such a way that income-earning opportunities will be assured to everyone, and that enough income will be universally assured to afford healthy diets that comprise food produced in a sustainable way?
- Will the emergence of a critical and informed civil society, and active citizenships, be able to determine governmental action to set off effective triggers leading to transformative processes of agrifood systems?

KEY MESSAGES

Agenda 2030, including agrifood-related targets, is tremendously off track

If current trends of drivers affecting agrifood systems do not change, the sustainability and resilience of agrifood systems will be seriously under threat and food crises are likely to increase in the future. Past and recent trends of almost all drivers are negatively impacting agrifood systems and seriously jeopardizing their sustainability. Trends such as increasing population and urbanization, macroeconomic instability, poverty and inequalities, geopolitical tensions and conflicts, fiercer competition over natural resources, and climate change are wreaking havoc in socioeconomic systems and damaging environmental systems. In the words of the United Nations Secretary-General, the world is "tremendously off-track" to meet Sustainable Development Goals (SDGs), including agrifood-related ones.

The development paths followed by high-income countries are not replicable in low- and middle-income countries…

Past conditions are no longer available to replicate the development formula adopted by current high-income countries (HICs). Very few low- and middle-income countries (LMICs), perhaps none, will have the possibility of achieving hegemonic power and the status of empires that many HICs made use of to benefit their well-being and welfare. Future global development patterns depend on the resolution of key questions: institutions providing solutions for sharing the "global commons"; the distribution political power and wealth; and the resolution of the extensive inequalities present in today's economies.

…and they are not sustainable

There is growing evidence that currently prevailing agricultural practices, which rely on the intensive use of agrochemical inputs and energy, are endangering the future of agrifood systems. As a result of the persistent overuse of natural resources, huge greenhouse gas (GHG) emissions and unprecedented loss of biodiversity, hunger and food insecurity are on the rise and billions of people lack access to healthy diets.

A change of mindset is needed – "more of the same" will lead the world to the point of no return

As it fatally compromises agrifood systems, the short-termism era will inevitably end either abruptly, with inestimable costs for everyone, or with a gradual and costly transition instigated by new mindset that prioritizes long-term objectives. Partial or local quick fixes resulting from uncertain decisions and commitments, piecemeal approaches and patchy reactive strategies are not up to the challenge. Neither can changes in production alone secure the sustainability and resilience of agrifood systems. They all fail to address the root causes of overall unsustainability and lack of resilience.

Changing the course of actions is far from easy, given the difficult trade-offs this entails

Achieving the four aspirational "betters" that FAO has placed at the heart of its strategic framework (better production, better nutrition, better environment and better life) requires balancing major trade-offs, such as: short-term productivity gains against greater sustainability and reduced climate impact; or efficiency, against inclusiveness; or short-term economic growth and well-being against greater long-term resilience and sustainability.

Gradual transition will have to be perceived as fair to be economically and socially viable

Countries and social groups that can reasonably shoulder the costs involved in the necessary transformations should provide support to those already affected by the negative effects of unsustainable development. However, selling to the public the message that well-off people have to lose out economically in the short run in order to reap environmental benefits and resilience for all in the medium and long term, is counterintuitive in this short-termism era. The size and potential of transformative actions are significantly influenced by the current and future preferences of political economy dynamics. Stakeholders need to understand and effectively "outsmart" these dynamics.

Agrifood sectors are key, yet no longer enough on their own, to ensure sustainable development and equitable access to food

Increasing labour and land productivity in agriculture is just a precondition for economic growth, not necessarily an intrinsic trigger of economic growth. Crops, livestock, fisheries and forestry continue to be important for employment and income generation everywhere. However, these sectors alone no longer provide enough jobs or income-earning opportunities, particularly in view of the increasing economy-wide capital and information intensity of production and distribution processes. Strong institutions, supported by efficient fiscal systems, are needed to support the emergence of other sectors, ensure economy-wide income-earning opportunities, effective social protection, protection of savings for capital accumulation and widespread asset ownership. In addition, interventions to reduce GHG emissions of agrifood systems will not pay off significantly if efforts to boost energy efficiency are not simultaneously undertaken on an economy-wide basis.

Indigenous Peoples' food and knowledge systems can help nourish the world but are at risk of disappearing in the future

In 2021, the Scientific Group advising the UN Food Systems Summit recognized Indigenous Peoples' food and territorial management systems as game changers for sustainability and resilience. Their territorial management and governance systems enable them to achieve high levels of food self-sufficiency, an efficient use of resources, to adapt to seasonality, domesticate wild species, and enhance biodiversity and *in situ* genetic resources. A number of lessons can be learned from their food systems about sustainability and resilience that can be useful for agrifood systems and for food security. Yet, Indigenous Peoples' food and knowledge systems are at risk of disappearing in the near future due to lack of dedicated policies and programmes supporting them. Internal and external drivers are jeopardizing their continuity: Extractive industries, deforestation, migration, violence, displacement, climate change and urbanization, among others, exert mounting pressure over the future of these ancestral food systems.

Key priority "triggers" of transformation are available and strategic policy options exist to activate them

Institutions and governance, consumer awareness, income and wealth distribution, and innovative technologies and approaches are key priority triggers that influence important drivers of agrifood systems. If activated through suitable strategies and policies they spread their impacts throughout agrifood, socioeconomic and environmental systems to achieve the desired outcomes, thanks to their multiple systemic linkages and feedback effects. Given their potentially highly transformative impacts, activating these triggers in the complex multilateral and global arena can be politically sensitive and requires outsmarting political economy dynamics and handling trade-offs. International organizations need to be fit-for-purpose to support countries and civil society bodies in this endeavour.

The future of agrifood systems may look like one of the four paradigmatic alternative future scenarios produced by this strategic foresight exercise…

More of the same (MOS). Muddling through reactions to events and crises, while doing just enough to avoid systemic collapse, will lead to degradation of agrifood systems sustainability and to poor living conditions for a large number of people, thus increasing the long-run likelihood of systemic failures.

Adjusted future (AFU). Some moves towards sustainable agrifood systems will be triggered in an attempt to achieve Agenda 2030 goals. Some improvements in terms of well-being will be obtained, but the lack of overall sustainability and systemic resilience will hamper their maintenance in the long run.

Race to the bottom (RAB). Gravely ill-incentivized decisions will lead the world to the worst version of itself after the collapse of substantial parts of socioeconomic, environmental and agrifood systems, with costly and almost irreversible consequences for a very large number of people and ecosystems.

Trading off for sustainability (TOS). Awareness, education, social commitment, sense of responsibility, participation and critical thinking will trigger new power relationships, and shift the development paradigm in most countries. Short-term gross domestic product (GDP) growth will be traded off for the inclusiveness, resilience and sustainability of agrifood, socioeconomic and environmental systems.

…but will depend on the strategic and policy orientations directed at achieving an effective transition towards sustainable and resilient agrifood systems

The choices to be made are between the following: more international cooperation in a multilateral context or pursuit of national interest within few siloed spheres of influence confronting each other; accepting or refusing to change the dominant development paradigm that gives priority to short-termism and productivism, and high-energy and resource intensity; strengthening global governance to address common issues and frame large transnational corporations or leaving global commons unregulated and at the mercy of the most powerful; supporting and joining action with civil society movements to promote sustainable agrifood systems at the global, national and local levels to regulate the economy, or disregarding or even silencing them. These choices could all trigger or undermine an effective transition towards sustainable and resilient agrifood systems and the concretization of the "four betters".

Better production starts from better, critical and informed consumption…

Consumers hold the power to trigger transformative processes by shifting demand towards more environmentally and socially responsible, and nutritious products. Dietary patterns with better nutritional and environmental outcomes can trigger environmental impacts on a scale not achievable by producers with the introduction of new technologies. However, improvements in knowledge and awareness, or changes in attitudes and beliefs of consumers, are not sufficient and will not lead automatically to a behavioural modification unless consumers are supported by a mix of coordinated policies, behaviour change initiatives (e.g. stimuli, food labelling, information and education) and consumer-driven actions supported by civil society associations. The emergence of a critical and informed civil society, and active citizenships able to determine governmental action are effective triggers for transformative processes of agrifood systems.

…but producing more with less will also be unavoidable

It is reasonable to expect billions of additional people on the planet. However, agrifood systems are already exceeding planetary boundaries for key natural resources, thus undermining the natural resource base on which they depend. Producers of agricultural commodities and food must improve land and water use, increase efficiency of their energy use, protect biodiversity, and restore soils and forests, thus contributing to reduced GHG emissions. These are just some of the challenges that a variety of strategic options need to take into consideration in any search to attain sustainability.

Technological innovations are part of the solution – provided new technologies and approaches are also accessible to the more vulnerable

With current technologies forming one of the factors of unsustainability of agrifood systems, research and development (R&D) and resulting technologies and approaches have major roles to play in triggering and supporting the transition towards sustainability. The reality is, however, that the bulk of R&D spending is concentrated in only few countries, with a considerable share in the hands of private corporations. This poses a risk of technological dependency and difficult access for a large part of the world. Biotechnologies, digital, agroecological and other innovative technologies and approaches have the potential to increase efficiency and sustainability of agrifood systems. It is essential that the more vulnerable producers are granted access to them and may create a fair share of the benefits they generate. Additionally, relying on technology as the panacea might be too risky as a strategy – it may not arrive in time to save humankind.

Investment in agrifood systems is attracting new investors, but disparities across countries and regions are considerable

Investment plays a central role in driving change in agrifood systems. Analysing it today provides precious indications about their future. Investment in agrifood systems has grown since the 2008 food price crisis and has attracted new investors such as pension funds, specialized investment funds, endowment funds and impact investors, in addition to traditional private and public investors. Newcomers are particularly active in global value chains. In HICs, investment per capita in agriculture was five times what it was in sub-Saharan Africa (SSA) in 2019. A reason for the disparity is that small-scale producers in LMICs have to rely mostly on self-financing to invest as their access to formal credit is constrained.

During the transition towards sustainability, food prices are likely to increase…

Resource degradation and climate change affect negatively agricultural supply, contributing to pushing up prices of agricultural commodities. Moreover, if only part of the externalities generated by the production and consumption of agricultural products – greenhouse gas (GHG) emissions causing climate change, loss of biodiversity and degradation of natural resources, and health impacts and social costs – is taken into account and expressed in monetary terms for creating incentives to reorient agrifood systems towards greater sustainability, food prices are likely to increase significantly.

…yet environmental sustainability and food security can still go hand in hand if more equitable income and wealth distribution are pursued

As the transition towards sustainable agrifood systems is likely to drive up prices, policies that favour of a more equitable distribution of income within and across countries need to be pursued, in the quest for food security, better nutrition and the environmental sustainability of agrifood systems. Options to fulfil this goal include: developing and promoting sustainable technologies and approaches; facilitating access to markets for small-scale producers; building stronger institutions to ensure competitive, transparent and fair agricultural input and output markets; implementing effective social protection schemes and equitable fiscal systems; and reducing illicit financial flows (IFFs) that drain resources from low-income countries (LICs). Secure and equitable access to assets, such as land, water, forest and capital, as well as to inputs, production technologies and approaches, information, enhanced skills and know-how, will significantly contribute to broadening the earning potential for poorer strata of society, both within and outside agrifood systems.

Immense masses of digital data and unprecedented analytical capabilities could trigger transformation of agrifood systems – this, however, is not free of potential hazards

There are great hopes that digitalization will help improve the operational efficiency of agrifood systems (input use, disease control, supply chains management, automation, etc.), thus reducing their environmental impact. By creating a traded resource of information, big data platforms entered into agrifood systems and may have already acquired dominating positions from where they implement novel and disruptive business models that threaten traditional operators, as illustrated by the changes since the beginning of the COVID-19 pandemic. Concerns also arise, moreover, as both big data and analytical capabilities are concentrated in the hands of a few players. Unless duly regulated, this will accelerate power concentration and imbalances, generate more inequality, and exclude poor and unskilled workers.

Agrifood systems should no longer be considered from the rural perspective only – urbanization, rural and urban areas should be seen as integrated entities

The rural–urban dichotomy does not appear to be an adequate axis with which to understand recent evolution of food systems. The borders between rural and urban areas are increasingly blurred and they are becoming more interdependent. To reduce their vulnerability, households adopt cross rural–urban boundaries strategies to improve access to services and employment. A considerable part of activities conducted in agricultural value chains are set within, or close, to towns or in peri-urban areas. Urbanization is a source of major changes in dietary habits, and cities offer a context in which food systems evolve rapidly and innovate. For transformations to be inclusive, particularly for small-scale farmers, strong institutions will be needed.

The "sustainable ocean economies" approach aims at developing sustainably all aquatic sectors, including fisheries – yet, several constraints hamper its implementation

Fisheries, and particularly aquaculture, have been growing at a particularly fast rate over the last three decades and have become a major source of high-quality animal protein, polyunsaturated fatty acids and micronutrients. This is especially true for aquaculture that is now the main provider of fish products. The practical application of the “sustainable ocean economies” approach is constrained by weak national capacities, dubious “sustainable ocean economies” interventions with deleterious consequences, and insufficient involvement of fishers and fish workers in decision-making. If governance of aquatic activities does not become more inclusive, the implementation of the “sustainable ocean economies” concept could favour activities other than fisheries that, in absence of appropriate rules and solid institutions, could conflict with fisheries (e.g. tourism, maritime transport, water desalinization and bioprospecting) and benefit only large economic operators, rather than fish worker and fish farmer communities.

Competitive and equitable domestic and international markets for inputs and outputs are a precondition for trade to become a trigger of development

International trade is essential for sustainably expanding food availability in countries where the population is expected to increase significantly. Trade has also a role to play in income generation if commercial agreements are set within a solid institutional context that ensures the respect of all stakeholders, including future generations. However, commodity dependence of LICs has to be broken by investing in economic diversification within and outside agrifood systems. Basing decisions on what to produce and trade only on the basis of narrowly-defined, short-term comparative advantages, may well lead to making distorted decisions. More holistic assessments, based also on achieving resilience and sustainability, are needed, as recent pandemics and conflicts show. Strong global and national institutions are also needed to coordinate efforts across countries and prevent unfair competition with countries that adopt more stringent environmental social and fiscal regulations.

The COVID-19 pandemic and the emergence of new conflicts both reveal the fragilities of agrifood systems, but lessons learned could trigger positive changes

On the one hand, the COVID-19 pandemic and its successive periods of lockdown have accelerated changes in consumption, particularly in high-income countries. Previously reluctant consumers have become platform clients, creating a boom of orders, including for food. This has provided incentives for retailers to venture into the digital market, and contributed to shift the retail and catering sectors towards more digital transactions. On the other hand, the pandemic has revealed the fragility of recent achievements by throwing tens of millions of people back into food insecurity and poverty, and by exacerbating inequality. Urban areas, and women and youths were the most affected by this setback. In addition, the recent conflict in Ukraine has shown that excessive dependence on essential items, such as grains, from few countries poses a serious threat to the food security of entire regions. Specialization and ensuing short-term efficiency need to be carefully traded off for longer-term resilience and sustainability.

Global governance for globally shared issues is needed

An overall institutional vacuum is perceived in the discrepancy between the global level of issues at stake, on the one hand, such as international capital flows, global climate change, international conflicts or local conflicts fed by external dynamics, big data generation, storage, use and control, and, on the other hand, the increasing weakness of most of sovereign countries in governing on such issues. With few exceptions, the size of most countries is actually clearly too small to be able to influence, at least to some extent, these global dynamics. Therefore, transformative processes require, as a precondition, much stronger, more transparent and accountable institutions and governance across all domains of agrifood systems, and their socioeconomic and environmental contexts. Therefore, given the multiple issues at stake and their interrelationships, clear, specific, well-designed institutional mechanisms with effective compliance rules need to be put in place.

All countries, starting with wealthier ones, must commit to implementing fundamental structural changes and shoulder their costs

Agrifood transformative processes require that each country decipher how to trigger sustainable engines of growth for broad economic development. Fundamental changes in the way all societies consume and produce are needed. Starting with wealthier societies that consume more, all countries have to renew the assets they use to produce goods and services, develop new solutions, implement innovative technologies and move along sustainable consumption patterns. In addition, in the spirit of solidarity enshrined in Agenda 2030, countries and social groups that can reasonably shoulder the costs involved in the necessary transformations have to provide support to those already affected by the negative impacts of unsustainable development, and help them construct a more equitable and better future for generations to come.

Drivers and triggers for transformation

Introduction

Goal of the report. The report, *The future of food and agriculture – Drivers and triggers for transformation*, aims at enriching the strategic thinking about, and inspire actions for, the necessary transformation that agrifood systems require, not only to progress towards the FAO's global objectives and the Sustainable Development Goals (SDGs) of Agenda 2030, but also, and perhaps more importantly, to move agrifood systems towards sustainability and resilience.

Indeed, agrifood systems face uncertainties that give rise to serious questions and concerns regarding their current and future performances and sustainability: will agrifood systems be able to meet the needs of a global expanding population, while the pressure on natural resources intensifies, greenhouse gas (GHG) emissions increase, and climate change raises unprecedented concerns? Will future socioeconomic, technological and environmental settings guarantee universal access to safe, sufficient and nutritious food? These questions and the significant trade-offs that they imply are not new, but the current conditions in which they are revisited, especially after the COVID-19 pandemic and emerging conflicts engaging superpowers, reveal the fragilities of past achievements.

Uncertainties revolve around different factors, including population growth, dietary and technological choices, income distribution, the state of natural resources, climate change, and the sustainability of peace. No one knows with precision how these factors will evolve over time; however, they will certainly shape the future of agrifood systems.[1] For this reason, countries, international organizations, civil society and academia are increasingly requesting authoritative foresight exercises that outline alternative scenarios and highlight potential pathways for food and agricultural systems.

All of these stakeholders will find in this report a comprehensive foresight effort that facilitates an examination of the questions raised above. The report indeed shows how major drivers influencing agrifood systems have recently changed and discusses how they might evolve and interact to determine possible alternative scenarios for the future; identifies the triggers that can kindle the transformation towards more sustainable agrifood systems; outlines the challenges and opportunities ahead; and proposes the possible strategic options to achieve these desired objectives.

Background. This report is grounded on a comprehensive Corporate Strategic Foresight Exercise (CFSE) that benefited from various consultations, surveys and thematic work, notably: an Internal Expert Consultation (IEC), that engaged more than forty FAO experts at headquarters and in Decentralized Offices, who, through the lens of a "theories and practices of change", highlighted a set of drivers and related trends, challenges and opportunities, likely to affect economic, social, political and agrifood systems;[2] a Staff Sample Survey that involved around 300 randomly selected FAO staff, through which visions about possible futures were elicited; a call-for-papers, addressed to FAO's technical divisions, which deepened the analysis of each of the drivers identified by the IEC;[2] and an External Expert Consultation (EEC),[3] that engaged representatives from civil society, academia, the media, the Informal Strategic Foresight Network of the United Nations High Level Committee on Programmes (UN HLCP), of which FAO is an active member, and the Futures Literacy Team of the United Nations Educational, Scientific and Cultural Organization (UNESCO), which coordinates this United Nations network.[4]

While providing the conceptual and technical backbone of this report, the findings of the above exercises contributed to the preparation of FAO *Strategic Framework 2022–31*.[5] This report provides a thematic and technical deepening of the analyses of drivers, triggers and challenges provided by the CSFE in the Strategic Framework and proposes pointers on how to achieve the four aspirational "betters" of the Organization: better production, better nutrition, better environment and better life.[a]

FAO has been carrying out global perspectives studies and foresight exercises for decades. This report therefore continues and benefits from this tradition and builds upon corporate, forward-looking reports and exercises, such as: *The future of food and agriculture – Trends and challenges*,[6] which provided the conceptual backbone to the FAO Medium Term Plan 2018–2021; *The future of food and agriculture – Alternative pathways to 2050*,[1] which provides quantitative projections of key agrifood variables under alternative scenarios; FAO's 2022 *Thinking about the future of food safety – A foresight report*;[1] and the findings of the workshop on *Agrifood systems 2042–2052: emerging technologies and social innovation*.[7]

The need for a transformative process of agrifood systems. It was already clearly stated in the first report of the series, *The future of food and agriculture – Trends and challenges*,[6] that "business as usual is no longer an option". If food and agricultural systems remain on their current paths, the evidence points to a future characterized by persistent food insecurity and unsustainable economic growth.[1]

The High-Level Political Forum (HLPF) held in June 2019, before a global pandemic and the Russian invasion of Ukraine, noted that:

> "[…] the progress is slowing down in many areas. Vulnerabilities are high and deprivations are becoming more entrenched. While poverty is the greatest global challenge and its eradication is an indispensable requirement for sustainable development, assessment show that we are at risk of missing the poverty eradication target. Hunger is on the rise […] Inequalities in wealth, incomes and opportunities are increasing in and between countries. Biodiversity loss, environmental degradation and climate change continues at rates that could bring potentially disastrous consequences for humanity" (UNGA, 2019, p. 3).[8]

The second edition of the FAO's report *Tracking progress on food and agriculture-related SDG indicators*,[9] launched September 2021 after more than one year and half of pandemic, echoes these findings: progress remains insufficient, and because of the COVID-19 pandemic, eradicating hunger, achieving food security and preserving natural and genetic resources, remain all the more challenging, considering the series of seemingly pessimistic trends of key drivers affecting agrifood systems and their performances:

- Public expenditure in agriculture relative to the total public expenditure has declined in most regions of the world since 2000, which suggests a public underinvestment in agriculture as compared to the sector's contribution to GDP.
- The labour productivity and incomes of small-scale producers are systematically lower than those of larger food producers on average.
- The proportion of countries facing high general food price volatility decreased in 2017–2018, but over a quarter remained nonetheless affected.
- Notwithstanding the reported increase in global holdings of plant genetic resources for food and agriculture, efforts to secure crop diversity continue to be insufficient, particularly for crop wild relatives (CWR) and underutilized crop species.

[a] The CFSE was implemented in synergy with the Strategic Framework process, with mutual relationships and continuous interactions between the teams in charge of the two processes. CFSE's contributions are reflected in FAO (2021)5 Section B, paragraphs 24–41; Table 1, Critical drivers of agrifood systems and related trends; and related annex on pages 31–36.

- Regions such as Central and South Asia and North Africa register very high-water stress levels, at over 70 percent.
- In nine out of ten countries assessed, relatively fewer women than men have ownership and/or control rights over agricultural land.
- While it is not possible to estimate the percentage of food waste at the retail and consumption stages, the percentage of food lost after harvest on-farm and at the transport, storage and processing stages is known to stand close to 15 percent of food produced.
- The proportion of fish stocks within biologically sustainable levels has continued to decrease, dropping from 90 percent in 1974 to close to 65 percent.
- The world forest area continues to decrease, although at a slightly slower rate than during the previous decades. The proportion of forest area fell from 31.9 percent of the total land area in 2000 to close to 31 percent in 2020.[9]

As a result, agrifood systems continue to suffer vast inequalities, the most striking, unjust and abhorrent are the persistence of hunger and food insecurity. After remaining relatively unchanged from 2015 until 2019 at around 8.0 percent, the prevalence of undernourishment (PoU), jumped in 2020 to 9.3 percent and rose again to 9.8 percent in 2021. 768 million people were affected by hunger in 2021, considering the middle of the projected range. This means 46 million people more than in 2020 and 150 million people more than in 2019, considering the middle of the projected range, before the outbreak of the COVID-19 pandemic. Moreover, after increasing sharply in 2020, the global prevalence of moderate or severe food insecurity remained mostly unchanged in 2021, but severe food insecurity rose higher. Around 2.3 billion people in the world were moderately or severely food insecure in 2021. Projections are that nearly 670 million people may still be facing hunger in 2030 – 8 percent of the world population, which is the same as in 2015 when the 2030 Agenda was launched.

In addition, the burden of malnutrition in all its forms remains a challenge. The gains made in reducing the prevalence of child stunting, the condition of being too short for one's age, by one-third in the previous two decades, by 33.1 percent (201.6 million) in 2000 to 22.0 percent (149.2 million) in 2020, are under threat by the triple crises of climate, the COVID-19 pandemic and conflict. Child wasting, the condition of being too thin for height, affected 6.7 percent of children under five years of age (45 million) in 2020, without factoring in the impact of the COVID-19 pandemic. Most regions are not on track to achieve the targets for reducing prevalence of childhood overweight. Adult obesity is on the rise in all regions. Healthy diets were unaffordable to many more people in every region of the world, owing to further increases in consumer food prices that were already on the rise before the pandemic and drops in incomes: almost 3.1 billion people could not afford a healthy diet in 2020 – 112 million more than in 2019. This was mainly driven by Asia, where 78 million more people were unable to afford a healthy diet, followed by Africa (25 million more people), while Latin America and the Caribbean (LAC) and Northern America and Europe had 8 and 1 million more people, respectively.[10]

In this context, the prospects to eliminate extreme poverty are also grim, as projected by the World Economic Forecasting Model of the United Nations Department of Economic and Social Affairs (UN DESA).[11] Only under a highly unlikely set of conditions, including incredibly ambitious assumptions for future economic growth and inequality reduction, would the world attain the much desired "poverty miracle" of extreme poverty eradication by 2030, as set by the Sustainable Development Goal 1.

Key drivers of agrifood systems and priority triggers for transformation. To trigger transformative processes to reverse these negative trends, it is imperative to understand which forces drive the pathways of agrifood systems, the way these forces interact and the possible ways to shift their patterns, trade-offs among different objectives that may emerge along transformative processes, and the actions needed to balance them in order to achieve desired objectives.

The CSFE identified eighteen interconnected socioeconomic and environmental drivers, and the related trends that can shape the future of agrifood systems (see Figure 1.1, left-hand side, in Chapter 1). Some drivers directly affect the whole agrifood systems (systemic overarching drivers) given their high interconnectedness with both supply and demand of food, and their linkages with the global socioeconomic context within which food and agricultural activities are set. Other drivers directly impact food access (food demand) and livelihoods, production and distribution processes, or the environment and natural resource base supporting agrifood systems.

This report analyses each of these drivers in detail, thanks to the contributions of the relevant FAO Technical Divisions. Several of these drivers had already been identified and discussed in previous FAO reports, others have been considered for the first time. In any case, given the changing circumstances and the short time remaining until 2030, this report puts more emphasis on certain aspects, such as: cross-country interdependencies; big data generation, control, and ownership; increasing food prices; science and innovation; capital and information intensification of agrifood production processes; market concentration; epidemics and degradation of ecosystems; and uncertainties at all levels. Throughout the report, the systemic nature of these drivers is underlined by highlighting their mutual linkages and interdependencies. The systemic approach adopted to investigate the future of agrifood systems also justifies the vast scope of the matters covered by the report. Refraining from considering and analysing key socioeconomic and environmental forces that are likely to influence the future patterns of agrifood systems is not advisable. Omitting some of them would have resulted in a simplistic and limited view of the complexity of agrifood systems, their mutual relationships with the broader socioeconomic and environmental systems, their causal linkages and dynamics.

The transformative changes needed to achieve a most desirable future, or, at least to avoid the most undesirable ones, require: a) a sound diagnosis of current agrifood systems; b) the design of theories and practices of change; and c) the implementation of such practices through strategies and policies. The CFSE identified key families of "triggers of change" to be considered in this process. They are effective starting points or boosters (depending on the context) for transformative processes to move away from "business as usual".

These families of triggers include: i) institutions and governance; ii) consumer awareness; iii) income and wealth distribution; and iv) innovative technologies (see Figure 1.1, top). These triggers, to be still further articulated, complemented and made context-specific, are expected to influence important drivers of agrifood systems and, through multiple systemic linkages and feedback effects, to spread their impacts throughout the socioeconomic and environmental systems for achieving the desired agrifood systems outcomes (see Figure 1.1, right-hand side). Given their potentially highly transformative impacts, activating these triggers in the complex multilateral arena can be politically sensitive.

Structure and content of the report. This report comprises three chapters:

- **Chapter 1** delves into the eighteen key, current and newly emerging, interconnected socioeconomic and environmental drivers that impact agrifood systems, and related performances. Although the structure of sections in Chapter 1 is flexible enough to adapt to the specific driver under consideration, all the sections outline the issues at stake and raise some questions to be investigated regarding the driver, provide facts and figures regarding recent trends of the driver and related variables, look at forthcoming work being done by others, and discuss some anticipatory signals that could reveal possible future trends and events. The findings of Chapter 1 feed into Chapter 2, notably as elements with which to build possible scenarios for the future of agrifood systems.
- **Chapter 2** outlines, after providing some highlights on the features of narratives in general, four possible alternative narratives for the future of agrifood systems. These narratives revolve around projected trends of the various drivers, but also outline possible prevailing "political economy" features, such as how and to what extent institutions, power relationships and political behaviour of stakeholders could shape economic, social and environmental phenomena. In providing the narratives for alternative scenarios, three broad milestones are adopted: 2030, with close reference to the SDG time frame; mid-century (medium to long run); and end of the century (very long run). While providing insights on the possible evolution of each driver, the narratives also capture the possible interactions among drivers, the strategic options adopted (or not adopted) and the way the emerging trade-offs among development outcomes would be addressed. The chapter also includes a section with a comparative analysis

of the proposed narratives with selected, important foresight exercises recently carried out within and outside FAO.

- **Chapter 3** looks at priority triggers of change, challenges and opportunities, and possible strategic and policy options to help move the future of agrifood systems towards sustainability. These triggers are expected to interact and generate systemic impacts on agrifood systems. The FAO Strategic Framework identifies some of these triggers as accelerators (e.g. innovation and technology) or complements (e.g. governance and institutions). This report takes a step further and articulates the proposed triggers by means of selected strategic options (broad sets of policy orientations), aimed at influencing agrifood systems patterns.

Given that the analysis of drivers is supported by a large amount of quantitative data, and the scenario narratives, albeit qualitative, rest on a set of projections of key variables, this report is complemented by a web-based data dashboard (available at www.fao.org/global-perspectives-studies/FOFA-dtt-dashboard) where users can visualize graphs and tables, download data files and interactively personalize their analyses.

This report, hopefully, helps to increase awareness about the fact that the determination of the future depends, at least in part, on the way trade-offs between short-term well-being and long-term resilience and sustainability could be addressed and balanced. As highlighted above, the world is off track on its road to Agenda 2030, possibly because the required transformations are painful and costly, thus requiring political determination and long-term commitment.[11] Changing the course of actions is a far cry from easy, because of the difficult trade-offs that this entails. The short-termism that tends to guide the average citizen and most, if not all, political leaders, continues privileging immediate benefits over resilience and sustainability in the long run. The size and potential of transformative actions are significantly influenced by the current and future preferences of power holders, power structures – political, economic, social, cultural and military – and by "political economy" dynamics. Stakeholders who are truly committed to transformation processes need to understand and effectively outsmart these dynamics that block the pathways towards sustainable and resilient agrifood systems.

Clearly, countries and social groups that can reasonably shoulder the costs involved in the necessary transformations should provide support to those already affected by the negative effects of unsustainable development, and help them prepare a better future for future generations.[1] However, getting public opinion to buy the message that well-off people have to lose out economically in the short run to attain environmental benefits and resilience for all in the medium and long term, is indeed a tall order. Unfortunately, the lack of global collective action and the inability, or unwillingness, to move along pathways towards sustainability and resilience, could be exponentially more costly for all, as the delay in moving along them increases.

1 | Drivers of agrifood systems

This chapter discusses eighteen interconnected socioeconomic and environmental drivers, and the related trends that could shape the future of agrifood systems. A systemic approach is used to analyse their recent trends and patterns because, to the extent possible, interrelations among drivers are thereby highlighted as they simultaneously, or through cause-effect relationships, contribute to determine agrifood systems outcomes, as illustrated in Figure 1.1. In most instances drivers are analysed both at the regional and global levels.[b]

This chapter articulates the fundamental questions regarding the sustainability and resilience of agrifood systems raised in the introduction, more specifically:

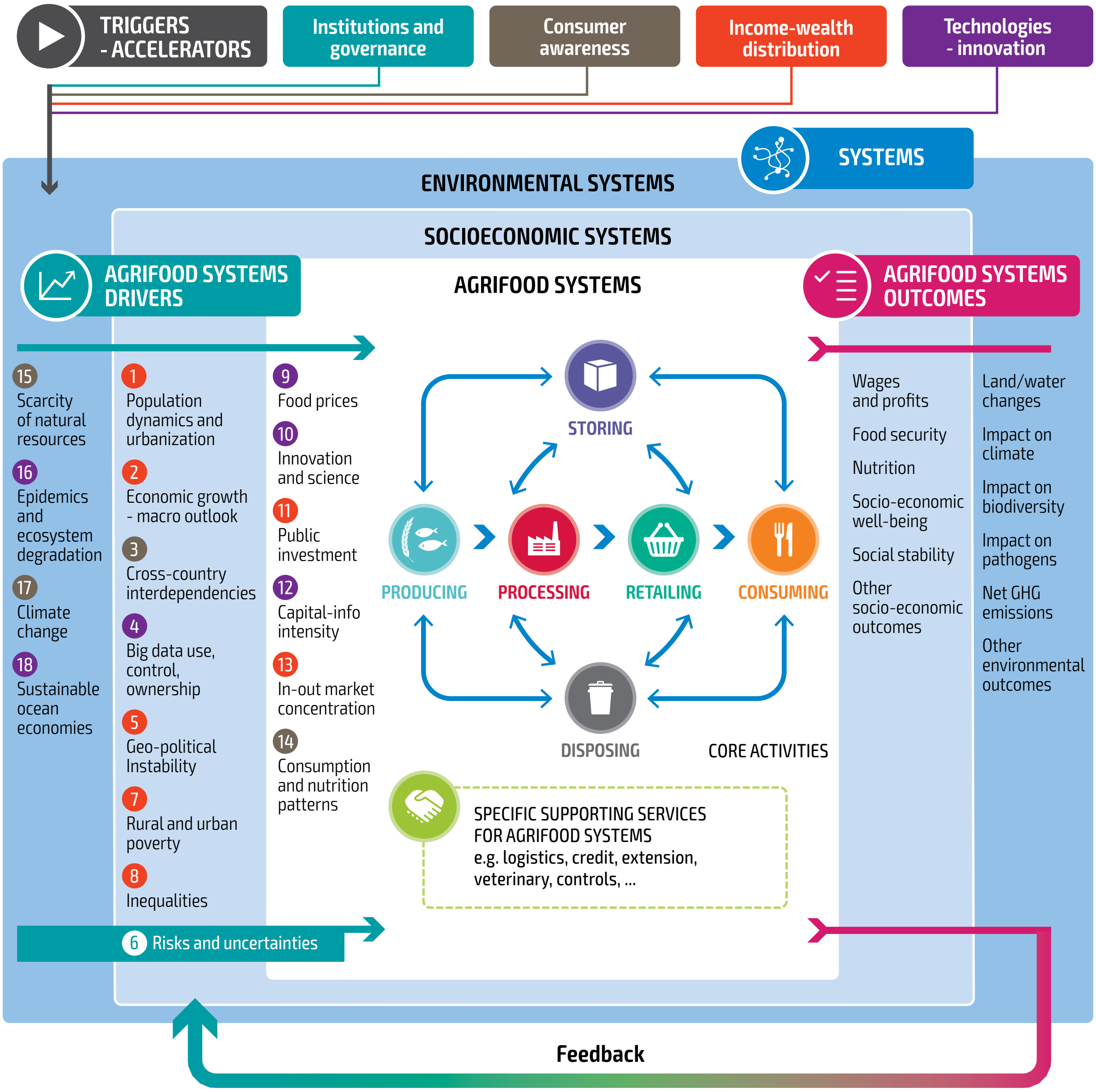
- Will agrifood systems be able to meet the needs of a global expanding population, while the pressure on natural resources intensifies, greenhouse gas (GHG) emissions increase, and climate change raises unprecedented concerns?
- Will future socioeconomic and environmental settings warrant universal access to safe, sufficient and nutritious food?

The articulation takes place through some specific ensuing questions relevant to each driver (see Table 1.1).

These questions, rather than forcing precise answers that are often not available, help to guide the understanding of the role of each driver in determining possible future patterns of agrifood systems.

[b] Country grouping is based on the World Bank Country Groups of 2021, downloaded from http://databank.worldbank.org/data/download/site-content/CLASS.xlsx. High-income countries (HICs) are classified in a single group, regardless their geographical location. All other countries, qualified as low- and middle-income countries (LMICs), are classified by geographical region, notably Europe and Central Asia (ECA), East Asia and the Pacific (EAP), South Asia (SAS), Latin America and the Caribbean (LAC), Near East and North Africa (NNA) and sub-Saharan Africa (SSA). If not otherwise specified, LMICs and EAP exclude China, which is considered as one country which comprises the Special Administrative Regions (SARs) of Taiwan, Hong Kong and Macao. Country groups and China are hereafter generally referred to as "regions" (see Annex 1). In some parts of the report, reference is also directly made to the World Bank classification: low-, lower-middle-, upper-middle- and high-income countries. In such instances, unless otherwise specified, no acronyms are used for lower- and upper-middle-income countries, while low-income countries are referred to as LICs. Furthermore, throughout the report the terms "developing countries" and "developed countries" are not adopted, apart from cases where other works are quoted. Even in those cases, no value judgement is implied regarding the level, stage or state of development of any country implicitly or explicitly referred to.

Figure 1.1 Agrifood systems: key drivers, activities, outcomes and priority triggers for transformation



Notes: Core activities of agrifood systems (production, processing, retailing etc.), which are interlinked through flows of goods and services (items in the white box at the centre), occur within broader socioeconomic and environmental systems (light blue and dark blue boxes). Socioeconomic and environmental drivers, as well as selected drivers determined within the agrifood systems themselves, (labels on the left-hand side of the figure), influence the state and dynamics of agrifood systems and their socioeconomic and environmental outcomes (labels on the right-hand side of the figure). Triggers of change (top of the figure) affect agrifood systems and their outcomes through their impacts on selected environmental, socioeconomic and agrifood drivers (labels on the left of the figure in the first, second and third columns, respectively). The different colours of drivers reflect their relationship with the trigger affecting them. The trigger designated "Institutions and governance'" affects all drivers and directly impinges on the functioning of the whole agrifood system and its relationships with the other systems. Given the systemic relationships among drivers, core activities of agrifood systems and their outcomes, the various triggers may concurrently affect different drivers, while each driver can be also affected by different triggers of change. The overall graph, core activities and outcomes were adapted from the Foresight4Food website (www.foresight4food.net/category/blog).

Source: Drivers and triggers based on FAO. 2020. *Transforming agri-food systems in an evolving socio-economic, political, and environmental context.* Report of the Internal Expert Consultation, June-October 2020. Corporate Strategic foresight exercise. Unpublished. Rome.

Table 1.1 Critical drivers of agrifood systems and related trends

A. Systemic (overarching) drivers
1. Population dynamics and urbanization. A recent United Nations report on megatrends states that "between 2020 and 2050, globally, the portion of people living in urban areas will shift from 53 percent to 70 percent",[12] with implications for agrifood systems.
2. Economic growth, structural transformation and the macroeconomic outlook may not always be conducive to the inclusive economic transformation of societies. The United Nations Conference on Trade and Development (UNCTAD) has acknowledged that "if the current policy stances continue, […] as labour shares across the world continue on their decreasing path, household spending will weaken, further reducing the incentive to invest in productive activities."[13]
3. Cross-country interdependencies tie together agrifood systems globally with both positive impacts and drawbacks. For instance, *The State of Food Insecurity in the World 2019* report states "eighty percent of the countries (52 out of 65) with a rise in hunger during recent economic slowdowns and downturns are countries whose economies are highly dependent on primary commodities for export and/or import."[14]
4. Big data generation, control, use and ownership enable real-time innovative technologies and decision-making in agriculture, but also raise some concerns because "a few players have come to dominate large shares of the market" and there are "big data platforms that are able to amass extraordinary amounts of information on consumer behaviour and preferences."[15]
5. Geopolitical instability and increasing conflicts, which include resource- and energy-based conflicts, undermine food security and nutrition. *The State of Food Insecurity in the World 2017* report, for instance, highlights that the vast majority of the chronically food-insecure and malnourished people live in countries affected by conflicts.[16]
6. Uncertainties materialize in sudden occurrences that are unpredictable, the COVID-19 pandemic being a critical case in point. As per the FAO 2018 report *The future of food and agriculture – Alternative pathways to 2050*, "the future of food and agriculture faces uncertainties that […] revolve around different factors, including population growth, dietary choices, technological progress, income distribution, the state of natural resources, climate change, the sustainability of peace."[1]
B. Drivers directly affecting food access and livelihoods
7. Rural and urban poverty, characterized by a high proportion of rural people living in poverty or extreme poverty. The number of food-insecure people is increasing and malnourishment is widespread because, as stated in *The State of Food Insecurity in the World 2020*, "the cost of a healthy diet is much higher than the international [extreme] poverty line."[17]
8. Inequalities are widespread and deep-rooted with regard to income, job opportunities, access to assets and basic services, which tend to affect women relatively more. There are also inequalities that emerge from the ways the fiscal burden affects people. The International Monetary Fund (IMF) and the Organisation for Economic Co-operation and Development (OECD) have highlighted that increased inequality can erode social cohesion, lead to political polarization and ultimately lower economic growth.[18]
9. Food prices – measured by the real FAO Food Price Index (FFPI), that calculates the average of the price indices of five commodity groups and deflates it with a price index of manufactured goods – after following a declining or stagnating trend until the end of the century, significantly increased in the last two decades, despite the fact that they still fail to capture the full social and environmental costs of food.
C. Drivers directly affecting food and agricultural production and distribution processes
10. Innovation and science, including biotechnologies, digitalization and systemic approaches (e.g. agroecology, conservation and organic agriculture), open up interesting avenues for agrifood systems, but also pose challenges, as highlighted in a recent report of the United Nations Secretary-General.[19]
11. Public investment in agrifood systems, which is often insufficient, decreased significantly in the last 15 years, as shown by the FAO Agriculture Orientation Index (AOI) for Government Expenditures.[20]
12. Capital and information intensity of production is increasing in agriculture as a result of mechanization, automation and digitalization, which, other things being equal, lowers labour demand. At the same time, a traditional absorber of excess agricultural labour, such as the manufacturing sector, is itself undergoing the same intensification.[21]
13. Input and output market concentration poses a challenge for the resilience and equitability of agrifood systems. A recent United Nations Conference for Trade and Development (UNCTAD) report highlights that "increased market concentration and rising mark-ups have become commonplace across many sectors and economies, with rent-seeking behaviour dominating at the top of the corporate food chain."[22]

Table 1.1 (cont.) Critical drivers of agrifood systems and related trends

D. Drivers regarding environmental systems
14. Consumption and nutrition patterns are shaped by consumer behaviour and, for them to become more sustainable, changes in global governance are needed. For instance, "carbon labelling could help shape consumer preferences, [but] would require an internationally recognized approach in setting the related standards."[23]
15. Scarcity and degradation of natural resources. The GEO-6 report of the United Nations Environment Programme (UNEP) states that "inefficient or unsustainable farming systems are often associated with environmental and soil degradation and biodiversity loss, and an increase in crop specialization and distribution can raise the risk of poor harvests."[24]
16. Epidemics and degradation of ecosystems may increase because of the encroachment of agriculture in forests, antimicrobial resistance, and the production and consumption of animal products. According to a report by UNEP and the International Livestock Research Institute (ILRI), "the pathogens originate in animals, and the emergence or spillover of the diseases they cause in humans is usually the result of human actions, such as intensifying livestock production or degrading and fragmenting ecosystems."[25]
17. Climate change is affecting agrifood systems and natural resources. However, as stated in a recent Intergovernmental Panel on Climate Change (IPCC) report, "an estimated 23 percent of total anthropogenic GHG emissions (2007–2016) derive from Agriculture, Forestry and Other Land Use (AFOLU)."[26]
18. The "sustainable ocean economies" notes that the development of economic activities related to the fisheries and aquaculture sector is increasing globally. A recent IPCC report highlights the importance of a reorganization and enhancement of ocean industries to reduce GHG emissions, adapt to climate change and achieve environmental, social and economic sustainability, and resilience.[27]

Sources: Adapted from FAO. 2020. *Transforming agri-food systems in an evolving socio-economic, political, and environmental context.* Report of the Internal Expert Consultation, June-October 2020. Corporate strategic foresight exercise. Unpublished. Rome; and FAO. 2021. *Strategic Framework 2022–31*. Rome. www.fao.org/3/cb7099en/cb7099en.pdf

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1.1 Population dynamics and urbanization (Driver 1)

Demographic dynamics and urbanization are expected to impact food demand with implications on food security and nutrition. Sub-Saharan Africa (SSA) and South Asia (SAS) are leading these changes. While population grows, its structure evolves too. Relative weight of age cohorts and gender balance in different locations vary, as consequence of internal and international migrations. A recent United Nations report on megatrends affecting global societies and economies states that "Between 2020 and 2050, globally, the portion of people living in urban areas will shift from 53 percent to 70 percent".[1] Population dynamics present interconnected implications for agrifood systems because demographic growth and structural change, urbanization and food demand are closely interlinked. Urbanization is seen as a challenge for food and agriculture when it happens in a disorganized manner, for instance because of encroaching on fertile land. In addition, the growth of young population cohorts, particularly in SSA and in SAS, prompts serious concerns regarding employment opportunities and the risks of degrading quality of jobs (remunerations, exploitation, safety), within and outside agrifood systems.

This raises several questions which are dealt with here or in other parts of this report:

- Why and to what extent has population growth affected and will affect agrifood demand?
- To what degree will the dynamics of the different cohorts in various regions impact labour supply?
- Is urbanization ineluctable or are there forces that in the future could reverse the intensity, if not the direction, of the trend and where is this likely to happen?

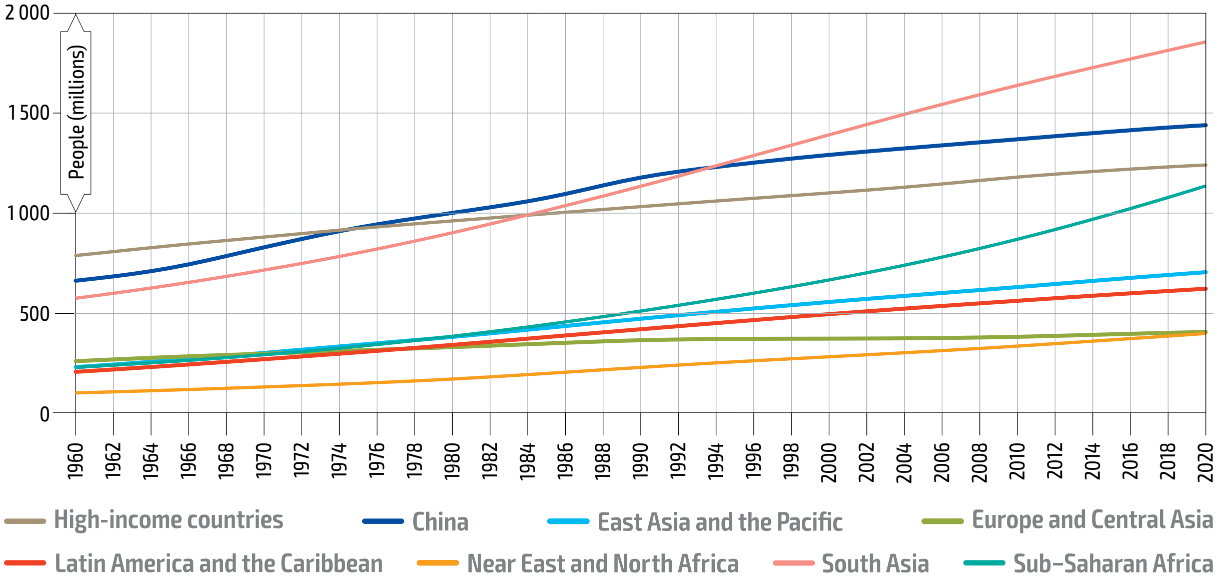
1.1.1 Demographic dynamics

People are at the heart of agrifood systems, and few drivers are as crucial as population dynamics in shaping them. While the number of people and the structure of population only evolves slowly over time, the spatial distribution and occupation of people may change rapidly and impact agrifood systems.

Demographic centre of gravity

The world's demographic centre of gravity is shifting to low-income countries (LICs). World population has multiplied by 2.5 since 1960 and reached an estimated 7.8 billion people in 2020. Figure 1.2 depicts the considerable demographic diversity with respect to population growth rates in the various country groups considered in this report.

Figure 1.2 Total population by region (1960–2020)



Source: Authors' elaboration based on United Nations. 2019. *World Population Prospects 2019, Online Edition. Rev. 1.* Department of Economic and Social Affairs, Population Division. New York, USA. Cited 23 June 2022. https://population.un.org/wpp/Download/Standard/Population

The data in Table 1.2 show that overall population growth decelerated in the second half of the period considered: world population had increased by 75 percent between 1960 and 1990, but rose only by 48 percent between 1990 and 2020. This deceleration is associated with a geographical shift of population growth hotspots. Between 1960 and 1990, East Asia and the Pacific (EAP) and China were where 32 percent of global population increase took place. This share fell to 21 percent between 1990 and 2020. Similar changes, although less pronounced, were observed in Latin America and the Caribbean (LAC) and in Near East and North Africa (NNA). On the contrary, SSA's share in the world population growth jumped from 13 percent of the total to 25 percent, with the region's population more than doubling since 1990, while SAS was by far the region with the highest population growth in absolute terms (+1.28 billion people from 1960 to 2020).

The rate of population growth in China has now become comparable to that observed in high-income countries (HICs), while it is still roughly three times higher in SAS, where 24 percent of world population lives. However, the loosening of restrictions on the number of children might restore some demographic growth in China.

Table 1.2 Population growth by region (1960–2020)

REGION	TOTAL POPULATION (millions)			CUMULATED GROWTH RATE OVER THE PERIOD (percent)	
	1960	1990	2020	1960–1990	1990–2020
High-income countries	772.5	1 004.9	1 207.9	30.1	20.2
China	674.5	1 203.4	1 471.3	78.4	22.3
East Asia and the Pacific	227.9	470.1	703.2	106.3	49.6
Europe and Central Asia	257.5	362.5	403.5	40.8	11.3
Latin America and the Caribbean	204.2	417.4	620.3	104.4	48.6
Near East and North Africa	98.6	226.4	396.4	129.5	75.1
South Asia	572.8	1 133.5	1 856.4	97.9	63.8
Sub-Saharan Africa	226.6	508.5	1 135.3	124.5	123.2
World	**3 034.7**	**5 326.8**	**7 794.3**	**75.5**	**46.3**

Source: Authors' elaboration based on United Nations. 2019. *World Population Prospects 2019, Online Edition. Rev. 1.* Department of Economic and Social Affairs, Population Division. New York, USA. Cited 23 June 2022. https://population.un.org/wpp/Download/Standard/Population

Age structure

World population is ageing, with implications for the size of the labour force and age dependency. The age structure of the population has changed and there have been important shifts in the share of the working age population in total population. Similarly, the size of dependent population evolved, compared to people of working age. This is a result of past evolution and contemporary patterns in fertility and mortality, as well as a gradual decline of the share of children and youth, combined with the rising importance of those considered to be elderly, because of increased longevity.

Working age population and labour force have grown faster than total population. The working age population is generally defined as the population aged 15 years and over, while the labour force is made up by those people of working age who are actively engaged in the labour market, whether employed or unemployed.[2]

Table 1.3 shows the detailed changes of the labour force observed globally and in different regions. The global labour force grew by 46 percent between 1990 and 2020, slightly slower than total population. More specifically, its growth slowed down in the last decade, particularly in China, and Europe and Central Asia (ECA) because of the combined effect of a moderate demographic increase and a rapidly ageing population. However, between 1990 and 2020 in EAP and LAC and NNA the labour force growth largely outpaced the growth of population. In SSA, over the same period, the labour force growth remained below the population growth (121.6 and 123.4 percent, respectively) despite the fact that additional 96 million workers became active.

Table 1.3 Labour force by region (1960–2020)

REGION	TOTAL LABOUR FORCE (millions)				CUMULATED GROWTH RATE OVER THE PERIOD (percent)
	1990	2000	2010	2020	1990–2020
High-income countries	479.8	523.9	571.4	606.8	26.5
China	644.8	733.1	776.1	796.7	23.6
East Asia and the Pacific	208.3	261.1	309.7	347.8	67.0
Europe and Central Asia	162.9	166.1	175.1	178.9	9.8
Latin America and the Caribbean	160.8	208.4	256.1	272.3	69.3
Near East and North Africa	59.7	80.7	101.6	112.4	88.3
South Asia	401.0	508.4	601.6	632.2	57.7
Sub-Saharan Africa	193.6	257.4	334.3	430.1	122.2
World	**2 310.9**	**2 739.1**	**3 125.9**	**3 377.2**	**46.1**

Notes: Labour force comprises people ageing 15 years and older who supply labour for the production of goods and services during a specified period. It includes people who are currently employed and people who are unemployed but seeking work as well as first-time job-seekers. Not everyone who works is included, however. Unpaid workers, family workers, and students are often omitted, and some countries do not count members of the armed forces. Labour force size tends to vary during the year as seasonal workers enter and leave.

Source: Authors' elaboration based on World Bank. 2022. Labor force, total. In: *World Bank*. Washington, DC. Cited 12 May 2022. https://data.worldbank.org/indicator/SL.TLF.TOTL.IN

Because of this evolution, from 1990 to 2020, HICs dropped from 21 to 18 percent and China dropped from 28 to 23 percent of the global labour force. SSA, by contrast significantly increased its share from 8 percent in 1990 to almost 13 percent in 2020 (see Figure 1.3).

The youngest segment of the world's working age population (aged 15 to 24 years) currently numbers 1.2 billion people, which corresponds to about 16 percent of the global population. This age group is still growing rapidly in Africa, whereas it is increasing much less, or is even declining, in other regions. For instance, in SSA, it more than doubled between 1990 and 2019, while in the same period in LAC and Eastern and South-Eastern Asia the rate was just above 10 percent and 20 percent, respectively.

The extent to which the occurrence of an unprecedentedly large cohort of young people represents an opportunity for LICs will depend on several factors, such as the quality of education they receive and the labour market's ability – including in the food and agriculture sector – to absorb large numbers of new workers. This will present a major challenge for the coming decades.

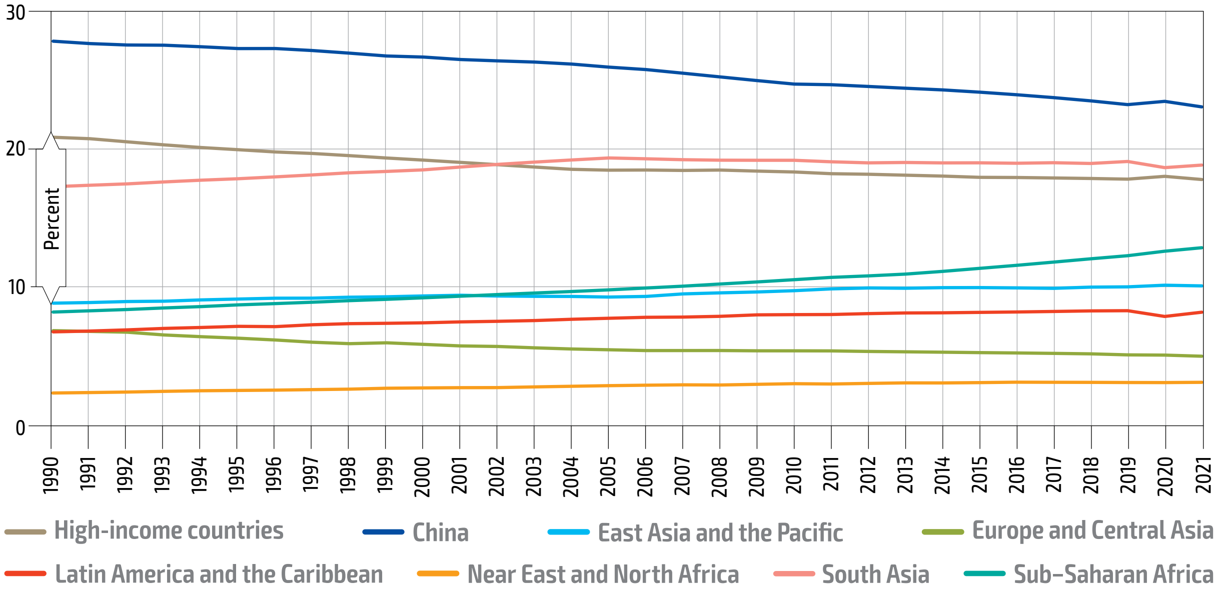
The contrasted evolution of youth and old age dependency ratios. The youth dependency ratio is the ratio between the number of people aged under 15 years and the number of those aged between 15 and 64 years. All regions have seen their youth dependency ratio decline since 1960, the slowest decrease being observed in SSA (-2 percent), and the highest in China (-64 percent). This is the result of a reduced demographic growth, mainly resulting from a falling fertility.

Despite this decline, the levels of the ratio remain quite high in SSA, NNA and SAS.

In contrast, the old age dependency ratio – measuring the ratio between the number of people aged 65 years and above, and the number of those aged between 15 and 64 years[3] – increased everywhere in the world except in SSA, where it fell by 2 percent between 1960 and 2019. The fastest growth was in HICs, where it more than doubled over the same period. This essentially signals a greater longevity.

The ratio is growing particularly fast in HICs and China.

Figure 1.3 Distribution of world labour force by region (1990–2021)



Notes: Labour force comprises people ageing 15 years and older who supply labour for the production of goods and services during a specified period. It includes people who are currently employed and people who are unemployed but seeking work as well as first-time job-seekers. Not everyone who works is included, however. Unpaid workers, family workers, and students are often omitted, and some countries do not count members of the armed forces. Labour force size tends to vary during the year as seasonal workers enter and leave.

Source: Authors' elaboration based on World Bank. 2022. DataBank | World Development Indicators. In: *World Bank*. Washington, DC. Cited 28 April 2022. https://databank.worldbank.org/source/world-development-indicators

Opportunities and challenges

Demographic dynamics create contrasted opportunities and challenges. Countries entering a period where the working age population has a lower proportion of dependents, and benefiting simultaneously from access to good health and education services, as well as decent employment opportunities, should experience a period of potential economic improvement. A smaller number of children per household usually leads to larger investments per child, more freedom for women to enter the formal workforce and more household savings for old age. When this demographic dividend takes place, the economic payoff can be substantial. Likewise, the projected decrease in youth dependency ratios may contribute to reduced public expenditures on education and school infrastructure, although this decline may not necessarily be significant enough to offset higher spending on the elderly,[4] as the ageing of the population worldwide poses major challenges in countries where this process is more advanced, particularly regarding the funding of social protection and health care for the elderly.[5]

In those regions where demographic growth continues at a comparatively high rate, high youth dependency rates, increased pressure on resources and the need for accelerated job creation are among the main present and future issues to be tackled.

Although demographic dynamics are relatively slow and their regularities well known, there are persistent uncertainties that could influence their outcomes substantially, such as infectious diseases, wars, natural disasters, scientific advances or political changes. Migration, for example, can be, concurrently, an essential enabler of social and economic development; an opportunity for people to respond to shifts in social, economic and environmental conditions; and a way for ageing countries to have access to additional labour force. In some cases, it may also be a source of political and social instability.

1.1.2 Recent trends: dietary requirements and food consumption

Minimum dietary requirements

Minimum dietary requirements have been growing even faster than population because of changes in demographic structure. Global minimum dietary requirement has grown by approximately 29 percent between 2000 and 2020,[c] reaching more than 14 trillion calories per day (see Table 1.4). This is the compounded result of the increase of population (around 26 percent) and of minimum daily dietary requirements per person (1.3 percent), the latter moving from 1 803 to 1 827 kcal/capita/day because of the changing demographic structure and other characteristics of world population. The trend in the minimum daily dietary requirement contrasted to some extent with different regions. ECA is the only region where it fell (-0.4 percent over the period) because of the ageing of its population, while it increased most in SAS (+4 percent), on the account of the high proportion of younger adults whose calorie requirements are greater than those for other age groups.

Table 1.4 Minimum dietary energy requirements (2000–2020)

REGION	TOTAL MINIMUM DIETARY ENERGY REQUIREMENTS (billion kcal/day)			CUMULATED GROWTH RATE OVER THE PERIOD (percent)	
	2000	2010	2020	2000–2010	2010–2020
High-income countries	2 056.1	2 209.5	2 321.6	7.5	5.1
China	2 457.4	2 647.0	2 769.2	7.7	4.6
East Asia and the Pacific	974.9	1 121.4	1 262.2	15.0	12.6
Europe and Central Asia	696.0	717.8	755.4	3.1	5.2
Latin America and the Caribbean	885.1	1 024.9	1 145.0	15.8	11.7
Near East and North Africa	496.4	601.1	714.5	21.1	18.9
South Asia	2 390.5	2 885.0	3 320.8	20.7	15.1
Sub-Saharan Africa	1 125.5	1 476.4	1 958.1	31.2	32.6
World	**11 081.9**	**12 683.1**	**14 246.8**	**14.4**	**12.3**

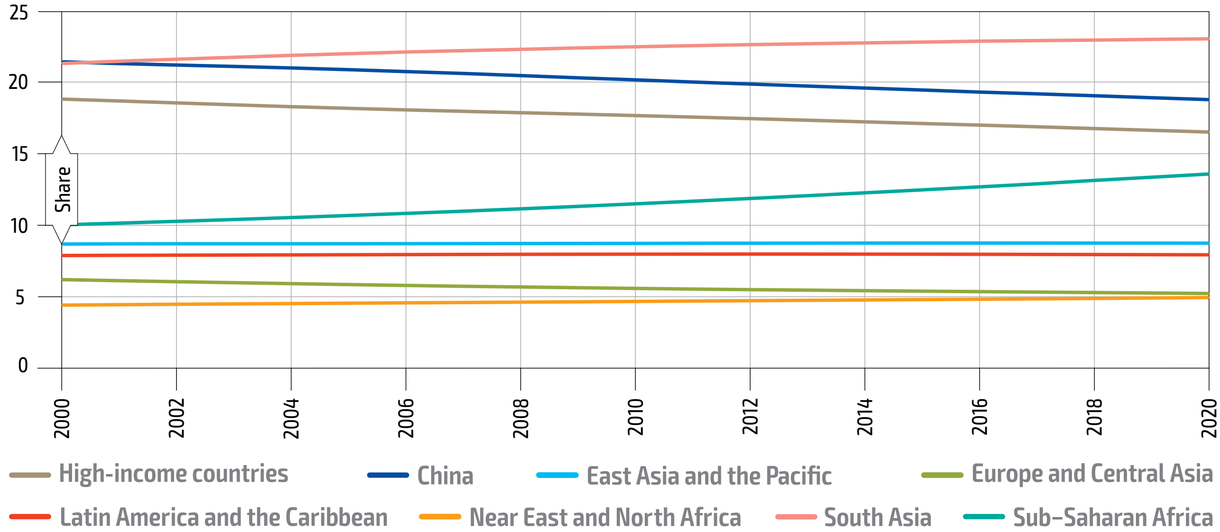
Notes: The minimum dietary energy requirement (MDER) is the minimum amount of dietary energy per person adequate to meet the daily energy needs in a specified age/sex category. At the country level, it is the weighted average of the MDER by age/sex category. The total MDER by region is computed by summing up the total MDER of the countries in each region.

Source: Authors' elaboration based on FAO. 2022. Suite of Food Security Indicators. In: *FAOSTAT*. Rome. Cited 2 June 2022. www.fao.org/faostat/en/#data/FS

Clearly, it is in SSA that the trend is most rapidly increasing, and this is reflected by the fact that the weight of the region in world dietary requirements grew from 10 percent in 2000 to almost 14 percent in 2020 (see Figure 1.4).

[c] The minimum dietary energy requirement is the minimum amount of dietary energy per person that is considered adequate to meet the energy needs at a minimum acceptable body mass index of an individual engaged in low physical activity. If referring to an entire population, it corresponds to the weighted average of the minimum energy requirements of the different age/sex groups The average dietary energy requirement is a proper normative reference for adequate nutrition in the population.[6]

Figure 1.4 Share of total minimum dietary energy requirements by region (2000–2020)



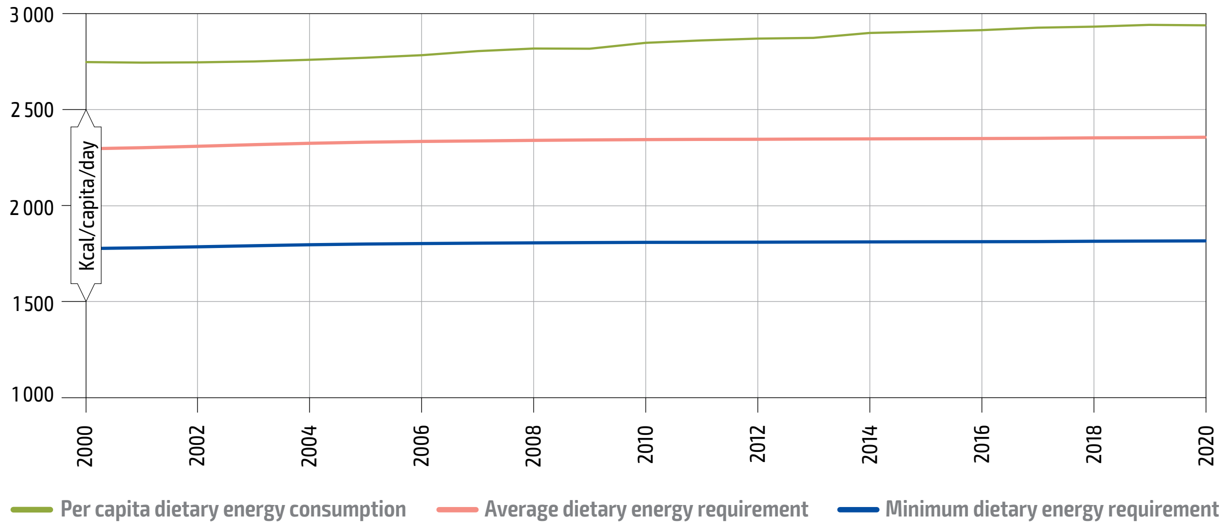
Notes: The minimum dietary energy requirement (MDER) is the minimum amount of dietary energy per person adequate to meet the daily energy needs in a specified age/sex category. At the country level, it is the weighted average of the MDER by age/sex category. The total MDER by region is computed by summing up the total MDER of the countries in each region.

Sources: Authors' elaboration. Population based on United Nations. 2022. Databases. In: *United Nations. Department of Economic and Social Affairs*. New York, USA. Cited 18 May 2022. www.un.org/en/desa/products/un-desa-databases; minimum dietary energy requirements based on FAO. 2022. Suite of Food Security Indicators. In: *FAOSTAT*. Rome. Cited 2 June 2022. www.fao.org/faostat/en/#data/FS

Food consumption

Food consumption has been growing faster than dietary requirements. Figure 1.5 shows that globally, per capita dietary energy consumption, measured in calorie value, grew faster than both per capita average and minimum dietary energy requirements.

Figure 1.5 Global per capita average dietary energy requirement, minimum dietary energy requirement and dietary energy consumption (2000–2020)



Notes: The average dietary energy requirement (ADER) is a proper normative reference for adequate nutrition in the population. The minimum dietary energy requirement (MDER) is the minimum amount of dietary energy per person adequate to meet the daily energy needs in a specified age/sex category. Dietary Energy Consumption (DEC) refers to actual per capita calories intake, calculated for many countries on the basis of the dietary energy supply (DES) from FAOSTAT Food Balance Sheets net of food waste at the retail and household levels. The global per capita ADER, MDER and DEC are calculated as averages of country data weighted with population are based on weighted mean by total population.

Sources: Authors' elaboration. ADER and MDER based on FAO. 2022. Suite of Food Security Indicators. In: *FAOSTAT*. Rome. Cited 2 June 2022. www.fao.org/faostat/en/#data/FS; DEC based on FAO, IFAD, UNICEF, WFP & WHO. 2022. *The State of Food Security and Nutrition in the World 2022. Repurposing food and agricultural policies to make healthy diets more affordable.* Rome. https://doi.org/10.4060/cc0639en

Between 2000 and 2020 alone, food consumption increased by more than 37 percent for the world as a whole, measured in terms of billions of kcal per day (see Table 1.5), significantly faster than population growth. The sharpest increase was observed in SSA where it grew by 88 percent, followed by EAP (52 percent).

Table 1.5 Total food consumption by region (2000–2020)

REGION	TOTAL FOOD CONSUMPTION (billion kcal/day)		CUMULATED GROWTH RATE OVER THE PERIOD (percent)
	2000	2020	2000–2020
High-income countries	3 641.8	4 174.5	14.6
China	3 685.8	4 905.5	33.1
East Asia and the Pacific	1 308.4	1 987.9	51.9
Europe and Central Asia	1 085.6	1 340.5	23.5
Latin America and the Caribbean	1 388.6	1 865.4	34.3
Near East and North Africa	818.6	1 184.8	44.7
South Asia	3 259.6	4 795.8	47.1
Sub-Saharan Africa	1 482.8	2 753.5	85.7
World	**16 671.2**	**23 007.8**	**38.0**

Source: Authors' elaboration based on FAO. 2022. Suite of Food Security Indicators. In: *FAOSTAT*. Rome. Cited 2 June 2022. www.fao.org/faostat/en/#data/FS

Despite this rapid growth of consumption, and because of the high level of inequality prevailing in all regions, almost 10 percent of the world's population was undernourished in 2021, while 11.7 percent of global population (around 920 million people) was severely food insecure in 2020 and more than 3 billion people could not afford healthy diets7 (see also the Introduction and Section 1.7).

The actual level of food consumed depends on the size of population and on the level of real per capita income and its distribution.[8] The composition of the food consumed is also affected by urbanization (see Figure 1.6) and by relative prices of various food products.

1.1.3 Urbanization and food systems

Structural transformation, urbanization and employment

Structural transformation of the economy, urbanization and employment. History provides evidence that, over time, the structure of the economy of countries evolves, moving away from agriculture towards manufacturing and services. This process of structural transformation involves a shift of labour out of rural and into urban areas, and the decline of the relative importance of agriculture in the economy in favour of industry and services (see Section 1.2).

In theory, the diversification of labour away from subsistence agriculture and towards other economic activities should increase productivity and lead to a reduction in poverty. Three interrelated processes are part of the structural transformation in the agriculture sector: improvements in productivity, shifts in composition of output and changes in mode of commercialization.[9] These processes themselves are driven by technological change, public goods and access to markets.

Successful structural transformations have been characterized by improvements in overall labour productivity, incomes and livelihoods, and have led to a reduction in poverty. In such a setting, rural areas are vibrant and the provision of public goods and services such as education, health care and social protection improve. However, successes in the socioeconomic sphere were often accompanied by widespread degradation of natural resources (see Section 1.14) and increased health problems (see Section 1.15).

Unsuccessful transformations, on the other hand, are associated with little or no increase in agricultural productivity, coupled with lack of growth in non-agricultural activities. This causes a "push" factor migration out of rural areas and towards urban ones (especially to megacities), and an overall aggravation of poverty, environmental degradation and vulnerability.

Agriculture, structural transformation and rural–urban migration. As countries undergo structural transformation, the proportion of their labour force in agriculture tends to decline. Agriculture shifts from low productivity, or mostly subsistence production, towards more productive systems with greater value addition and surpluses.[10] As incomes increase and new opportunities in downstream activities are created, agricultural value chains evolve from local to longer chains, with deeper food market integration.[11]

There are significant regional disparities. In some parts of the world, such as SSA and Asia, it is estimated that 80 percent of food is produced by small-scale producers who operate on less than two hectares.[12] This may not be the case in other regions, where farm size tends to increase during structural transformation. A comprehensive examination of changes in farmland distribution over time shows greater land concentration as economies grow.[13]

Rural–urban migration is a key feature of the process of structural transformation. The increase of agricultural productivity is usually associated with labour-saving technologies which release labour forces for the expansion of other sectors mostly located in urban or peri-urban areas. Rural–urban migration, in this case, is a consequence of economic growth. This is the ideal scenario in which the agriculture sector thrives as productivity increases and labour requirements decrease, while urban expansion is driven by increased productivity of other sectors that contribute to reduced poverty.

However, as agriculture becomes increasingly commercialized and integrated into new commercial value chains, rural poverty may actually increase as small-scale producers face higher barriers to engage in new activities (cost of inputs and equipment and loss of traditional intermediaries). Deprivation of other resources, including land (because of debt or appropriation by investors or projects), or access to water, may push them into poverty and prompt them to leave rural areas. Low agricultural prices, the attraction of cities seen as offering opportunities and environmental degradation threaten food security and drive people towards urban areas.

Conflict and insecurity may also be a driving force towards urbanization. Once in cities, migrants who lack the skills for finding formal employment are likely to live in poverty from low-paid, informal jobs and become slum dwellers. By 2050, the world's urban population is expected to rise to 68 percent, over 90 percent of this increase occurring in low-income countries, especially in Africa and Asia.[14]

There have been fundamental changes in the rural–urban continuum which often break the sharp dichotomy between what can be considered urban and rural. In 2018, 55 percent of the world's population resided in urban areas and 85 percent lived in or within three hours of an urban centre of at least 50 000 inhabitants. Progress in transportation and communications facilitates rural–urban interactions and the links between food production and consumption points.

Urbanization is not just the result of rural–urban migration; it can also be a consequence of a spatial transformation of a territory. It may be the effect of natural demographic growth and the reclassification of areas from rural to urban as they become more densely inhabited (see Box 1.1).

Box 1.1 *In situ* urbanization: Is it an alternative to migration to megacities?

Urbanization is not limited to a process of reallocating people and economic activity across different areas. *In situ* urbanization, in which a rural area becomes more urban, is a process observed in many HICs where industrialization and centralization “have shaped the classical urban substructure and facilitated rapid urban growth”.

In essence, *in situ* urbanization is the transformation of a rural area so that it gains more urban features, infrastructure and services. For example, in some areas of SAS, and to some extent in SSA, the rural sector has experienced an increase in jobs in industry and services. This increase absorbed a portion of the job losses in agriculture, preventing a potential increase in rural–urban migration.

The urban transformation of rural areas has the potential of closing the gap in living standards between urban and rural areas, reducing rural poverty and stemming mass migration to cities. Successful examples are found in China and Sri Lanka. In China, since the 1970s, *in situ* urbanization has been facilitated by the authorities in southeastern coastal regions. At its early stages, higher value-added, labour-intensive manufacturing was developed to attract workers from nearby villages.

However, not all *in situ* urbanization experiences have led to improvements in living standards. In unsuccessful cases, the creation of urban-like activities in rural areas were not sufficient to accommodate labour forces leaving agriculture and, therefore, migration to cities continued. In the early 2000s, a new form of urbanization occurred in rural areas of SAS, where population growth in some places resulted in densities similar to those in urban areas, but most jobs available remained informal, low-skilled and low-wage, outside higher value-added activities.

It follows that *in situ* urbanization can be an alternative to mass migration to cities if it is supported by purposeful policy action through the provision of infrastructure and incentives for the creation or relocation of industries.

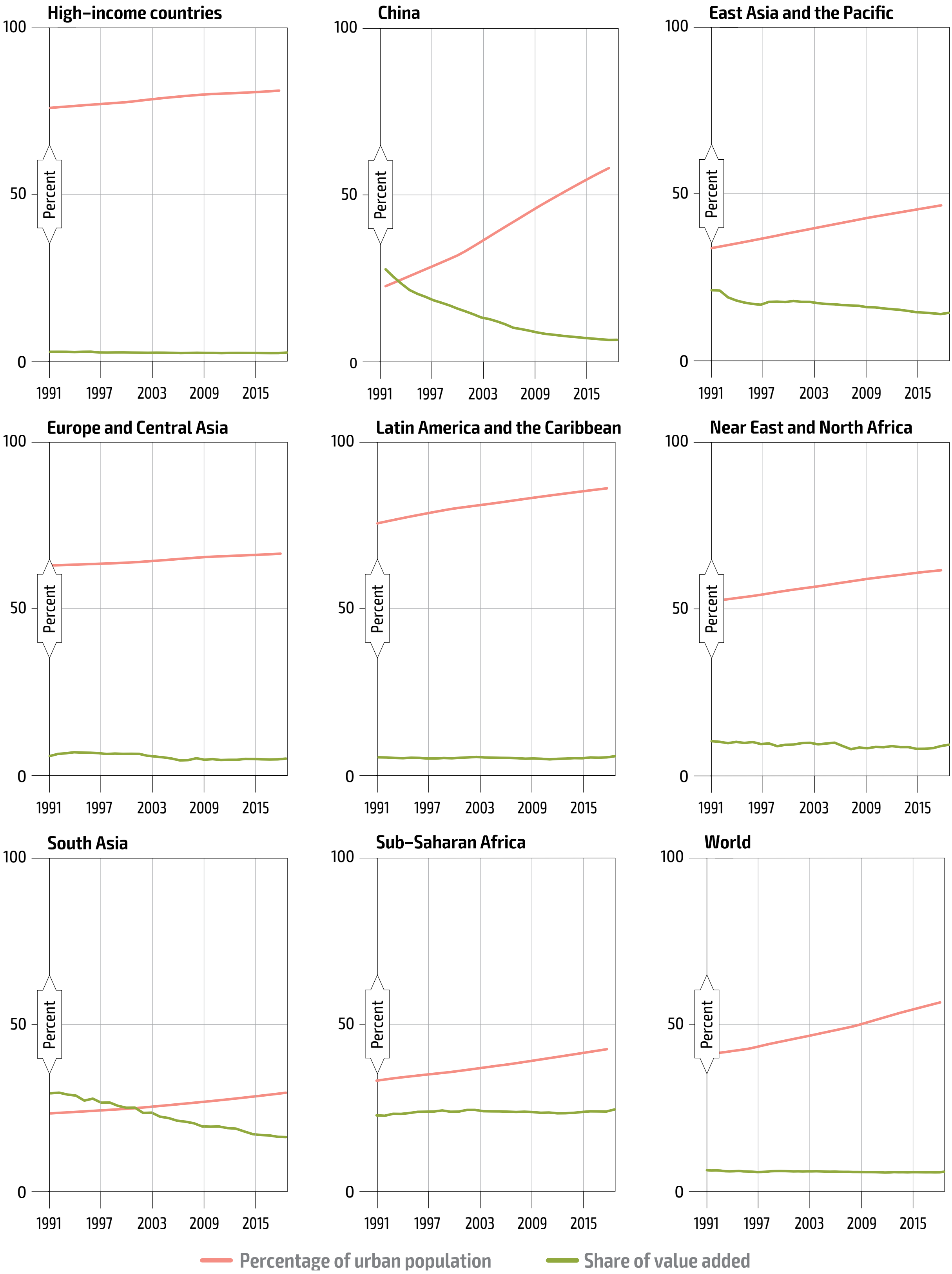
Source: United Nations. 2021. *World Social Report 2021. Reconsidering Rural Development.* UNDESA (United Nations Department of Economic and Social Affairs). New York, USA.

Structural transformation and urbanization: too fast or too slow? From the above discussion, it appears that successful structural transformation and urbanization can be the results of the same process.

Figure 1.6 illustrates how the relationship between the share of urban population in total population and the share of agriculture, including forestry and fishing, in total gross domestic product (GDP) evolved between 1970 and 2019 in different regions.

At the global level, the share of urban population grew from 37 percent in 1970 to an estimated 56 percent in 2019, while the share of agriculture in global GDP decreased from 5.3 to 4.2 percent.

Figure 1.6 Shares of urban population in total population and agriculture value added in gross domestic product by region (1970–2020)



Note: Value added (agriculture, forestry and fishing) is measured in constant USD of 2015.

Sources: Authors' elaboration. Value added (agriculture, forestry and fishing) based on FAO. 2022. Macro Indicators. In: *FAOSTAT*. Rome. Cited 2 June 2022. www.fao.org/faostat/en/#data/MK; urban population based on United Nations. 2018. *World Urbanization Prospects: The 2018 Revision, Online Edition*. Department of Economic and Social Affairs, Population Division. New York, USA. Cited 22 June 2022. https://population.un.org/wup/Download

A more detailed analysis shows very diverse trends in different regions. HICs, ECA, and to a lesser extent LAC and NNA, had already largely been through structural transformation before 1970, with agricultural GDP being around or below ten percent of total GDP, while urbanization was quite advanced, with urban population representing more than 50 percent of total population (more than 70 percent in the case of HICs).

As for the three Asian groups (China, SAS and EAP, they have seen a spectacular decrease of the contribution of agriculture to total GDP (from more than 70 percent in 1970 to less than 10 percent in 2020, for China). The process was slower in EAP, where it had started before 1970, but has not yet reached a comparable result to that of China or HICs. It was also much more gradual in SAS, which remains mostly rural. SSA stands out as the case where urbanization is higher than in SAS, but where the share of agriculture in the economy continues to be stable at around 20 percent, reflecting a relatively slow development of industry and services and, consequently, less employment and income opportunities for a growing urban population (see Box 1.2).

Box 1.2 Urbanization in Africa

Urbanization without industrialization

Africa's transformation in recent years masks a great heterogeneity across countries. Those with particularly severe challenges experienced fast population growth and urbanization in the absence of significant productivity growth and dynamism in either agriculture or non-farm sectors. This process, termed urbanization without industrialization, has occurred in countries such as Angola, Equatorial Guinea, Zambia and others, where natural resource exports (for example, oil and mining products) are a main driver of growth but do not show strong linkages with rural areas. In these countries, growth has resulted in little or no poverty reduction.[15]

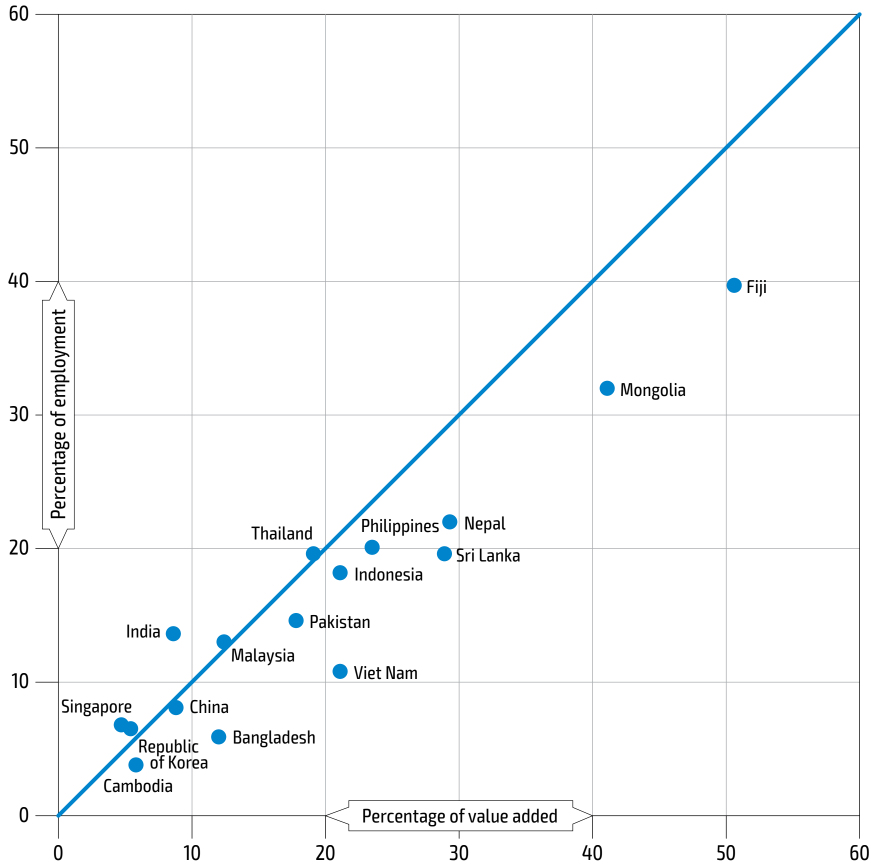
Hidden cities

Africa's urban population increased to 454 million in 2019, from 58 million in 1970.[16] However, official data mask important developments in the distribution of urban agglomerations. According to a recent OECD study, 97 percent of Africa's urban areas have fewer than 300 000 inhabitants.[17] The study also reveals the existence, in rural areas, of hundreds of urban agglomerations that are not recorded in official statistics. The extent of this phenomenon is striking and does not only concern small towns or the suburbs of big cities, but affects agglomerations of all sizes, some having more than 1 million inhabitants!

According to the above-mentioned study, "the extent of in-situ urbanization across Africa also challenges the influence still attributed to rural exodus and residential migration in driving urban growth". In fact, in many current urbanization hotspots, the absence (or weakness) of rural migration drives the growth of rural agglomeration as the failure of successful economic transformation discourages rural migrants from moving to cities. *In situ* urbanization without industrialization can either be successful in raising living standards and stemming premature migration to large cities or can fail and generate "rurban" pockets of poverty.

Interactions between rural and urban areas are an important ingredient of successful structural transformation.[18] As agrifood systems expand, opportunities should arise in food transformation, processing, distribution and retail activities. New technologies should increase agricultural productivity and food availability, and reduce the cost of food for a growing urban population. This change could turn into an opportunity for small farmers or small- and medium-sized enterprises if they are supported to become involved in the collection, processing, transport or distribution of agrifood products, if constraints to commercialization faced by (especially) small-scale producers are alleviated, and if access to new technologies is made easier for them. However, the Asian and Pacific experience suggests that the development of agro-industries offers relatively less employment opportunities, as they are less labour-intensive than other industries[19] (see Figure 1.7).

Figure 1.7 Share of food and beverages employment in manufacturing employment and share of food and beverages value added in manufacturing value added for selected Asia and the Pacific countries (2011)



Note: Line in figure is a 45-degree line.

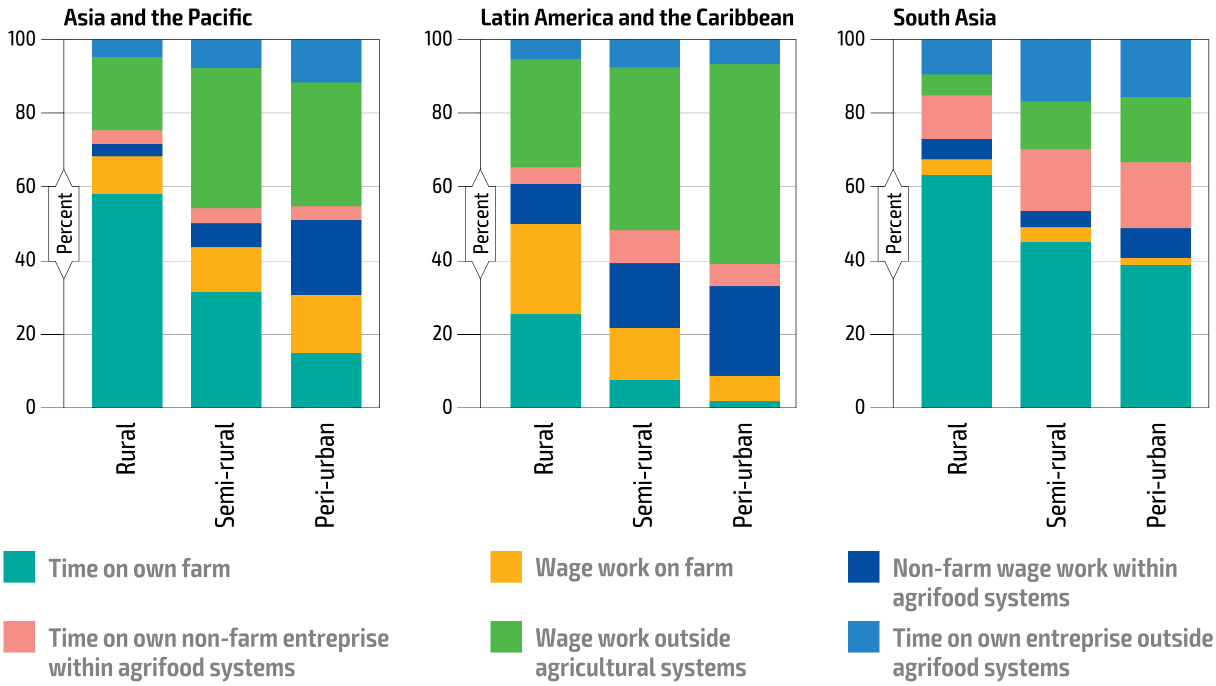
Source: FAO. 2018. *Dynamic development, shifting demographics, changing diets.* Bangkok. www.fao.org/3/I8499EN/i8499en.pdf

In urban areas, economies of scale, increased demand for higher value domestic agrifood products (see Table 1.6) and the development of industries and services, create opportunities for more income and employment for rural migrants, and a market for agricultural producers.

Structural transformation and employment opportunities for youth. Migration flows from rural areas towards urban centres are particularly important for rural youth (aged 15 to 24 years) seeking employment outside agriculture. Migration patterns are highly influenced by the availability of decent opportunities, which themselves are affected by the degree of structural transformation of a country's economy and exogenous factors, including stability, existence and access to resources, and the quality of public goods and services. Globally, 72 percent of the rural youth in LMICs live in countries with low levels of rural transformation (defined as agriculture value added per worker below USD 1 530).[20] Around 88 percent of the world's 1.2 billion young people (aged 15 to 24 years) live in LMICs, predominantly in rural areas. They spend more than half of their working time on farming (see Figure 1.8), with some disparity across regions. More than one out of five of them is not in employment, education or training, with girls being more likely to be unemployed than boys. Globally, youth makes up 23.5 percent of the working poor,[21] and more than half live in LMICs in Asia, and 18 percent in Africa.

The International Labour Office (ILO) highlights that young people are more likely to work in less secure, often informal, lower-wage employment with limited legal rights, social protection or representation. Youth, and more specifically young women, are overrepresented in sectors most impacted by the COVID-19 pandemic (wholesale and retail trade and repair, manufacturing, rental and business services, and accommodation and food services).[21]

Figure 1.8 Distribution of working time of urban, semi-rural and rural youth by region (various years)

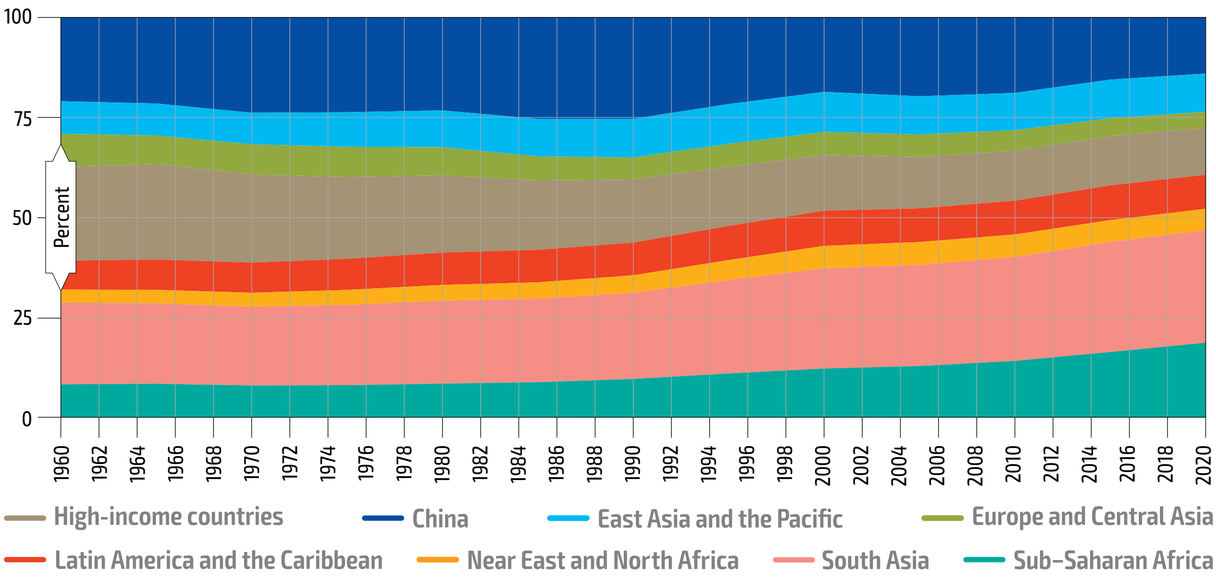


Note: Based on household surveys carried out in 12 countries in various years.

Source: Arslan A., Tschirley, D.E. & Egger. E.M. 2021. Rural Youth Welfare along the Rural-urban Gradient: An Empirical Analysis across the Developing World. *The Journal of Development Studies*, 57(4): 544–570. https://doi.org/10.1080/00220388.2020.1808197

Figure 1.9 shows that almost half of the world's youth in 2020 lived in SAS and SSA, where structural transformation has been slowest and where agriculture still constitutes a high share of GDP, compared to other regions. In these regions, young people find themselves in a situation where in rural areas, agricultural productivity is low, while other sectors, in urban areas, do not offer them good job opportunities.

Figure 1.9 Share of youth aged between 15 and 24 years, in global youth in the same age range by region (1960–2020)



Note: Data available every five years.

Source: Authors' elaboration based on United Nations. 2019. *World Population Prospects 2019, Online Edition. Rev. 1.* Department of Economic and Social Affairs, Population Division. New York, USA. Cited 10 June 2022. https://population.un.org/wpp/Download/Standard/Population

Urbanization and food systems transformation

Urban diets tend to rely on an increasingly narrow base of staple grains, as well as on a greater consumption of animal sourced foods, oils, salt, sugar and processed foods. Obesity and overweight prevalence are found among both the richer and the poorer urban dwellers, as the latter consume inexpensive processed foods high in calories and low in nutritional value. Although healthy diets are more affordable in urban areas because of higher incomes and despite often higher food prices, the urban poor (such as slum dwellers) frequently lack physical and economic access to healthy diets. Moreover, urban expansion is typically advancing at the expense of agricultural land, forests and biodiversity.[22] These, among others, are the reasons why urbanization transforms food systems.

Urbanization changes dietary patterns. Table 1.6 depicts the differences between consumption patterns in rural and urban areas. First, urban households spend much more per person than rural households. This reflects the fact that, regardless of the country income group or the level of household income, the share of urban households' consumption is always higher than their demographic share of total population, probably as a result of their higher levels of income and the importance of home consumption in rural areas.

Table 1.6 Differences in consumption expenditure between rural and urban areas (2010)

INDICATOR	ALL COUNTRIES	COUNTRY INCOME GROUP			HOUSEHOLD GROUP	
		Low-income	Upper-middle-income	High-income	Lower-income	Upper-income
Per capita spending (USD PPP)	1 645	738	983	2 703	639	3 197
Rural households	916	636	719	1 378	603	2 203
Urban households	2 628	1 044	1 444	3 800	751	3 593
Urban share of population (%)	42.6	25.1	36.4	54.7	23.9	71.5
Urban share of spending (%)	68.0	35.5	53.4	76.9	28.0	80.4
Non-food goods and services	73.4	43.5	60.5	79.3	30.9	82.5
Food and beverages	59.4	29.6	45.8	72.1	25.6	76.1
Cereals and roots	40.8	21.7	35.9	62.5	23.1	63.6
Fats and oils	52.7	36.7	44.2	66.5	26.5	72.5
Fruits	64.5	36.1	51.7	72.1	24.3	77.0
Vegetables	57.1	26.4	43.6	72.6	26.3	76.4
Meat and eggs	66.0	36.0	53.9	71.3	26.2	77.4
Milk and dairy	58.4	26.0	45.6	77.4	25.7	77.5
Fish and seafood	59.3	44.6	46.8	69.1	26.7	75.2
Sugar and confectionary	49.8	36.3	40.6	64.3	24.4	69.1
Bread and baked goods	72.6	65.3	59.5	78.1	41.6	80.6
Other foods	56.9	26.5	44.6	69.2	24.4	74.7
Beverages	67.1	36.4	58.4	72.8	28.2	78.0
Restaurants and vendors	74.0	40.8	65.4	77.0	28.0	82.7

Notes: Data refer to 2010. The sample used comprises 77 countries; 2015 population coverage is 85 percent for low-income countries, 91 percent for lower-middle-income countries and 80 percent for upper-middle-income countries. The table uses official urban definitions. Households are grouped across countries based on the average level of per capita consumption spending, including consumption of self-produced food. The lower-income household group spends less than USD 2.97 per person/day after adjusting for 2005 purchasing power parity (PPP); the upper-income household group spends more than USD 2.97.

Source: Dorosh, P.A. & Thurlow, J. 2021. Agricultural growth, urbanization, and poverty reduction. *In* K. Otsuka & S. Fan, eds. *Agricultural development: New perspectives in a changing world.* Part III, Chapter 9, pp. 285–320. Washington, DC, IFPRI.

This is also true for their consumption of food and beverages. This implies that, provided urban populations consume locally produced food, their demand for food can be a major source of demand for local agriculture and thereby generate important linkages between urban and rural areas.

A detailed analysis reveals that the only food category for which urban households consume less than their demographic share is "cereals and roots", i.e. staple food. They consume a great deal more in other food and beverage items, the differential being highest for restaurants and vendors, bread and baked goods, beverages, meat and eggs, and fruits. This is true for all countries, even for LMICs.

In other words, urbanization does not only increase overall demand for food, but it also changes the composition of demand and, as a result, has the potential to impact the structure of national food systems.[23] The large share of urban consumption in total food consumption means that shifts in urban diets and urban demand for food have the potential to transform the food system.

Informal and traditional food outlets have an important function in cities. Informal markets are an essential part of food systems and are crucial for the sale of a variety of fresh produce, especially in low-income areas of LMICs.[24] They ensure the physical availability of diverse and traditional fruits and vegetables that are not found in supermarkets and are often the preferred outlets of poorer people because of price and proximity.[25]

Traditional food stalls, which are mostly informal, tend to be takeaway food outlets and/or sites for dining, and they have been known to sell ultra-processed foods. Despite their instability and the lack of protection for their workers, traditional and informal outlets are a source of employment for the most vulnerable population groups, particularly women. The main challenges related to these informal facilities concern the compliance with food safety and quality standards, and the availability of an appropriate policy and institutional framework facilitating business through clear rules, standards and commercial protocols. Their operations require access to public infrastructure, such as roads and electricity networks, and innovation in primary processing, packing and transportation.[26]

Traditional and informal markets and food stalls coexist in urban areas with supermarkets which have expanded rapidly around the world over the last century, and more recently in LICs. Evidence shows that supermarkets sell food items that appeal to the poor,[27] and that their prices for processed foods can be lower than those of traditional shops.[28] Low-income customers are buying food in supermarkets attracted by cheap, time-saving processed foods,[29] while prices of fruits and vegetables sold in local municipal markets and traditional wholesale markets remain usually lower than those in supermarkets.[25]

Shifts have also been occurring in urban settings towards consumption of food away from home as seen by the spread of independent restaurants and fast-food chains. For both retail and food services, the most recently appeared means of purchase is e-commerce.[30]

The main consequences of all these changes include the replacement of jobs in traditional and informal markets by new formal employment opportunities in supermarkets, particularly for women, that lead to often precarious and poorly paid jobs; a possible exclusion of smallholders from the dynamic markets of metropolitan cities; and a greater availability, access and consumption of ultra-processed foods, with well-known deleterious health implications for consumers (see Section 1.13).

Urbanization is a multifaceted process. There is great diversity in urbanization patterns in terms of size and distribution of agglomerations and socioeconomic outcomes. In 2018, 58 percent of the world population lived in cities with fewer than 1 million inhabitants, while one in eight people (or 12.5 percent) resided in 33 megacities with more than 10 million inhabitants. In 2020 close to 45 percent dwelled in settlements with fewer than 5 000 000 inhabitants (see Figure 1.10).

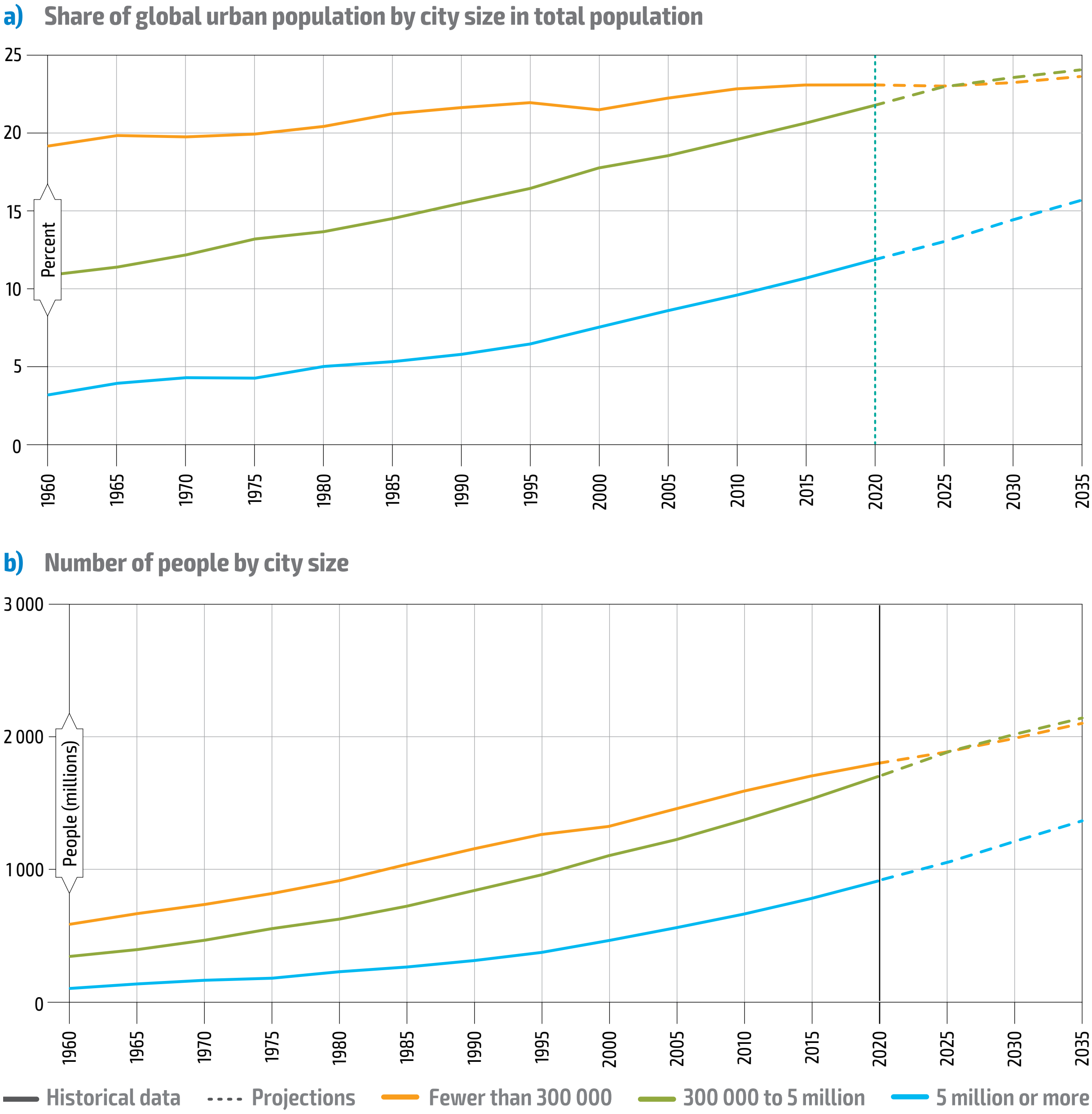
While some people in LMICs live in the rural hinterland (remote, sparsely populated areas), the bulk of them are close to an urban centre.[d] The latter are estimated to constitute between 75 percent and 85 percent of world rural population or between 2.5 and 2.8 billion people.[31]

New evidence challenges the centrality of large cities in urbanization and development, as one-fourth of the global population lives in peri-urban areas of intermediate and smaller cities and

[d] Less than one percent of global population lives in isolated hinterlands.

towns. In LICs, 64 percent of the population lives in small cities and towns or in their catchment areas, with major implications for access to services and employment opportunities, as well as for policies and investments for strengthening linkages between these centres and their hinterland.[32]

Figure 1.10 Global urban population by city size: historical (1960–2020) and projected (2021–2035)



Source: United Nations. 2018. *World Urbanization Prospects: The 2018 Revision, Online Edition.* Department of Economic and Social Affairs, Population Division. New York, USA. Cited 18 May 2022. https://population.un.org/wup/Download

Rural–urban linkages

The rural–urban dichotomy does not appear to be an adequate axis with which to understand recent evolution of food systems. It has modified the relationship between urban and rural areas: the borders between the two are increasingly blurred and they are becoming more interdependent. There is some degree of continuum between rural areas and the various urban agglomerations made of small, intermediary and large cities.

In LICs, for example, rural–urban connections are strengthened by regular seasonal population flow from rural to urban environments and vice versa. In many African countries, rural–urban migration cannot be considered as a one-time relocation of all members of a household.

Circular migration or reorganization of households as multilocal units with members living and working in different locations, often across rural–urban boundaries, is an important strategy for reducing vulnerability, improving access to services (e.g. education and health care) and for diversifying sources of employment.

A food systems perspective highlights the critical linkages between urban and rural areas. Many activities that are part of agricultural value chains are frequently set within or close to towns (e.g. processing, storage and retail facilities). This is particularly the case for small cities and towns, but also for peri-urban areas of medium and large cities. Similarly, there are agricultural activities, especially the production of perishables, that are located near towns.

Intermediary cities play a primary role in providing basic facilities and services to rural areas. They may offer opportunities to rural people seeking employment or act as a step towards migration to large cities. They also act as regional market centres or hubs, connecting traders and producers with customers and markets in larger metropolitan areas. Intermediary cities could even play a greater role in food systems by hosting farmer markets, agroprocessing units, farm equipment and inputs centres, and other food and agriculture-related facilities, thus stimulating agricultural production in surrounding areas and offering employment opportunities.

This means that whoever is concerned with the future of food and agriculture will need to consider rural and urban areas as an integrated whole.

1.1.4 Future trends

Population

The United Nations project world population to reach 9.8 billion people by 2050, in their medium variant and estimate, with a certainty of 95 percent, that the size of the global population will be between 9.4 and 10.1 billion in 2050.[5,33]

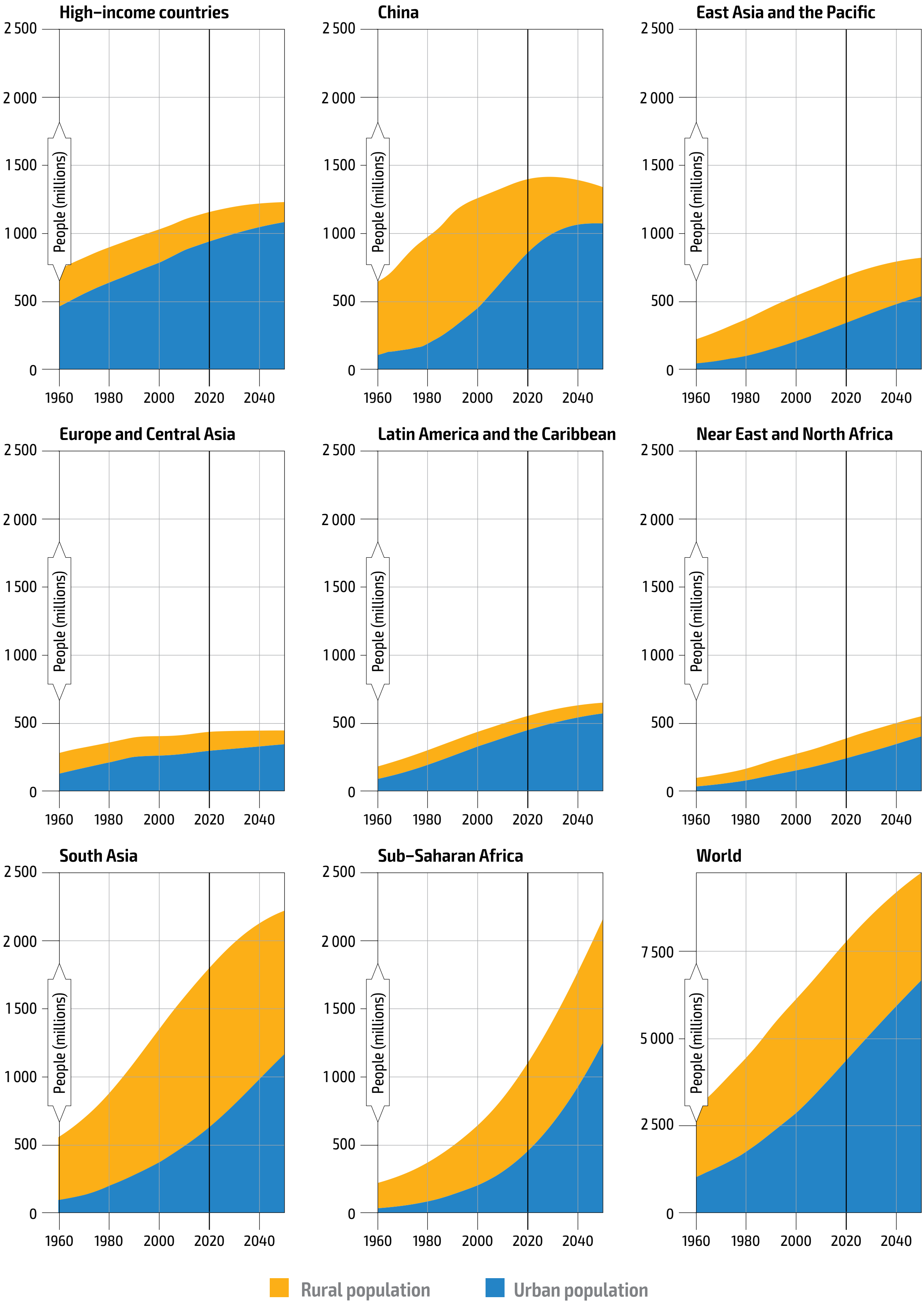
Figure 1.11 illustrates how population is projected to evolve in the various regions considered in this report and the global level. China, HICs and ECA clearly show a stabilization of population, and even a reduction in the case of China. In contrast, demographic growth is expected to continue to be quite dynamic in SSA and in NNA, with other regions following an intermediate path. By 2050, SAS is projected to reach a total population of almost 2.3 billion people, with SSA very close to this mark. Meanwhile, China would see its population fall a few tens of millions below what it is currently.

In all parts of the world, urbanization is foreseen to continue, population in rural areas being projected to account only for little less than one-third of the total population by 2050. By then, SAS would be the region with the highest proportion of rural people, in part as a result of the specific type of *in situ* urbanization occurring there (see Box 1.1), followed by SSA, both with more than 40 percent of their populations living in rural areas. In contrast, rural population would be reduced to hardly more than 10 percent in HICs and in LAC.

Food consumption

In *The future of food and agriculture – Alternative pathways to 2050*,[33] FAO projects food consumption according to three scenarios in which daily energy consumption in kcal/person/day would, by 2050, stand at between 2 810 kcal/person/day and 2 940 kcal/person/day, as compared to 2 779 kcal/person/day in 2012.

Figure 1.11 Urban and rural population by region: historical (1960–2020) and projected (2021–2050)



Note: Projected population refers to the United Nations medium variant projection.

Source: Authors' elaboration based on United Nations. 2018. *World Urbanization Prospects: The 2018 Revision, Online Edition.* Department of Economic and Social Affairs, Population Division. New York, USA. Cited 18 May 2022. https://population.un.org/wup/Download

1.1.5 Summary remarks

The world's demographic centre of gravity has been shifting to LICs and urban areas. World population has been ageing, creating in many countries the issue of old-age dependency.

The provision of employment to youths is a major challenge now and it will be in the future, particularly in regions such as SSA, where the development of industries and services is not taking place fast enough to offer jobs to new urban dwellers.

Population growth remains a major factor contributing to an increased demand for food, while urbanization impacts on food systems by changing diets and intensifying rural–urban linkages.

There is a lot of inertia in the evolution of population growth, structure and dietary requirements. This is probably one of the domains dealt with in this report about which there is comparatively less uncertainty.

For consumption, there could be a shift towards more sustainable and healthy diets, although this would mean reversing the tendency observed as a result of urbanization.

Regarding urbanization, one of the main issues for the future is whether SSA will or will not be able to accelerate the development of non-agricultural activities and generate jobs in urban areas, as, for the time being, urbanization has been advancing there without a commensurate reduction of the relative importance of agriculture in the economy and strong growth in other sectors.

The growing importance of small- and medium-sized cities and the concentration of population in peri-urban areas or areas, along with the parallel developments in technology and communications, will increase the size of the catchment areas of cities where larger investments in agrifood systems will be required.

Migration to megacities is not unavoidable: towns, and small and intermediate cities could become hubs for downstream agrifood system activities, provided policy and public investment catalyse the establishment of agro-industrial zones and the adoption of productivity-enhancing innovations.

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1.2 Economic growth, structural transformation and macroeconomic stability (Driver 2) [e]

Economic growth and macroeconomic stability do not always deliver their expected results in terms of inclusive socioeconomic transformation of societies. Transformation processes of agrifood systems are closely tied to structural transformation of socioeconomic systems at large, and their macroeconomic stability. Economic growth and economy-wide structural transformation is at the same time a result and a driver of agrifood transformation processes. A recent World Bank report suggests that economic growth is an important driver of poverty reduction.[2] However, poverty reduction only materializes if the gains of economic growth are shared across social strata. Sub-Saharan Africa (SSA), for instance, which was expected to undergo the economic transformation that has already been experienced elsewhere, still awaits substantive economic transformation in spite of the very high economic growth experienced in the last two decades. As stated in a recent report from the United Nations Conference for Trade and Development (UNCTAD):

> "If the current policy stances continue, the global economy from here to 2030 will face slower growth and higher instability. As labour shares across the world continue on their decreasing path, household spending will weaken, further reducing the incentive to invest in productive activities" (UNCTAD, 2019, p. 56).[3]

The outbreak of the COVID-19 pandemic further added to the already existing macroeconomic imbalances of several countries. A recent United Nations report highlights that "while the global shift towards more accommodative monetary policies has eased short-term financial market pressures somewhat, long-term fault lines create significant uncertainty".[4]

The narrative of the shift of labour out of agriculture and into higher productivity economic activities that bring higher wages, growth and well-being, is the conventional wisdom regarding structural transformation and development. Yet, this interpretation faces two deep problems today: first, the benefits of the transformation are failing to materialize for many low-income countries (and people), thus revealing its social unsustainability; and second, economic activities, specifically in today's high-income countries, are unsustainable on environmental grounds. From an ecological economics perspective, this implies that, at some point, growth cannot remain an intrinsic goal.

This section sheds some light how agrifood systems have transformed over the past as a result of linkages with the broader economic system, and how those mutual relationships may evolve in future. To address this rather broad topic, some key questions can help guide the more in-depth investigations:

- Is it legitimate to assume the dynamics and linkages between agriculture and the broader economic systems in currently high-income countries (HICs) are necessarily paradigmatic for currently low- and middle-income countries (LMICs)?
- How do patterns of saving and investment affect agricultural capital, land ownership and natural re-source use across countries? And how do those different patterns of ownership and use influence the structural transformation of economic systems?
- Under which conditions, and to what extent, might external deficits influence growth processes and agrifood systems?
- To what extent, and in what ways, can endogenous growth processes in LMICs be triggered by domestic processes and/or have to rely on external relationships and funding?
- To what extent may the way in which gross domestic product (GDP) is currently measured, e.g. excluding many environmental costs, provide misleading signals to decision-makers about the potential for further growth?

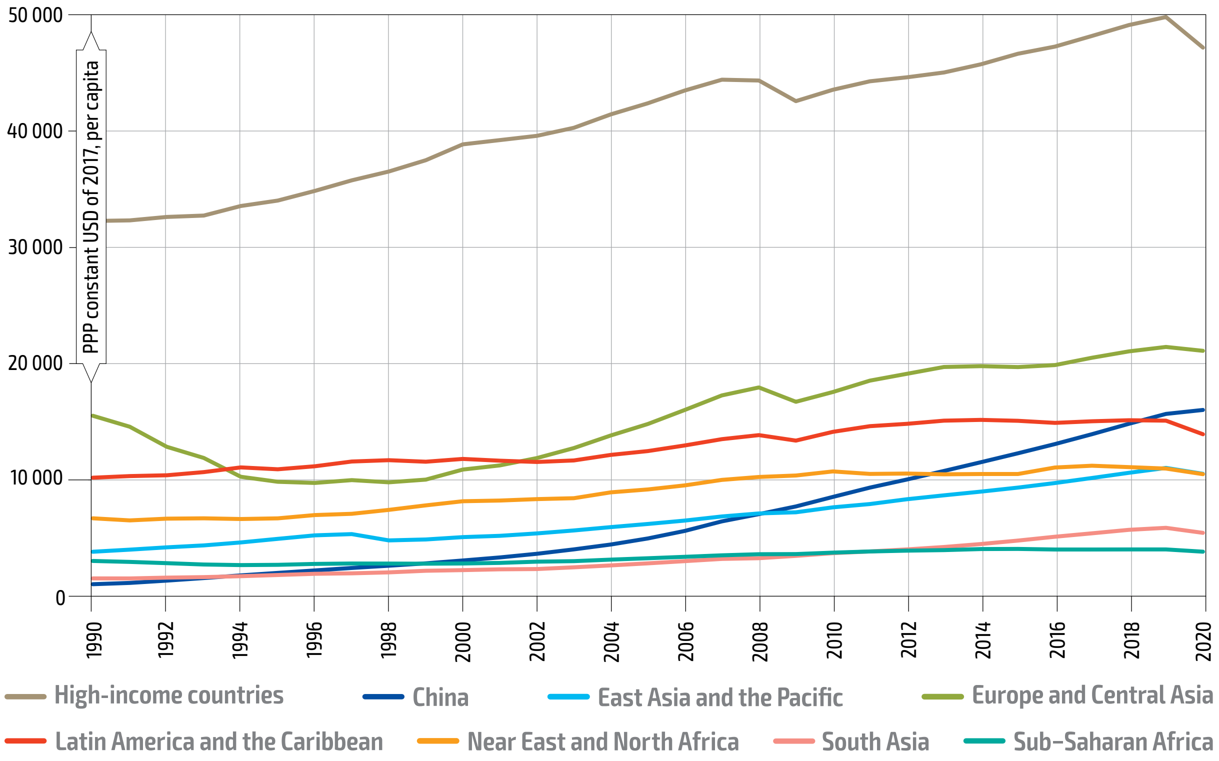
[e] This section partially draws from Kemp-Benedict (2021).[1]

After providing selected facts and figures that help contextualize agriculture within the broader socioeconomic setting, this section provides a secular retrospective on the relationships between agriculture and economic growth. This allows for a discussion around the conventional wisdom that traditionally sees upward shifts of agricultural productivity as an engine of growth. The analysis of the interactions between HICs vis-à-vis LMICs, regarding asset ownership and financing, further contributes to highlight how the global setting influences the role of agriculture within the broader socioeconomic context. A traditional, but still prominent, wisdom about development considers the so-called "developing" countries engaged in a catching-up exercise with the so-called "developed" ones. However, as the "developed" countries are moving along a pattern that is undoubtedly not sustainable for a wide variety of reasons, this section could not omit providing some elements to help place economic growth in an ecological perspective. The section closes with a short discussion of some signals that may reveal possible futures.

1.2.1 Economic growth and agricultural transformation: new emerging patterns?

In the last three decades, the world has been characterized by stark economic differences across groups of countries. Figure 1.12 shows average GDP per capita in purchasing power parity (PPP) terms by region.

Figure 1.12 GDP per capita at purchasing power parity by region (1990–2020)



Note: Purchasing power parity (PPP) at constant USD of 2017 USD refers to USD at constant prices of 2017 converted into a virtual currency unit that reflect the purchasing power in a specific country of a USD converted in local currency.

Source: Authors' elaboration based on World Bank. 2022. DataBank | World Development Indicators. In: *World Bank*. Washington, DC. Cited 4 June 2022. https://databank.worldbank.org/source/world-development-indicators

Despite the decline in GDP per capita in HICs after the 2007–2008 financial crisis, and the impressive growth in middle-income countries, particularly China and India in the 2000s, the gap among regions remains extremely wide. There is little evidence of convergence between LMICs and HICs. SSA appears to be in a desperate condition as there is no sign of growth in per capita terms.[f]

[f] In the figure also the strong decline in Europe and Central Asia after the collapse of the Soviet Union and the 1997 East Asian financial crisis are evident.

Exploring the so-called "stages" of growth. Traditionally, all these "developing" countries have been considered to be at an earlier stage of development compared to "developed" ones. In fact, according to this traditional wisdom, economic growth progresses through stages. From traditional societies, characterized by a high share of value produced and labour force employed in agriculture, countries transition to an economy in which the manufacturing and services sectors become prominent, with lower levels of employment in agriculture, and with a specialized labour force and greater reliance on technological processes. Intermediate stages involve a structural transformation across all economic sectors, including agriculture. Agricultural productivity increases, farms shift from multi-cropping to single crop production, become larger, more specialized, export-oriented and integrated into markets, adopting modern agricultural technologies and enjoying economies of scale. Farmers who stay in agriculture earn higher incomes, while others move away from rural areas and take higher-paying jobs in other sectors.[5,g]

Whether this traditional perspective can still guide an understanding of the ongoing economic dynamics in LMICs relative to HICs, and could still be adopted as the guiding principle in identifying strategic options for sustainable growth, has been questioned:

> "There is a strong and persistent representation in development thinking that this is a 'universal' pathway for agricultural development. But […] some key countries strongly differ in their development trajectory from the 'classical pathway'. Does it mean that they are underperforming? Or just that they are following a more adequate trajectory to their particular circumstances with respect to food security and sustainable economic development?"
> (HLPE, 2013, p. 57).[7]

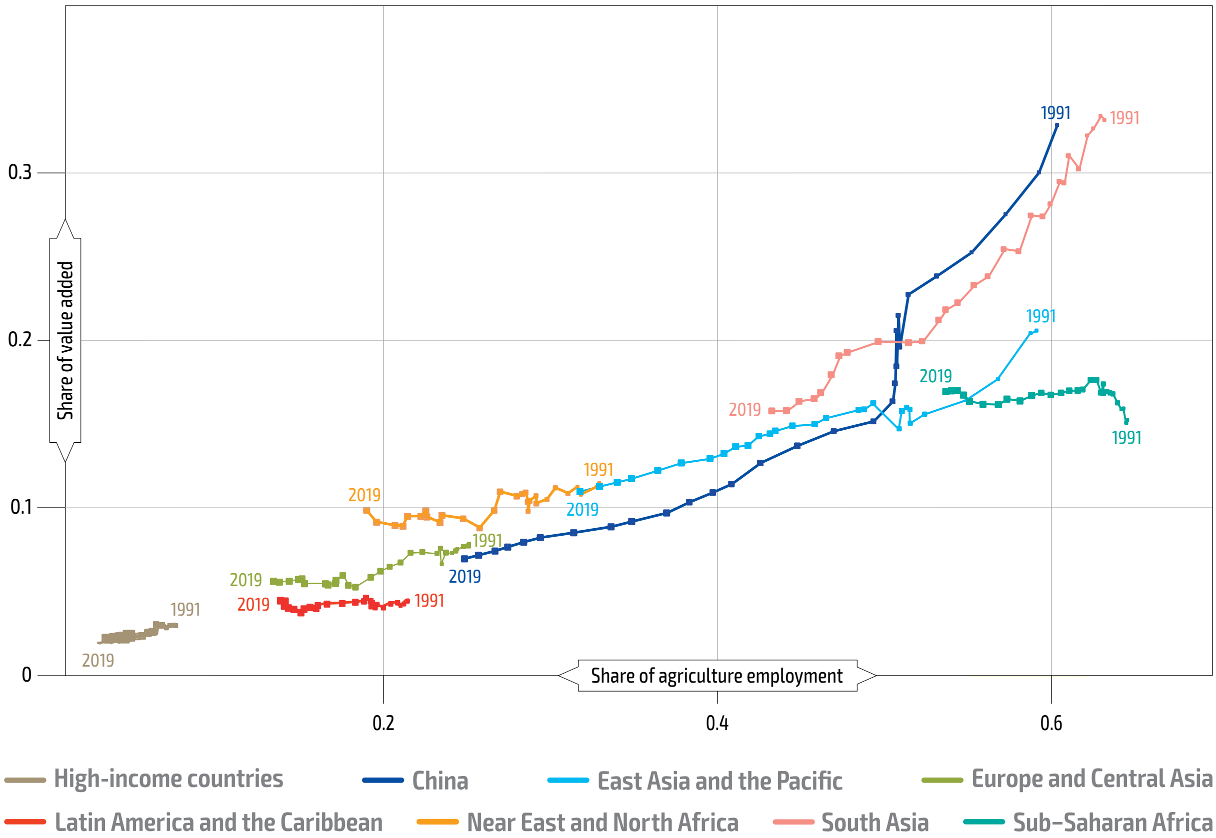
In fact, many LMICs are following long-term patterns that, at least in some respects, seem to diverge from this stage-by-stage paradigm.[8]

In many LMICs, the average farm size has been definitely decreasing in recent decades, shrinking, between 1960 and 2010, from 2.9 to 1.6 hectares in SSA, 2.6 to 1.4 in South Asia (SAS), 7.7 to 3.6 in Near East and North Africa (NNA) and from 70.4 to 39.8 in Latin America and the Caribbean (LAC). This contrasts with the average size increase in HICs from 39.8 to 53.7 hectares.[9,10] Moreover, a divergence from the conventional pattern is also reflected in the wage gap between agriculture and other sectors, the so-called "urban premium", which in recent decades has not shrunk globally, while showing a dramatic increase in SAS and East Asia and the Pacific (EAP), and decreasing only slightly in SSA.[10]

Furthermore, in the last thirty years, the share of agriculture value added in GDP has not decreased in LAC while some per capita GDP growth is observable, and has barely decreased in NNA and ECA where, analogously, there has been some per capita growth (see Figure 1.12 and Figure 1.13). SSA is definitely following a different pattern, showing an increase of the share of agriculture associated with an almost constant per capita GDP (see Figure 1.13).

[g] According to this wisdom, the so called "developing" countries, are considered at an earlier or lower stage of development relative to "developed" ones.[5] In line with Rostow's model, "[…] theorists emphasized increased savings and investment as the key to development and argued that international trade in products particularly suited to national factor endowments would enable more efficient resource allocation and greater earnings, and these could be translated into savings and then used to promote development. By disseminating technology, knowledge, managerial skills, and entrepreneurship; encouraging capital inflow; stimulating competition; and increasing productivity, foreign trade, together with foreign investment and aid, would be the engine of growth for developing countries".[6] Although this wisdom has been heavily criticized by other schools of thought, such as the "dependency theory" or "world systems theories", it still has some influence on development strategies globally.

Figure 1.13 **Share of agricultural value added in GDP and the share of agricultural employment (1991–2019)**



Note: Value added (agriculture, forestry and fishing) and GDP are both expressed in constant USD of 2015.

Sources: Authors' elaboration. Employment based on ILO. 2022. Employment statistics. In: *ILO*. Geneva. Switzerland. Cited 4 May 2022. https://ilostat.ilo.org/topics/employment; value added (agriculture, forestry and fishing) and GDP based on FAO. 2022. Macro Indicators. In: *FAOSTAT*. Rome. Cited 8 May 2022. www.fao.org/faostat/en/#data/MK

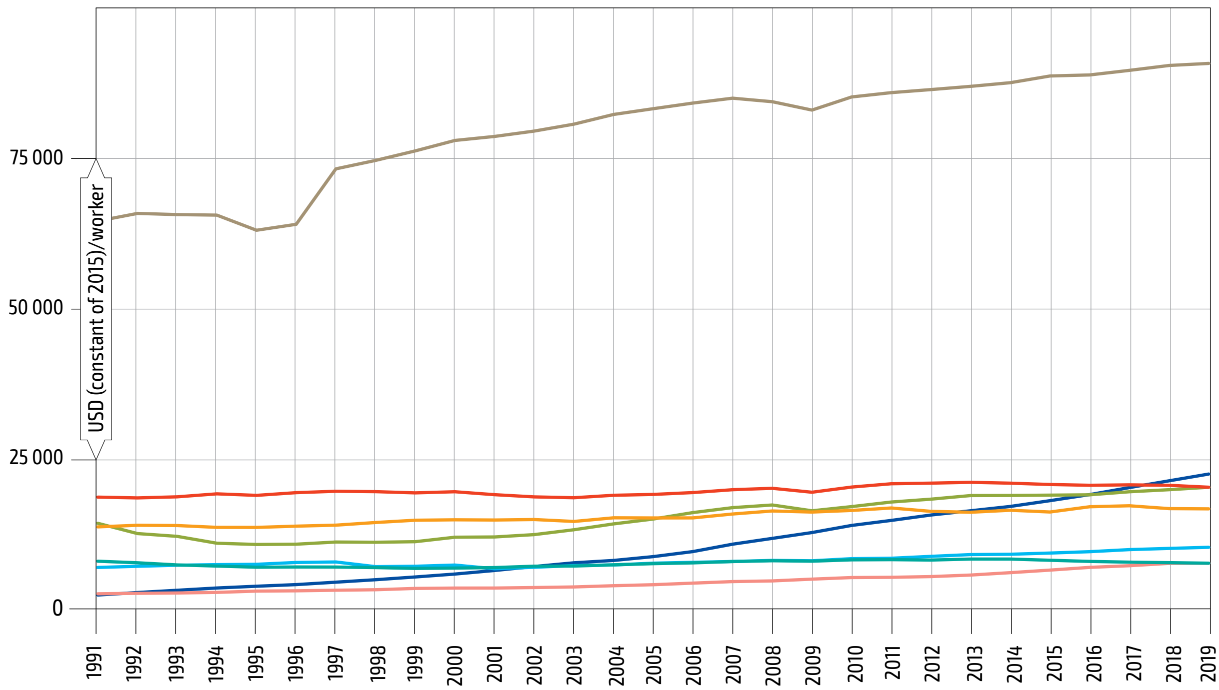
Furthermore, while in the last thirty years, proportionally, labour has left the agricultural sector for manufacturing and services almost everywhere (Figure 1.13), in LMICs, labour productivity in these sectors has remained almost constant, while it expanded during the structural transformation in HICs. Indeed, labour productivity in the rest of the economy has almost stagnated in SSA, LAC and EAP, while it has barely increased in SAS and NNA (see Figure 1.14a). In those regions, in contrast, agricultural labour productivity increased compared to the rest of the economy (see Figure 1.14b). While this may not be an issue as such since development processes may entail faster productivity growth in one sector compared to another, the question is what sector can deliver sustained productivity growth while absorbing labour. Agriculture may not be suitable for that in the long run.

It is interesting to note that despite a decrease in percentage terms, the share of employment in agriculture has dramatically increased in most LMICs relative to HICs: in the 1990s, it was around ten times that of HICs, and is currently ranging between fourteen and twenty times that of HICs depending on the LMICs region (Figure 1.15), thus signalling diverging long-term relative dynamics of employment in agriculture for LMICs in comparison to HICs.

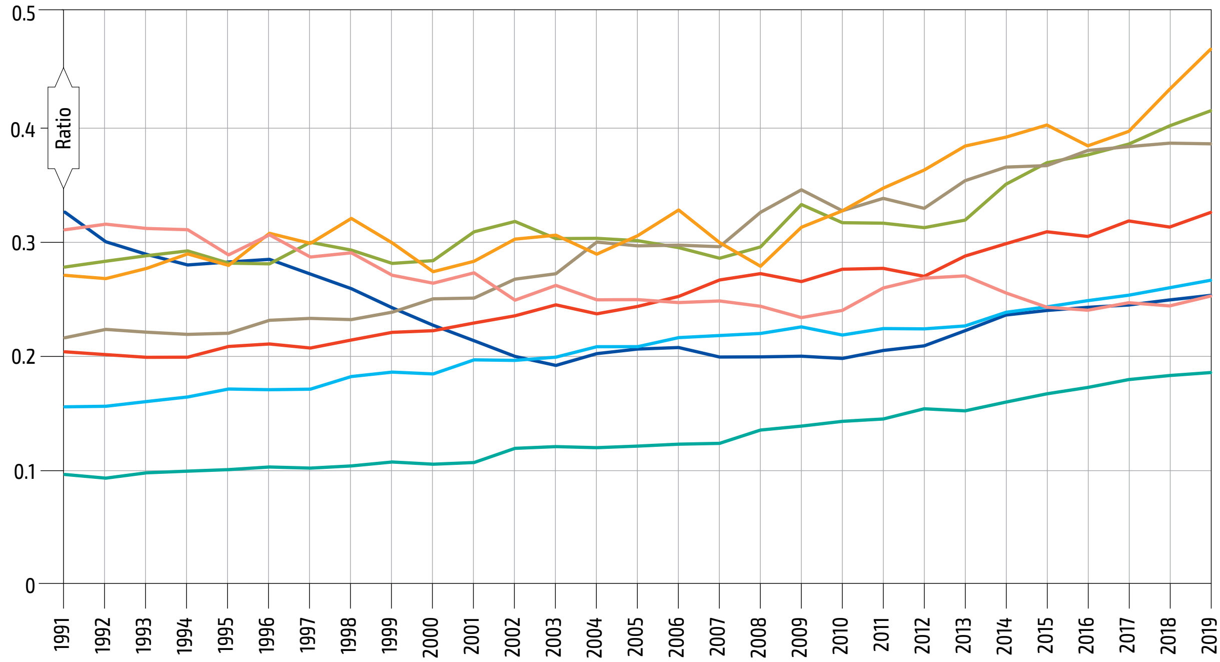
Overall, some of the macroeconomic facts highlighted above, such as the concurrent increase of agricultural value added in GDP associated with a stagnant per capita GDP in SSA, could simply signal that the traditional growth pathway is idle. However, other facts may reveal the concurrence of different country-specific agricultural development models that range from the progressive marginalization of smallholders in search of possible jobs in other sectors to the central role of smallholders in providing highly valued environmental services.[7]

Figure 1.14 Labour productivity in the rest of the economy and in agriculture relative to the rest of the economy by region (1991–2019)

a) Labour productivity in the rest of the economy



b) Labour productivity in agriculture relative to the rest of the economy

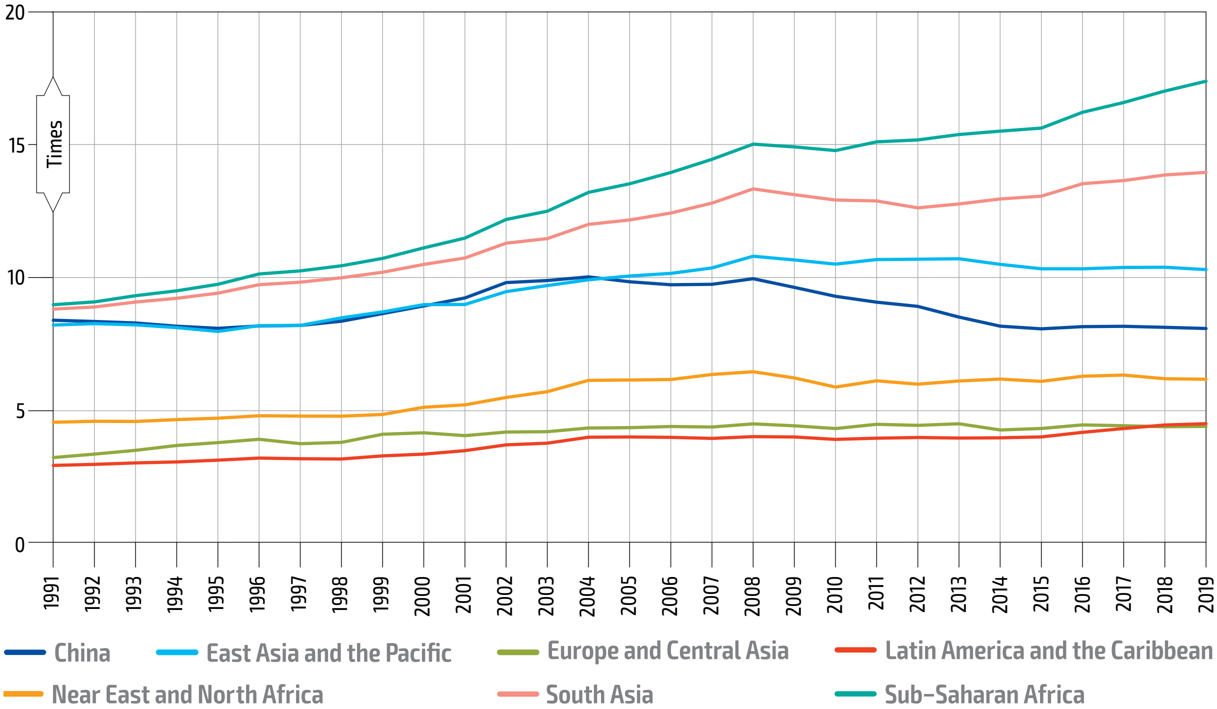


High-income countries; China; East Asia and the Pacific; Europe and Central Asia; Latin America and the Caribbean; Near East and North Africa; South Asia; Sub-Saharan Africa

Note: The expression "rest of the economy" indicates values of indicators related to the total economy minus those relating to the agricultural sector.

Sources: Authors' elaboration. Employment based on ILO. 2022. Employment statistics. In: *ILO*. Geneva. Switzerland. Cited 4 May 2022. https://ilostat.ilo.org/topics/employment; value added (agriculture, forestry and fishing) and GDP based on FAO. 2022. Macro Indicators. In: *FAOSTAT*. Rome. Cited 8 May 2022. www.fao.org/faostat/en/#data/MK

Figure 1.15 Share of employment in agriculture relative to the share of employment in agriculture in high-income countries by region (1991–2019)



Note: The share of agricultural employment in total employment for each region is divided by share of agricultural employment in total employment in high-income countries.

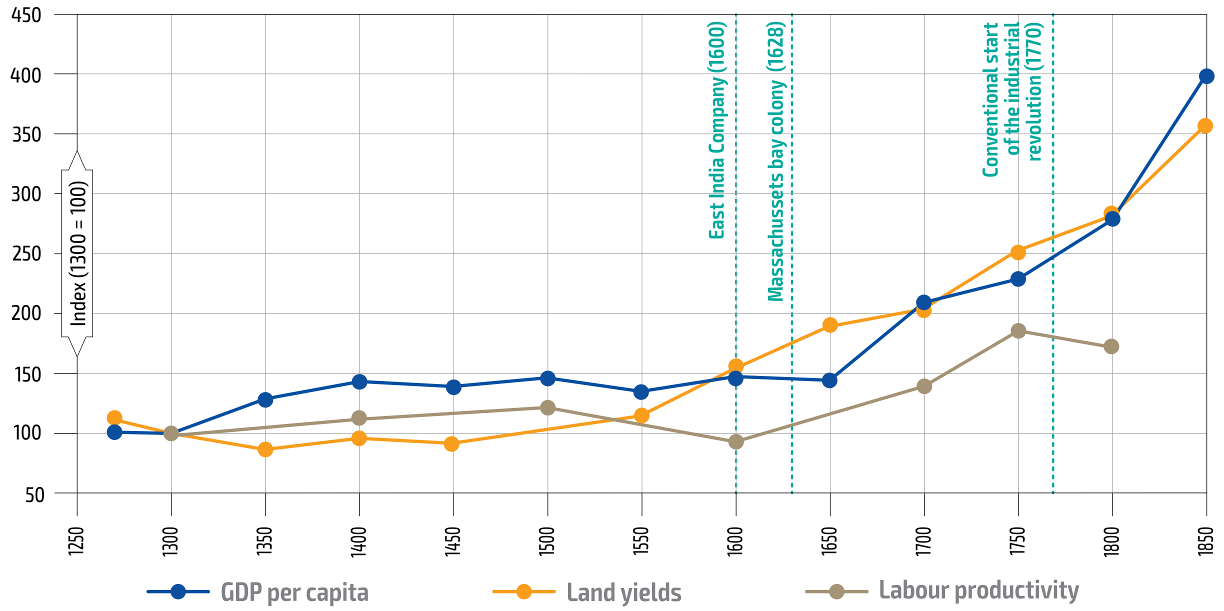
Source: Authors' elaboration based on ILO. 2022. World Employment and Social Outlook Data Finder. In: *ILO*. Geneva, Switzerland. Cited 8 May 2022. www.ilo.org/wesodata

A secular retrospective. A secular retrospective analysis of the interlinkages between economic growth and agriculture in Great Britain – a country for which multisecular time series of GDP and agriculture exist – suggests a more articulated interpretation than the simple cause-effect relationship between improved agricultural productivity and economic growth.[h] Figure 1.16 portrays a comparison between per capita GDP and agricultural productivity, expressed both in terms of crop yields and output per worker. While in some centuries, say from 1300 until around 1600, agricultural productivity improvements largely follow per capita GDP growth, and thus cannot possibly be considered its cause, in the subsequent centuries they appear to accompany a more general economic dynamic, triggered or supported by other factors. Indeed, up until 1500, per capita GDP increased despite steady land productivity and decreasing labour productivity. Between 1500 and 1600, land and labour productivity exhibit opposite trends, as if yield increases were only possible with concurrent increased labour intensity. This is also testified by a substantially stagnant total factor productivity in the same period.[11] After 1600, the economic structure progressively changed as a result of mercantilist ventures, such as the creation of the East India Company and the progressive expansion of the British Empire. In fact, these imperial ventures most likely reinforced capital accumulation and concentration processes, thereby creating a critical mass of wealth favouring research, development, investment, further economic growth and, later, the first industrial revolution. As causal relationships among historical agricultural development, development of the British Empire and industrial revolution are most probably intertwined, drawing a direct causal relationship between agricultural development and industrialization would appear to be somewhat simplistic. The fact that the growth in agricultural efficiency may indeed be a response to the development of the non-agricultural sector,[11] rather than vice versa, and that the surplus that triggered and supported the British industrial revolution was appropriated directly or indirectly

[h] The term "Great Britain" is used here as reference to a territory for which historical data exist, without any intended implication for the current setting of boundaries or denominations.

from abroad, at least partially, rather than endogenously generated,[i] tweaks the conventional narrative of the relation between agriculture and industrialization. Such an adjustment may pave the way for substantially different development strategies for current LICs.

Figure 1.16 **Economic growth and agricultural productivity: a retrospective analysis for England (pre-1700) and Great Britain (after 1700) (1270–1850)**



Note: The denominations "England" and "Great Britain" refer here to historical territories for which time series are available in historical records (see the sources below).

Sources: Authors' elaboration. GDP per capita of England (pre-1700) and Great Britain (1700 and after) based on Groningen Growth and Development Centre. 2020. *Maddison Project Database 2020.* Cited 13 June 2022. www.rug.nl/ggdc/historicaldevelopment/maddison/releases/maddison-project-database-2020?lang=en and Bolt, J. & van Zanden, J.L. 2020. *The Maddison Project Maddison style estimates of the evolution of the world economy. A new 2020 update.* Maddison-Project Working Paper WP-15. www.rug.nl/ggdc/historicaldevelopment/maddison/publications/wp15.pdf; labour productivity (output per worker) based on Allen, R.C. 2000. Economic structure and agricultural productivity in Europe, 1300-1800. *European Review of Economic History*, 4(1): 1–26. www.jstor.org/stable/41377861; land yields based on Broadberry, S., Campbell, B., Klein, A., Overton, M. & van Leeuwen, B. 2010. *British economic growth: 1270-1870.* Working Paper. Coventry, UK, Department of Economics, University of Warwick. http://wrap.warwick.ac.uk/57581

Reading the present or investigating the future using the same lenses used to read the past, may be misleading, particularly if these lenses filter out significant aspects of the reality and reinstate a simplistic view of historical facts. Indeed, it is crystal clear that the opportunities available to today's LMICs are starkly different to those that were available to the currently HICs in the eighteenth and nineteenth centuries. In part, that is a result of the prior extraction of available surplus from current LMICs through colonial expansion. That transfer of wealth shifted the starting point for subsequent wealth accumulation, as the wealth can be used either to finance the purchase of additional assets or as collateral to obtain loans.

In light of the observed trends, it is therefore doubtful that the traditional wisdom, based on a retrospective analysis of current HICs, would actually be the main and only reference to explain the present and future mutual relationships between economic growth and agriculture in LMICs. In fact, it may also be debatable whether the conventional wisdom per se might have been grounded on an oversimplification of historical facts, and the complex intersectoral and international relationships that governed them.

[i] "The empire established in the seventeenth and eighteenth centuries also contributed to growth. The greatest impact was on city size. Over half of England's urban expansion is attributed to empire in these simulations" and "Britain's growth emerged from commerce and the urbanization that it generated from the early sixteenth century. Urbanization created incentives and externalities that led to productivity growth".[11] Harley (2013)[12] on the role of the imperial system on British industrialization, states that: "There is no question that the growth of British trade and industrialization was heavily intertwined with the British Atlantic Economy of the old Imperial System and its mercantile basis. The trade of the Americas rested on the slave-produced staples of the West Indies and to a lesser extent the Southern mainland colonies."

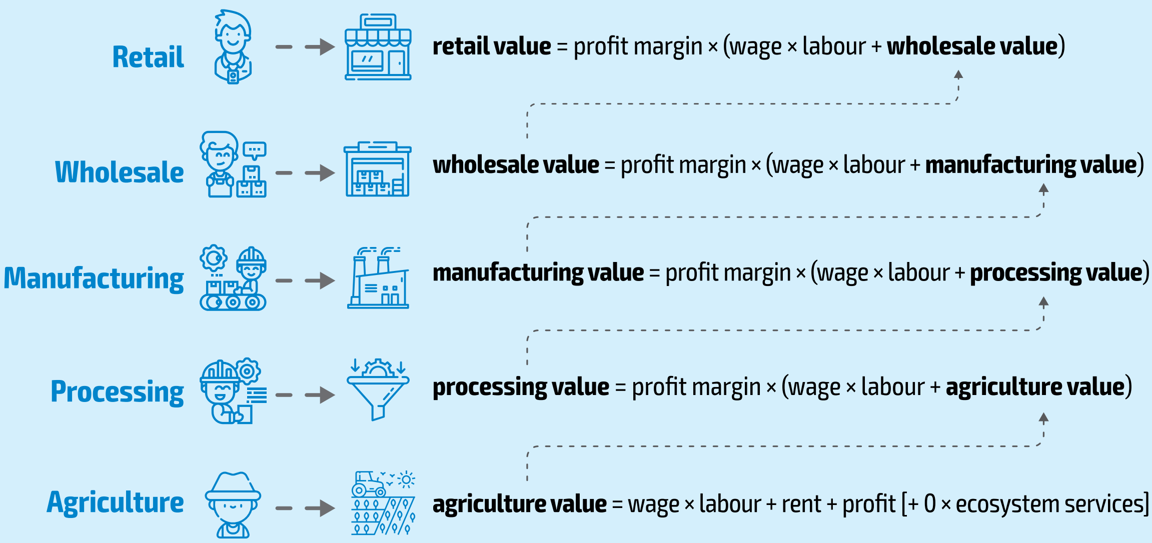
Agriculture as the foundation of the "tower of value added". Regardless of the specific role of agricultural productivity shifts in supporting economic growth, it is incontrovertible that the income of socioeconomic systems is built on primary products, including agricultural ones. Agriculture indeed acts as the foundation of the whole "tower of value added" that pertains to agrifood systems (see Box 1.3). An implication of this tower of value added, is that total value added from all stages – plus the implicit value of ecosystem services – will be much larger than the agriculture value added.

Currently, in HICs, the agricultural value added is a much smaller share of total value added compared to LMICs. In addition, its share has been declining, as economies grow, i.e. they generate more value added downstream in agrifood systems. The reasons for this are structural, as shown schematically in Box 1.3. If further layers are added downstream, e.g. restaurant services, or a single layer is expanded horizontally (for example, further food processing to produce convenience food), the proportion of agricultural value added in the total agrifood value added is diluted. The same dilution process applies if more value added is produced outside agrifood systems.

Box 1.3 The "tower of value added"

In Figure A, the agriculture value added is given by the sum of wages (unit wage times labour) plus profits and rents. This corresponds to the agricultural output value, say, of the physical quantity of commodities times the respective unit prices, net of the inputs external to agriculture, e.g. energy, agrochemicals, machinery, etc.*

Figure A. The tower of value added



Source: Authors' elaboration based on Kemp-Benedict E. 2021. *Economic growth, structural transformation and macroeconomic stability.* Background paper for *The future of food and agriculture – Drivers and triggers for transformation.* Stockholm, SEI (Stockholm Environment Institute). Unpublished.

Between the farm and the consumer lay all the other stages in the agrifood value chain. Each stage takes as an input the cost of the output from the previous stage. For downstream stages of the value chain, that input cost (plus the cost of inputs external to the value chain) adds to the cost of labour and to the profit margin, thus generating the output value of that stage.[13] Eventually, the retail value of agriculture-based products results from the piling up of value added of each stage of the value chain (plus the cost of inputs external to the value chain).

* Note that one critical input to agricultural production is not explicitly priced – the ecosystem services on which agriculture relies. Ecosystem services are therefore multiplied by zero in the figure. The procedure of ecosystem services valuation attributes the flow of rents, wages and profits to the ecosystem services on which they rely. Should ecosystem services be priced, their value would add up to determine the agricultural output.

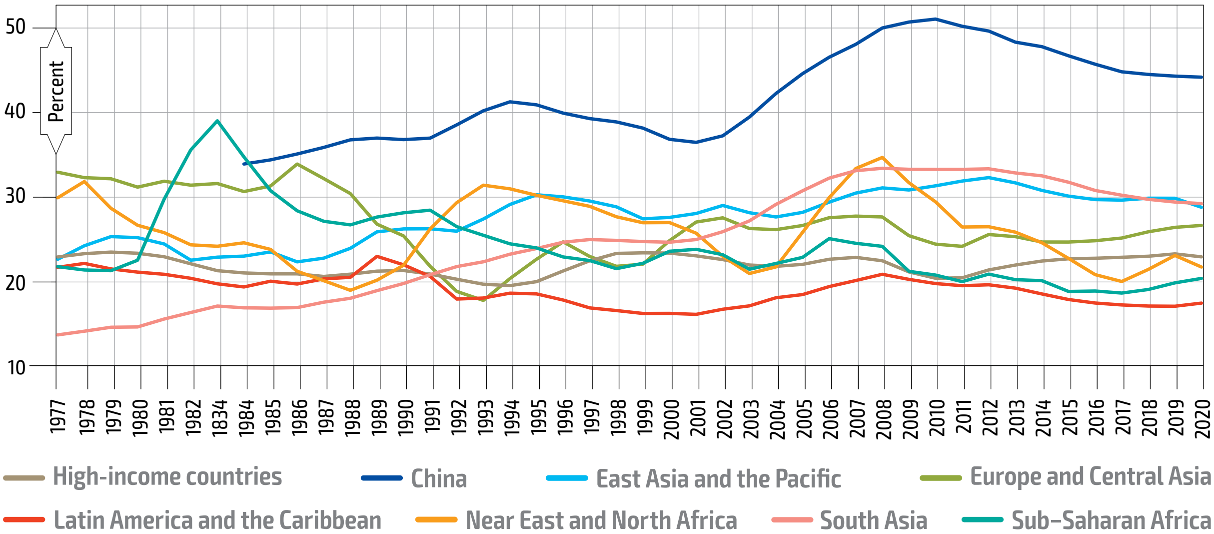
At a fundamental level, agriculture and other raw materials sectors are the foundation of the whole economy. To sustain human activity in the economy, food, together with certain levels of shelter, water and energy, are biological necessities.14 Moreover, natural resource inputs are essential to all economic activity, which cannot proceed without a steady flow of energy,[15] and nothing can be produced without materials. The enormous tower of value added in today's economies is built both upon a flow of fossil carbon, fixed by plants hundreds of millions of years ago, and on living trees and crops that construct complex carbon-based compounds. The nearly universal phenomenon of essential inputs declining in share of value as economies develop is observed for all goods that supply human basic needs and the raw materials that underpin manufacturing.[16,17]

However, as foundations are just a precondition upon which to building a tower and not the tower itself, the generation of downstream value added requires much more than primary products. Transformation processes have to be set up, material and immaterial factors of production must be available, such as physical capital, labour, knowledge, organization, financing, etc., and demand for transformed products has to materialize. Therefore, increasing labour and land productivity in agriculture is just a precondition for economic growth, not necessarily a trigger in and of itself.[j] Much more is needed to trigger economic growth and income distribution: notably the emergence of other sectors able to occupy and remunerate the workforce released from agriculture. More broadly, development is characterized by coordination problems, where a set of synergetic events have to happen mostly simultaneously.

1.2.2 Savings, external deficit and asset ownership

Savings differentials and asset ownership. The per capita income differentials highlighted in Figure 1.12, particularly between HICs and selected LMICs, not only have evident and immediate implications for the well-being of citizens, but have also strong implications for long-term asset ownership and further income-generating prospects. While savings rates as a share of GDP are higher in the more rapidly-growing middle-income countries than in HICs (Figure 1.17), and China's savings per capita have been growing rapidly, savings per person are still much higher in HICs than elsewhere (Figure 1.18).

Figure 1.17 Gross national savings as a share of GDP by region (1977–2020)

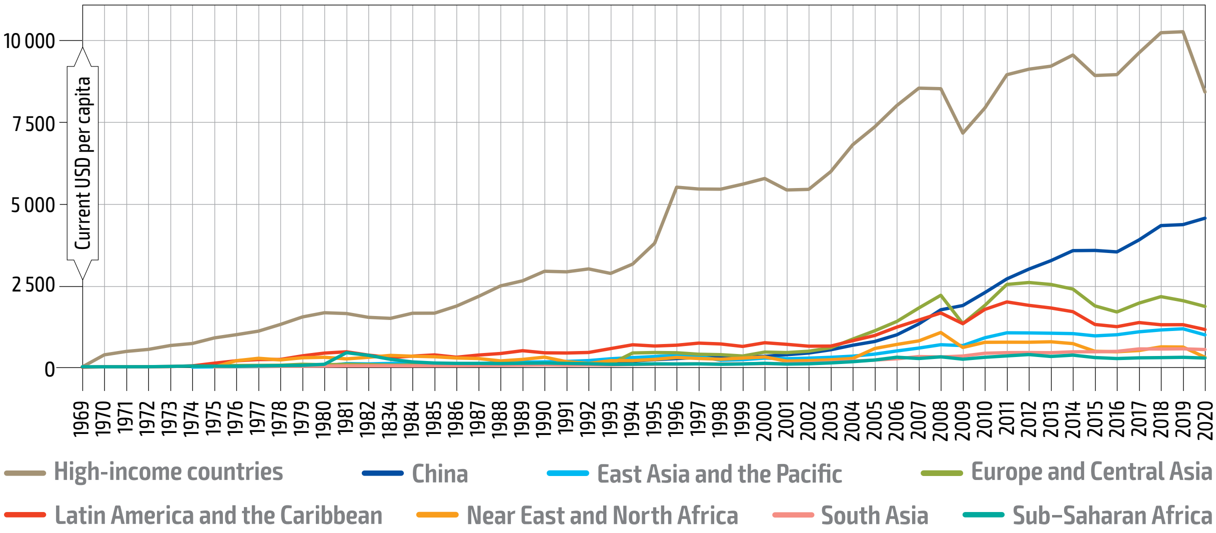


Note: Gross national savings as a share of GDP, both measured in constant USD of 2015, are represented by a three-year right-aligned moving average.

Source: Authors' elaboration based on World Bank. 2022. DataBank | World Development Indicators. In: *World Bank*. Washington, DC. Cited 4 June 2022. https://databank.worldbank.org/source/world-development-indicators

[j] Though, if this precondition does not materialize, this could constitute a brake to growth if labour is needed in other sectors and is not released from agriculture. However, the emergence of capital and information intensive manufacturing activities could downplay the importance of labour supply.

Figure 1.18 Gross national savings per capita by region (1969–2020)



Note: Gross national savings by region for each year are represented by a three-year right-aligned moving average.

Source: Author´s elaboration based on World Bank. 2022. DataBank | World Development Indicators. In: *World Bank*. Washington, DC. Cited 4 June 2022. https://databank.worldbank.org/source/world-development-indicators

Although the relationship between savings rates and capital assets ownership concentration requires further investigation, the macroscopic savings imbalances suggests that the high capital formation potential of HICs extends its influence well beyond their borders.

Thus, the conventional wisdom about the role of agriculture in development processes is also questioned whenever agricultural asset ownership is shifted outside local economic systems, as this may interfere with local development processes through different channels. For instance, technologies transferred from abroad may change the quantity of labour per land unit and may speed up the expulsion of labour from agriculture if capital intensive techniques are adopted, create new jobs if new land is used, and thus changing the prevailing contractual arrangements (e.g. contract farming), the output mix (e.g. specializing agriculture towards exports) and eventually expatriate profits, thereby reducing domestic multiplier impacts.

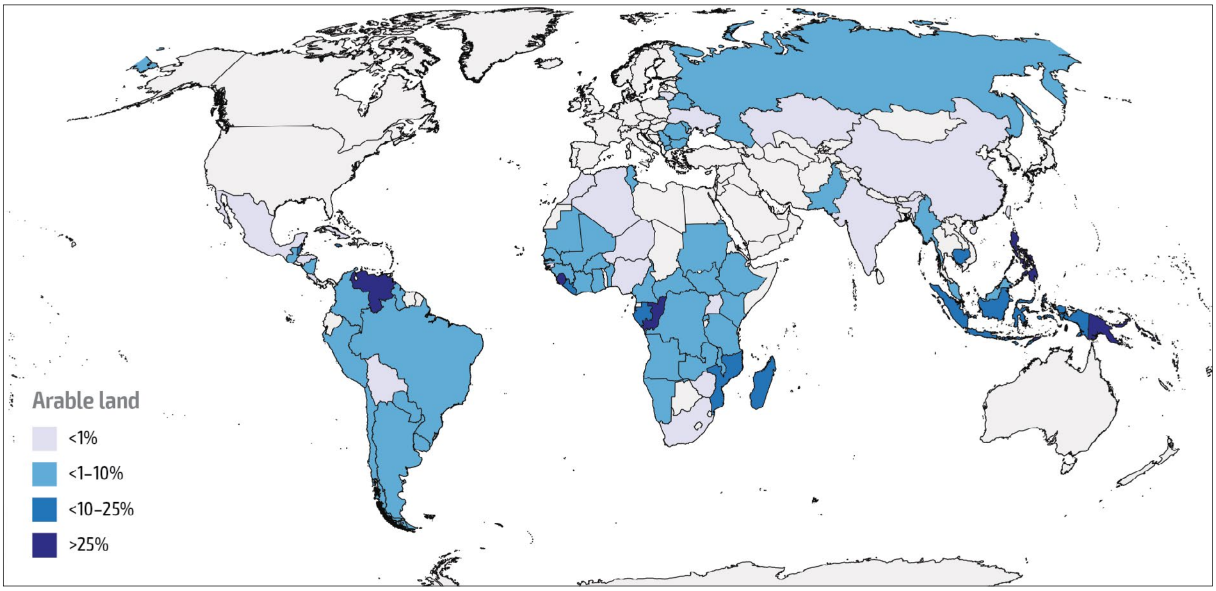
The recent wave of land acquisition has been driven in part by food security concerns because of the mid–2000s price rise, but may also be a response to long-standing drivers of vertical integration. As noted by Rama and Wilkinson (2008),[18] while contract farming became the norm starting in the 1980s, vertical integration continued to occur for "radically new products", such as biofuels, or "where agricultural conditions are exceptionally favourable but existing farming practices inadequate," as in some low-income and low- and middle-income countries.

Commodity price rises of the mid–2000s, and particularly the spike in 2007–2008, were a trigger for a substantial change in the global distribution of agricultural land ownership.[19] The commodity boom raised costs for countries reliant on food imports, thereby reducing workers' purchasing power. Rising food prices arguably contributed to political crisis in food-importing countries.[20, 21] Countries with financial resources but poor agricultural resources, particularly oil-rich, arid countries such as Qatar and the United Arab Emirates,[22] reconsidered their strategy of importing food and turned to purchases of agricultural land itself.

Direct ownership of agricultural assets is a strategy that has been pursued for many decades by Japan, and more recently by China,[23] but it expanded rapidly after 2008. The counterparties to these transactions are low-income countries (LICs) with abundant agricultural land but little financial resources.[23] In the wake of rising agricultural commodity prices, private businesses also saw an opportunity to secure a supply of agricultural commodities through ownership of land, while investors saw opportunities for speculative profit. The result has been a wave of large-scale land acquisitions, whether through outright purchase or long-term lease, by food-importing countries, agribusiness firms and speculators.

The size of the deals for agricultural production or land speculation is substantial. As shown in Figure 1.19, deals struck between 2000 and the present, in excess of 200 ha, span much of the globe outside of the Near East and the HICs, although in some countries – notably China and India – the amount of outside finance is very small. Thailand has joined the Near East and HICs through land acquisitions in Cambodia, Lao People's Democratic Republic and Viet Nam. Land acquisitions have occurred throughout much of EAP, ECA, LAC and SSA.[k] Furthermore, some of the deals involve a transfer of rights to a nontrivial amount of the country's arable land.

Figure 1.19 Area of large-scale land acquisitions as a share of arable land (2000–2022)



Notes: The map reports land acquisitions greater than 200 ha, from 2000 to 2022, as a share of arable land, excluding failed deals. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties. Final boundary between the Sudan and South Sudan has not yet been determined. Final status of the Abyei area is not yet determined.

Sources: Authors' elaboration. Deals based on Land Matrix. 2022. *Land Matrix*. Cited 29 May 2022 https://landmatrix.org/list/deals; arable land based on FAO. 2022. Land Use. In: *FAO*. Rome. Cited 29 May 2022. www.fao.org/faostat/en/#data/RL

Premature deindustrialization and the middle-income trap. Further differences in development dynamics are the very high levels of labour productivity in industry historically enjoyed by HICs compared to LMICs, and the different speed of structural changes that occurred in the past compared to what is currently taking place in LMICs. Historically, today's HICs first saw a rising share of manufacturing in value added relative to agriculture, also characterized by increasing labour productivity. Then, high productivity in the industrial sector yielded a high surplus, which was spent increasingly on services, with an increase in services sector employment and a rising share of services in value added, thus leading first to a process of industrialization and then of deindustrialization. It has been observed that, particularly in middle-income countries, the processes of industrialization and deindustrialization are occurring much more quickly, before the growth of the manufacturing sector can produce impacts on the whole economic system, thus originating a process of premature deindustrialization.[24]

[k] Most projects have multiple partners, and foreign firms may register local or offshore subsidiaries, so the country of ownership can be difficult to establish. For example, the Kuramo Africa Opportunity Offshore Co-Investment Vehicle III, L.P. is registered in the Cayman Islands, and that is the registration listed in the Land Matrix database (https://landmatrix.org/list/deals). However, from US Security and Exchange Commission records (https://sec.report/Document/0001140361-18-028647/), the firm is related to the Kuramo Africa Opportunity Co-Investment Vehicle III, L.P., which is registered in Delaware, USA but has offices in New York City. Given this complexity, no systematic attempt was made to trace the national origin of multinationals.

At a global level, manufacturing as a share of either value added or employment has not changed in the past 40 years.[25] However, at a national level, once economies begin to industrialize and subsequently raise their incomes, multinational firms move production to lower-income, lower-productivity economies because of the greater mobility of manufacturing operations.[25] Seen from this global perspective, premature deindustrialization appears to be a symptom of what has been called the "middle-income trap", where countries' GDP per capita growth slows down once a country approaches an intermediate level of wages, making them unable to reduce significantly the income gap with HICs. A trap in the sense that countries find themselves unable to compete with low-income, low-wage economies in manufactured exports and are unable to compete with HICs in highly skilled innovations.[26] Figuring in among the proximate causes of premature deindustrialization may be the international mobility of manufacturing.

In light of the above considerations, the questions raised in the introduction – how do patterns of saving and investment affect agricultural capital, land ownership and natural resource use across countries? And how do those different patterns of ownership and use influence structural transformation of economic systems? – can be addressed by observing that investment is necessary for structural change, at any level of income. Investment may take place in any country, but the financing for it tends to come from wealthier countries. There are two reasons for this: first, thevolume of savings per person is higher in those countries; and second, ownership of assets recognized by financial markets provides collateral for loans, which can then be used to grow further wealth. Thus, present and future patterns of ownership are strongly shaped by past patterns of ownership.

The main asset of LMICs, in the eyes of global economic actors, is their natural resources. However, the 'ecosystem services' those resources provide, while valuable, often cannot be used as collateral. The challenge for those countries is to retain ownership of their natural assets and the income flows arising from them in order to build other assets, which can support an increasing diversity of economic activities.

Finance flows towards investments that have a sufficiently high risk-adjusted rate of return. When investment is used to build knowledge and networks needed for innovation, as well as physical capital, then the recipient of that finance can benefit in the long run – but that outcome is far from guaranteed. To the extent that foreign savings are needed to finance economic growth, there is a persistent risk of indebtedness, dependence or a long-lasting transfer of natural capital.

1.2.3 Imports, exports, external debt and industrial strategy

Borrowing for technological change. One fundamental question is: to what extent and how endogenous growth processes in LMICs can be triggered by domestic processes and/or have to rely on external relationships and funding? And a logically ensuing question is: under which conditions, and to what extent, might external deficits influence growth processes and agrifood systems?

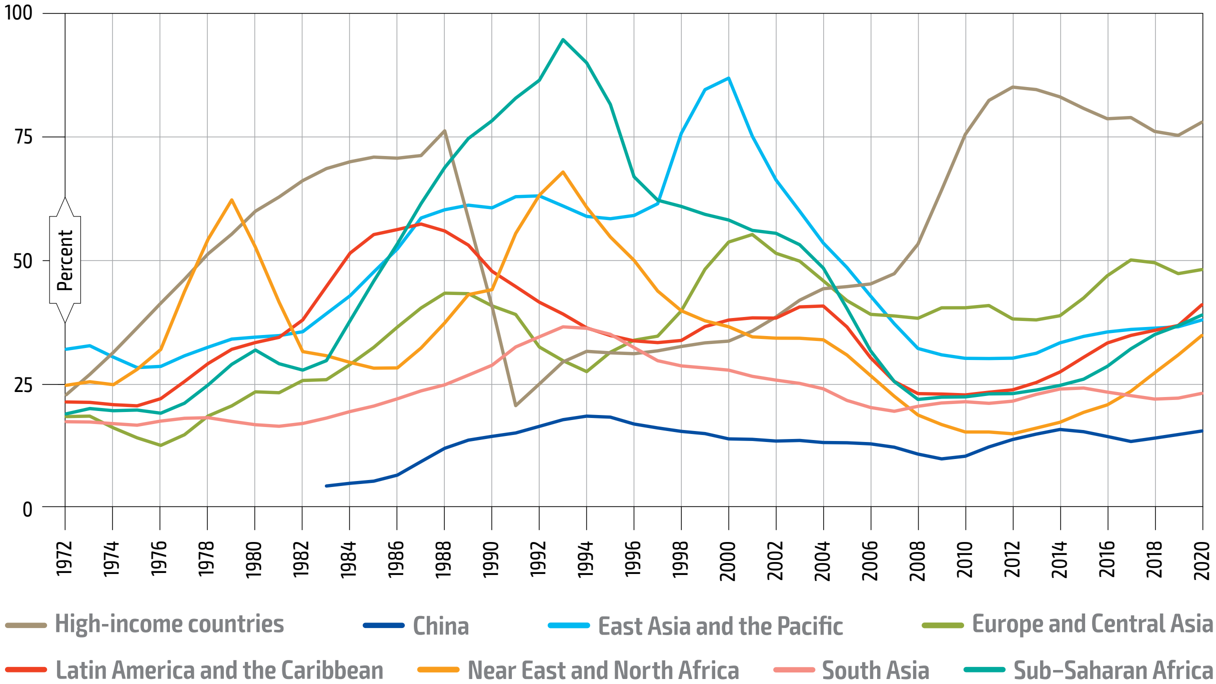
There is wide consensus about the fact that whatever growth and development paradigm a country decides to adopt, there is no way that it can be fully isolated from the international context. The possibility to temporarily increase the external deficit by borrowing to import labour-enhancing technologies or increasing the domestic human capital, provides an opportunity for LMICs to trigger development processes and accumulate wealth. But, while, on the one hand, this raises the opportunities to overhaul capital, acquire new technologies and enhance domestic human capital within and outside agrifood systems, on the other hand, the pressure from unsustainable external deficits can orient agrifood sectors towards the immediate generation of foreign exchange, instead of allowing them to diversify and nurture domestic production sectors, including the agroprocessing, and integrate within the socioeconomic systems at large.

On a conventional development pathway, if LICs are to raise their incomes over the long run, they must eventually shift from low-productivity activities generating basic goods to high-productivity activities generating goods and services, with a market that expands with the global economy. A "blueprint" approach to technological change that dominated development economics for a long time suggested productivity be increased through technology transfer – that is, by providing high-productivity equipment to LICs,[27] while attention was to be paid to the still very demanding problems of insertion into the global economy,[28] domestic coordination through forward and backward linkages,[29] and navigating macroeconomic constraints.[30]

Regardless of the strategy that LMICs pursue for development, a critical issue is that the machinery and intermediate manufactured inputs for higher-productivity technologies must nearly always be imported. The need for exports has some immediate macroeconomic implications, because a basic accounting relationship says that any trade deficit – an excess of the value of imports over exports – must be matched by a savings deficit meaning, basically, a net inflow of money from abroad.

External finance in the form of loans, rather than aid, is a financial liability vis-à-vis the rest of the world, risking a rising external debt. The external debt of SSA and EAP as a share of gross national income (GNI), for example, rose massively in the 1990s, as shown in Figure 1.20. Moreover, the debt is nearly always denominated in an international currency, such as US Dollars, Euro or Yen, while wages and other local costs are paid in the national currency. As a consequence, the ability to repay the debt depends not only on the health of the domestic economy but also on the exchange rate, which is influenced by capital inflows and outflows, as well as by trade.[31] Rising debt can increase the perceived riskiness of investment, triggering capital flight which depreciates the currency, thereby making it harder to repay the debt. It was only through a round of defaults and debt renegotiations in the mid–2000s that unsustainable external debt in SSA and EAP was brought below 40 percent of GNI in recent years.

Figure 1.20 External debt stocks as a share of gross national income by region (1972–2020)



Notes: Data are represented by a three-year right-aligned moving average. Total external debt is debt owed to non-residents repayable in currency, goods, or services. Total external debt is the sum of public, publicly guaranteed, and private nonguaranteed long-term debt, use of IMF credit, and short-term debt.

Source: Authors' elaboration based on World Bank. 2022. DataBank | World Development Indicators. In: *World Bank*. Washington, DC. Cited 4 June 2022. https://databank.worldbank.org/source/world-development-indicators

The import-debt link is a central challenge for development in today's global economy: conventional development requires labour-enhancing technologies, but the associated equipment and intellectual property is almost always created abroad. Relying on international borrowing to import such technologies carries significant risks of producing a growing debt, and exchange rate fluctuations affect both the cost of imports and the ability to repay outstanding debt. In addition, there is the possibility of deteriorating terms of trade – a fall in the price of exports relative to that of imports on international markets. The defaults of several LMICs observed in recent decades highlight the risk of a de facto loss of sovereignty resulting from the need to enter into unfavourable deals with other countries or multinational companies, which imply a sell-out of natural resources, such as land, or increasing commodity dependency.

Alternative development paradigms. Over the second half of the twentieth century and until now, LMICs have followed a variety of development paradigms and related strategies to trigger or accelerate development while lowering the risk of technological, financial and logistical dependency that accompanies such a process, including import substituting industrialization (ISI), adherence to the Washington Consensus and open-economy industrial strategies. The latter paradigms are employed to maximize the benefits of international trade while autonomously developing strategic domestic sectors, thus avoiding the drawbacks of commodity dependency, or others.[32] The strategic choices are usually informed by both political and economic considerations, and are constantly adapted in light of experience (see Box 1.4).

Box 1.4 Alternative development paradigms and related strategies

In the 1950s and 1960s, colonies gaining independence were concerned about dependency on former colonial powers, worsening terms of trade between the commodities they exported and the manufactures they imported, and putting pressure on their balance of payments. They looked to the success of wartime planning in all the major belligerent countries, and particularly to the USSR as a country that had successfully followed an autarkic path from poverty to industrial power through planning. Building on these observations led to the strategy of import substituting industrialization (ISI).[33] Admittedly, countries were trying to develop manufactures, which, unlike agricultural products, do not face structural declines in the terms of trade. However, by taxing agriculture to fund the government and to appease urban consumers and employers through low-priced food, policies tended to be biased against agriculture.[34] The ensuing challenge to ISI approaches, however, came from a different direction, and it was a trigger for change. Import substituting industrialization was severely tested by the oil price shocks of the 1970s. Rising oil prices raised the cost of a crucial raw material, creating balance of payments crises in many countries. These shocks occurred against a backdrop of growing disenchantment with economic planning, while countries pursuing inward-directed planning found that they had not escaped dependency, "where [growth] consists essentially of foreign technology and capital being pumped into a limited 'modern sector'."[35] As a further blow to ISI, countries in EAP that had been following an export-oriented strategy performed comparatively better, and they were initially (although mistakenly) thought to have pursued liberal policies without state intervention.[36]

Development theory was perceived to be in crisis, leading to influential critiques arguing against both ISI specifically, and government intervention more broadly.[36]

The advice that replaced ISI, and economic planning more fundamentally – the Washington Consensus[37,38] – sought to create conditions for growth. It emphasized reduced public budgets, liberalization of trade and financial markets, and flexible labour markets, among other recommendations. But by the end of the 1990s, it became clear that some of the rapidly-growing Southeast Asian countries had in fact been characterized by highly interventionist governments, and all relied on government activity to some degree.[39] Subsequently, it was recognized that all countries that had experienced significant and prolonged periods of growth had done so with the aid of government intervention, even the currently high-income countries.[40] This suggested there was a case for open-economy industrial strategies, with targeted attention to certain sectors, combined with an external orientation and low tariffs.[41] The emphasis in this approach is on facilitation and coordination (rather than direction) of otherwise independent private actors.

However, by the early 1990s, it had become clear that technological change in LICs – and indeed in all countries – is an evolutionary process in which domestic producers actively learn about and modify imported technologies.[42]

Agricultural comparative advantage in the long run. The evolutionary view of technological change emphasizes learning in networks, facilitated by supporting policies.[43, 44] As an evolutionary economic theory,[45] it differs in its underlying assumptions from the endogenous growth models of the New Growth Theory.[46] Nevertheless, both approaches share an observation that accumulation of resources and knowledge is a self-reinforcing process – there are increasing returns to scale. This observation leads to different conclusions than those of the conventional notion of "comparative advantage". From a (static) comparative advantage perspective, countries with predominantly agricultural economies should specialize in agricultural production. Yet, Thirlwall and Engel tell us this is a problematic long-run strategy (see Box 1.5). Moreover, whatever "comparative advantage" there might be, it is clear that it does not stand still. If comparative advantage has any relevance at all, it must be seen as dynamic, with the potential for active industrial policy.[47]

Box 1.5 No-go for agricultural export-oriented countries?

The monetary value of every country's export must, as a long-run tendency, grow at the same rate as the monetary value of its imports. This is known as the balance of payments constraint on growth.[48, 49] It should be noted that this does not mean that the gap between exports and imports converges to zero – deficits can repeatedly grow and then fall through expansion and contraction of net exports, recurring debt crises, currency devaluations and bailouts. Rather, it means that, over the long run, trade surpluses and deficits will more or less cancel each other out.

Expressing the growth rate of imports as a multiple of the country's rate of domestic GDP growth rate (the multiplier is the import elasticity with respect to domestic GDP), and exports as a multiple of global GDP growth (the export elasticity with respect to global GDP), setting the growth rate of exports and imports equal to each other shows that national GDP growth is, in the long run, equal to global GDP growth multiplied by the ratio of the export elasticity to the import elasticity. This rule is known as Thirlwall's Law. It has been tested and found to hold in practice.[50, 51, 52]

One of the best-established, empirical results in economics is Engel's Law, which states that the share of food in total expenditure falls as incomes rise; that is, food is relatively income inelastic. Engel's Law implies that if a country is exporting food products and importing manufactures, then the export elasticity with respect to global GDP will be lower than the import elasticity with respect to domestic GDP. Thirlwall's Law then says that the very long-run growth rate of an agricultural exporter's GDP will typically lie below the world average, so few countries can rely exclusively on exporting food products as a growth strategy.

The rule is not absolute. For example, a small country, such as New Zealand, can specialize in exports of high-end food products. New Zealand's food exports are valuable because they are specialties, but this is not a strategy that can be widely copied.

From the evolutionary perspective, the question for agriculture is: what role can it have in developing technological capabilities,[53] and innovation systems,[54] to set countries on a path towards greater sophistication in their major products?[55] One source, which has been well explored, is manufacturing based on already existing crops, which is the idea motivating the African Development Bank's (AfDB) programme on staple crops processing zones.[56] Yet, as services increasingly drive economic activity in the face of premature deindustrialization, the retail sector emerged as a further generator of international networks in agrifood systems. An extremely rapid expansion of supermarkets in middle-income countries in recent years has arguably been driving changes in supply chains, relationships between suppliers and buyers, and technological upgrading,[57] although the role of global transnationals as appropriators of agrifood surpluses, rather than domestic development engines, has yet to be fully investigated.

Foreign direct investment as main source for the creation of engines of growth? Similar reasoning applied to borrowing may apply also to the choice to incentivize foreign direct investment (FDI) (see Box 1.6). In both cases, the strategies require a careful choice of where and how to use foreign resources. There are three key questions that arise regarding foreign direct investment from the point of view of host countries. First, does FDI enhance, diminish, or leave unchanged, the innovative capacity of the country? Second, does FDI lead to larger or smaller import volumes, worsening the current account balance? Third, does FDI link the country to foreign markets, thereby improving the current account balance? The answer to the third is "usually not".[18] However, the answer to the first two questions depends on the nature of the investment. Multinational corporations (MNCs) may enter a country to secure raw materials; sell into local markets; or carry out production within vertically coordinated operations.[18]

Box 1.6 Foreign direct investment: opportunities and drawbacks

While LICs receive very little of total FDI flows, they make up a significant portion of their financing – between 10 and 20 percent since 2000, higher than any other income group. The surge of investment flows to LICs, particularly to Africa, began in 2007 as investors withdrew from HICs most affected by the Great Financial Crisis.[58] The flows are increasingly South–South or South–North, as FDI from middle-income countries has been growing.[59]

FDI inflows tend to appreciate the domestic currency, affecting the exchange rate and the external balance. Rising exports also bring in foreign exchange, but in recent decades financial flows have dominated, because of both their large volume and their volatility.[31] When investment flows to a country increase, this leads to a rise in foreign purchases of assets in the recipient country's currency. Other things remaining equal, the increased demand for the country's currency causes it to appreciate relative to international currencies, such as euros, United States dollars or Japanese yen. An appreciated exchange rate makes the country's exports more costly on international markets, while lowering the cost of imports.

When the main export sector is based on a natural resource such as oil, the result is dubbed Dutch disease,[60] in which there is excessive foreign investment in a single sector. Other sectors producing tradeable goods and services are at a disadvantage on international markets. A similar impact can occur when policies encourage foreign investment in particular export-oriented sectors. This may come about through investment promotion. While investment promotion agencies provide services to foreign firms in order to reduce red tape and facilitate coordination with local partners, FDI is also encouraged through fiscal measures, such as tax incentives and subsidies.[61,62] Combined with low wages, investment promotion policies can make targeted sectors attractive to investors by offering comparatively high profits while reducing perceived risk. As investment flows in, the exchange rate appreciates, driving the profit rate downward towards the internationally competitive level. The result is an exchange rate that is overvalued for the rest of the economy. Profits are remitted to foreign firms, while the exchange rate bias in favour of imports and against exports for the sectors that are not being promoted can create a current account deficit. Bresser-Pereira *et al.* (2015)[63] identify further mechanisms, such as persistently high interest rates, that attract foreign investment, but discourage domestic investment. The result is chronic current account deficits and increasing debt, but investors and lenders will not withdraw funds as long as the debt is not excessive compared to GDP. Once debt grows high enough that investors and lenders become nervous, they may withdraw funds, leading to the depreciation of the currency. This causes further difficulties in servicing the debt and can trigger a debt crisis.

There is also evidence that FDI, in some instances, does not contribute to economic growth in LICs, particularly in selected SSA countries and primary commodity export-dependent ones (also referred to in some documents as "commodity dependent developing countries", or CDDCs), where FDI is concentrated in export sectors with little backward and forward linkages with the rest of the

Box 1.6 (cont.) Foreign direct investment: opportunities and drawbacks

economic system. In addition, domestic investors may be crowded out when multinational companies compete with domestic ones for scarce resources, such as skilled labour or land. Furthermore, repatriated earnings through transfer prices may enchain negative welfare effects of FDI.[64] As stated in the document:

> The greater control exercised by processors, traders, and retailers has effectively curtailed the policy space of CDDCs and limited their ability to influence global value chains. Similarly, CDDCs have in the main struggled to use commodity revenues to promote structural change (productive capacity building, investment) and poverty reduction (through increasing social expenditure) (UNCTAD, 2011, p.3).[65]

For these reasons commodity dependency tends to trap such countries in poverty and food insecurity.[66]

1.2.4 Economic growth from an ecological perspective: a safe and just space

From an ecological economics perspective, economic growth cannot remain a goal in and of itself. Taken as a whole, humanity is exceeding biophysical "planetary boundaries",[67] leading to calls for a transition to "prosperity without growth" in HICs.[68,69] For the world as a whole, a goal of sustainable development is to live within a "safe and just space", as shown in Figure 1.21, and remaining within the Earth's ecological ceiling while also providing a social foundation.[70] The social foundation in Figure 1.21 goes well beyond the basic necessities of food, energy and water, providing a variety of capabilities that support human flourishing.[71,72,73]

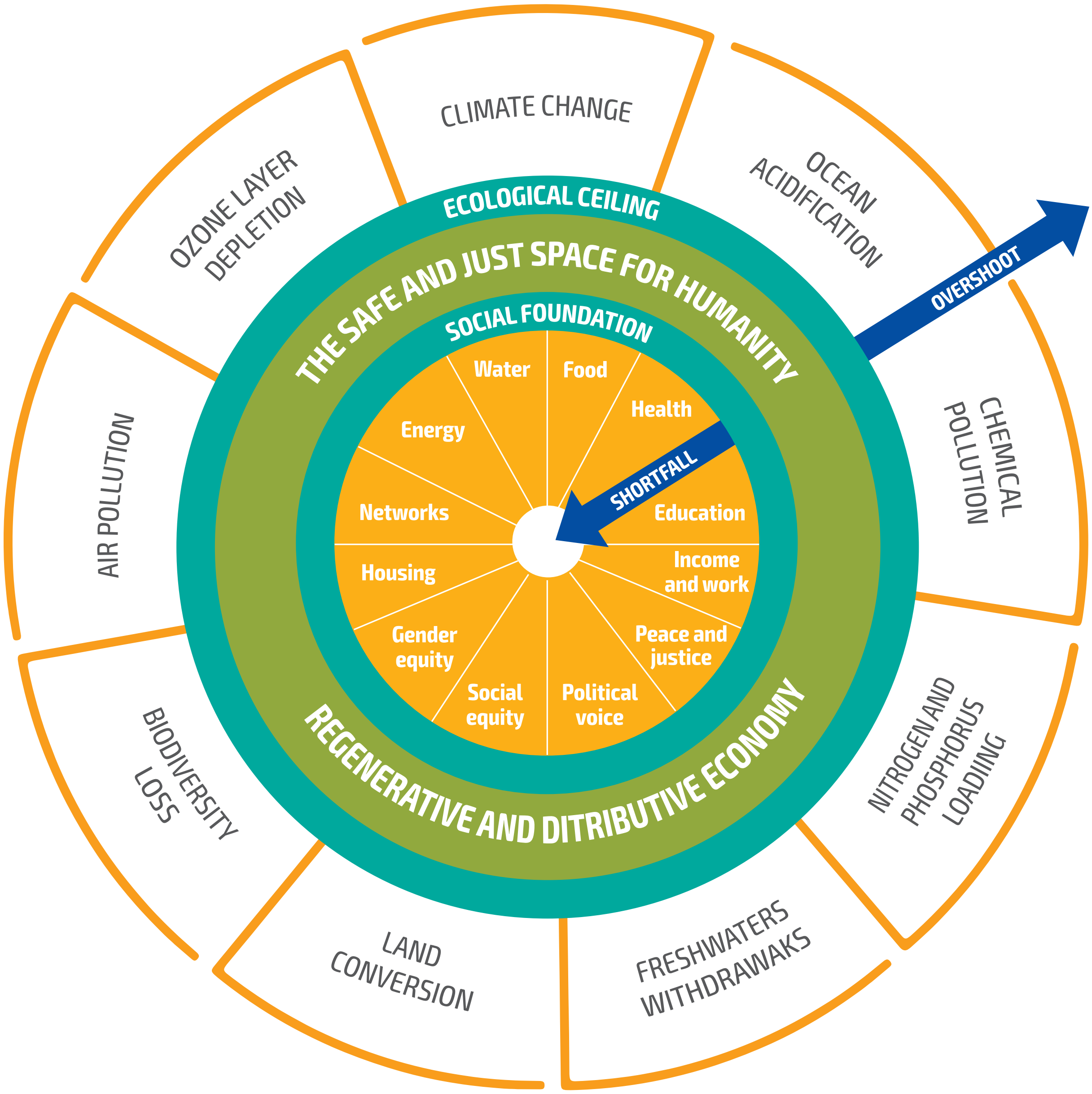
Regarding ecosystems, humanity is already extracting massive amounts of carbon fixed by primary producers – the human appropriation of net primary production (HANPP).[l] One estimate of global HANPP gives a range from 14 percent to 26 percent.[74,75] Even at the lower end of the HANPP estimate, for one species to commandeer 14 percent of primary production is extraordinarily disproportionate. There are an estimated 8.7 million species of eukaryotes (organisms that, like humans, have cells with nuclei);[76] expanding the list to include prokaryotes (cells without nuclei), the estimated total rises to 1 trillion.[77] The maximum sustainable global biomass yield will ultimately constrain the bioeconomy, although the potential is not well understood.[78]

When heavy demands are placed on finite resources, two consequences normally follow. The first is a rise in price; for example, rising demand for biofuels was one factor explaining rising crop prices in the mid–2000s.[79] Price increases need not persist, if production can expand to match altered demand, but production cannot expand indefinitely in a finite world. The second consequence, in part a result of the first, is an attempt to control the resources. This pattern can be seen in the recent wave of large-scale land acquisitions,[80] discussed above.

In the 1970s, natural capital was put forward solely as an analogy to financial assets; just as a prudent investor would not spend principal, humanity should not deplete the natural environment upon which it relies.[81] However, over time, the notion began being taken more literally as a quantifiable financial asset that should be maintained at least at a constant level.[82] Figure 1.22 shows the depletion of resources – forest, energy and mineral – as a share of gross national income, as calculated using the methodology in *The Changing Wealth of Nations*.[83] The figure makes clear that the world as a whole is not achieving Schumacher's aim of preserving natural capital. Nevertheless, it is not high everywhere. Depletion rates have generally been low in HICs and SAS. They have also been low in China recently, although resource depletion increased during the growth-oriented Tenth, Eleventh and Twelfth Five Year Plans.

[l] The organisms responsible for primary production are known as primary producers or autotrophs, and form the base of the food chain. In terrestrial ecoregions, these are mainly plants, while in aquatic ecoregions algae predominate in this role (Wikipedia, Primary production, consulted on 10 May 2020).

Figure 1.21 The safe and just space for humanity (the "doughnut")



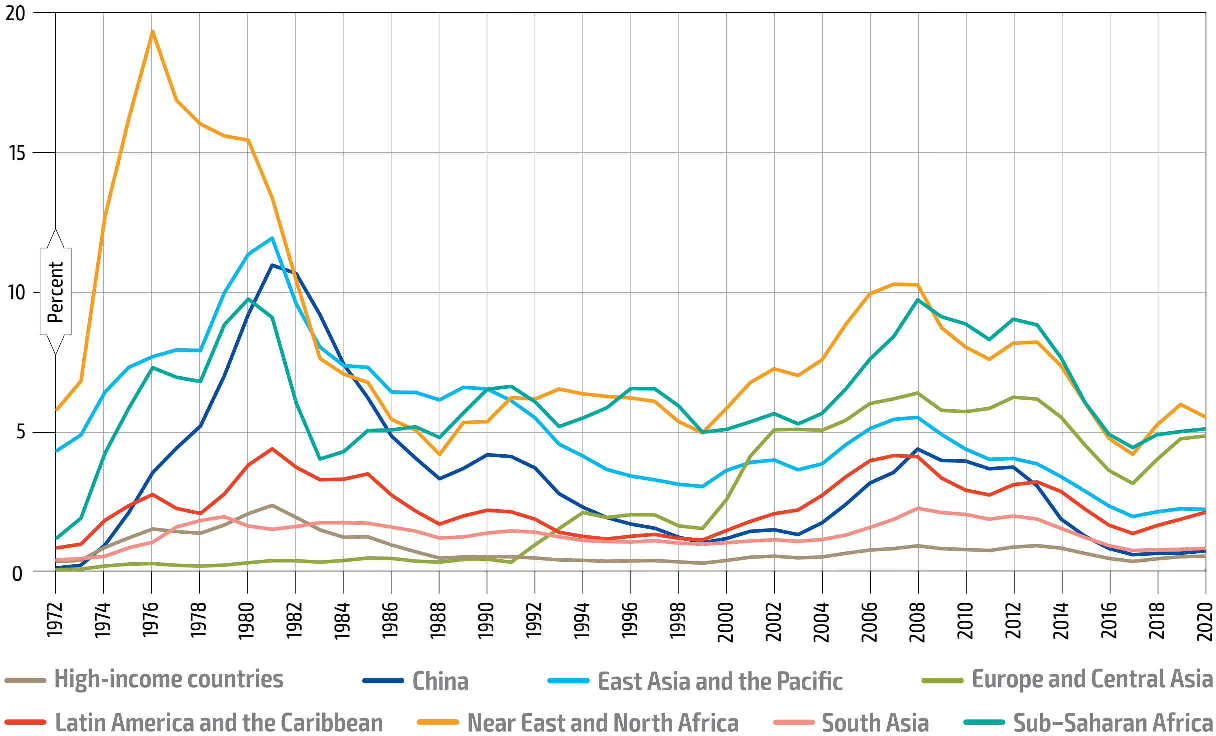
Source: Adapted from Raworth, K. 2017. *Doughnut Economics*.

In light of the progressive depletion of natural resources illustrated in Figure 1.22, the relevance of the question highlighted in the introduction – "to what extent the way GDP is currently measured, e.g. excluding many environmental costs, may provide misleading signals to decision-makers about the potential for further growth?" – becomes evident.

In the words of the United Nations Secretary-General:

> "Now is the time to correct a glaring blind spot in how we measure economic prosperity and progress. When profits come at the expense of people and our planet, we are left with an incomplete picture of the true cost of economic growth. As currently measured, GDP fails to capture the human and environmental destruction of some business activities. I call for new measures to complement GDP, so that people can gain a full understanding of the impacts of business activities and how we can and must do better to support people and our planet" (United Nations, 2021, p. 4).[84]

Figure 1.22 Depletion of natural resources as a share of gross national income by region (1972–2020)



Notes: Data for each year are represented using a three-year right-aligned moving average. Regional aggregations are computed with as weighted average by the gross national income.

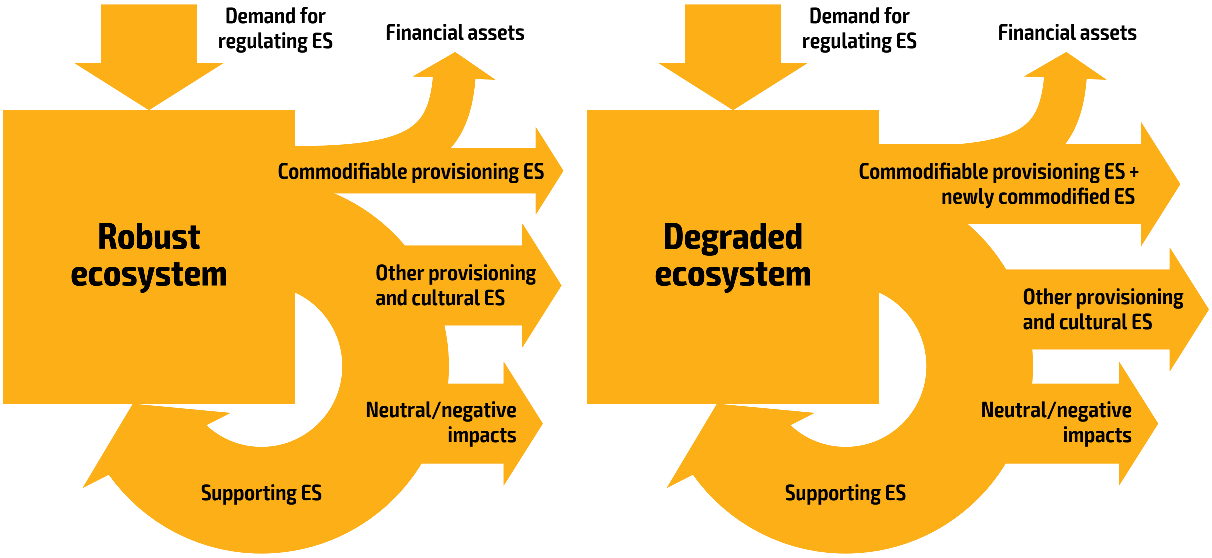
Source: Authors' elaboration based on World Bank. 2022. DataBank | World Development Indicators. In: *World Bank*. Washington, DC. Cited 29 May 2022. https://databank.worldbank.org/source/world-development-indicators

The exclusion of environmental costs and ecosystem services from key growth and development indicators is certainly distorting the view of decision-makers. For this reason, numerous attempts are being made to capture the value of natural resources and their degradation. Among the most prominent is the Genuine Progress Indicator (GPI), which subtracts monetary measures of social and environmental harm from GDP.[85] As argued by Dasgupta (2021), measures such as GPI are those most relevant for policy; through the "wealth/well-being equivalence theorem" social well-being is maximized if, and only if, inclusive wealth is maximized.[86]

Ecosystem services valuation and loss of natural capital usefully highlight what is lost by degrading the natural environment. Some natural capital is tied directly to an income flow, particularly mining, energy extraction, commercial agricultural land and managed forests. These types of readily commodified provisioning services are those that enter into the natural resource depletion trends shown in Figure 1.22. Yet, they are only a few of the services that ecosystems provide,[87] which include regulating, cultural and supporting services.

The relationship between ecosystems and the ecosystem services (ES) associated with them are illustrated in Figure 1.23. A robust ecosystem, for example, a mixed forest-agricultural landscape, might provide commodifiable provisioning services such as timber, charcoal and crops, but, in addition, it might provide a great deal more of non-commodifiable provisioning services, such as non-timber forest products used for subsistence, regulating services around soil maintenance, carbon sequestration, hydrological flows, and cultural or socially relevant services, and featuring a broad range of largely unobserved supporting services that maintain the ecosystem in its robust state. The right-hand side of Figure 1.23 illustrates how bringing natural capital into markets expands the flow of already commodified services, such as large-scale timber extraction and monocultures; and encourages commodification of other services, such as markets for non-timber forest products, eco-tourism, agricultural tourism, carbon markets and payments for ecosystem services. These provide more or less reliable streams of income and, of those, a few of will be sufficiently reliable and fungible to underlie a financial asset.[88, 89]

Figure 1.23 Ecosystem service (ES) flows, commodification and financial assets



Source: Adapted from Kemp-Benedict, E. & Kartha, S. 2019. Environmental financialization: What could go wrong? *Real-World Economics Review*, 87. www.paecon.net/PAEReview/issue87/Kemp-BenedictKartha87.pdf

1.2.5 Signals of possible futures

Achievement of ecological sustainability and social equity is currently far from guaranteed, and different futures are possible. Conventional development approaches aim to reduce inequalities, but inequalities have great staying power, and development strategies threaten to compromise ecological sustainability.

Current barriers to sustainable development for LMICs, despite the focus of Agenda 2030 on poverty reduction and environmental sustainability, may persist if their dependence on HICs – both as a source of productive technologies and as a destination for exports – is not broken. The phenomena of chronic indebtedness and the middle-income trap constrain their growth and independence.

Surpluses generated at any link in an agrifood value chain present an opportunity for extraction by the politically influential class. That class may take over ownership of profitable businesses as an ongoing source of revenue, but they may also take a one-time transfer of wealth. The result is high inequality, low growth and a strong disincentive to innovate.

In a negative setting, the approach to the global commons would be one of acquisition – a system of private property rights, to be sure, but without even the pretence of a mutually beneficial transfer of those rights. The security of a politically powerful class would depend on a certain degree of social stability, which would be supported by broad and robust access to staple foods. However, varied and nutritious diets would be reserved for the small governing class.

Eventually, we must live within the biophysical limits of Earth. Ideally, we will achieve that goal while also meeting human needs: a safe and just space for humanity. In contrast to conventional approaches to development, but in line with evolving thinking, that goal can be supported by actively developing innovative capacities in currently LMICs in order to reduce their dependency on the currently HICs.

Strong centralized regimes for protecting natural capital and the global commons can potentially keep global economic activity within planetary boundaries, but at the risk of high and persistent inequality. Abandoning global goals for society and the environment risks a damaging race to the bottom.

Therefore, future features of socioeconomic systems depend on the resolution of key questions, namely the need for: institutions to share the global commons; a fair distribution political power and wealth; and the resolution of the wide inequalities present in today's economies.

Agrifood systems could play an important role in that task, both as a sector in which to gain skills and build networks, and as the basis for a bio-based economy. Agrifood systems have a significant role to play in the development of the global economy, even as they are strongly shaped and influenced by it. Choices made today will shape any future possibilities.

One way to escape the combined implications of Thirlwall's and Engel's laws is to produce non-food goods from agricultural commodities. That is the promise offered by the bioeconomy,[90] in which diverse outputs are produced from biorefineries.[91] As a new industrial sector with room for productivity growth, there is potential for a revitalization of economic growth, or a "golden age", as Perez (2013)[92] has called it. The potential for income-elastic demand for processed agricultural products has led to calls for bioenergy-driven economic development in Africa.[93] Yet, this positive economic development narrative is challenged by more negative assessments from ecological economics and political economy perspectives.

It is possible that the global commons will be managed through a continually evolving system of polycentric governance. Locally adapted solutions, which may or may not feature private ownership, could be linked through global networks. The emphasis on technological change would be for innovative capacities and core technologies to be widely available, reducing the dependence of LMICs on technology transfer from HICs. The aim of food policy, consistent with a broadly shared good quality of life, would be wide access to varied and nutritious foods, consistent with the maintenance of robust ecosystem functioning. Food could be more expensive, both because agriculture would be comparatively labour-intensive and because environmental externalities would be reflected in prices. Nevertheless, meeting food needs would not be prohibitive because of low inequality of income and wealth.

The already large diversity of agrifood systems found in today's economy would be even greater. Locally adapted systems for local provision would coexist with globally connected agrifood value chains. Indeed, those value chains would go beyond food, as agriculture provides raw materials for the rest of the economy. The supply of those raw materials could be extended indefinitely if ecosystem function is maintained, but the supply in any given time period will be limited. The challenge is to maintain a globally connected network of locally devised systems of resource management, so as to preserve the global commons.

NOTES – SECTION 1.2

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1.3 Cross-country interdependencies (Driver 3) [m]

Cross-country interdependencies arise for a multiplicity of reasons. Almost all the domains of social, economic and cultural activities generate, influence or rest upon, cross-country relationships that in many instances create mutual or unidirectional dependencies once these relationships become stable and socioeconomic systems become structured accordingly. These comprise, for example: exchanges of goods and services, including capital goods and transport; countervailing flows of payments, migrations and related remittances; financial flows owing to lending, borrowing and investing; more immaterial cross-country flows of technical knowledge; cultural influence at large; as well as geopolitical influence, security and military relationships. Interdependencies also arise in fields such as transboundary epidemics and other animal and plant diseases, as well as natural resource use and management, including biodiversity, cross-boundary pollution, greenhouse gases emissions and related climate impacts. All these relationships, that directly or indirectly affect agrifood systems, have always existed, but have dramatically increased in the last decades to determine the current global integration.

Some of these relationships are explored in other sections of this report. This section specifically focuses on the implications for sustainable and resilient development arising from agricultural commodity dependence, the rules governing international trade and the extent to which countervailing payments of agrifood commodities generate illicit financial flows. The following questions therefore arise and drive the focus of this section:

- Does dependency of low-income countries (LICs) on manufactures from high-income countries (HICs), combined with dependency of HICs on commodities produced by LICs contribute to keep LICs at the periphery of global development processes?
- To what extent do current international trade rules and trade-related policies favour or disfavour transformative processes towards sustainable and resilient agrifood systems?
- Is there evidence of the impacts of illicit financial flows (IFFs) on agrifood systems and their role in development for LICs? If so, what can be done about them?

Without making an attempt to provide exhaustive answers, this section offers a perspective on interactions across different countries and country groups that are likely to shape the future of agrifood systems. Section 1.3.1 discusses the constraints on international trade imposed by the balance of payments and their implications for agrifood systems. Section 1.3.2 analyses the commodity dependence and the structure of agrifood imports and exports to assess resilience of the various regions to international shocks. In Section 1.3.3, the extent to which rules governing international trade favour or disfavour transformative processes is addressed. Section 1.3.4 addresses the issue of IFFs in agrifood systems. This issue, targeted by the SDG 16.4, is important because it may reduce incomes and hamper the accumulation of capital in originating countries. Section 1.3.5 concludes by highlighting a few anticipatory signals of possible futures.

1.3.1 The balance of payments constraint

In addressing this issue of interdependencies, it is important to first understand why interdependencies arise and how agrifood systems fit within those networks. To legally secure the provision of goods and services not produced domestically for investment, intermediate inputs or household consumption, countries have to buy them from other countries. The same applies if countries want to purchase assets abroad. Of course, they need to sell something else or borrow money to secure the funds for the countervailing payments. They enter therefore into commercial relationships, and trade commodities and assets with external partners, thus becoming inserted within the global economy.[2] Agricultural products and commodities are no exceptions to this system. Only very large territories have even the possibility of autarkic development. Empires and current superpower countries may have managed in some periods to do so, but only by physically absorbing neighbouring states.

[m] This section partially draws from Kemp-Benedict (2021).[1]

Countries trading on international markets encounter recurring, and possibly persistent, trade surpluses or deficits. The counterpart to those surpluses and deficits is financial flows, so trade interdependencies go hand-in-hand with interdependencies of indebtedness and ownership (see Box 1.7).

Exports of agricultural and other commodities, as well as manufactured goods, contribute positively to the current account. Any imported agricultural inputs, such as fertilizer, pesticides, seeds and fuel, subtract from the current account, as do food imports, such grains as staple food or exotic foods demanded by urban consumers seeking to diversify their food consumption. As discussed in Section 1.2, the prevailing wisdom is that countries that export agricultural commodities are subject to long-run decline in the prices of their exports, while high-productivity, high-input agriculture entails imports of inputs which may increase in price. This held true in the past, and continues to hold true also in the future, and thus agricultural exports will risk deteriorating (declining) terms of trade (see Box 1.7).

In a context of declining ToT, and given the limited potential for economic growth through agricultural commodity exports, countries seeking to increase their economic output in addition to producing for the domestic market, aim to develop high-productivity sectors with the potential for expanding markets, particularly manufactures and high-end services or tourism, to capture a part of the global surplus. These dynamics lead to increasing and deepening interdependencies.

In addition, agriculture and manufacturing activities entail imports themselves. For example, when manufacturing plants are being established, the machinery, if not produced domestically, must be imported from abroad, putting downward pressure on the current account. Subsequently, any intermediate products needed for production, such as preservatives or stabilizers that are not manufactured domestically, subtract from the current account. These observations strongly suggest that the commonly accepted conclusion that development entails interdependency makes sense. The question therefore is not whether or not to accept interdependencies, but on what terms interdependencies can favourably support development processes.

Box 1.7 Balance of payments and the terms of trade

The balance of payments (BoP) is an account that keeps track of the payments to and from a country. The BoP must, for the accounts to be in balance, sum up to zero. The total BoP equals the sum of the current account, the financial account and the capital account. The current account is dominated by the trade balance, or the net trade in goods and services. To that are then added remittances, such as when individuals send part of their wages to relatives in another country, when foreign employees are paid, or when profits are remitted to owners in another country. The BoP ensures that any current account deficit is compensated by a financial and capital account surplus. In this way, foreign savings finance current account deficits. Conversely, when a country runs a current account surplus, some its savings finance the current account deficits of other countries.

Countries entering a period of rapid growth often seek external investment, particularly foreign direct investment (FDI), and typically experience a current account deficit as a result. A deficit is not necessarily problematic if the long-run result is economic growth and transformation that generates expanded output with stable prices. However, the initial transfer is nearly always followed by flows in the other direction, whether savings enter in the form of loans (through debt repayment), FDI (through remitted profits and wages of foreign workers), or grants and debt forgiveness (through conditionality).

The terms of trade (ToT) express the ability of a country to secure foreign exchange through export earnings in order to purchase goods from abroad. In practice, a term of trade index is calculated as a ratio of a price index of the goods a country exports to a price index of its imports. Deteriorating (declining) terms of trade create difficulties for importing, financing investment and repaying external debt. Improving terms of trade provide a windfall in foreign

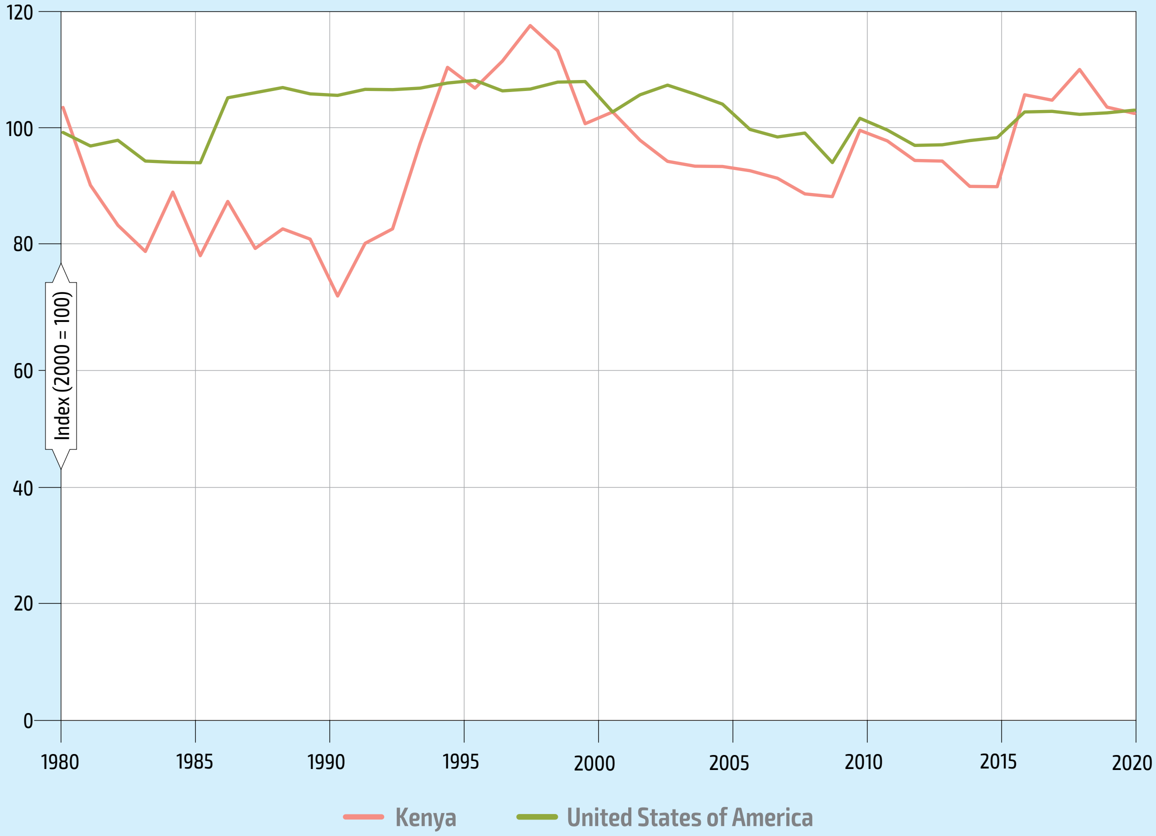
Box 1.7 (cont.) Balance of payments and the terms of trade

exchange, but may not persist. Commodity exporters, in particular agricultural exporters, typically face more variable terms of trade than do countries that specialize in manufactures.

By way of example, Figure A shows the trends in the ToT for Kenya and the United States of America from 1980 to 2019. About one-third of Kenya's gross domestic product (GDP) comes from agriculture; for the United States of America, agriculture contributes less than 1 percent of GDP. Kenya exports both mineral and agricultural commodities, but its main exports are agricultural, particularly tea.

The large volatility of Kenya's ToT is apparent if contrasted with the terms of trade for the United States of America, which are comparatively steady.

Figure A. Net barter terms of trade index for the United States of America and Kenya (1980–2020)



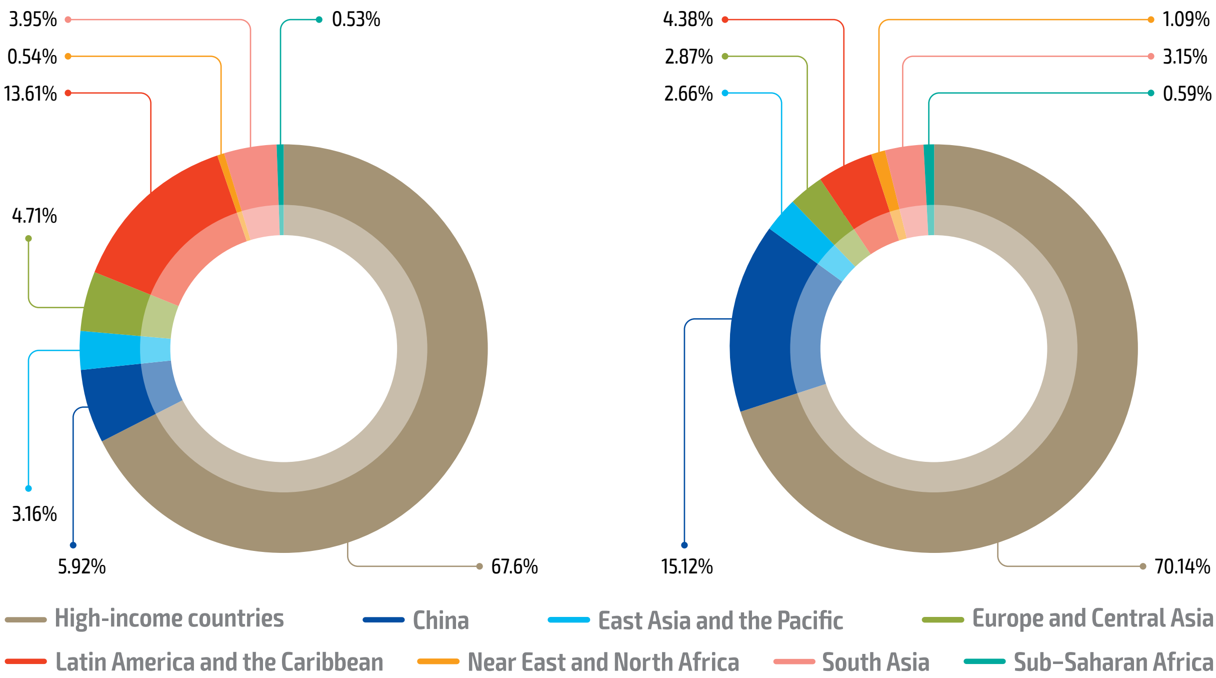
Source: World Bank. 2022. DataBank | World Development Indicators. In: *World Bank*. Washington, DC. Cited 4 June 2022. https://databank.worldbank.org/source/world-development-indicators

1.3.2 International trade of agrifood commodities: some facts and figures

By value, most agrifood exports and imports come from and go to HICs, as shown in Figure 1.24. The HIC share of world agrifood imports is larger than its share of exports, which is also true of China and, to a smaller extent, Near East and North Africa (NNA). Latin America and the Caribbean (LAC) is a major exporter, providing an outsized share of exports compared to its share of imports, which can be seen by comparing exports and imports in Figure 1.24.[n]

[n] In all figures, trade values are given by countries in the region vis-à-vis the world; intraregional trade is not netted out, although, both for imports and exports it barely exceeds 20 percent of the total trade apart from East Asia and the Pacific (EAP) and Europe and Central Asia (ECA) (see FAO [2020].[3]).

Figure 1.24 Share of agrifood exports and imports values by region (2021)

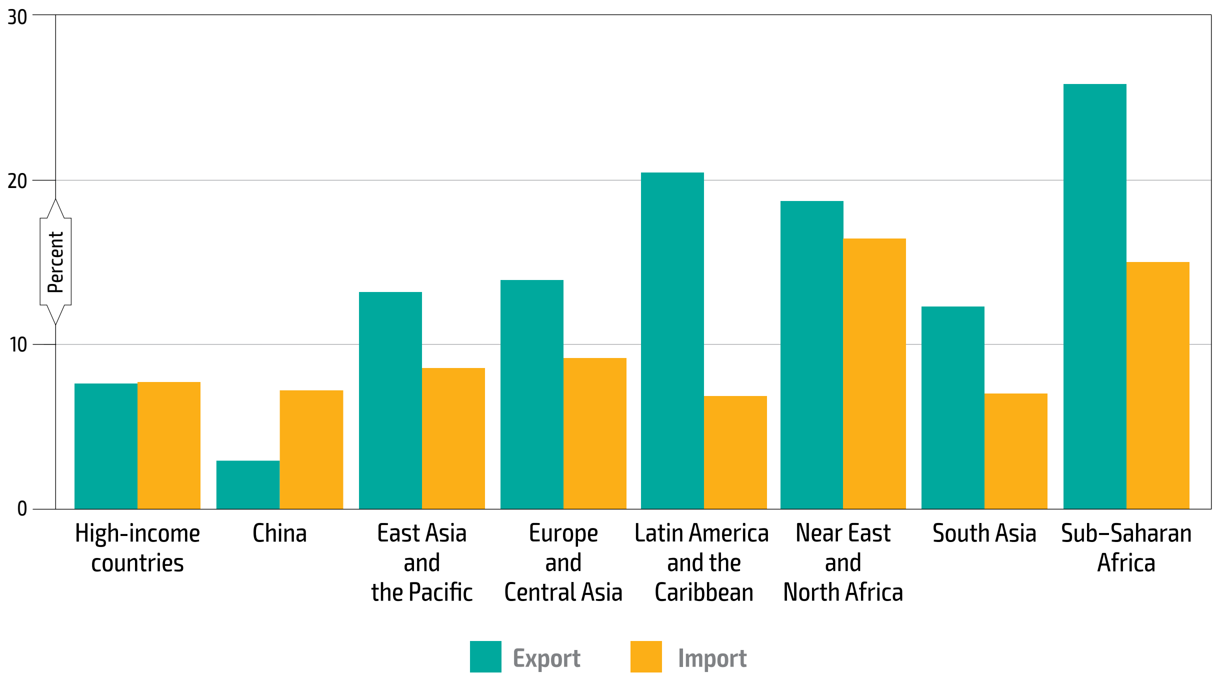


Note: The classification of commodities is based on the Broad Economic Categories (BEC) adopted in the UN Comtrade database.

Source: Authors' elaboration based on United Nations. 2022. *UN Comtrade Database.* New, York, USA. Cited 29 May 2022. https://comtrade.un.org/data

As can be seen in Figure 1.25 referring to 2021, agrifood exports are important to sub-Saharan Africa (SSA) and LAC trade revenues, accounting for more than 26 and 20 percent, respectively. In addition, for both SSA and NNA agrifood products are substantial components of both exports and imports, exceeding 15 percent of the total.

Figure 1.25 Agrifood products as a share of imports and exports by value (2021)



Note: The classification of commodities is based on the Broad Economic Categories (BEC) adopted in the UN Comtrade database.

Source: Authors' elaboration based on United Nations. 2022. *UN Comtrade Database.* New, York, USA. Cited 29 May 2022. https://comtrade.un.org/data

A direct implication is that whenever a crisis occurs in agricultural production or on agricultural markets this would significantly reflect on the overall exports, with ensuing trade imbalances and negative impacts on domestic incomes. On the import side, for NNA and SSA, agricultural goods constitute a non-marginal share of their imports. Crises affecting international markets as, for example, those generated by the COVID-19 pandemic or the Russia–Ukraine conflict, that entailed both price increases and shortages, heavily reflect on the balance of trade, on domestic food prices and on food availability, with clear implications for food security of importing countries. A similar reasoning applies to the imports of agricultural inputs.

Further longer-term considerations concern the composition of agricultural trade. Trading primary or processed goods on the one hand, or intermediate inputs or final consumption goods on the other, has implications for the balance of payments and the terms of trade (see Box 1.7):

- **Primary goods vs processed goods.** Primary goods are, for the most part, commodities, meaning that any one country's output is indistinguishable from that of another.[o] The generic nature of most commodities means that countries cannot mark up their products by claiming some specific features, but must accept the price determined by international markets, thus exposing countries to comparatively lower prices and higher volatility.
- **Goods for household consumption vs inputs for industry.** As household income rises, expenditure on food tends to rise, but more slowly than income – a rule known as "Engel's Law" (see Section 1.2). In a context of generally rising incomes, countries exporting food items, or even worse, primary food commodities, may face a demand for exports that grows more slowly than incomes in the importing countries, with negative impacts on economic growth differentials.[p]

Examining the composition of agrifood exports in more detail (Figure 1.26a), about half of exports by value from the LAC, SSA and NNA are of primary goods. HICs, China and South Asia (SAS), in contrast, mainly export processed foods for household consumption, while EAP also exports processed agrifood goods, but a substantial share is intended for industrial use.

Figure 1.26b shows the corresponding breakdown for imports. What is most notable is the difference, or lack of difference, between the structure of imports and exports. HICs are, for the most part, exchanging goods of the same type – mostly processed goods intended for household consumption, with the shares in all categories being very similar between exports and imports. By contrast, LAC and SSA substantially export primary goods and mainly import processed goods for household consumption. In NNA, the proportions of primary and processed exports and imports are similar, but exports are mostly for household consumption, while imports are primarily for industrial use.

As a general rule, a country exporting agrifood products for household consumption is very likely to find demand for its output growing more slowly than the overall rate of economic growth of its trade partners. Thus, even without any changes in the terms of trade, as a food-exporting country's economy grows, together with its demand for imports, comparatively slow growth in demand for its exports will lead, other things being equal, to a worsening current account balance. Exports of agrifood products for industrial purposes, such as cotton, latex or flax oil, normally experience more robust demand growth than food products, because demand rises more or less along with the growth of the industrial sector. Even if individual firms, or even entire industries, tend to use inputs more efficiently over time, thereby using less of those inputs for the same amount of output, absolute levels of use can still grow as industrial output expands.

o Many countries record commodities using the Harmonized System (HS) managed by the World Customs Organization (WCO). At the detailed six-digit level, HS categories include, for example: rice in the husk (paddy or rough); husked (brown) rice; rice, semi-milled or wholly milled, whether or not polished or glazed; and so on. Some countries specialize, although specialized commodities are grown by multiple producers within the country, such as the highly distinctive Trinitario variety of cocoa from Trinidad and Tobago, or Thai jasmine rice. These sorts of fine distinctions are not available at the six-digit HS level.

p The possibility to shift to exporting high-priced specialty food products that should rise in price more proportionally than incomes should permit producers and countries to benefit from specialization, but this requires investment in physical capital, skills, logistics and marketing, and therefore not easy to implement.

Figure 1.26 Value of agrifood exports and imports by product type and region (2021)

Note: The classification of commodities is based on the Broad Economic Categories (BEC) adopted in the UN Comtrade database.

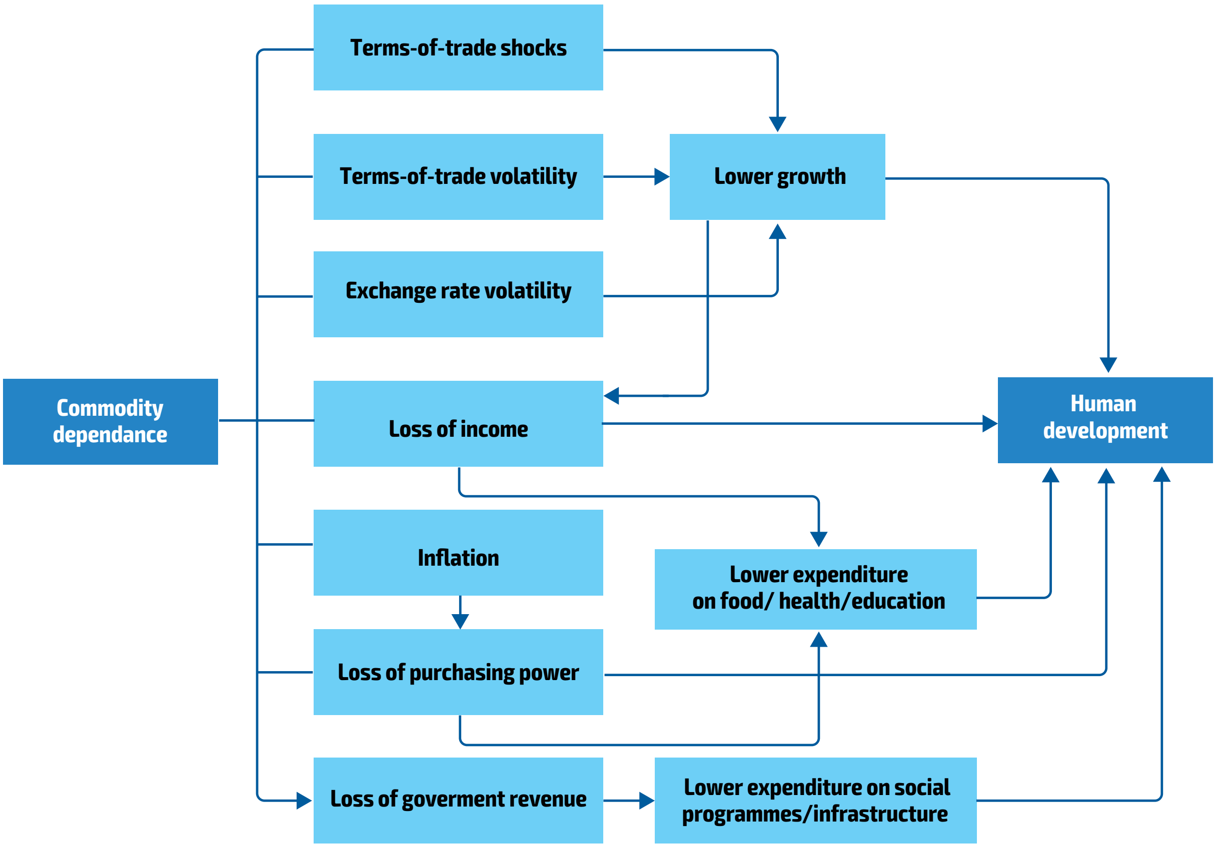
Source: Authors' elaboration based on United Nations. 2022. *UN Comtrade Database.* New, York, USA. Cited 29 May 2022. https://comtrade.un.org/data

1.3.3 Agrifood trade and commodity dependence

Commodity dependence of a country arises when it exhibits large shares of commodities in import and/or exports.[q] Commodity dependence, both from the export and the import side, renders a country's socioeconomic system more vulnerable, less resilient to shocks and more prone to hunger and malnutrition (Figure 1.27). FAO (2019)[5] states that "eighty percent of the countries (52 out of 65) with a rise in hunger during recent economic slowdowns and downturns are countries whose economies are highly dependent on primary commodities for export and/or import".[5]

[q] As per UNCTAD and FAO (2017),[4] export commodity dependence exists when a country generates more than 60 percent of its merchandise export revenues from food, agricultural raw materials, minerals, ores and metals, and/or energy commodities. Import commodity dependence exists when the share of the value of food and fuel imports in total merchandise imports of a country exceeds 30 percent (see Annex 6 of UNCTAD and FAO [2017][4] for the methodology and list of countries by different categories).

Figure 1.27 Potential negative impacts of commodity dependence on development



Source: UNCTAD & FAO. 2017. *Commodities and Development Report 2017. Commodity markets, economic growth and development.* New York, USA. https://unctad.org/system/files/official-document/suc2017d1_en.pdf

The implications of commodity dependence had been highlighted already in the 1950s, and the domestic impacts on lower- and middle-income countries' economies of foreign direct investment associated to export sectors, including agrifood ones, has come into question:

> "[…] the import of capital into underdeveloped countries for the purpose of making them into providers of food and raw materials for the industrialized countries may have been not only rather ineffective in giving them the normal benefits of investment and trade but may have been positively harmful […] because it diverted the underdeveloped countries into types of activity offering less scope for technical progress" (Singer, 1950, p. 476).[6]

Whether, in the early 1950s, the destiny of most LICs that in the subsequent decades would have relied on FDI to develop their vocation of exporters of agricultural and other primary commodities, was already foreseen, is an interesting hypothesis that would deserve further investigation. What is certain is that the option to adopt a strategic behaviour towards the achievement of national objectives by using a mix of policies, comprising selective openings for essentials and capital goods associated with protective measures in sensitive areas (e.g. infant industry, minimum food stocks, etc.), was already foretold at that time.[7] In this light:

> "[…] the purposes of foreign investment and foreign trade ought perhaps to be redefined as producing gradual changes in the structure of comparative advantages and of the comparative endowment of the different countries rather than to develop a world trading system based on existing comparative advantages and existing distribution of endowments […] Perhaps the most important measure required in this field is the reinvestment of profits in the underdeveloped countries themselves, or else the absorption of profits by fiscal measures and their utilization for the finance of economic development" (Singer, 1950, p. 484).[6]

A further question arises with the participation of countries in global value chains (GVCs), that is, the insertion into an internationalized production system. From this perspective, where borders can be traversed more than once and in both directions, in the course of producing a final good from raw materials.[2] A report from FAO argues that:

> "Generally, GVCs could be a significant source of socio upgrading opportunities. Participation in agrifood GVCs can improve the food security of smallholder farmers by promoting productivity, which in turn can increase rural incomes, reduce rural poverty and foster pro growth opportunities" (FAO, 2020, p. 57).[3]

Nevertheless, consistent with Figure 1.26, countries in SSA, for example, are mainly suppliers of primary products for downstream processing, with all the implications in terms of resilience highlighted above.

Regarding environmental impacts of GVCs, the same report claims that:

> "Global value chains that are coherent with sustainable development objectives can spread sustainable technologies and practices. However, the case of Brazilian Amazon could be seen as a counterexample: In the Brazilian Amazon, connecting isolated areas through road network expansion contributed to reduced transportation costs, greater market integration and increased land values and thus provided an additional incentive for deforestation. At the same time, these forces made agriculture an important pillar of the Brazilian economy. The sector is well integrated into the global economy and commodity markets, which makes it sensitive to market forces and international calls for more sustainable production and lower deforestation rate" (FAO, 2020, p. 55).[3]

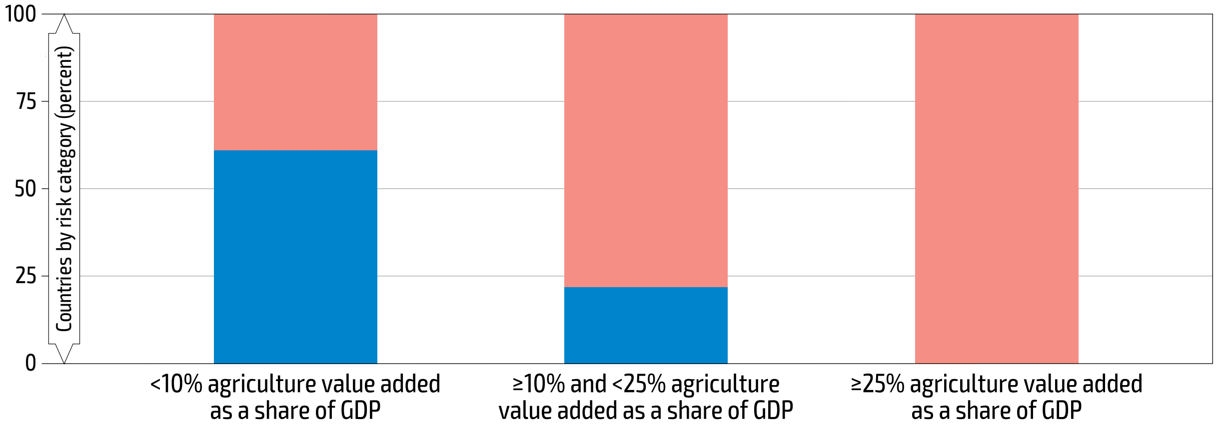
Agricultural commodity dependency may make it difficult for countries addressing environmental and social concerns because, *inter alia*, multilateral trade agreements leave uncertainties for countries that want to address these concerns.[r]

Furthermore, while riskiness can be affected by a variety of factors for countries at all income levels and with any production structure, agriculture-dominated economies tend to be scored as being at higher risk. Figure 1.28a shows the proportion of countries with low and high risk within three country groupings: those where agriculture constitutes less than 10 percent of GDP, those where agriculture is between 10 and 25 percent and those where agriculture exceeds 25 percent of GDP. The thresholds are somewhat arbitrary, but are chosen to lie between the averages for countries identified as "urbanized" (6 percent), "transforming" (13 percent) and "agriculture-based" (29 percent) by the World Bank (2007).[9] The proportion of countries with a higher risk score rises with the share of agricultural value added. The relationship between risk and the cost of loans for private actors is shown in Figure 1.28b. Whereas Figure 1.28b shows considerable spread in lending rates, particularly at higher risk levels; the median, mean, minimum, and highest extreme lending rates tend to rise with the risk indicator. Higher risk signifies higher costs for borrowers; thus, agriculture-dominated countries pay higher interest rates compared to other countries.

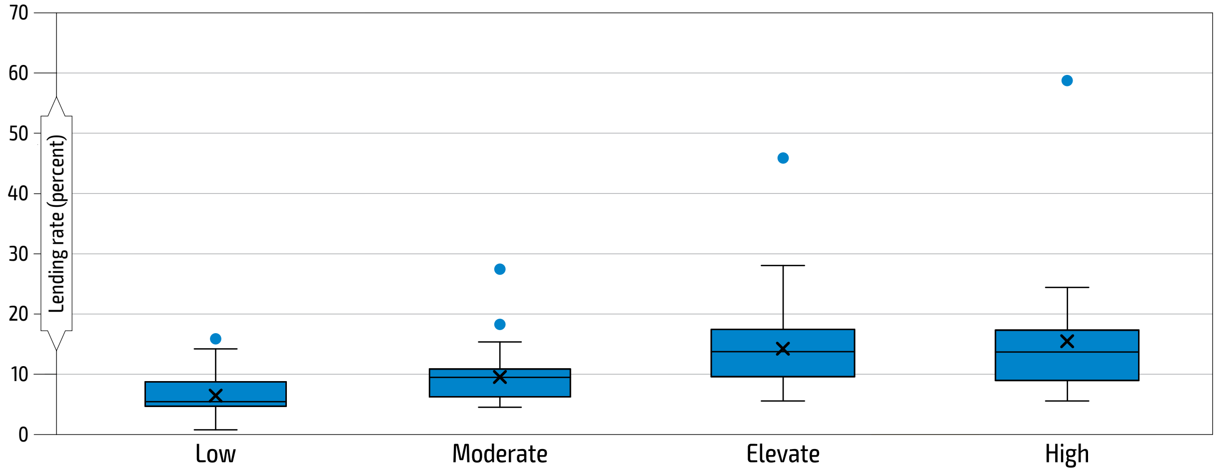
[r] "Since carbon footprint is not in essence a physical part of products […] the implications of the TBT [Technical Barriers to Trade] Agreement requirement for the equal treatment for imports of 'like' products remain untested" (FAO, 2018, p.77).[8]

Figure 1.28 Share of countries by risk category and lending rates against risk ranges

a) Share of countries by risk categories (2021)



b) Lending rates by risk ranges (2013)



Notes: Notes: Panel a) share of countries for groups of countries with agricultural value added as a share of GDP within the given range. Panel b) lending rates against ranges of IHS Market risk rankings in 2013 (low: <1.5; moderate; 1.5–2.3; elevated: 2.3–3.1; high: ≥3.1). Lending rate is expressed as annual percent of outstanding debt. In every boxplot in panel b, the lower horizontal line represents the minimum (smallest value of the dataset); the first quartile (Q1) is the lower side of the box; the median (Q2) is shown as a line in the centre of the box; the third quartile (Q3) is shown at the top of the box; the maximum (the largest number in the data set), is shown with an horizontal line at the top of the line above the box; the mean is represented by the X in the centre of the box and the dots along the vertical axis of each boxplot indicate the presence of outliers. Note that the threshold for risk used for panel a is 2.1 in 2021. The threshold for "moderate" risk used in panel b is 2.3 for 2013. Lending rates were available for a large number of countries in 2013, so the corresponding risk values were collected for that year. IHS Markit was an information handling company recently merged with S&P Global.

Sources: Authors' elaboration based on data from IHS Markit. 2022. IHS Markit. Cited 26 July 2021. https://ihsmarkit.com/index.html for risk categories and lending rates.

Ultimately, whether the expansion of agricultural trade implies an improvement in domestic well-being depends on the institutional settings of exporting countries. The outbreak of pandemics is likely to have exacerbated the difficulties of commodity-dependent countries. As a reaction to the COVID-19 pandemic, selected countries and communities may have started moving towards self-reliance,[10] or other more resilient ways to provision food, such as promoting short supply chains (buying from closer sources) and strengthening rural–urban linkages to adequately support food systems:

> "While there is a global call to not disrupt international trade, the crisis has put a strain on distribution channels, and the importance of domestic food supply has come to the fore. The crisis provides an opportunity to underline the multiple benefits of local food systems, enabling local

actors to better coordinate during such crisis to avoid main gaps in food distribution, and above all, making cities more food resilient to such crisis thanks to existing urban and peri-urban food production, processing and the setup and maintenance of local food reserves" (FAO, 2020, p. 6).[11]

One of the questions raised in the introduction: Does dependence of LICs on manufactures from high-income countries, combined with dependence of HICs on commodities produced by low-income countries, contribute to keep LICs at the periphery of global development processes? can be addressed in the light of the considerations outlined above. Countries that currently export agricultural commodities face serious challenges both in terms of sustainability and resilience. They require diversification of activities within and outside agrifood system. However, paradoxically, in very many instances this implies the creation and maintenance of interdependencies based on finance and, to a good extent, on trade.

However, agricultural exports are not the only way to secure foreign exchange. Such countries are challenged by the need to attract investment also outside agriculture. If this investment is private, investors may expect a reliable and reasonably high return. Returns on investment depend on the skills available in the country, as well as the economic and political climate. Less-than-satisfactory performance on those dimensions can lead potential investors to demand higher returns as a compensation for a perceived risk, thereby placing what can be a high hurdle for cost competitiveness. Thus, at least in the short run, commodity dependency in itself is just a possible signal that a country is in the periphery of the global economic system. The positioning of a country much depends on the power that low-income agricultural commodity exporters exert in setting the terms of the commercial agreements. If the terms are unilaterally set by the most powerful actors in the global economy – the largest, high-income economies and multinational corporations – LICs may barely benefit from entering international markets. On the one hand, HICs may further increase their per capita income by supporting the growth and international reach of their domestic firms, or gain influence by forming multinational blocs to overcome the limitations of their small or moderate geographic size, while LMICs cannot use their current comparative advantage to accumulate capital and invest to build futures that are more diversified and resilient, with sustainable agrifood and economic systems.

1.3.4 Trade rules: regulating interdependencies to support development

As a significant part of interdependencies among countries relevant to development arise in the trade domain, countries seeking to develop have always attempted, in one way or the other, to influence international trade flows in view of protecting or incentivizing domestic production or appropriating strategic goods and assets.

Various policy measures are traditionally used, ranging from import quotas (physical restrictions to imports), price incentives or disincentives (taxes or subsidies on imports or exports) and other forms of interventions to alter domestic prices relative to the prevailing prices on external markets. Despite the fact that almost all countries, for various reasons, have always implemented and maintained in place such policy measures, the prevailing wisdom is that such policies alter (distort) the functioning of markets by modifying (distorting) prices, thus reduce global well-being.[s]

In an attempt to increase global well-being by reducing the so-called "market distortions", countries established the World Trade Organization (WTO). For members of the WTO, the basic rules governing agricultural trade are embodied in the Agreement on Agriculture (AoA), part of the Marrakesh Agreement that established the WTO.[13] The primary thrust of the AoA is to limit government intervention in agricultural trade to tariffs only, although the tariff structure can depend on quantities (tariff-quotas).[t] Also allowed are measures that minimally impact trade, including those supporting infrastructure and food security.

The Doha Round of WTO negotiations, launched in 2001, sought to address this concern, among others. It focused on development, and pursued a holistic approach to resolving longstanding trade

[s] Most indicators aimed at measuring distortions are based on the divergence between an observed domestic price and the respective prevailing price on international markets, somehow adjusted to make them comparable, regardless of whether the international prices are distorted themselves or not.[12]

[t] From the summary on the WTO website: www.wto.org/english/thewto_e/whatis_e/tif_e/agrm3_e.htm

disputes within a single undertaking. The Doha Round is still formally in process, but does not enjoy the confidence of all of the member states, and is effectively dead.[14] The most challenging problems lie in agriculture, and the insistence on resolving them within the single undertaking meant that no agreements were reached on emerging issues, including newly important types of trade, such as in services and e-commerce, and the concerns of growing importance to HICs, including intellectual property rights and investment. These are being resolved through parallel processes within bilateral or multilateral free trade agreements (FTAs).

A highly contentious and persistent issue for LMICs is the use of price incentives for food security, in particular farmer subsidies. The AoA only allows for measures that have a minimal impact on trade, such as household income subsidies for food purchase that can be put in a so-called "green box".[15] However, many LMICs provide farmer subsidies or a guaranteed minimum purchase price in order to stabilize food prices and farmer incomes. These are only allowed up to a certain level, which is either set to a minimum value or to a negotiated higher level. Such arrangements are put in an "amber box". India has been particularly vocal on this issue, but other countries have similar policies. Suggested changes to treaty language seek either to move food security policies of LMICs from the amber box to the green box, or to exempt the quantities of goods affected by those policies when determining whether countries have exceeded their targets. Counterproposals have put forward weakened versions, while emphasizing the need for transparency, and therefore data collection.[15] The only agreement so far has been a "Peace clause", adopted at the Ninth Ministerial Conference in Bali, which essentially provides a moratorium on legal action against countries that breach the agreed limits.[16]

The ground rules for global trade in agricultural goods are therefore: a) only tariffs or tariff-quotas may be applied (from the AoA); and b) all export subsidies must be eliminated or be scheduled to be eliminated in the near future (from the Nairobi Ministerial Decision on Export Competition). Exceptions are noted, as in the special safeguard mechanism (SSM) that allows low- and middle-income countries to temporarily increase tariffs to protect domestic farmers.[14] Nevertheless, these two rules broadly govern trade in agricultural goods.

Despite the fact that the most recent decisions in the AoA framework were requested by LMICs, there is some evidence that the net result may harm SSA,[17] highlighting the somewhat blunt nature of global trade rules.

Each of the multiplying array of FTAs adds specificity to those basic rules. The collection of FTAs around the world presents a bewildering patchwork. Given the WTO ground rules, the agreements mainly focus on the level of tariffs or tariff-quotas. In separate bilateral or multilateral treaties, a given country may agree to stronger or weaker protection for any given agricultural commodity category, either eliminating tariffs entirely, allowing some tariff-free imports under a tariff-quota schedule, or retaining tariffs.[18] There is some evidence that regional trade agreements (RTAs) have increased the agricultural trade of their members, with greater increases evident after a phase-in period.[19] That may be a good sign, but given the specificity of individual agreements, the multiplicity of agreements a country may enter into, and the time lag between signing an agreement and observing its outcomes, the combined impact of WTO rules and FTAs for any given country cannot be assumed.

Overall, despite the AoA, many countries in all income categories continue to subsidize agricultural exports and protect against imports. HICs, in particular, and most notably the United States of America and the European Union, which still adopt significant price incentives.[u] A recent report from FAO, United Nations Environment Programme (UNEP) and the United Nations Development Programme (UNDP) claims that price incentives and fiscal subsidies are forms of support that may have significant negative implications on food systems, as they incentivize production practices and behaviours that might be harmful to the health, sustainability, equity and efficiency of food

[u] Although more recent commitments on export subsidies may soon be fulfilled. Indeed, under intense criticism of HICs' continued subsidization of agriculture, within the Doha Round at the 10th WTO, the Ministerial Conference held in Nairobi in 2015 decided that, "Developed Members shall immediately eliminate their remaining scheduled export subsidy entitlements as of the date of adoption of this Decision," while "Developing country Members shall eliminate their export subsidy entitlements by the end of 2018." (Ministerial Decision of 19 December 2015: WT/MIN(15)/45 – WT/L/980). Although this agreement is not binding and countries are still bound by the AoA,[20] the WTO Committee on Agriculture[21] reports that the United States of America has eliminated its agricultural export subsidies, and the European Union has not reported any budgetary outlays for export subsidies since the Nairobi conference.

systems. For example, they may favour the overuse of agrochemicals and natural resources, or promote monoculture or bias nutritional outcomes by disproportionately fostering production of staples versus fruits and vegetables. The report highlights that unhealthy products, like sugar, and emission-intensive commodities (e.g. beef, milk and rice) receive the most support worldwide but, while removing or repurposing this support is possible, it is a challenging process as actors may respond differently in different countries.[22] Overall, the ultimate impacts of removing or repurposing this support would depend very much on the specific reasons why the support measures were introduced, and on the way that saved funds are going to be allocated. These aspects can only be clarified by means of a sound investigation, as suggested in the report.

Overall, going back to the second question raised in the introduction: to what extent do current international trade rules and trade-related policies favour or disfavour transformative processes towards sustainable and resilient agrifood systems? Possible pointers can be put forward based on the previous considerations. Current trade rules allow for subsidizing agricultural practices that present critical nutritional and environmental aspects, and can possibly induce further commodity dependence. Furthermore, it is not so clear whether countries that adopt more stringent environmental, social and fiscal measures can protect themselves against environmental, social and fiscal dumping by countries with more relaxed legislations.[v]

1.3.5 Illicit financial flows and agrifood systems

Commodity dependency or other forms of asymmetric trade and investment relationships, resulting from, *inter alia*, weak institutions, are also likely to pave the way to IFFs that may draw resources from LMICs towards HICs or fiscal havens.

IFFs do not have a fixed definition, but various working definitions generally require IFFs to be both: a) financial transfers across borders; and b) related to illegal activity.[23, w] The Tax Justice Network, the Independent Commission for the Reform of International Corporate Taxation and the Global Alliance for Tax Justice wrote open letters to the United Nations Secretary-General in 2017, “urging him to make sure that the commitment to tackle multinational tax abuse is not eliminated from the UN SDGs”.[25] The particular target of concern is SDG 16.4, which includes a call to significantly reduce illicit financial flows, and the associated indicator 16.4.1, “Total value of inward and outward illicit financial flows (in current USD).” The proposed indicator would encompass tax abuse, which the United Nations terms “aggressive tax avoidance” (see Box 1.8).[x]

Some preliminary work to assess the magnitude of IFFs has been carried out, for instance, by the United Nations Economic Commission for Africa (UN ECA),[26] which estimated that between USD 50 to USD 148 billion per year leave SSA as IFFs. According to these estimates, IFFs more than offsets the Official Development Assistance (ODA) to SSA that ranged, in the period 2010–2019, between USD 44 and USD 55 billion per year. A more systematic source of headline numbers for IFFs is the non-profit organization, Global Financial Integrity (GFI), which makes use of global trade and BoP datasets to calculate an indirect measure, the so-called “value gap”, that allegedly approximates IFFs.[y] For the period 2008–2017, GFI reports an average annual “value gap” of USD 873.4 billion of outflows.[z]

v Environmental dumping is referred here as not only as direct dumping of hazardous waste from one country into another but as indirect dumping of goods cheaply produced with high environmental impacts in countries of origin.

w The non-profit organization GFI, which coined the phrase “illicit financial flows” chose the word “illicit” over “illegal” to keep the meaning broad enough to include a large array of instances.[24] Forstater (2018)[23] argues that multinationals are much more likely to use completely legal means to avoid paying taxes, including transfer prices that do not reflect the real value of goods and services exchanged between units of the same corporation in different countries and other means to overinvoicing costs and underinvoicing revenues.

x As proposed in the metadata found at: https://unstats.un.org/sdgs/metadata/?Text=&Target=16.4

y The proposed indicator 16.4.1 would not make use of the GFI dataset or methodology; but would use bottom-up estimates Unfortunately, the SDGs indicator database does not provide any estimate yet (accessed 21 May 2022).

z GFI estimates have been plausibly criticized,[23,27,28] and one notable feature of the GFI statistics is that estimated inflows to “developing countries” from “advanced economies” exceed estimated ***outflows*** by nearly USD 500 billion,[29] although the opposite is true for SSA.[29] As noted by GFI itself, if the discrepancy indeed reflects illicit inflows, then they are highly problematic, being “a type of resource curse in that a) their origin is unknown, b) inflows are invisible to governments, c) they are not taxed, and d) they often times fuel illegal activities such as drug trafficking.” Nevertheless, it belies the narrative of “capital flight”.

Box 1.8 A methodology to assess illicit financial flows

The GFI methodology relies on calculated discrepancies in the BoP and bilateral trade statistics, as reported in the United Nations Comtrade database. These discrepancies are ascribed to illicit financial transfers.[30] For example, suppose that the reported trade deficit declines, but there are no recorded changes in FDI flows, remittances, external debt or reserves. As the BoP must balance, there is now a discrepancy in the statistics; the decline in the trade deficit must be balanced by some unreported financial outflow, which is ascribed to capital flight.[31]

The GFI has consistently estimated that the largest IFFs are attributable to trade misinvoicing, which is estimated from trade statistics using mirror trade analysis. The method in this case is to subtract imports from exports after correcting for the cost of carriage, insurance and freight (CIF) over the cost of goods free on-board (FOB). In the GFI's most recent calculations, actual CIF-FOB margins are used where they are available, but otherwise a margin of 6 percent is assumed, following IMF practice. This is a concern in itself, because margins vary over an extremely wide range,[27] and differ between source and destination countries and according to the goods being traded.* Nevertheless, GFI's current practice is a considerable improvement over their original assumption of a uniform 10 percent margin, and improvements in the methodology have not substantially altered the qualitative conclusion of large volumes of missing financial flows.

Discrepancies in mirror trade analysis that truly arise from illicit behaviour occur when traders or firms misstate prices or quantities when they report imports or exports. The presumption is that they then make up the difference to the supplier or purchaser through some other, hidden means, such as payment through an offshore account.[29] However, discrepancies can arise from a variety of sources, including such common, but innocent, causes as accidental misrecording of a shipment under the wrong commodity code.[23] One important systematic discrepancy that the GFI now takes into account arises from the role of the special administrative region (SAR) of China, Hong Kong as a transfer hub, accepting goods and then re-exporting them while applying a markup. The impact of this correction to GFI's statistics was substantial. It led to a reduction in IFFs ascribed to China from USD 274 billion between 2001 and 2010 to USD 108 billion between 2002 and 2011.[27] While the correction for the SAR of China, Hong Kong was a welcome improvement to the GFI methodology, other ports play a similar role, such as Rotterdam, and as do free trade zones and bonded warehouses. In the latter case, the registered country of ownership (for instance, Switzerland) may be recorded as the destination by the exporting country, while the actual destination country (for instance, Germany) records the source as the actual country of origin, rather than Switzerland, while the warehouse is in London. In such cases, the opacity of trade statistics offers an opportunity for, and therefore a risk of, IFFs, but gaps in the mirror trade statistics fail to prove that IFFs are present.[28]

For example, as reported in the OECD Database on International Transport and Insurance Costs (available at www.oecd.org/sdd/its/statistical-insights-new-oecd-database-on-international-transport-and-insurance-costs.htm).

The GFI headline numbers cover trade in all commodities, or for all LMICs in aggregate. No primary or processed agricultural commodities appear in the top ten gaps by value,[29] and only specialty agriculture-based goods appear in the top ten gaps by share of total trade:[29] fur and artificial fur; prepared feathers; leather articles; and straw and wicker products. Estimates for agricultural commodities are only available in GFI's country reports, and there are only a handful of those. Perhaps unsurprisingly, for countries for which agricultural trade is important, estimates of revenue losses as a result of import underinvoicing are large for agricultural goods. For example, for India, the estimated revenue loss for cereals is 18 percent,[32] while for Kenya, estimated tariff revenue losses for prepared meat and fish exceeded 60 percent.[33] However, for the reasons given above, as well as other problems with mirror trade analysis,[23,28] these numbers should be treated with a great deal of caution.

Going back to the question raised in the introduction: Is there evidence of the impacts of IFFs on agrifood systems and their role in development for low-income countries? If so, what can be done about them? A major conclusion that can be drawn from the literature on IFFs is that they are present and, despite the existence of high-profile estimates, essentially unknown. In countries with weak enforcement, regulation and data collection, there is ample opportunity, and hence high risk, of IFFs, including ample evasion of taxes applied at the border. Of possibly greater concern is the use by multinational firms, including those operating in agrifood markets, of legal, yet aggressive, tax avoidance.

A key question for the 2030 Agenda and the SDGs is whether and to what extent measures of IFFs under Target 16.4 will capture abuse; the background paper submitted to UNCTAD by Cobham and Janský (2017)[34] provides useful guidance in this respect.

1.3.6 Anticipatory signals for possible futures

The subsections above have highlighted that: cross-country interdependencies abound within agrifood systems; the global economy, and the global agrifood system within it, are linked both through trade and finance; and the national institutional set-up, contractual power relationships and global governance matter to determine the performances and sustainability of resilience of food systems. In light of the considerations presented above, some signals that may anticipate alternative futures for agrifood systems can be detected:

- The high number of countries currently classified as commodity-dependent signal that balancing the trade-off between the need to invest to diversify economies and the need to export commodities to finance investment or to borrow at reasonable rates and fair conditions, has not been easy to solve until now and may continue to be so even in the future, especially in light of the weak institutional set-up of many commodity-dependent countries.
- The stagnant progress in the AoA may signal that the momentum for discussing and implementing new trade rules conducive to sustainable development has yet to be reached, although increased public awareness about the fact that Agenda 2030 is "off track" could act as a catalyst for initiatives in this direction. More clearly designed and operationally applicable and effective rules regarding trade, including rules to protect against various forms of dumping that may jeopardize the sustainability of agrifood systems, would probably play an important role in triggering transformative processes.
- The way agricultural subsidies are set now do not appear to be conducive to sustainability. The possibility to repurpose agricultural subsidies to achieve more sustainable and resilient agrifood systems could be blocked or neglected. Decisions taken in one direction or another could contribute to increasing or jeopardizing the sustainability and resilience of agrifood systems.
- The "known unknowns" (and, possibly the "unknown unknowns") about IFFs may reveal that so far little attention has been paid to this aspect, despite its explicit inclusion among the SDG targets. Whether or not this target is going to be seriously addressed, through additional research, statistics, effective rules and their enforcement, could increase or hamper the possibilities for countries to retain additional wealth within their boundaries with non-marginal multiplier effects on their economies.

Ultimately the different choices and policy decisions regarding the aspects discussed above may determine or undermine the possibility for countries to follow practicable development patterns. Along that route, international trade rules could be used as one device within a more articulated policy mix, to pursue a sort of strategic openness that would allow countries to benefit from international trade while pursuing national medium- and long-term strategic objectives.

NOTES – SECTION 1.3

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1.4 Big data (Driver 4)

Big data generation, control, use and ownership enable real-time innovative decision-making. However, digitalization of many aspects of human life, social interactions and production, including agrifood value chain processes, increasingly depend on oligopolistic markets. A small number of transnational corporations manage extraordinary amounts of information on production and consumption processes, provided through the use of smart phones, geo-localization, sensors, social media, credit cards and all other sorts of wearable and smart connected devices.[1] This issue is definitely under the United Nations radar, as the United Nations Chief Executives Board, in one of its recent reports stated that

> "… The large economies of scale that exist in digital industries have encouraged oligopolistic structures, in which a few players have come to dominate large shares of the market. A similar concern is raised about the economic benefits of big data platforms that are able to amass extraordinary amounts of information on consumer behaviour and preferences."
> (United Nations, 2019, p. 3).[2]

Capacities in the National Statistical Systems and awareness of consumers and civil society need to be built on data harvesting, storage, management and control, to ensure country-driven independent, transparent and accountable data generation, validation and use processes as well as their conversion into statistics. This is particularly important for small national states, whose size, relative to the weight of transnational corporation, may make peer-to-peer partnerships difficult to design and implement.

This raises several questions that are dealt with here or in other parts of this report:

- What are the agrifood systems-related big data currently generated? For what purpose? What are the prospects?
- To what extent are big data governance issues (ownership, control, storage, elaboration, access…) going to affect the way agrifood systems generate and use big data?
- Is there room to break or govern existing monopolies (oligopolies) dominating big data? To what extent can agrifood systems contribute to this?

1.4.1 Defining big data

Big data is the process of gathering, storing, analysing and extracting knowledge from high-volume and complex data, often by means of artificial intelligence (AI),[aa] and algorithms, including machine learning.[3] Big data has been popularized by its four "Vs": variety (number of data sources), velocity (speed at which the data changes), veracity (trustworthiness) and volume (size).

Big data, along with its data-driven analysis, seems to be successful in many domains, but it started being applied to agriculture only relatively recently,[4] particularly in the context of precision agriculture, smart farming and digital farming. In simple terms, it is expected to perform descriptive analytics (what happened), predictive analytics (what will happen) and prescriptive analytics (what should happen).

By combining big data and machine learning, it is possible to carry out predictive analytics, a type of analytics that is evolving very fast. For example, it can provide users future perspectives on variables such as weather, soil erosion, humidity and market prices. These perspectives can be used then to choose, for example, the best moment for sowing a particular crop in a specific location. Prescriptive analytics can also recommend a change in agriculture practices.

Big data platforms can be conceptualized within three layers: data acquisition, data analysis and data visualization. Data (including imagery data) acquisition is accomplished through mobile phones, drones, satellites and sensors fixed in fields, or on machines (Internet of Things [IoT]) (see Figure 1.29). These devices for data collection, that are part of what is defined as the IoT, allow farm vehicle tracking, livestock monitoring, storage monitoring and open field monitoring (e.g. crop yield, terrain features and topography, organic matter content, moisture levels and nitrogen levels).

[aa] Technical terms are defined in Box 1.9.

Box 1.9 Big data related terms

Algorithm. A set of steps that are followed in order to solve a mathematical problem or to complete a computer process.

Artificial intelligence (AI). AI refers to the simulation of human intelligence in machines that are programmed to think like humans and mimic their actions. The term may also be applied to any machine that exhibits traits associated with a human mind, such as learning and problem-solving. The ideal characteristic of AI is its ability to rationalize and take actions that have the best chance of achieving a specific goal. A subset of AI is machine learning, which refers to the concept that computer programs can automatically learn from and adapt to new data without being assisted by humans. Deep learning techniques enable this automatic learning through the absorption of huge amounts of unstructured data such as text, images or video.

Blockchain. A technology that provides decentralization, immutability and transparency for data, and where the data are organized in a growing list (chain) of data structures (called blocks). Examples of blockchains are Bitcoin and Ethereum, of which the latter added the notion of smart contracts.

Cloud computing. Cloud computing is the delivery of different services through the internet. These resources include tools and applications like data storage, servers, databases, networking and software. Rather than keeping files on a proprietary hard drive or local storage device, cloud-based storage makes it possible to save them to a remote database. As long as an electronic device has access to the World Wide Web, it has access to the data and the software to run it

Data point. An individual item in a set of electronic data. Synonyms are information element, (key) data element and data attribute.

Deep learning. Deep learning is an AI function that imitates the workings of the human brain in processing data and creating patterns for use in decision-making. Deep learning is a subset of machine learning in AI that has networks capable of learning unsupervised from data that is unstructured or unlabelled. It is also known as deep neural learning or deep neural network.

Digital agriculture. Digitalization in food and agriculture, often referred to as digital agriculture, is a process involving digital technologies (internet of things, AI, blockchain, etc.) that covers access, content and capabilities, which, if appropriately combined for the local context and needs within the existing food and agricultural practices, could deliver high agrifood value, and thrive to improve socioeconomic, and potentially environmental, impact.

Digital farming. The essence of digital farming lies in creating value from data. Digital farming intends to go beyond the presence and availability of data to develop actionable intelligence and meaningful added value from such data. Digital agriculture is integrating both precision farming and smart farming.

Internet of things (IoT). The IoT is a computing concept that describes the idea of everyday physical objects being connected to the internet and being able to identify themselves to other devices and to send and receive data. The IoT is significant because an object that can represent itself digitally becomes something greater than the object alone. No longer does the object relate just to its user, but it is connected to surrounding objects and database data.

Machine learning. Machine learning is the concept that a computer program can learn and adapt to new unstructured and unlabelled data without human intervention. Machine learning is a field of artificial intelligence.

Platform economy. The platform economy is economic and social activity facilitated by platforms. Such platforms are typically online sales or technology frameworks (e.g. advertising platforms, cloud platforms, industrial platforms, production platforms, transaction platforms or digital matchmakers, and innovation platforms).

Box 1.9 (cont.) Big data related terms

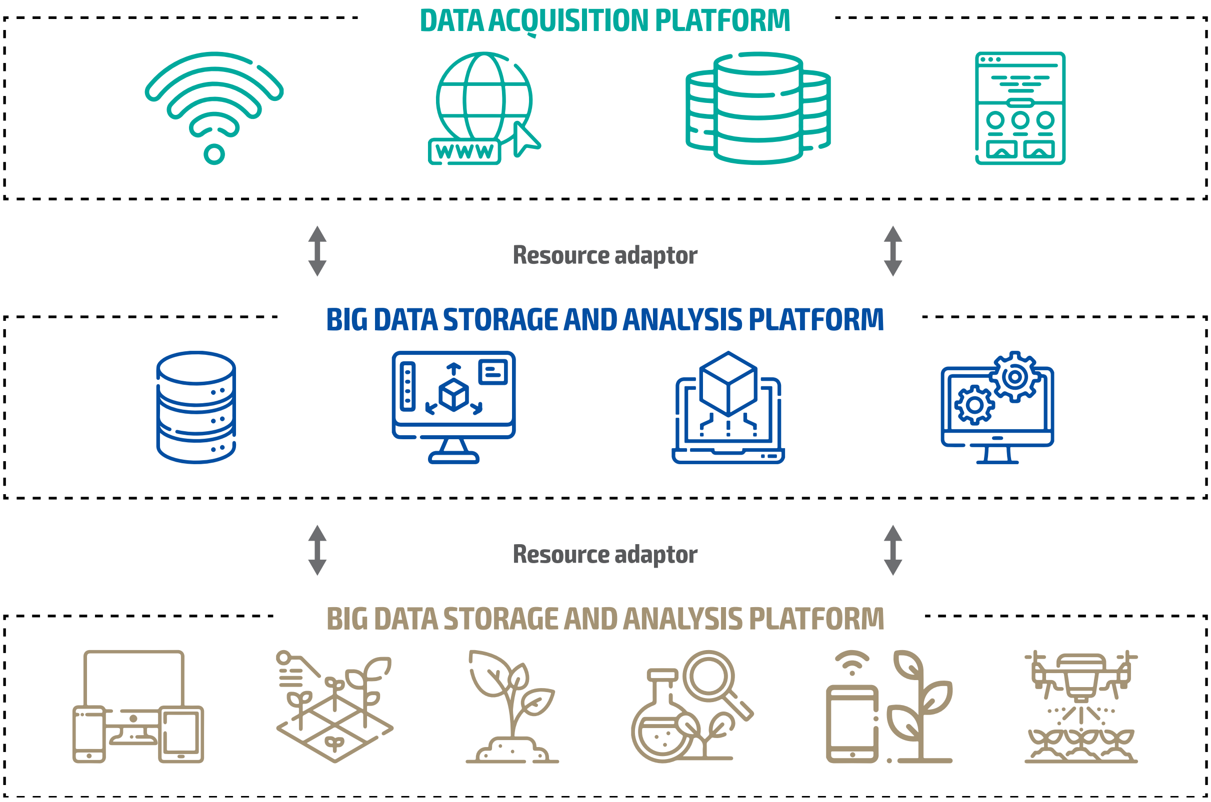
Precision agriculture. Precision agriculture is the use of guidance and steering systems, yield monitoring, variable rate application and telematics that gather, processes and analyse temporal, spatial and individual data and combine it with other information to support management decisions about on-farm activities and performance, such as yield variation and the characteristics of production assets.

Sensor. A sensor is a device, machine or subsystem that detects events or changes in its setting and sends them in sequence to other electronics, often a computer processor. It can detect the magnitude of a physical parameter and changes it into a signal that can be processed.

Smart farming. Basically, smart farming is applying information and data technologies for optimizing complex farming systems. The focus is on access to data and how farmers can use the collected information intelligently. The goal is to increase the quality and quantity of the products while optimizing human labour production. The technology used in smart farming range from IoT and robotics to drones and AI. With these tools, farmers can monitor field conditions without physically going to the field. This enables them to make decisions for the whole farm, for a lot, or even for a single plant. The entire process of smart farming is software-managed and sensor-monitored.

Value chain. A value chain can be defined as the full range of activities that are required to bring a product or service from conception, through the different phases of production (involving a combination of physical transformation and the input of various producer services), to delivery to final customers and final disposal after use.

Figure 1.29 The three layers of big data



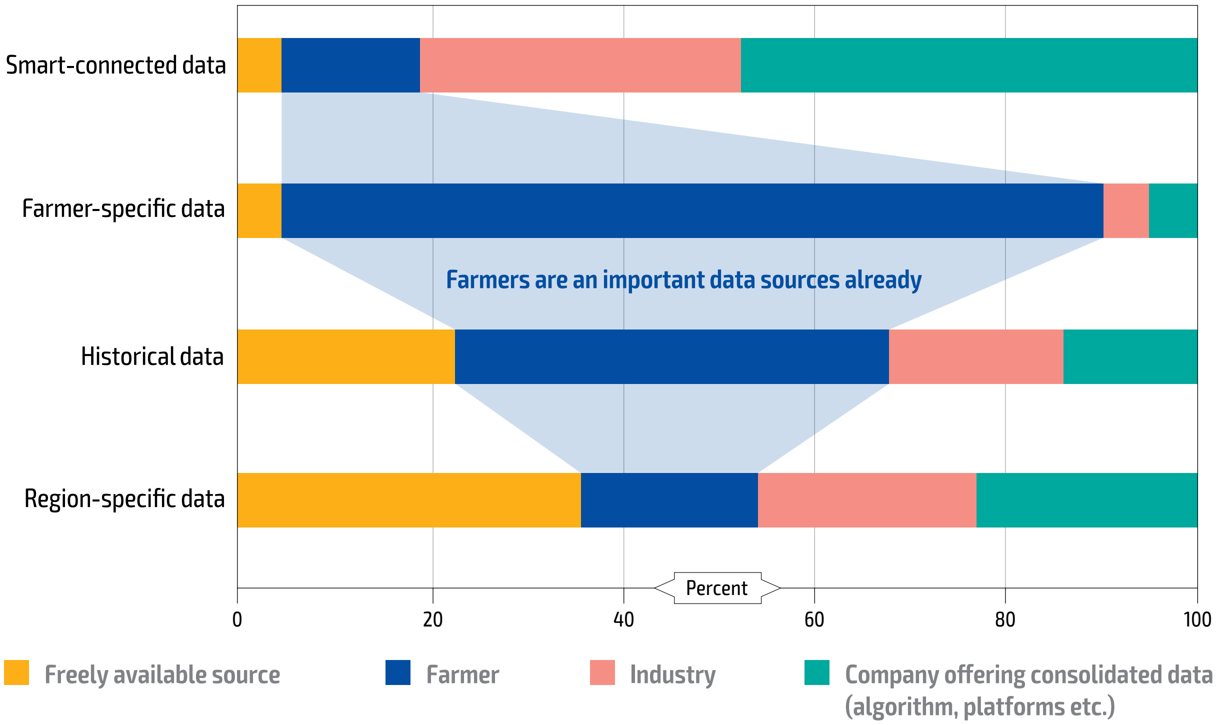
Source: Gopal, M.P.S. & Chintala, B.R. 2020. Big data challenges and opportunities in agriculture. *International Journal of Agricultural and Environmental Information Systems*. 11(9): 48–66. https://doi.org/10.4018/IJAEIS.2020010103

1.4.2 Recent trends – big data and agrifood systems

Big data technologies have formalized and systematized knowledge that was previously 'locked up' in the minds of the most astute farmers, agribusinesses and other actors. They are expected to contribute to optimization of farm production, minimization of disaster-related risks,[5] reduction of costs of fertilizers application,[6] more effective management of crop diseases[7] and natural resources,[8] mitigation of climate change[9] and an enhanced food security.[10]

In the agrifood context, data are obtained from four main sources: freely available data, farmers, industries and the company offering consolidated data (see Figure 1.30). Some of these can be easily and freely acquired from actors of agrifood value chains, while others must be combined, processed and modified in a logical way to create data intelligence.[11]

Figure 1.30 Sources of data for data-driven agriculture



Source: PA Consulting, 2015. *Digitizing Agriculture: Unlocking the potential in the agricultural value chain.* London. www2.paconsulting.com/Digitisingagriculture_download.html

The ongoing progress in computing infrastructure (e.g. cloud computing), and the introduction of IoT and advanced algorithms (e.g. deep learning and AI) created opportunities for big data entering the mainstream of smart farming,[12] that takes into account infield variability and context, and real-time events occurring along the value chain.[13]

Some big data programme providers offer to cut considerably water consumption in agriculture by using field sensor arrays to collect variables (e.g. soil moisture and pH) and deep learning to impute or predict data points from sensor nodes and drone images.[14] Similarly, FAO's WaPOR (Water Productivity Open-access portal) proposes a remote sensing-based water management solution that helps increase water productivity and agricultural production.[15] Others offer big data solutions for reducing pesticide use or fuel consumption through agricultural equipment by optimizing their routes, or for forecasting failure of equipment and minimizing machinery downtime, or for improving livestock rearing by tracking and recognizing behavioural patterns, preventing diseases, optimizing food intake, estimating milk production and reproductive performance.

Furthermore, monitoring of agriculture and food supply chains, based on big data such as IoT and blockchain ledgers, offers agribusinesses greater transparency, possibility of mappings products approaching their expiration date and more efficient recalls of unsafe or contaminated food, as well as insights into customer behaviour and buying patterns[16] while also ensuring accountability.[17]

1.4.3 Big data and agrifood systems

Peer-reviewed studies of the actual impact of the use of big data in food and agriculture are as yet rather limited in number. Below are a few examples.

In Tamil Nadu, India, an experiment found that with a remote sensing-assisted irrigation system, production could be increased by up to 40 percent if plants "were getting water at the proper time".[18] Moreover, in the United States of America, a study measured that site-specific variable rate sprinkler irrigation could reduce water usage by up to 26 percent.[19]

Precision agriculture practices (variable rate nutrient application, variable rate irrigation, controlled traffic farming and machine guidance, and variable rate planting or seeding) requiring high-tech equipment and big data were also found to have the ability to minimize agricultural inputs through site-specific applications. This can result in lower greenhouse gas (GHG) emissions and have a positive impact on farm productivity and economics, as it provides higher, or equal, yields with smaller production costs than conventional practices.[20]

The application of precision agriculture and data analytics can diminish pesticide use, as illustrated by a ten-year on farm trial on potatoes conducted in the Netherlands that found that savings on pesticides were, as a result, on average around 25 percent.[21]

Precision Agriculture could also contribute to cutting GHG emissions from fertilizer application and fuel use, and prove to be profitable even in farms of less than 50 hectares in a Mediterranean context. For example, in the case of maize production, with a cost of about USD 600 per flight, data analysis and the elaboration of a prescription plan the operation could bring a likely return of approximately USD 6 300.[22]

The data obtained from the sources available, although very partial and often based on small experiments in very specific conditions, suggest that there is a potential in the use big data technologies for improving production. However, there are many different factors affecting the benefits of these technologies, and they vary widely depending on which exact technology is applied,[23] as well as from user to user.[24]

In 2018, the World Economic Forum (WEF) positioned big data as part of a wider technological movement that could not only impact the agrifood systems by 2030, but also contribute to achieving the SDGs (Table 1.7).

Table 1.7 Projected potential impact of big data in agriculture by 2030

BIG DATA TECHNOLOGIES	IMPACT ON AGRICULTURE AND FOOD SYSTEMS BY 2030	DRIVERS ENABLING BIG DATA IN AGRICULTURE AND FOOD SYSTEMS	IMPACT ON SDG TARGETS
Mobile service delivery **Precision agriculture using satellite data and the Global Positioning System (GPS)**	• 3–6% increase of income and yield • 2–5% of reduced food loss • 0–1% of reduced agricultural GHG emissions • 1–3% reduced water use	• Mobile phone data and social media data for better access to payments, markets, information, farming practices, inputs and seeds. • Use of AI and machine learning for better coordination and decision-making on efficient inputs and water application. • GPS for reducing fuel use and optimizing use of the mechanization. • Satellite data for drought monitoring, water productivity and early crop yield assessment.	• Target 1.1 • Target 1.2 • Target 2.1 • Target 2.3 • Target 2.4 • Target 2.5 • Target 6.4
Blockchain enabled transparency	• 1–2% reduced food loss	• Improved value-chain efficiency driven by improved collaboration and data visibility. • Online transaction data, scanner data, and social media data for tracking food and agriculture commodities.	• Target 2.c • Target 14.6 • Target 15.1 • Target 15.2

Table 1.7 (cont.) Projected potential impact of big data in agriculture by 2030

BIG DATA TECHNOLOGIES	IMPACT ON AGRICULTURE AND FOOD SYSTEMS BY 2030	DRIVERS ENABLING BIG DATA IN AGRICULTURE AND FOOD SYSTEMS	IMPACT ON SDGs TARGETS
Big data and advanced analytics for insurance	• 0–2% increased income • 1–2% increased yields	• Increased willingness to take risk, experiment with new methods and technologies. • Satellite data to better inform crop yield estimation.	• Target 2.3 • Target 2.a • Target 2.c
IoT for real-time supply chain transparency and traceability	• 1–4% reduced food loss	• Improved ability to manage temperature, humidity, gas, etc. and better shelf-life management.	• Target 12.3
Remote sensing for food safety and quality	• 5–7% reduced food loss	• Reduced domestic food waste from individualized and real-time expiration dates.	• Target 12.3

Source: Adapted from WEF (World Economic Forum). 2018. *Innovation with a Purpose: The role of technology innovation in accelerating food systems transformation*. Geneva, Switzerland; Van Halderen, G., Jansen, R., Ploug, N. & Truszczynski, M. 2021. *Big Data for the SDGs. Country examples in compiling SDG indicators using non-traditional data sources.* Working Paper Series SD/WP/12/January 2021. Bangkok. ESCAP (Economic and Social Commission for Asia and the Pacific) and United Nations.

It is clear that further evaluations of the socioeconomic and environmental impact of big data are needed, as the investment in big data technologies could be quite costly for all actors in the value chain, both in terms of finance as well as time spent on gaining the digital skills required.[22]

1.4.4 Challenges

Several constraints must be overcome for big data to develop in the sector, the least of them being the assurance that big data users will draw benefits from it. In the United States of America, for example, while most producers admit they will eventually adopt precision agriculture of site-specific management technology, what they see are the initial costs, uncertain economic returns, and the complexity as limiting factors.[25] Other constraints are reviewed below.

Data ownership, privacy and security

With the multiplication of data and of the means of collecting them, users will increasingly want to protect the ownership and privacy of their data.

While policy and regulations that govern personal data, such as the European Union's General Data Protection Regulation (GDPR), are becoming more frequent, there are currently no legal or regulatory frameworks aimed specifically at agriculture and food data.[26] Recently, the European Union launched the Data Act that is part of the overall European strategy for data, and complements the Data Governance Regulation by clarifying who can create value from data and under which conditions. It also introduces rules concerning the use of data generated by devices connected to the IoT. In terms of agrifood, at the time of drafting this report, there are four examples of countries where private stakeholders (mostly farmer organizations, private companies and industry associations) have set common standards for data sharing and governance structures for agricultural data (Table 1.8).

Table 1.8 Farm data governance frameworks

COUNTRY	OBJECTIVE	DATA GOVERNANCE FRAMEWORK
Australia (farm data code)	Ensuring farmers have confidence in how their data are collected, used and shared.	**7 principles** (transparency, fairness, access, documentation, portability, security and compliance)
United States of America (privacy and security principles for farm data)	Principles, policies and practices to be consistent with the contracts with farmers and to have an ongoing engagement and dialogue regarding the rapidly developing technology.	**12 principles** (education, ownership, access, notice, transparency, portability, terms, disclosure, retention, unlawfulness and liability)
New Zealand (farm data code of practice)	Define disclosures and behaviours for storing, handling and moving data. To give confidence that information is secure and being managed in an appropriate manner.	**14 principles** (corporate identity, rights security, access, sovereignty, security, regulatory compliance, self-audit, review non-compliance, complaints, withdrawal)
European Union (code of conduct on agricultural data sharing by contractual agreement)	Data sharing, setting principles, responsibilities and creating trust.	**7 principles** (contract, details, permission, access, originator, no restrictions, protection)

Source: Authors' elaboration.

The absence of regulation creates opacity regarding who owns data retrieved from farms and who controls their use. This contributes to weakening farmers' positions and offers opportunities to others (commodity traders, agribusinesses, data service providers or data brokers) for trading them, thus generating mistrust.[27,28] More generally, farmers and consumers are concerned about the potential misuse of information related to their farming and shopping activities by seed companies, machinery equipment providers, groceries, and wholesale markets,[29] as these companies have no obligation to make their data available and have control over those who are allowed access to data.[30] The overpowered position of big data service providers causes their clients, particularly farmers, to agree to terms and conditions on which they are not well enough informed, as they may have no choice but to remain with their provider for fear of reprisal. Evidently, once the raw data has been processed or arranged as a database, whoever undertook the work may be given copyright protection.

Data accuracy and user capabilities

Because of the increasing amount of useful data emerging from all sorts of technologies, for many big data applications in agriculture, the problems start as soon as data are collected, as the diversity of sources bringing abundant data types and complex structures creates difficulties in integration.[31] Remote sensors, cameras, robots, drones, e-commerce platforms and other technologies such as machine learning, AI and IoT, deliver an ever-growing mass of data. Moreover, it is also challenging to judge its accuracy within a reasonable period of time. For example, agricultural data such as weather forecasts change very fast, and their relevance and accuracy might be very short-lived, thus providing recommendations that could cause harmful outcomes.[4,32] Processing and analysis based on these data might produce useless or misleading conclusions, eventually resulting in mistakes in decision-making processes. Animals may also interfere sometimes with technologies by affecting the radio signals used to communicate, by being too close to sensors or disrupting the equipment.[33] If the big data algorithms do not take these possible errors into consideration, they may bring about low productivity, post-harvesting losses and impact consumers' interests.

No matter how accurate the underlying data are, some judgment is still required to determine whether a particular decision support arising from its analysis is adequate or not. Decision support provided by software may work well for an "atomic" decision, but it may not be so suitable for a contextualized decision. Data analytics and decision support are fundamental for a fully enabled, data-driven agriculture. However, to date, the interpretation and use of results from big data technologies are not matching expectations and the capability to effectively analyse the data to achieve promised improvements in the agrifood systems is still limited.[34] This means that it is essential for farmers to be not only educated regarding these matters, but also trained in how to use new tools.[35]

Power asymmetry and dependency

Lack of regulation and of user capabilities create an asymmetry of power between big data service providers and their clients that is reflected in the service provision contracts. First, the weakness of the position of farmers manifests itself through their growing dependency on digitalization, both from a business as well as a data ownership and security point of view.[36, 37] From a purely individual perspective, this dependency is comparable to that felt by anyone who suddenly sees their telephone or their Internet access not function any more. Professionally, however, it means that farmers transfer an increasing share of their decision-making power to the big data service provider, and cease to conduct their own analysis and reflect in a way that adds to their experience. With time, this might impact negatively on their analytical capacity and, to paraphrase a quote from Nietzsche, big data tools will take a growing part in the forming of farmers' thoughts. This process may lead to affecting their intelligence so that it "flattens into artificial intelligence",[38] causing their dependency to become irreversible.

Second, the trend towards concentration observed in big data, as the "platform economy" emerges,[37, 39] is a further source of power imbalance (see Section 1.12). With the abundance of mergers and acquisitions among technology providers, competition is reduced[40] and agribusinesses and farmers are likely to have fewer choices and thus might become readier to accept restrictive customer-binding practices. Many well-established multinational companies have been absorbing small, promising digital technology firms, thereby increasing corporate control in agriculture and food through big data.[36] Over time, monopolies are emerging as a result of data concentrating in the hands of few large players, leaving farmers and authorities with little room for price negotiation for the acquisition of big data technologies and services, while dependency, control and unfair policy could turn out to be a substantial threat to other stakeholders' viability.[41]

Third, big data is bringing about a form of structural power that circumvents political deliberation or regulation which aim to establish and impose new technological standards, by deliberately structuring a lack of alternatives from among which to select, i.e. leaving no real choice to farmers who want to be effective and successful but to use a particular set of tools (i.e. smartphone, sensors, cloud, etc.).[37] There are, however, a few farmer-led initiatives seeking to break this dependence (see Box 1.10).

The key players profiled in the global big data and business analytics market analysis, such as Amazon, Microsoft Corporation, Oracle Corporation and others, have already adopted various strategies to increase their market penetration and strengthen their position in the industry. Similarly, major upstream agribusiness giants like Bayer-Monsanto, DuPont, Dow and others, have followed the same evolving curve, from being seeds and chemical companies to becoming leading big data service providers today. All of them are owning or building their big data platforms, covering millions of hectares of land, and operating with large numbers of farms and consumers that supply them with data in exchange for advice and discounts on the application of their products and services.

This issue has progressively come under the United Nations radar:

> "Digital technology needs of low- and middle-income countries depend increasingly on big-data platforms managed by a small number of corporations. Such platforms contain extraordinary amounts of information on production and consumption processes, yet their implications for economic growth and the reduction of poverty and income inequality have not been fully explored" (United Nations, 2020, p. 19).[1]

Box 1.10 People-owned digital services?

There are several initiatives that aim to break with the dependence on corporate-controlled high-tech digital services that are now being pushed upon farmers. One of these is known as FarmHack, a worldwide community of farmers who build and modify their tools and share information freely online. Furthermore, some new information technology (IT) companies are driving a shift towards crowdsourced, non-proprietary exchanges of information and research, not only within local communities but also among small producers and processors facing similar conditions around the world, for example, on pest control techniques.

Over the past decade, numerous farmer-to-farmer networks have sprung up to share information and advice, many of them using digital tools to communicate. The question is whether they can withstand the onslaught of platforms and services that corporations are now developing and rolling out, which are all highly biased in favour of industrial agriculture.

Source: Authors' elaboration based on GRAIN. 2021. Digital control: how Big Tech moves into food and farming (and what it means). In: *GRAIN*. Barcelona, Spain. Cited 21 January 2021. https://grain.org/en/article/6595-digital-control-how-big-tech-moves-into-food-and-farming-and-what-it-means

Lack of infrastructure and the digital divide

Big data in agriculture and food require the existence of broadband infrastructure to provide a fast and reliable connectivity necessary for rapid data and advice transmission, and for remote control of connected machines. This prerequisite may not be met in sparsely populated areas with low priority for deployment of the latest technology, and particularly in low- and middle-income countries where the urban-rural digital divide is greater.[42]

Initial investment (smartphones, computers, sensors, drones, etc.), cost of connection and amounts charged by service providers, make big data a prohibitive option for many smallholder farmers.[ab] Furthermore, in some places, there may be a lack of localized digital agriculture solutions and expertise, and limited availability of reliable infrastructures to collect and analyse big data.[44,45] Other risks of exclusion arise from the capacity of businesses to use the data they have on farmers to exclude them from business.[36]

1.4.5 Future trends

The expected rapid growth of big data

All sectors included big data companies are expected to create and manage 60 percent of data in the near future. Artificial intelligence, specifically machine learning, is expected to change the future drastically. Forecasts envision 6 billion users, or 75 percent of the world's population, interacting with online data every day by 2025. Currently, the big data industry, worth USD 198 billion in 2020 (around 0.2 percent of the value of global gross production), is set to proceed with rapid growth and should reach USD 684 billion by 2030,[46] driven by the increased adoption of cloud computing, AI and the IoT, of which connected devices are expected to arrive at a stunning figure of 75 billion by 2025,[47] with a value of EUR 5 trillion to 11 trillion.[48] In addition, projections see the market for remote sensing and geospatial analytics rise from over USD 2 billion in 2018 to more than USD 8 billion by 2025.

The world's data volume is bound to grow by 40 percent per year: it has already reached an estimated 33 Zettabytes (ZB) in 2020 and is expected to rise to 175 ZB in 2025.[48,ac] By 2022, public cloud services will be essential for 90 percent of data and analytics innovation, and nearly 30 percent of data will be real time, thus allowing faster and contextualized decision-making.[49] This growth will contribute to information and communication technologies becoming major energy users, with a potentially high impact on GHG emissions.[50]

[ab] The International Telecommunication Union (ITU) regularly publishes figures demonstrating that information and communication technologies continue to remain unaffordable for part of the world population, particularly for women.[43]

[ac] ZB stands for zettabyte, following kilo-, mega-, tera-, peta- and exabyte, counting 10^{21} bytes.

The use of big data technologies is also expanding in the area of food and agriculture. The digital agricultural market was projected to reach USD 15 billion in 2021,[11] equivalent to around 0.4 percent of global value of gross agricultural production, as farms become more connected through the IoT platforms. Northern America should be the biggest market because of its large farms with best-in-class equipment. The Asia and Pacific region is expected to increase investments in digital agriculture, particularly in China (see Box 1.11), while in Africa, the COVID-19 pandemic has boosted the adoption of digital tools (see Box 1.12).

Box 1.11 China's development plan for digital agriculture and rural areas (2019–2025)

Approved in 2019, this plan envisages that, by 2025, the agricultural digital economy will represent 15 percent of China's agricultural GDP, double what it was in 2018, with an annual growth rate of more than 10 percent.

E-commerce is also projected to grow rapidly, with the proportion of agricultural products sold online reaching 15 percent of total agricultural output, compared to 9.8 percent in 2018.

To achieve these targets, the rural penetration rate of the internet should reach 70 percent, as compared to 38.4 percent in 2018.

The plan also envisages building databases on: natural resources for agriculture, important germplasm, shared rural assets, homestead data, farmers and new agricultural businesses.

Digitalization is expected to transform the seed industry, encourage new approaches in agriculture, establish start-to-finish quality and safety controls, and profoundly modify agricultural decision-making. In parallel, the continuous improvement of digital technologies and infrastructure is expected to occur.

The ultimate objective is to reduce input use, improve the sustainability of agriculture, release further labour from farming and increase profitability.

Source: Authors' elaboration based on Ministry of Agriculture and Rural Affairs Central Cyberspace Affairs Commission. 2019. *Development Plan for Digital Agriculture and Rural Areas (2019-2025).* www.fao.org/3/ca7693en/ca7693en.pdf

Box 1.12 Adoption of digital tools in Kenya's agricultural sector boosted by COVID-19

As in most countries, the lockdown brought about by the COVID-19 pandemic strongly disrupted business operations in Kenya, particularly access to agrifood inputs and outputs.

A survey conducted by Global System for Mobile Communications (GSMA), an association grouping mobile network operators worldwide, revealed that 70 percent of Kenyan farmers increased their use of mobile phones to send and receive mobile money during 2020.

Between March and May 2020, users of the youth-run agricultural marketplace, Mkulima Young, increased fourfold, and many agribusinesses started offering novel digital services or changed business models. For example, groups of rural youth, assisted by the Vijabiz project and supported by International Fund for Agricultural Development (IFAD), the Technical Centre for Agricultural and Rural Co-operation (CTA) and the Ustadi Foundation, generated new income by marketing and selling their products via social media platforms, thus offsetting part of their losses caused by the closure of the hospitality industry they were serving.

To respond to the increased financial needs of farmers and citizens, the government eased mobile money regulations and provided subsidies to poor people via mobile money. Other strategic digital transformation moves have been made since then. The use of digital agriculture services, such as advisory services, financial services and market linkage services (i.e. e-commerce), has skyrocketed with the COVID-19 pandemic.

Source: Authors' elaboration based on GSMA. 2021. *COVID-19: Accelerating the Use of Digital Agriculture*; CTA & USTADI. 2020. *Growing Rural Youth Agribusiness in Kenya: Stories and best practices of the Vijabiz project*. Wageningen, The Netherlands, CTA.

The next generation of big data technologies in food and agriculture

Data Analytics is growing in scale and at an unprecedented speed. It is a potential game changer that will continuously reinvent new data-driven agribusiness models and shape the future of food and agriculture, despite the many obstacles and challenges identified earlier.

Farm management, processing and retail operations will be modified because of access to real-time data and forecasting, and tracking of products and consumer patterns. Artificial intelligence, cloud computing and IoT developments will be driving this change. For all these new technologies to have a significant impact, they are integrated onto Platform-as-a-Service (PaaS) that deliver detailed analytical results based on customized models for site-specific farming or value chains. Forecasts for big data would be incomplete without taking edge and quantum computing, and the next generation of 5G and 6G technologies, into consideration (see Box 1.13). Remote sensing is also gaining more importance in agriculture, through the use of imagery collected by satellites or drones.

Box 1.13 The next generation of big data technologies

Platform as a service (PaaS)
PaaS is a group of services, including the provision of servers, storage and back-up, that allows developers to develop, test and launch applications, without the complexity of building and maintaining the infrastructure typically associated with developing and launching applications.[51]

Edge computing
Today, big data analytics tends to be executed in cloud platforms because of the need for high computing power. Edge computing breaks with this trend and moves some of the tasks near to where the data are collected. Moving the computation close to the edge of the network reduces latency and response.[52]

Quantum computing
The next giant leap in computer technology is quantum computers. Quantum computing is based on the principles of quantum mechanics. A notable quantum supremacy claim was reported in 2019: a particular task was performed in 200 seconds which would have taken a classical supercomputer approximately 10 000 years to run.[53] However, further advances will need to be made before quantum computing is fully operational. For this, five to ten years will be required. By then, small devices will have become so powerful that the trend of edge computing will be boosted even more.

5G and 6G
One of the latest generation mobile telecommunication services protocols, 5G, is now being implemented in some parts of the world. It enables high-volume data transfers.[52] It is likely that 6G will be available by 2030 as it takes around ten years to move up one "G".

Nanotechnology
Nanotechnology is the production and manipulation of matter at length scales between 1 nm and 100 nm (one nanometre = 10^{-9} metre). In agriculture, nanotechnology has been developed to promote plant growth and protection, including smart nanocarriers for fertilizers, macronutrients and micronutrients and pesticides, genetic engineering of plants with increased photosynthetic capacity and sensors for real-time crop health monitoring.[54]

The United Nations prepares for the next generation of big data through the concept of "digital public goods",[55] defined as: open-source software, open data, open AI models, open standards and open content. Future big data could evolve through a public-private sector collaboration consisting of a base layer of digital public goods with a top layer of commercial goods. Increasing goods in the public space would give new players in the commercial space more of a head start because part of the heavy lifting is done in the public space, thus allowing for more small players.

This approach could break existing monopolies and oligopolies that are currently dominating big data in agriculture. Additionally, the public space could provide basic concepts, practices and frameworks for the widespread implementation of data governance and data management policies and guidelines. Examples of public normative works in this space are FarmStack[56] and AgStack,[57] which, in essence, render intrinsic architectures explicit. This also allows for a broader discussion on power asymmetries that currently take place in digital agriculture.[36]

1.4.6 Summary remarks

Big data is expanding in the area of food and agriculture. There are great hopes that it will help improve agricultural production by: cutting and leading to a more efficient use of inputs, including water; better managing pest and disease outbreaks; optimizing food supply chains; and reducing the impact of food on the environment.

So far, however, there is limited evidence of these desired results, and several challenges hamper the development of big data in agriculture, such as high initial investment (e.g. in infrastructure), uncertain returns as well as issues of governance, power asymmetry, dependency and inclusiveness.

Big data is likely to further develop in food and agriculture because it is promoted by strong forces (e.g. governments and high-tech companies) that depict it as representing twenty-first century modernity, and have great hopes it will help improve efficiency of agrifood systems.

Depending on how big data will be governed, there will be more or less risk of exclusion of smallholder farmers, as barriers to entry are high for them, and their capacity to adopt technological changes advised by big data-backed systems may be limited. Unless they are provided with appropriate support, they may not be in a position to benefit from the digital revolution.

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1.5 Geopolitical instability and increasing impact of conflicts (Driver 5)

Geopolitical instability and increasing impacts of conflicts, including resource- and energy-based ones, form a major driver of food insecurity and malnutrition. *The State of Food Security and Nutrition in the World 2017*[2] report highlights that the vast majority of chronically food insecure and malnourished people live in countries affected by conflicts. Furthermore, as suggested by the joint United Nations/World Bank report, entitled *Pathways for peace*,[3] 40 to 60 percent of armed conflicts over the past 60 years have been caused, funded, or sustained by the lack of natural resources. Conflicts reduce food availability, disrupt access to food and health care, and undermine social protection systems.[ad] This driver, interacting with climate change, degradation of renewable natural resources and desertification, is disrupting agricultural livelihoods and food systems.

Extractive activities tend to be concentrated in rural areas, particularly affecting Indigenous Peoples' territories, where the majority of the remaining natural resources and biodiversity are concentrated. This has been a recurrent reason for socioeconomic and territorial conflicts, generating displacement and violence. In this regard, attacks to defenders of Indigenous Peoples' land and other rights have increased in recent years at an alarming rate. In 2020, a third of the 227 land and environmental activists murdered were Indigenous leaders and five of the seven mass killings recorded in 2020 targeted Indigenous Peoples.[60]

Military expenditures are often a large part of public budgets and absorb resources that could otherwise be allocated to development. Almost two-thirds of people facing high levels of acute food insecurity are affected by conflict and insecurity,[4] which destroy livelihoods, valuable assets and capital. A world in disorder, where international and national conflicts emerge and persist, is among the possible future scenarios. In such a scenario, agrifood systems would be impacted by disruptions in different parts of socioeconomic and environmental systems, with different impacts on social groups depending on their socioeconomic features (gender, age, culture, language, ethnicity, socioeconomic status, etc.).

This raises several questions that are dealt with here or in other parts of this report:

- Are the current structure and features of global and regional agrifood systems contributing to fuelling and/or increasing the likelihood of geopolitical instability in its various forms?
- Are agrifood systems transformations, the expansion of extractive industries, energy conversion processes and related investments leading to further displacement, conflict and violence?
- Are there prospects of growing geopolitical instability that can jeopardize the livelihoods of people? Where and why?
- To what extent may a possible "decarbonization" of economies to mitigate climate change and societies, actually fuel international and/or national instability and conflicts?

Geopolitics is the analysis of the existing distribution of power and its consequences, how patterns of power evolve over time, how stable relationships among countries are, and which kind of geopolitical alignment brings higher or lower perceived risks. Power refers to countries' capacity to shape their external environment through economic strength and spheres of influence, military capacity and networks, diplomatic reach, cultural and economic leverage (soft power), as well as resilience. This report identifies violent conflict as the ultimate expression of geopolitical instability.

1.5.1 Recent trends

Decreasing multilateralism

Multilateralism is arguably on a downward trend, with rules grounding the existing international system being questioned and not being complied with. Most analysts acknowledge that the foundation of multilateralism is currently under significant strain, be it from great power competition or populist nationalism. Tensions between major powers and deadlock in intergovernmental

[ad] The number of forcibly displaced persons, an important impact of conflicts, in 2019 reached almost 80 million people, the maximum level in the last seventy years.[1]

institutions, from the World Trade Organization (WTO) to the United Nations Security Council (UNSC) (see Box 1.14), have diminished any space there may have been for global cooperation.

The intensification of geopolitical rivalry, where states vie for control over territory, resources and values, is consistently identified in longer-term projections.[5] This evokes a world of competing great powers, in which post-Second World War multilateral institutions are undermined, sometimes ignored and become less relevant with time. Overall, most geopolitical forecasts are pessimistic about political developments, where they envisage a multipolar, increasingly conflict-ridden world, with a more limited role for international institutions.[6]

Several countries are feeling the pressure of growing nationalist and protectionist forces, and are being driven by hard realism and a desire to be unrestricted by international commitments. Inwardness and isolationism increasingly resonate with large sections of the population. Rising wage and income inequality, mistrust in both government and the private sector, long-term unemployment, underemployment and job precariousness, have contributed to creating more economic anxiety and sparking a backlash against a skewed and unequal globalization. Lack of effective and capable governance goes hand in hand with the deficit in confidence that citizens display towards governments and, by association, multilateral bodies. In recent years, the United Nations Secretary-General has written to member states following an all-time low in annual contributions, creating a troubling financial situation for the United Nations, caused primarily by delayed payments to the regular budget. This is an additional symptom of the transition from unipolar order to a multipolar dis(order).

The shift towards a more multipolar world (also described in terms of a "return to geopolitics") presents significant challenges.[3,7] The post-Cold War balance of power is reconfiguring and states are repositioning themselves within what is a yet uncertain international order. Power transition among states from the West to the East[8] and power diffusion from governments to non-state actors worldwide have created strategic shocks resulting in more instability and unpredictability.

Box 1.14 The United Nations Security Council

With a crisis in multilateralism, alternative global governance institutions, championed by emerging and resurgent powers, are likely to challenge existing international organizations as they seek a voice in decision-making structures.

The United Nations Security Council (UNSC) is the premier body for maintaining international peace and security. It has a critical role to play in ensuring geopolitical stability and in preventing and managing conflicts. However, the structure of the UNSC has not changed since 1971, when the People's Republic of China took the seat previously occupied by the Republic of China (Taiwan). It is becoming less and less responsive to crises, and faces steady calls for reform to better meet twenty-first century challenges.

The global economy has experienced tectonic shifts, especially in the past 30 years. In 1989, the seven largest economies of the Western world – three of which are permanent members of the Security Council – accounted for 51 percent of global economic output. Today, their share amounts to only around 30 percent. Reflecting this shift, powers such as Brazil, Germany, India, Japan, Nigeria and South Africa have sought to enlarge the UNSC or secure permanent seats of their own. Others have called for France to cede its permanent seat to the European Union. Various reform proposals have been put forward, but none has had the unanimous support of the permanent UNSC members, or that of two-thirds of United Narions Member States.

It is likely that criticism over ineffective action and tensions among the five permanent members will continue, as the body is less able to defuse crises, address multipolar tendencies and respond to the complexities of the twenty-first century.

Source: Authors' elaboration based on CFR (Council on Foreign Relations). 2022. The UN Security Council. In: *CFR*. New York, USA. Cited February 2022. www.cfr.org

Technological disruptions bring new threats. Technology continues to be a driver of change through developments such as artificial intelligence, biotechnologies and robotics (see Section 1.9). Digitalization, for example, transforms how people interact and receive (dis)information, which can be used to influence and drive geopolitical instability and conflict. Many countries are realizing that their countries face palpable threats in this domain.[9] Both state and non-state actors are seeking to influence *below* the threshold of traditional armed conflict, but *above* the level of outright peace, via a combination of activities that aim to target states' vulnerabilities. For instance, cyber-attacks on critical national infrastructure, and the subversion of democratic institutions and processes, are now discernible challenges to national security.[10]

Trend towards violent conflicts. Between 2010 and 2020, the world has witnessed a decline in global cooperation and security. There have been multiple internationalized wars – civil wars with involvement of external parties and ongoing large-scale humanitarian crises, rising nationalism, transnational terror organizations, cyber-attacks orchestrated by marginalized states, sustained levels of violence in nominally "post-conflict" countries and a drastic increase in the number of non-state violent agents.[11] This evolution has been accompanied by an intensification of violence. Using the large Armed Conflict Location and Event Data Project (ACLED) dataset of almost one million events in over 100 countries, four broad patterns were identified that summarize both the current as well as the possible future conflict landscape:

1. Political violence is rising and manifesting in multiple forms; it is persistent and consistently adapting to changing political circumstances.
2. Political violence is increasing most quickly in upper-middle-income countries. Continuing conflicts in the Democratic Republic of the Congo and Somalia demonstrate the uncontrollable nature of same wars. Conflict is most persistent in poorer states and is a tool of the powerful, rather than of the poor and marginalized.
3. Unprecedented levels of militia and gang violence are often a consequence of externally imposed peacebuilding and stabilization efforts, forced elections and corruption. This type of violence is directly linked to the domestic politics and the economic benefits of conflict.
4. Demonstrations are increasing radically, but most peaceful protests have no effect on political structures and elite politics.[11] In addition, violence and killings against activists defending human rights, land and natural resources are increasing disproportionately, particularly in Latin America. Indigenous Peoples are among the most affected, often being forcibly displaced from their territories.[60]

COVID-19 pandemic accelerates geopolitical rivalries. The COVID-19 pandemic has thrown some geopolitical tensions and threats to multilateralism into disarray. Rivalries between the United States of America and China are being sharpened, and the pandemic may hasten the shift of the balance of power from the West to the East – a small insight is perhaps already apparent in how vaccines are being provided to particular countries within the spheres of influence of China and the Russian Federation as a form of soft power. Indeed, some developments that had previously gone largely unnoticed, such as the way in which China has established spheres of influence in parts of the world, are becoming more evident. The Economist Intelligence Unit (EIU) identifies four post-pandemic turning points that could further undermine multilateralism: (i) China may emerge as a bigger global player with growing spheres of influence; (ii) the diminishing global leadership of the United States of America as many countries see them increasingly as less reliable, trustworthy, and unable and unwilling to lead; (iii) the weakening of the European Union because of internal rifts and lack of coordination; and (iv) powers such as the Islamic Republic of Iran, Russian Federation and Türkiye, and others more likely to try and further capitalize on the increasing fragmentation of the global order by asserting leadership in their regional backyards.[12]

The increase in violent conflicts

Violent conflicts are increasing, harming economic growth. They reached the highest levels ever observed during the past three decades. They have become more frequent, complex and protracted, involving more non-state groups, regional and international actors, and are increasingly linked to global challenges such as climate change. Furthermore, military expenditure has risen in recent years, absorbing resources that could have been allocated to sustainable development. Fragility, conflict and violence are critical development issues that threaten SDG efforts to end extreme poverty and eliminate hunger, affecting low- and middle-income countries.[3] Conflicts also drive 80 percent of all humanitarian needs and reduce economic growth by two percentage points per year, on average.[13]

The end of the Cold War led to a dramatic decline – more than 60 percent below peak levels – in interstate and intrastate conflict during the 1990s and into the twenty-first century. While intrastate conflicts had been increasing regularly between 1945 and 1990, this trend was inverted between 1995 and 2003. However, the prevalence of conflicts has risen markedly since the early- to mid-2000s. This is particularly true for civil conflicts, which have now become the most common form of armed conflict.

Strong surge in violence in recent years with a shift in its nature. In 2016, more countries experienced violent conflict than at any time in nearly 30 years.3 In 2019, there were 54 active armed conflicts in the world, up from 52 in 2018 and matching the post–Cold War peak of 2016.[14] It is commonly agreed that the nature, intensity and frequency of conflicts have evolved recently, shifting from wars fought directly between states to various forms of internal violence, including insurgencies, guerrilla wars, terrorism, organized and large-scale criminal violence, and protests.[15] This shift in type of conflict corresponds with a long-term decline in traditional symmetrical conflicts and an increasing number of intrastate conflicts and asymmetric wars (e.g. between state and militias or non-state armed groups).

The rise of extremism (including political and religious one) presents a complex challenge, as governments have to contend with issues surrounding their own credibility, legitimacy and accountability. The world is now at an unprecedented level of minor conflicts, defined as conflicts with more than 25 deaths per year but less than 1 000.[14] Their presence is troubling as many of them have the potential to escalate into major conflicts. The increase is mainly caused by Islamist organizations active in several areas, including Southeast Asia, the Near East and the Sahel. Coupled with this is the threat of growing criminalization and corruption, as the trafficking of drugs, weapons and people is expanding.

This surge in violence also afflicts LMICs that have relatively strong institutions, and calls into question the long-standing assumption that strong institutions ensure peace, will induce income growth and fulfil expectations of steady social, economic and political advancement. Violent conflicts frequently take place against a background of domestic grievances, particularly a breakdown in the prevailing social contract. Such conflicts have been and are exploited by extremist groups, drawing in regional and global powers, who may influence or support, but rarely fully control them. In Mali, for example, an extensive organized criminal network present in 2012, coupled with a serious national security crisis and active transnational political groups, has been argued to underpin the ongoing Sahel-wide crisis, where over 100 distinct militia groups were operating in 2019.[16]

Forced displacement

Intrinsically linked to the violent conflict trends, the pace of forced displacement – both internally and across borders – continues to rise. The number of forcibly displaced people has doubled over the last ten years, outpacing countries' ability to generate durable solutions. Most conflict-related internal displacements took place in sub-Saharan Africa (SSA) and Near East and North Africa (NNA). The world is facing the largest forced displacement crisis ever recorded, with at least 100 million people forcibly displaced in the decade since 2010.[1]

By the end of 2019, the number of internally displaced persons had reached an all-time high, with 45.7 million people forcibly displaced by conflict and violence, and 5.1 million by disasters.[17] There were 14.6 million new internal displacements in the first six months of 2020 alone, including 4.8 million triggered by violent conflict.[18] By mid–2020, there were 26.4 million refugees worldwide.[19] More than two-thirds of them come from just five countries – Afghanistan, Myanmar, South Sudan, the Syrian Arab Republic and Venezuela (Bolivarian Republic of).[1] Displaced people spend an average of more than 17 years in camps or with host communities.[20]

An additional cause of forced displacement, often not known to the general public, is the establishment of conservation and protected areas to preserve natural resources and ecosystems, under the assumption that the only way to conserve ecosystems and biodiversity is to remove people from the territory (see Box 1.15).

Box 1.15 Forced displacement for conserving and protecting areas

Several governments have established natural protected areas as key environmental policy instruments to counter pressure on natural resources and the effects of climate change. This conservation mechanism has increased following the establishment of the Aichi Biodiversity Target 11 of the Convention on Biological Diversity (CBD) action plan.[61] This target aims to preserve 17 percent of the global terrestrial and inland water areas and 10 percent of the coastal marine areas with high rates of biodiversity, through conservation mechanisms such as the creation of protected areas. Increasing evidence shows the connections and overlap between areas with high biodiversity and Indigenous Peoples' territories. These territories cover around 28 percent of the global terrestrial area and are home to 80 percent of the world's remaining biodiversity,[62] 36 percent of world's intact forests[63] and at least 24 percent of aboveground terrestrial carbon,[64] as well as major repositories of plant genetic material and agrobiodiversity critical for global agriculture and food systems.[65]

In some instances, the establishment of national parks and conservation areas has resulted in serious and systematic violations of Indigenous Peoples' rights through the expropriation of their traditional lands and territories, forced displacement and killings of their community members, non-recognition of their authorities, denial of access to livelihood activities and spiritual sites and subsequent loss of their culture, marginalization and poverty. This is the case, for instance, of the Batwa, hunter-gatherers in the forests of southwest Uganda, who were evicted from their ancestral forest home in the 1990s to make way for a national park. They are now part of a growing group of "conservation refugees" worldwide. In the Democratic Republic of the Congo, the Batwa of Kahuzi-Biega in South Kivu were also evicted in the 1970s from what would become a World Heritage Site.[66, 67]

In 2018, the United Nations Permanent Forum on Indigenous Issues (UNPFII) dedicated a full expert meeting to analyze the impacts of conservation and protected areas on Indigenous Peoples, recognizing the urgent need to develop a set of universally recognized standards for engaging in conservation efforts on the lands, waters and territories of Indigenous Peoples.[68] The UNPFII has emphasized that Indigenous Peoples should gain benefits from the environmental and ecosystem services derived from their territories and resources. Indigenous Peoples are providing unique services to humankind that, as of today, have not been acknowledged nor retributed. While some of them are often labeled as ecosystem services that counterbalance the effects of climate change, several other public benefits provided by Indigenous Peoples have not been accounted for.

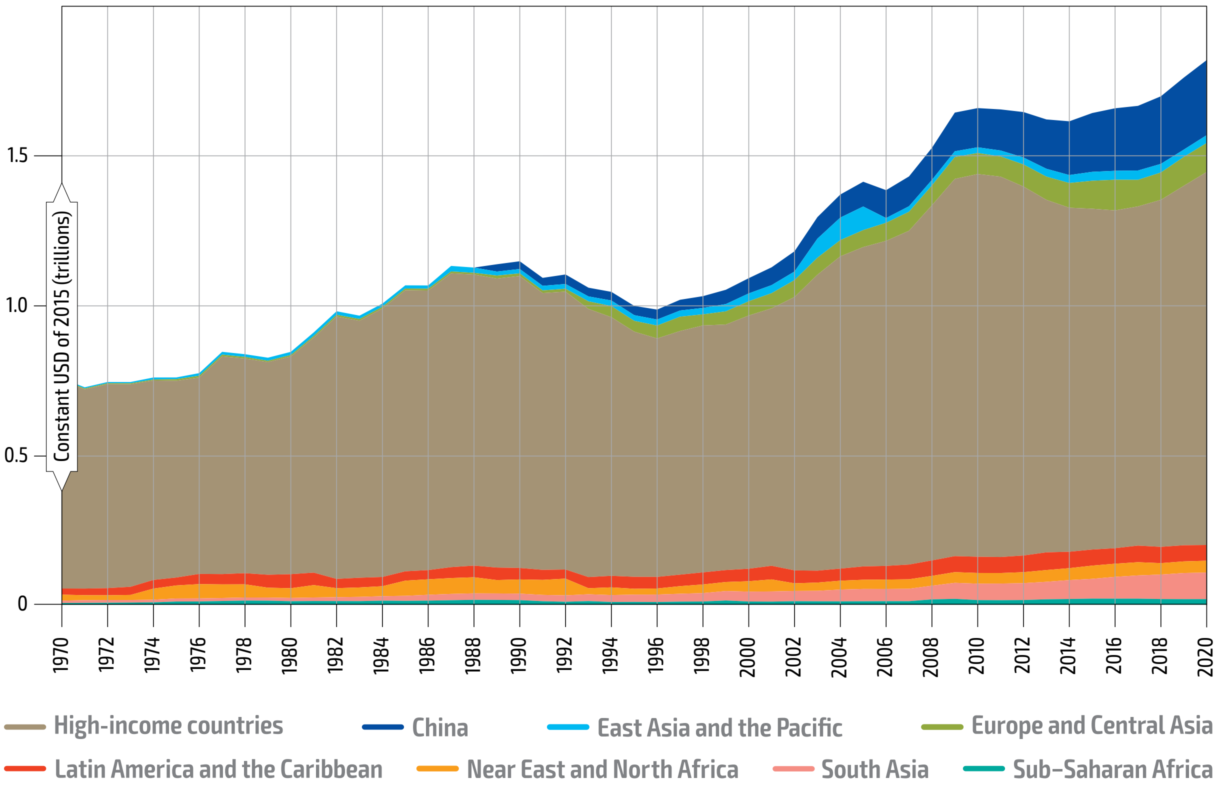
The CBD's post-2020 Action Plan, which is under negotiation, may increase the percentage of protected areas to 30 percent, thus increasing the risks of further displacement of Indigenous Peoples. Scientists and practitioners are increasingly questioning the advantages of displacing Indigenous Peoples from their ancestral territories, where the ecosystems and biodiversity have been preserved and enhanced for hundreds of years. Over time, however, there are also a growing number of cases in which the creation of new conservation and protected areas avoid displacement and include Indigenous Peoples in their management.

Catalysts of displacement and migration. In addition to forced displacement, increased inequality and climate change can be catalysts for migration and have secondary effects, such as fractured and conflictual societies, violent extremism, nationalism, isolationism and protectionism. During the past 60 years, 40 to 60 percent of armed conflicts have been caused, funded or sustained by competition over natural resources – which can take place either because they are scarce or because they are plentiful.[3]

Military expenditure

Military expenditure is increasing. Global military outlay is estimated to have been USD 1 820 billion in 2020 (at constant USD of 2015). It accounted for 2.36 percent of Gross World Product (GWP), or USD 233 per person. Spending in 2020 was 3.4 percent higher than in 2019 and 9.6 percent more than in 2010. The trend over the decade 2010–2020 shows that expenditure grew in each of the seven years since 2014, having decreased steadily from 2011 until 2014, following the global financial and economic crisis (see Figure 1.31).

Figure 1.31 Evolution of world military expenditure by region (1970–2020)



Notes: Rough estimates for the Near East and North Africa are included in the world totals after 2015. Original data are deflated with GDP deflator from current USD to constant USD of 2015, available in FAOSTAT database. Military expenditures data from SIPRI are derived from the North Atlantic Treaty Organization (NATO) definition, which includes all current and capital expenditures on the armed forces, including peacekeeping forces; defence ministries and other government agencies engaged in defence projects; paramilitary forces, if these are judged to be trained and equipped for military operations; and military space activities. Such expenditures include military and civil personnel, including retirement pensions of military personnel and social services for personnel; operation and maintenance; procurement; military research and development; and military aid (in the military expenditures of the donor country). Excluded are civil defence and current expenditures for previous military activities, such as for veterans' benefits, demobilization, conversion, and destruction of weapons.

Sources: World Bank. 2022. Military expenditure (current USD). In: World Bank. Washington, DC. Cited 24 June 2022. https://data.worldbank.org/indicator/MS.MIL.XPND.CD and FAO. 2022. Deflators. In: FAOSTAT. Rome. Cited 24 June 2022. www.fao.org/faostat/en/#data/PD

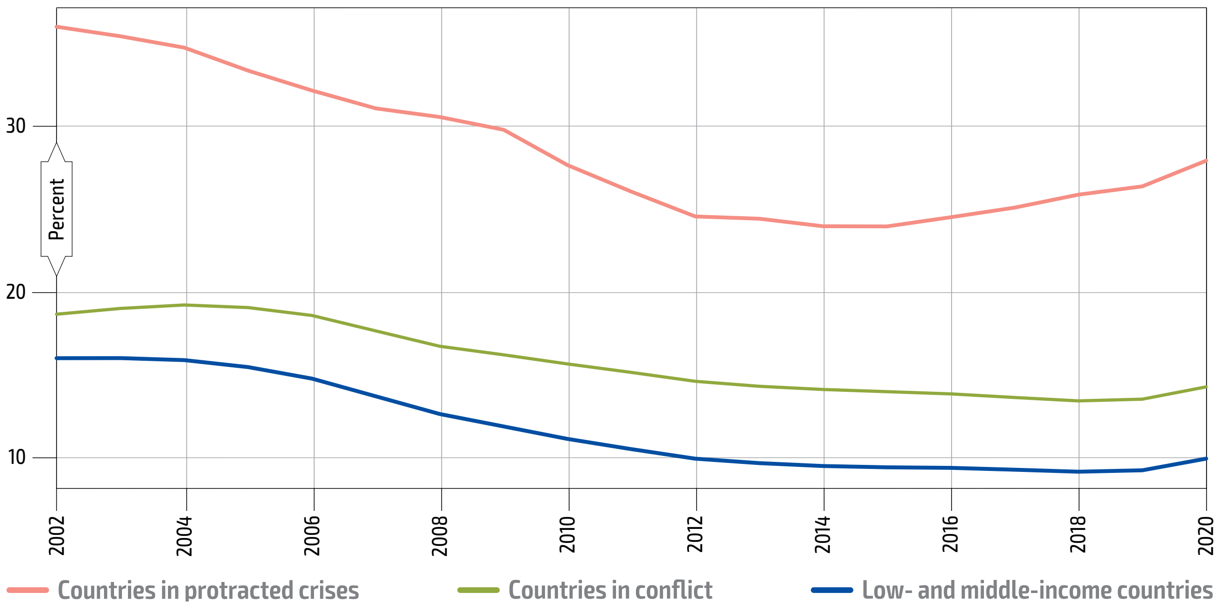
Higher military expenditure = higher income inequality? Since 2010, military expenditure increased in six of the world's eight regions considered. The five biggest budgets in 2019 were in China, India, Russian Federation, Saudi Arabia and the United States of America, accounting for 62 percent of global military spending.[21] Evidence shows a positive relationship between military expenditures and income inequality in Pakistan and in a panel of OECD studies.[22, 23]

Protracted crises

The number of protracted crises does not decrease. FAO currently classifies 22 countries with a protracted crisis. All these countries are affected by insecurity, conflict and violence, which can manifest at a subnational level at different intensities, and which are typically compounded by adverse climatic events, such as prolonged droughts, that severely impact food production and livelihoods.[24]

The overall trend is for there to be a significant number of (often neglected), long-running crises (e.g. Afghanistan and the Democratic Republic of the Congo) that have remained highly volatile for decades. Past analysis has shown that, on average, the proportion of undernourished people living in low-income countries (LICs) with a protracted crisis is between 2 and 3 times greater than in other LMICs (see Figure 1.32).

Figure 1.32 **Prevalence of undernourishment in countries affected by protracted crises (2002–2021)**



Note: Data are calculated as three-year right-sided moving average.

Source: Authors' elaboration based on the database for FAO, IFAD, UNICEF, WFP & WHO. 2022. *The State of Food Security and Nutrition in the World 2022. Repurposing food and agricultural policies to make healthy diets more affordable.* Rome. https://doi.org/10.4060/cc0639en

The World Bank Group's fragility, conflict and violence (FCV) Group annually releases a list of fragile and conflict-affected situations in which the World Bank strengthens their investment.[25] This increased attention and financing points to a recognition of a trend in fragility, conflict and violence.

Water scarcity

Water scarcity is becoming a significant catalyst of conflict. Water scarcity has caused conflicts and disputes within countries and among nations. Dramatic swings in seasonal water supplies, because of climate change or inappropriate water basin and watershed management and control, can threaten stability. More than 2 billion people already live in countries experiencing high water stress, and about 4 billion experience severe water scarcity for at least one month of the year. Water use has increased by 1 percent per year for the last four decades[26] and pressure on renewable water resources has reached its highest levels in arid and semi-arid regions such as NNA and Central Asia (see Section 1.14). Agriculture is a major factor in disputes related to transboundary water resources in water scarce regions.[21]

In 2017, water was a crucial local conflict factor in at least 45 countries, particularly in the NNA.[27] In Yemen, the government estimates that around 4 000 people a year die as a direct result of water-based conflicts.[28] International and transboundary cooperation, through water basin organizations or agreements, has been essential to avoid deepening tensions between countries. Consequently, there have only been a handful of militarized disputes over water, and cooperation is the norm.

Climate change and security

Climate change's threat to security is building up. It has been repeatedly stated that climate change will upend the twenty-first century world order, changing the systems of production, trade, economics and finance. Yet, the world is woefully underprepared for its cascading impacts. From the

United Nations to the G7[29] to the US Department of Defence, there is emerging consensus that climate change is an existential threat and poses risks to security through complex and interrelated channels[30] It will be difficult for least peaceful countries (classified according to the annual Global Peace Index) to mitigate the effects of climate change or address its adverse impacts.[26] A combination of lower resilience and higher risk could mean that some of these countries will descend into cycles of instability and violence. This latter effect is particularly important in countries where socioeconomic and political drivers of conflict and unrest are already present.

Transition to green economies

Mismanaged transitions to green economies might ignite further conflicts. There is the distinct possibility of unintended consequences of policies seeking to address the climate crisis that could start or exacerbate violent conflicts. The extraction of disputed supplies of oil, gas or minerals has often triggered and financed conflicts, disrupted peace efforts and led to the collapse of peace agreements. However, the link between such resources and wars is not frequently discussed in climate change negotiations. Such a focus is necessary to address the risk of conflict proactively and to help countries navigate the transition to a green economy.[31]

A global transition from fossil fuels to clean energy technologies will rely on minerals. The International Institute for Sustainable Development has identified 23 of them.[32] Demand for these, including lithium and cobalt, could surge by 500 percent by 2050 – and many of the known reserves of these resources are in conflict-affected and fragile states with weak, often corrupt, governance. The rising demand for these minerals will likely drive new rivalries, conflicts and violence, particularly in South America, SSA and Southeast Asia. How such natural resources are sourced will determine whether this aspect of decarbonization supports peaceful, sustainable development in those countries where strategic reserves are found, or whether it will reinforce poor governance and exacerbate local tensions and grievances.

Similarly, there are the dangers associated with the rapid loss of oil revenues in fragile oil-exporting states – what has been termed "traumatic decarbonization". Where governance institutions are weak and unaccountable, and where elites typically control most, if not all, of the oil sector, the reduction or collapse of oil-derived income may generate instability for several reasons, including the implosion of patronage politics.[33]

About 30 percent of global energy usage can be traced back to the food sector.[34] Shifts to greener economic models and decarbonization that do not take into account the conflict risks outlined above may well have unintended impacts on food system stability, unless mitigated by policies that create green energy networks that are more distributed and conflict-sensitive.

1.5.2 Geopolitics and agrifood systems – "conflicts-hunger" and "hunger-conflict" impacts

Geopolitical instability and conflicts cut across multiple areas where unilateralism and zero-sum approaches to security directly hamper efforts to eradicate hunger, compromise food systems and undermine the frameworks that support them. And this can be a circular relationship. Competition for agricultural resources can be both a cause and a consequence of geopolitical rivalry and conflict creation or perpetuation. International trade, while essential for food security, also generates vulnerabilities through supply disruptions that are, at times, politically motivated. Conflict is a driver of food insecurity, but food security can itself feed social unrest and violence.

Economic shocks – including the ongoing impact of the COVID-19 pandemic – have a compounding effect on food insecurity at the household level through, for example, decreased revenues from remittances, tourism and industrial production. At the national level, this is manifested in reduced commodity exports, increasing expenditure aimed at supporting populations whose incomes have been disrupted by movement restrictions and the near-total shutdown of vital economic sectors.

Climate change interacts with these phenomena, reshaping both the agroecological and physical landscape, as well as political calculations. Weather and climate extremes in many countries are having a negative impact on existing high levels of vulnerability and food insecurity (see Section 1.16).

Geopolitical instability and the effects of conflict are known to be a major driver of food insecurity and malnutrition, undermining food systems in a variety of ways. The vast majority of the chronically food-insecure and malnourished people live in countries affected by conflict.[2] In 2020, 155 million people in 55 countries and territories were in urgent need of food, and livelihood and nutrition assistance as a result of conflict, pre-existing and COVID-19-related economic shocks, and weather extremes, or a combination of any of these factors.[4]

Conflicts reduce food availability, disrupt access to food and health care, and undermine existing social protection systems.[ae] As a critical driver, conflict interferes with agricultural livelihoods and food systems, and aggravates food insecurity through population displacement, disruption of trade, abandonment of agricultural land, and loss of life and food system assets. It also affects delivery of humanitarian assistance to the most vulnerable and food insecure.

Conflicts impact food systems

Conflicts affect food systems and food security on many levels, including causing direct impact on, and disruptions to, production, processing and distribution (see Box 1.16). Violent conflict can result in the destruction of crops, livestock, and land and water systems, as well as disruptions in the infrastructure and human resources required for food production, processing, distribution and safe consumption.[2] In South Sudan, almost 50 percent of harvests were destroyed in areas extensively affected by violence.[36]

Long-term damage to food production and trade. The consequences of conflict contribute to shortfalls in food measurable in terms of lost production, which not only affects domestic production and food availability (including from imports), but also reduces quantities available for exports.[37] The impact is long term, and when coupled with unchecked climate change, it could set back a country by decades. The broader geopolitical context influences the operation of food systems, as this often affects how conflict is shaped at the local level, as well as through more macrolevel impacts on trade flows because of the interconnectivity of global trade, and how this may be manipulated for political reasons. Food systems that are repeatedly put under stress by conflict tend to move from predictability to instability and volatility. Food supply chains may function during long-term, protracted conflicts, such as in Yemen, where food importers on all sides have adopted dynamic operational methods in a complex and politicized environment. However, this kind of functionality comes at a cost. For instance, food prices in Yemen doubled between 2015 and 2019, and have continued to rise since.[38]

Rising inequalities as a consequence of conflicts. Consequences of conflict, including extreme coping mechanisms for survival, differ according to livelihood system, age and gender of those affected. During conflicts, power relations and social marginalization tend to be amplified, and opportunities for exploitation increase. Gender inequalities faced by women and girls limit their access to productive resources, services and decision-making processes even more than in times of peace.

Reduced labour supply. Recruitment into military and armed groups drains sources of labour for agricultural production. This persists over the long term because of war-related disabilities, with a consequent increase in the workloads of women and the elderly. During conflict, women take up new economic roles, while their domestic burden grows.[39]

Undernourishment. Countries with the highest levels of undernourishment tend to be those engaged in, or recently emerged from, violent conflicts. Existence and high risk of conflict is a key characteristic of fragile states and protracted crises, and the prevalence of hunger rises exponentially with the degree of fragility, and vice versa.

Deliberately induced hunger. In some occurrences, parties to a conflict deliberately use hunger as a weapon. Access to food has been used in conflicts throughout history. Some years ago, in Somalia, the Islamic group Al-Shabab prevented food aid from reaching the people it wanted to control. While tens of thousands starved to death, the World Food Programme (WFP) had to suspend operations as the security situation deteriorated and humanitarian staff were killed. The flipside of this was that starving young men were more likely to join Al-Shabab that controlled food, thus perpetuating the cycle.

Famine-related deaths. In South Sudan, analysis demonstrated an inverse correlation between cereal production and instances of violence, when conflict spreads to major producing areas.[40]

[ae] Four billion people do not have *any* social protection coverage and only 45 percent of the global population is effectively covered by at least one social benefit, while the remaining 55 percent are left unprotected.[35]

Mortality caused by conflict through food insecurity and famine can far exceed deaths resulting directly from violence.[41] Between 2004 and 2009, approximately 55 000 people a year lost their lives as a direct consequence of conflict or terrorism.[42] In contrast, as a result of famine caused by conflict and compounded by drought, more than 250 000 died in Somalia alone between 2010 and 2012.[43]

Longer-term impacts. The impact of conflicts on food security and nutrition often lasts long after violence has subsided, as a result of assets having been destroyed, people having been killed or maimed, populations displaced, landmines scattered, the environment damaged, and health, education and social support networks and services shattered. One of the greatest and most pressing challenges is to help countries affected find a path towards sustainable peace and development.[44]

Box 1.16 Civil conflict, food security and food systems in northern Nigeria

Violence in northeastern Nigeria, driven by an Islamist extremist insurgency, intensified in late 2020, mainly centred in Borno State, displacing populations across several other states. Non-state armed group attacks and clashes with government forces impacted agricultural and other income-earning activities, while intercommunal conflicts and banditry led to a below-average harvest in the north-central and northwestern regions.

The deteriorating security situation has severely affected agricultural output. Sixty-five percent of households in Borno, Yobe and Adamawa states are reliant on farmland, but limited access to land and population movement resulting from conflict caused a significant fall in food production. In some areas, cultivation of arable land decreased over 90 percent between 2010 and 2020. In late November 2020, for instance, more than 100 agricultural labourers harvesting rice were killed during a raid. Fear of attacks and military restrictions to ensure safe zones around communities, limited farmers' access to land. Even when land could be reached, often less than a hectare of land would be accessible, severely reducing food production levels.

Attacks by armed groups have been shown to be strongly correlated with a decline in normal market operations in northeast Nigeria. Significantly, the vast majority of markets that experienced diminishing activities were those affected by a threat or perceived threat of violence. Consequently, while markets and traders in the northeast have been resilient in recent years, the underlying insecurity resulted in sharp increases in product transportation costs, with these costs being passed down to consumers in increasingly market-dependent households.

Sources: Authors' elaboration based on ACLED (Armed Conflict Location & Event Data Project). Data export tool. In: *ACLED*. Cited 18 May 2022. https://acleddata.com/data-export-tool; WFP (World Food Programme). 2019. Emergency Food Security Assessment (EFSA) North West and South West regions, Cameroon. January 2019. Washington, DC; WFP. 2021. *Nigeria: Satellite Imagery Analysis - Cropland change analysis in hard-to-access areas (February 2021)*. Washington, DC; Agence France-Presse. 2020. Boko Haram kill dozens of farm workers in Nigeria. In: *The Guardian*. Cited 18 May 2022. www.theguardian.com/world/2020/nov/28/boko-haram-reported-to-have-killed-dozens-of-farm-workers-in-nigeria; France24. 2020. Boko Haram claims Nigeria farm massacre as toll rises to 76. In: *France24*. Cited 18 May 2022. www.france24.com/en/live-news/20201201-boko-haram-claims-nigeria-farm-massacre-as-toll-rises-to-76; Van Den Hoek, J. 2017. *Agricultural market activity and Boko Haram attacks in northeastern Nigeria*. West African Papers No. 9. Paris, OECD.

Food system can contribute to conflicts

There can often be a close link between food security and human security. It has been argued, as stated by Swaminathan (1994),[45] that "hunger anywhere threatens peace everywhere".

Price of food. The Arab Spring, which toppled governments in Tunisia, Egypt and Libya, had the high price of food as a motivating factor, among others. Initial protests were demonstrations against high bread prices. With poor people spending over 50 percent of their income on food, even a slight increase in food prices is therefore significant, particularly in urban areas. Higher food prices may simply form the conduit or catalyst through which other, wider, grievances such as unemployment, low incomes, unpaid salaries, political marginalization and access to basic services are expressed.

Control over natural resources. Equally, control over natural resources such as land and water, required for food production, can catalyse wider intergroup conflict. As such, the incentive to join or support a conflict may stem from the desire to protect one's own source of food security.

Vicious circles. In fragile states, there can also exist a vicious cycle of instability where food insecurity both results from, and contributes to, repeated rounds of armed conflict. When national governance fails, conflict can lead to large-scale food insecurity and famine. This interconnection can also go the other way. In Somalia, livestock husbandry underpins income earnings for more than 60 percent of the population. Increasing drought frequency and intensity often bring about livestock price collapses, creating conditions for food insecurity. If the economic incentive exists to engage in conflict (based on an expected income) rather than normal livestock husbandry activities, the opportunity to participate in violence is seen as worthwhile.[46]

In post-conflict situations, persistent high food insecurity can be an incentive to lapse back into conflict, particularly if food insecurity is perceived to have derived from persecution, marginalization or injustice. An estimated 40 percent of fragile and post-conflict countries relapse into conflict within ten years.[47]

Food trade as a catalyst for geo-economic and geopolitical conflict. Trade is a key feature of the global food system, with commerce in agricultural commodities representing between 34 and 40 percent of the value of agricultural production over the 2016 to 2018 period.[48] There are clear geopolitical risks associated with trade, and heightened international tensions increase the likelihood of "geopolitically motivated food-supply disruptions".[49]

Every country in the world relies on trade to fulfil its overall food needs. Examination of the networks of trade in major commodities reveals multifaceted interdependencies, with production concentrated in a handful of countries exporting to many, some of which in turn export them onwards.

Market imperfections (such as asymmetric information, asymmetric negotiating power, oligopolies and oligopsonies), political interference and reactions may extract rent and shift value added or create a cyclical chain that exacerbates vulnerabilities. Economic rewards of trade do not necessarily fully recognize the value of goods produced or the needs of the people (such as smallholder farmers) that contribute to making the system work (see Section 1.8).

The growth of trade interconnectedness generates a systemic risk,[50, 51] in that events in one place (e.g. conflict, extreme weather events, biofuels policy and trade restrictions) can interact via multiple routes to drive impacts in other places. Today's global trade networks have been seen as not dissimilar to network diagrams of banking interconnectivity prior to the financial crisis of 2007–2008, in that the food system exhibits " … characteristics consistent with a fragile one that is vulnerable to self-propagating disruptions".[50, 51] Transnational trade linkages are essential for food security, alongside local production. But if they become politicized and without a well-functioning and equitable framework, trade can be just as harmful – because of asymmetric dependencies – as it may be helpful.[52]

Power inequalities of agrifood systems exacerbating conflict. Inequalities exist between actors across and within food systems, including between women and minorities,[53] and between investors and local agriculturally reliant populations. And, thus, there is a high risk of excluding many such stakeholders from natural resources, which may well trigger further and deeper civil conflicts and food crises in the years to come.

Since 2007, there has been a significant investment by sovereign states and transnational companies in natural resources, particularly land, but also water. Although data are scarce, recent estimates show that land deals cover about 30 million hectares and involve diverse global investors originating from the Global North and South, and from tax havens. This is quality land that is close to other resources, especially water, as well as infrastructure (roads and transport) and services.[54] This implies a higher risk of local conflict as populations are often excluded and denied access – including to what was previously grazing and pasture land managed by customary and traditional institutions and conflict-resolution mechanisms, or to water sources. There is evidence that discrepancies in the means required to formalize land rights between companies and communities provide significant advantages to investors seeking extractive or productive rights incompatible with traditional land management practices.[55]

Acquisitions (be it long-term leases, purchases or other mechanisms) of land, water and other natural resources can be problematic with regard to both food security and human security more broadly, since many investment projects have not delivered on their promises, with regard to both food production as well as job creation and service/infrastructure development.[56] Less labour-intensive approaches may also heighten the risks of excluding key stakeholders, especially small-scale and family farmers who produce 80 percent of the food supply in SSA and Asia,[2] a trend that, in turn, may trigger further discontent, civil conflict and food crises.

The realization of Indigenous Peoples' rights, as they are identified in 2005 in the Right to Food Guidelines[69] and later in 2007 in the United Nations Declaration on the Rights of Indigenous Peoples, is a precondition for the preservation of their food and knowledge systems. Indeed, Indigenous Peoples' language, beliefs regarding the universe (cosmogony), culture and livelihoods are negatively impacted by the lack of recognition of and respect for their territorial rights. The ongoing reduction of collective rights to communal lands and natural resources and the increasing obstacles and rules against mobile practices, are negatively affecting their food systems and the biodiversity of these areas. The evidence collected by FAO strongly suggests that the use of communal resources by Indigenous Peoples is directly related to the health of their food system and the level of conservation of biodiversity.[70]

The trend in acquisitions has been reported to have severely dented collective property rights over land, water and other natural resources.[57]

The manner in which natural resource disputes are playing out affects different users in various ways. In some countries, for example, pastoral communities have been involved in an increasing number of land and water conflicts, and have suffered from the loss and fragmentation of grazing land, barriers to mobility and the breakdown of customary institutions. Such factors have fuelled conflict in areas where farming and herding overlap. In many cases, livelihood system-based conflicts have been co-opted by Islamic extremists, or politicized by elites. In addition, over the past five years, the killing of Indigenous Peoples' leaders for defending their territories, lands and natural resources has increased year by year, fuelled by pressure over extractive resources.[60]

1.5.3 Future trends

Some great powers' approaches to human rights and international law challenge the fundamental premise of a rules-based international order. A further misalignment of shared common values among countries could lead in the future to a transition from a unipolar to a multipolar world order with a weak and unsatisfactory global governance. Concurrently, changes in the patterns and nature of violence could present major obstacles to potentially effective and coordinated responses to some of the most serious international (and humanitarian) crises.

A continued increase in violent conflicts can be expected. This is true of Africa, where there were eight conflicts in 2005, compared to 25 in 2019.[14] It is also true for Indigenous Peoples' communities, against whom attacks have increased at an alarming rate in recent years.[60] In the longer term, it is possible that further deterioration of relations between the United States of America and China or the Russian Federation (e.g. over Ukraine), alongside weakened multilateralism, could lead to more tension and the return of proxy wars. New superpower rivalries will also likely present Europe with serious strategic dilemmas and exacerbate existing internal incompatibilities and dissension.

By 2050, climate change is expected to generate up to 86 million additional migrants in SSA, 40 million in South Asia (SAS) and 17 million in Latin America.[26] Migration resulting from climate change in the coming decades may also lead to more food insecurity and malnutrition in resettlement areas. Those locations that host displaced people experience a rapid rise in population and suffer from disruptive consequences on local food systems.[56]

With increasing water demand and climate change, along with acceleration in economic activity and population growth, competition for water will intensify. This will test societal resilience within countries, as well as the capacity of multilateral bodies to mediate during hostilities and manage secondary effects, such as mass population displacement. In a less multilateral world, cooperative arrangements may well be facing further risks, as water becomes more critical to national security. To add to the concern, many of the major river basins are governed by archaic treaties that lack effective dispute-resolution mechanisms or joint management strategies.

Trends analysis commissioned for the European Union claims that by 2035, climate change and resource competition could increasingly make food and water scarcity in SSA and NNA a geopolitical and security issue for the European Union, rather than primarily a development issue. There will likely be a sharp rise in the number of climate migrants seeking to reach Europe.[58]

Looking ahead, it appears that the situation could get worse. The World Bank estimates that by 2030, approximately two-thirds of the population suffering from extreme poverty and high levels of food insecurity will be found in fragile states.[59] Protracted national and subregional crises continue to see a high prevalence of acute food insecurity, particularly in the Democratic Republic of the Congo, Afghanistan, the Lake Chad Basin, the Central Sahel and Yemen, among others, as well as compromised food systems, especially at the local level.

1.5.4 Summary remarks

Recent trends relating to geopolitical instability and conflict comprise: the crisis of multilateralism; an increase in violent and highly damaging conflicts; the emergence of new dangers created by technological disruption; the rising pace of forced displacements; expanding military expenditure; a large number of protracted crises; greater risks of water conflicts, as scarcity spreads; and growing threats over climate security, including those resulting from the possible mismanagement of transition to a greener economy.

Multilateralism is experiencing a downward trend as competition among great powers intensifies. In addition, the COVID-19 pandemic appears to be accelerating and exacerbating these and other geopolitical rivalries. Looking ahead a decade, a "world in more disorder", where existing international and national conflicts persist and deteriorate and/or new ones emerge for a variety of reasons, does not bode well.

Agrifood systems have been seriously impacted by disruptions to political stability, increased clashes over natural resources and weakened socioeconomic and environmental systems. This affects people in various ways and to differing degrees, depending on their location, gender, age, socioeconomic status, and proximity to food production.

Obviously, conflicts keep impacting agrifood systems whose weaknesses, in turn, contribute to conflicts. It is important to note that international agrifood trade can be used as a blackmail tool within or act as a catalyst for geo-economic and geopolitical conflict, and that power inequalities within agrifood systems can exacerbate conflict.

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1.6 Risks and uncertainties (Driver 6)

All drivers affecting agrifood systems are subject to multiple systemic risks and uncertainties. FAO's report, *The future of food and agriculture–Alternative pathways to 2050*,[1] highlights that:

> "The future of food and agriculture faces uncertainties that give rise to serious questions and concerns […]. Uncertainties revolve around different factors, including population growth, dietary choices, technological progress, income distribution, the state of natural resources, climate change, the sustainability of peace" (FAO, 2018, p. xv).[1]

The timing, speed, geographic spread and scale of the COVID-19 pandemic, and the magnitude of its impact or the recent outbreak of an armed conflict involving superpowers, are just examples of the realization of such uncertainties.[af] Extreme climate events such as droughts, floods and storms, weather seasonal variations, and slow-onset processes such as sea level rise linked to climate change, are also unfolding interconnected emergencies. The 2020 locust plague, together with other high-impact and transboundary food chain crises are threatening agrifood systems. Multiple risks of disasters and crises, often combined with conflicts and further stresses, generate damage and losses. Their impact on agrifood systems is difficult to forecast and measure, but it may be reduced by disaster and crisis risk management, including emergency preparedness and response, as well as by actions to increase the overall resilience of agrifood systems in the medium and long run.

This raises several questions, which are dealt with here or in other parts of this report:

- Are there trade-offs between growth and resilience? So far, to what extent has growth of agrifood systems been traded off against their resilience?
- To what extent have the accumulated knowledge and experience, and the technologies developed over time, made agrifood systems more resilient to possible local and international shocks?
- Assuming that technological innovations are not going to deliver expected results in terms of yield increases or reduction of ecological footprint, are there other mechanisms that could ensure sustainable global food security?

Box 1.17 Risks and uncertainties related terms

Crisis. Defined as times of difficulty. Further specifications to mark this challenging period are provided by the adjectives that precede the word crisis. For example, a food crisis can be designated using the internationally recognized parameters of the *Cadre Harmonisé* (CH) and Integrated Food Security Phase Classification (IPC) data.

Disaster. A serious disruption of the functioning of a community or a society (or a broader system) at any scale as a result of hazardous events interacting with conditions of *exposure*, *vulnerability* and *capacity*, leading to one or more of the following: human, material, economic or environmental losses and impacts.[3]

Events. Manifestations of *threats* or *hazards*, or a combination thereof, in a particular place during a particular period of time.[3]

Exposure. The presence of people; livelihoods; species or ecosystems; environmental functions, services and resources; infrastructure; or economic, social or cultural assets in places and settings (locations) that could be adversely affected.[4]

[af] FAO has traditionally covered animal and human disease relationships and prevention (see, for instance, FAO [2018][1]). Protecting people and animals from disease threats.[2] However, the speed, geographic spread and the magnitude of disease outbreaks remain largely subject to uncertainties. This also applies to the outbreak of armed conflicts.

Box 1.17 (cont.) Risks and uncertainties related terms

Hazard. A process, phenomenon or human activity that may cause loss of life and livelihoods; injury or other health impacts; property damage; social and economic disruption; or environmental degradation.[3] The concept of "hazard" is sometimes termed as "threats", depending on different disciplines/contexts. Hazards or threats include both shocks and stresses.

Resilience. The ability of individuals, households, communities, cities, institutions, systems and societies to prevent, anticipate, absorb, adapt and transform positively, efficiently and effectively when faced with a wide range of risks, while maintaining an acceptable level of functioning and without compromising long-term prospects for sustainable development, peace and security, human rights and well-being for all.[5]

Resilience capacities. Overall approaches to building resilience focus on strengthening five key capacities:[5]

1. Preventive capacity: the ability to implement activities and take measures to reduce existing risks and avoid the creation of new risks. While certain risks cannot be eliminated, preventative capacity aims to reduce vulnerability and exposure in such contexts where, as a result, the risk is reduced.
2. Anticipative capacity: the ability to take early action in anticipation of a potential threat to reduce its potential negative impacts; including through early-warning systems early action and forecast-based financing.
3. Absorptive capacity: the ability to take protective action and recover after a shock, using predetermined responses to preserve and restore essential basic structures and functions. It involves anticipating, planning, coping and recovering from shocks and stresses.
4. Adaptive capacity: the ability to make incremental adjustments, modifications or changes to the characteristics of systems and actions to moderate potential changes, in order to continue functioning without major qualitative changes in function or structural identity.
5. Transformative capacity: the ability to create a fundamentally new system when ecological, economic or social structures make the existing system untenable. Transformative capacity is required when the change needed goes beyond the system's preventive, anticipative, absorptive and adaptive abilities, and when there is recognition that ecological, economic or social structures are keeping people trapped in a vicious circle of poverty, disasters and conflict that make the existing system unsustainable.

Risk. In the case of risk, the actual outcome is unknown, but there is information on the probability distribution governing possible outcomes. It is important to make the distinction between risk and uncertainty. Whereas risks can be managed, uncertainty cannot. Risk is an information-based factor, while uncertainty is marked by a lack of information.[6]

Shocks. External abrupt, short-term deviations from long-term trends that have substantial negative effects on people's current state of well-being, level of assets, livelihoods or safety, or their ability to withstand future shocks.[7]

Stresses. Medium- to long-term, slow and gradual pressures that undermine the stability of a system, and increase vulnerability and decrease capacity within the system.[7] Stresses can result from natural resource degradation, geopolitical instability, economic decline or slow-onset climate processes.

Stressors. Also known as risk multipliers or aggravating trends, stressors are processes or conditions, often related to development and inequality, that influence the level of risk by contributing to exposure and vulnerability or by reducing capacity.[3]

Box 1.17 (cont.) Risks and uncertainties related terms

Threat. Threats or hazards are terms mainly related to natural, human-induced and technological hazards, epidemics, economic shocks, conflicts, insecurity and human rights violations. The concept of "threat" is sometimes termed "hazard", depending on different disciplines or contexts. Threats or hazards include both shocks and stresses.

Uncertainty. Uncertainty, simply defined as the lack of certainty, implies doubt regarding the future. In uncertain times, future events are unknown, as are their outcomes or their probability, which cannot be measured or inferred on the basis of past information and modelling. When there is uncertainty, non-linear change means that the principle of stationarity (i.e. future predictions can be made based on past performance) is lost.[6]

Vulnerability. The conditions determined by physical, social, economic and environmental factors or processes that increase the susceptibility of an individual, a community, assets or systems to the impacts of threats or hazards.[3]

1.6.1 Defining risk, uncertainties and resilience

The ongoing COVID-19 pandemic has served a wake-up call from several perspectives. One of these has been to challenge the view that humanity was fully in control. The crisis has shown that, despite the knowledge accumulated and the technologies developed by humanity, the world remains full of risks and uncertainties. In fact, uncertainty may have become the *zeitgeist* of a period marked by a human health crisis, which aggravates unfolding global emergencies associated with climate change, biodiversity loss, pollution, conflicts and crises.

This is an unprecedented moment in history, the Anthropocene, in which human activity has emerged as a dominant force shaping the planet.[8] In this new geological epoch, linear changes, predictable through our current models, coexist with non-linear transformations, that are much harder to foresee and potentially far more dangerous.[9] Surprise and turbulence are becoming more common than before,[10] and problems are overlapping and complex, calling for comprehensive and complementary solutions.[11] Humankind has been transforming the world into an increasingly insecure and precarious place, despite years of development, destroying natural ecosystems and widening inequalities, both within and between countries.

The idea of uncertainty has become prevalent in written material (Ngram Viewer), official documents and institutional statements, often accompanied by references to instability and risk. Declarations by public figures on future instability and insecurity frequently use the terms risk and uncertainty interchangeably. However, risk and uncertainty are distinct in concept and have different implications when it comes to action.

Risk management, as employed in economic and insurance schemes, conventionally aims at minimizing possible loss and damage, and maximizing opportunities for co-benefits. When going beyond simple idiosyncratic risks affecting individuals or households to addressing covariate risks involving groups of households, communities, regions or countries and their context, risk can be defined as: the potential loss of life, injury, or destroyed or damaged assets which could occur to a system, society or a community in a specific period of time, determined probabilistically as a function of hazard, exposure, vulnerability and capacity.[3]

In other words, covariate risk can be conceptualized as the probability for negative consequence of the interaction between a threat or hazard, the characteristics that make people, places and systems exposed and vulnerable to that threat or hazard, and the capacities available to manage them.[5]

The manifestation of hazards includes events such as shocks and stresses, while stressors influence the characteristics that make people, places and systems vulnerable, and their capacities to deal with risk.

In the context of agrifood systems, enhancing the resilience of communities and systems appears to be the best way to face risk and uncertainty in the future and prevent, anticipate, prepare and adapt with regard to potential future crises or instability.

This is why FAO has been adopting a systemic and risk-informed approach that can be summarized as **multi-risk and crisis management for building resilient agrifood systems**.

Immersed in a context of uncertainty, four interconnected global emergencies contribute now to the future uncertainty of agrifood system outcomes and societies at large:

- climate change
- biodiversity loss
- pollution, waste and resource degradation
- human health pandemic.

1.6.2 Recent trends

The cumulative impact of multiple risks and crises

There is no doubt that the global environment is changing. For climate change, there is ample evidence of global warming when reviewing the hottest years on record,[12] and in successive Intergovernmental Panel on Climate Change (IPCC) reports. The same goes for biodiversity loss with clear signs of the worldwide disappearance of pollinators,[13] reports stating that a third of fish stocks are overfished, and studies finding that a third of freshwater fish species assessed can be considered threatened.[14, 15] As for natural resources, about half of the planet's liveable surface is now employed to nourish humanity,[8] while agricultural land is degrading worldwide.[16]

In recent years, the number of recorded disasters – and their impact on livelihoods and economies – has risen dramatically. Agriculture is particularly affected, absorbing a disproportionate share. According to the latest reports under the Sendai Framework, for 2019 alone, 67 percent of all direct economic losses from disasters were in the agriculture sector, equivalent to USD 6.4 billion.[17]

Moreover, this decade began with the COVID-19 pandemic; huge locust swarms, worsening conditions for tens of millions people facing acute food insecurity in the Greater Horn of Africa, the Arabian Peninsula and Southwest Asia;[18] an increase in yearly deforestation rates in primary tropical forests;[19] and a record-breaking 30 named storms in the Atlantic Ocean.[20]

These are just a few among many proofs of the ongoing change in which the technologies adopted in agrifood systems play a major role.

The four global emergencies are intimately connected and interdependent, as illustrated in Box 1.18, where Figure A depicts schematically the synergies existing between climate change, land degradation and biodiversity. The mutually reinforcing character of these crises is a source of risks and uncertainties regarding the possible outcome of ongoing processes.

The call for mainstreaming a multi-risk and crisis management approach is not just based on future scenarios.[21] Rather, it is an urgent response to the current four global crises of climate change, biodiversity loss, pollution and natural resource degradation, as well as the human health pandemic that we are already experiencing now. These emergencies, with poorly grasped spillover and cascading effects, generate uncertainty about the future, as their simultaneous occurrence may lead to unknown outcomes.

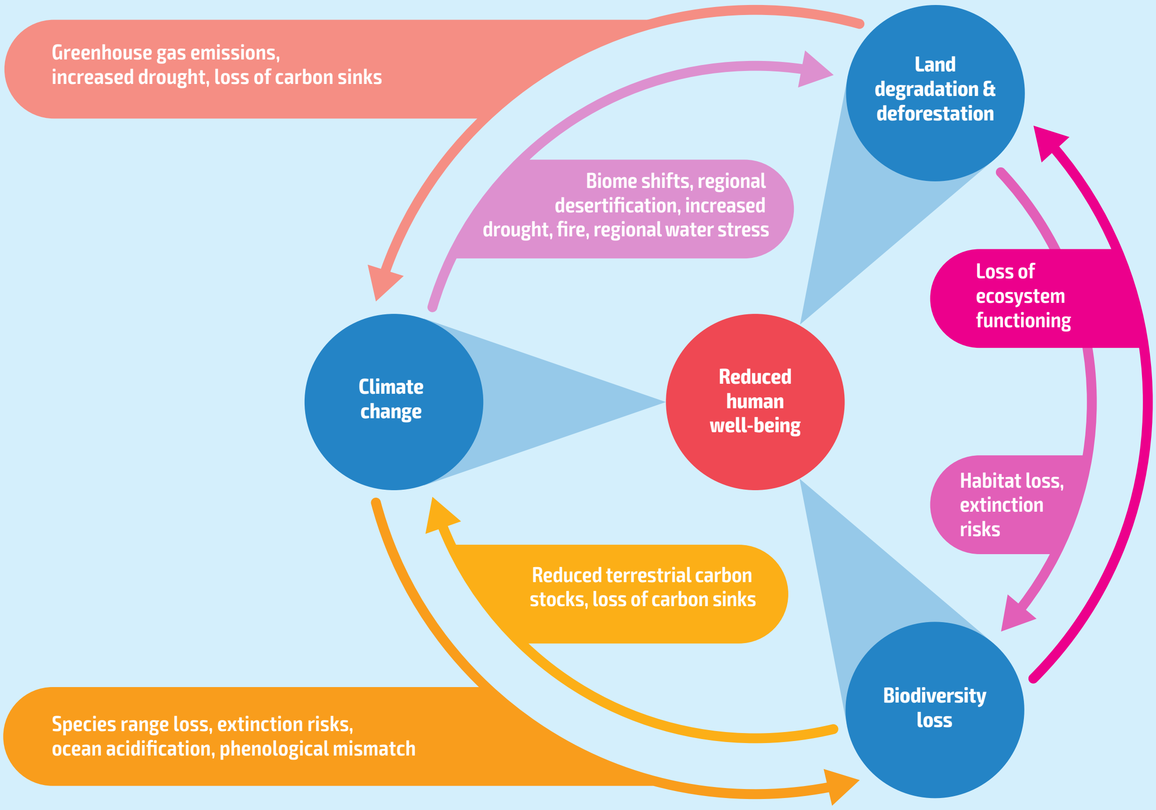
In order to manage these multiple risks, it is necessary to recognize urgently the ongoing crises on different scales, including armed conflicts and protracted crises, where global shocks and stresses aggravate food insecurity and malnutrition in all its forms.[22] Given the interconnected nature of the four global emergencies, it is essential that the sources of these problems are well understood and tackled together immediately.[23]

In the words of the United Nations Secretary-General in December 2020, the world is facing a devastating pandemic, new heights of global heating, new lows of ecological degradation and new setbacks in our work towards global goals for more equitable, inclusive and sustainable development. To put it simply, the state of the planet is broken.[24]

Box 1.18 Interdependence among climate change, land degradation and deforestation, and biodiversity loss

Figure A illustrates how climate change, land degradation and deforestation, and biodiversity loss mutually reinforce one another. Cascading, cumulative and synergetic processes have the potential for creating a snowball effect and constitute a source of uncertainty about the future, if adequate actions are not taken, particularly in the domains of agriculture and food.

Figure A. Interactions between climate change, land use and biodiversity



Source: UNEP. 2021. *Making Peace With Nature*. Nairobi.

Climate crisis

The world climate is changing. Record-breaking levels of heat year after year, reduced ice cover over the North and South Poles, extreme weather events and modifications in seasonal patterns, are everyday proof that climate change is not just a future scenario, but current reality.

It is striking harder and more rapidly than many expected. The last years are the warmest on record, climate-related disasters are becoming more intense and more frequent, and 2019 witnessed unprecedented extreme weather throughout the world.[25] Alarmingly, global temperatures are on track to increase, exceeding limits of 1.5 °C or even 2 °C rise.[26]

Climate change is a key driver of transformation of agrifood systems (see Section 1.16). It is one of the main causes behind the increase of the number of people affected by hunger in the world.[27] By the middle of this century, higher average temperatures, alteration of rain patterns, rising sea levels, as well as anticipated greater damage caused by plant and animal pests and diseases, and subsequent food safety threats, are expected to affect several agricultural subsectors.[28] In particular, the frequency and intensity of recorded extreme climate events are increasing significantly. They destroy critical agricultural assets and infrastructure, interfere with production cycles, trade flows and livelihoods.[29]

These extreme climate events impact food security and cause additional disruptions throughout value chains.[30] Millions of people are being displaced by climate and weather-related events,[31, 32] and the economic, social and environmental safety nets on which vulnerable groups rely for their livelihoods are being eroded, making their lives ever harder.

Data from 71 post-disaster needs assessments, conducted between 2008 and 2018, show that agriculture bears the brunt of disaster impacts, and particularly those resulting from climate change The agrifood sector is also one of the main sources of greenhouse gas (GHG) emissions,[18] responsible for climate change, because of the technologies upon which it relies. At the same time, it has a great potential to offer emissions efficiency gains, absolute reductions and carbon sinks. Urgent action is therefore needed to transform the sector and make it part of the solution of the climate crisis (see Section 1.16).

Biodiversity crisis

Biodiversity – the variety of life at ecosystem, species and genetic levels[15] – is diminishing rapidly. It is critical in sustaining human life, health and well-being. Yet all of the world's ecosystems show the hallmarks of human influence, and many are under acute risk of collapse,[33] with consequences for habitats of species and genetic diversity, ecosystem services and sustainable development. Globally, species continue to decline at an alarming and accelerating rate. One million of the world's estimated 8 million species of plants and animals are threatened with extinction, and the erosion of the ecosystem services essential for human well-being is intensifying.[19, 23]

Biodiversity underpins the wealth and health of societies, and is critical for the effective functioning of agrifood systems. It provides vital ecosystems services on which life depends. It creates and maintains healthy soils necessary for plant growth, plays a key part in pollination and participates in water and air purification, among many other crucial services. Biodiversity for food and agriculture (BFA) is the subset of biodiversity that contributes in one way or another to agriculture and food production (see Section 1.14). The ongoing loss of diversity of native and endemic domesticated plants and animals is undermining the resilience of agricultural systems against pests, pathogens and climate change.[34] Declining diversity of fish species is correlated with lower catches and higher incidence of stock collapse.[15, 24]

Biodiversity loss has critical implications for humanity, from the disruption of entire supply chains to the possible collapse of food and health systems. Loss of pollinators threatens annual global crop output worth between USD 235 billion and USD 577 billion.[23] Loss of soil biodiversity (earthworms, mushrooms and other microorganisms) endangers biological activity indispensable for the growth and health of plants and for sustaining above-soil life.[35] Soils contain an abundance of biologically diverse organisms that perform countless important functions in processes such as plant growth,[36] nutrient cycling, soil structure maintenance, carbon transformation and the regulation of pests and diseases.

Habitat loss and chemical pollution resulting from agricultural intensification, based on the adoption of large-scale monoculture and generalized use of agrochemicals, have been identified as major driving factors.[37]

Pollution, waste and resource degradation crisis

Global pollution, waste production and resource degradation are increasing. To satisfy growing demand, humans use an ever larger fraction of the Earth's resources (land, freshwater and oceans) for the production and extraction of food, fibre, energy and minerals, as well as for industrial facilities, infrastructure and settlements. Thus, they release greenhouse gases and pollutants, including nutrients and toxic chemicals, in addition to household, industrial and human waste, that accumulate in the biosphere. Up to 400 million tonnes of heavy metals, solvents, noxious sludge and other industrial wastes enter the world's waters annually. Chemicals of particular concern feature those that are carcinogens, mutagens, bioaccumulative and toxic, and those with endocrine-disrupting or neurodevelopmental effects. Simultaneously, air pollution is surging, pollutant emissions being largely the result of use of fossil fuels. Currently, more than 90 percent of world population dwells in places breaching World Health Organization (WHO) guidelines for particulate matter in the air. This contamination adversely affects ecosystems and human health, resulting in the premature deaths of millions of people and impacting agrifood systems.[38, 23]

Air pollution is the biggest environmental risk factor contributing to the global burden of disease. Outdoor air pollution causes some 4.2 million premature deaths annually[39]– a pandemic in its own right with greater loss of life than that caused by many illnesses and wars.

Water pollution. Pollution also affects the world's water bodies, with severe impacts (unsafe drinking water, loss of fish stock and dead zones). Water quality degradation is a global issue fuelled predominantly by human pollution.[40] Discharge of pollutants and runoffs – 80 percent of which goes untreated – threatens freshwater resources, human security, food security and contributes to the release of methane.[41] About one-third of all rivers in Latin America, Africa and Asia are contaminated with bacterial and other pathogenic microorganisms.[42]

Recently, plastics have become a major and quite visible source of environmental degradation. From 1950 to 2015, 8.3 billion metric tonnes of plastic were produced mainly from fossil fuels. Without action, the annual flow of this material into the ocean will nearly triple by 2040, to reach 29 million metric tonnes per year, equivalent to 50 kg per metre of coastline worldwide. Women and vulnerable communities disproportionately bear the brunt of environmental degradation caused by plastic pollution and its toxic ingredients (see Sections 1.14 and 1.17).[43]

Land degradation. Land degradation is a pervasive and systemic phenomenon: it occurs in all parts of the terrestrial world and can take many forms. It is negatively impacting the well-being of billions of people, causing species extinction and costing more than 10 percent of the annual global gross domestic product. Soil degradation includes loss of soil through erosion at a rate faster than it is formed, nutrient removal in harvest greater than what is replaced, depletion of organic matter, surface sealing, compaction, and thereby increasing salinity, acidity, metal or organic toxicity to the point where it cannot support former uses.[16] Sources of soil pollution are, in order of importance, industries, mining, waste treatment, agriculture, fossil fuel extraction and processing, and transport emissions (see Section 1.14).

Human health crisis and COVID-19 pandemic

People and the environment in which they live are integral parts of a system that makes them interdependent, and within which humanity acts on the environment and vice versa. This creates a strong connection between human health and the health of the ecosystems to which people belong. This means that with deforestation and globalization, and emerging infectious diseases of zoonotic origin are becoming more frequent and more devastating (see Section 1.15).

The COVID-19 pandemic magnifies underlying systemic problems, including ineffective policies, social and economic inequalities, and weak health care systems.[44] It lays bare the complex connections between agrifood systems, the environment and health. In addition, the COVID-19 crisis exposes how human health is affected by socioeconomic status and how it affects economic and social systems in return. The COVID-19 pandemic is not the first, nor is it the last, of its kind.[45]

The damage from COVID-19 has been worsened by long-standing gender, race, age and income inequalities. Women, youth, unskilled workers, migrant workers and poor urban dwellers are being hit hardest (see Section 1.7).

Fiscal and financial responses to the COVID-19 crisis should have seized what could have been an opportunity to accelerate the transition towards a more resilient and sustainable economic system. However, one year from the onset of the pandemic, recovery spending has fallen short of nations' commitments to build forward more sustainably. An analysis of expenditures planned by leading economies found that only 18 percent of the announced recovery spending can be considered "green",[46] while another report pinpoints that from January 2020 to March 2021, G7 nations pumped more money into fossil fuels than into clean renewable energy, despite pledges to "build back better".[47]

The profound changes observed in the global environment, and the potentially dramatic consequences of their simultaneous occurrence, make those pledges to take action all the more urgently needed.

Food crises

After decades of decline, the number of food insecure people has been slowly increasing since 2014. For example, in 2019 close to 750 million people, roughly one in ten globally, were exposed to severe levels of food insecurity. An estimated 2 billion people did not have access to safe food of sufficiently nutritious quality.[48] In September 2021, around 161 million people were in crisis or worse (IPC/CH Phase 3 or above), or equivalent, in 42 out of 55 countries/territories included in the *Global Report on Food Crises 2021*[49] already surpassing the figure of 155 million in 2020.

Regional and national food crises are a result of multiple causes, including climate change, economic downturns and conflicts,[49] colliding with risks linked to biodiversity loss, pollution and the COVID-19 pandemic, as well as additional high-impact and transboundary plant and animal diseases and pests (such as locusts or fall armyworm).

Conflict, climate extremes and economic downturns are challenging efforts to end hunger and all forms of malnutrition,[30] and their negative impacts are made worse by high and persistent levels of inequality, and by inappropriate policies and investments. Even in peaceful settings, food security deteriorated as a result of economic slowdowns and inappropriate policies that threaten access to food by the poor.

1.6.3 Uncertainties and agrifood systems – shocks, stresses and stressors

Hazards, shocks and stresses impacting agrifood systems

The typology of events presented here is rooted in FAO's work of managing multiple risks and responding to different crises threatening and affecting agriculture and food-based livelihoods (see Table 1.9).

Table 1.9 Shocks and stresses for agrifood systems

TYPES OF EVENTS	EXAMPLES AND RECENT TRENDS
a. Geophysical events	
Earthquakes, tsunami, volcanic eruptions, landslides	Geophysical events comprise hazards with a geological origin in line with United Nations Office for Disaster Risk Reduction (UNDRR) *Sendai Hazard Definition and Classification Review. Technical Report*,[50] including Earth internal seismogenic and volcanogenic processes and surface, or near-surface, shallow processes causing some type of mass/soil movement.
b. Climate and weather-related events	
1. Extreme weather events (shocks), including: tropical cyclones or storms, temperature extremes, heatwaves and cold waves, drought, storm surges and floods	Given its reliance on meteorological conditions, agriculture is especially vulnerable to the increased frequency and intensity of extreme weather-related and climate-induced events.[18] Dury *et al.* (2021)[34] state that "Over half of all shocks to crop production systems have been the result of extreme weather events, reinforcing concern about the vulnerability of arable systems to climatic and weather volatility around the globe".Drought has been established as the single greatest culprit of agricultural production loss (also see Section 1.16).
2. Climate slow-onset events (stresses), seasonal changes in temperature and precipitation patterns, glacial retreat and related impacts, sea-level rise, climate-induced water scarcity	Changes in weather patterns are currently impacting agricultural yields, while generating greater vulnerability to pests and diseases.[51] They can lead to loss of suitability of certain crops, potentially inducing land-use change. Glaciers in the Hindu Kush Himalayan region could lose more than a third of their volume by 2100, even if global warming is kept below 1.5 °C.[52] Over a fifth of the world's basins have recently experienced either quick increases in their surface water area indicative of flooding, a growth in reservoirs and newly inundated land, or rapid declines in surface water area, symptomatic of the drying up of lakes, reservoirs, wetlands, floodplains and seasonal water bodies.[53]
c. Biodiversity/ecosystem-related events	
Erosion of biodiversity (ecosystems, species and genes), ecosystem degradation (e.g. forest loss, loss of fisheries), land and water salinization, soil degradation; eutrophication, ocean acidification	Environmental hazards arise through degradation of ecosystems and their services upon which humanity relies. The elements listed here are often gradual and can also be result of a combination of several global environmental changes. Around 75 percent of our food crops and nearly 90 percent of wild flowering plants depend at least to some extent on animal pollination.[13]

Table 1.9 (cont.) Shocks and stresses for agrifood systems

TYPES OF EVENTS	EXAMPLES AND RECENT TRENDS
	The International Union for Conservation of Nature (IUCN) Red List assessments indicate that 16.5 percent of vertebrate pollinators are threatened with global extinction (as high as 30 percent for island species).[54] Soils are under pressure from increased population, rising demand for food and competing land uses: approximately 33 percent of land used for food, fibre and feed production has deteriorated.[35] Soil erosion from agricultural fields is estimated to be currently from 10 to 20 times (no tillage) to more than 100 times (conventional tillage) higher than the soil formation rate.[55] Harmful algal blooms, dead zone and fish kills are the results of a process of eutrophication which occurs when water becomes enriched with nutrients and is poor in oxygen, pushing upwards the amounts of plant and algae in estuaries and coastal waters (see Section 1.14).
d. Biological events (or food chain threats)	
1. Plant pests and disease	There are many transboundary and high-impact plant pests and diseases that threaten and affect agrifood systems, such as locust, fall armyworms and various bacteria, virus and fungi. A single outbreak of desert locust can affect as many as 65 of the world's poorest countries, and up to 20 percent of the Earth's land surface.[56] Fall armyworm is an endemic insect to tropical and subtropical regions of the Americas. In its larva stage, it can cause significant damage to crops, if not well managed. Fusarium wilt disease has been a major constraint to monoculture banana production for more than a century. The disease is caused by a soil-borne fungus, and it is one of the most destructive diseases of banana worldwide (see Section 1.15).
2. Terrestrial and aquatic animal diseases	Transboundary animal diseases, such as Peste des Petits Ruminants (PPR), Foot-and-Mouth Disease (FMD), African Swine Fever (ASF), Contagious Bovine Pleuro-Pneumonia (CBPP), and Newcastle disease (NCD), directly affect production, livelihoods, food security and nutrition of farming households, and have negative effects along national and international livestock value chains, such as through trade restrictions (see Section 1.15).
3. Food safety events: food chain contamination by microorganisms or harmful substances they produce	Unsafe food can be defined as food containing harmful microorganisms (bacteria, viruses, parasites, etc.) or dangerous amounts or combinations of substances produced by microorganisms (cyanide, aflatoxin, melamine and others) or accumulated by plants during their lifetime (pesticides). It causes a wide array of animal and human diseases (see Section 1.15).
4. Human epidemics and pandemics affect human health and impact agrifood systems: COVID-19, SARS, HIV/AIDS, malaria, Zika	Human health is intrinsically linked to animal, plant and environmental health, in line with the One Health approach co-led by FAO, the World Organisation for Animal Health (OIE) and World Health Organization (WHO) (see Section 1.15). Over the past decades, more than 70 percent of emerging diseases afflicting humans originated in livestock and wildlife. Examples of recent large outbreaks, epidemics or pandemics include COVID-19 (from 2019), Ebola in the Democratic Republic of the Congo (2018–2020) and West Africa (2013–2016), and the Zika virus in the Americas and Pacific regions (2015–2016). Antimicrobial resistance (see Section 1.15).
e. Technological events	
Chemical hazards (shocks), industrial accidents and major infrastructure collapse (shocks), pollution (stress)	Examples of technological hazards include industrial pollution, nuclear radiation, toxic wastes, dam failures, transport accidents, factory explosions, fires and chemical spills. Technological disasters may also arise directly as a result of the impacts of a natural hazard event. The Beirut fertilizers explosion in 2020 marks a story of mismanagement of dangerous materials. It led to the partial destruction of port infrastructure

Table 1.9 (cont.) Shocks and stresses for agrifood systems

TYPES OF EVENTS	EXAMPLES AND RECENT TRENDS
	essential for food imports and exports, as well as key grain storage facilities in the port area, leading to food price increases and shortages for the most vulnerable populations.[57] Ten years after the triple disaster in Fukushima, caused by an earthquake, tsunami and nuclear meltdown, the removal of nuclear fuel and the management of contaminated land and water are still pending issues. Air pollution levels remain dangerously high in many parts of the world, causing millions of deaths (see Section 1.6.2). Equally harmful: pesticide, water and plastic pollution (see Section 1.6.2).
f. Economic events	
Global price instability, financial crash (shock), fuel price crisis, pervasive incentives (stress)	The most illustrative example of an economic event is the 2008 food prices crisis. As a result of COVID-19, food prices have risen, while public investment in agrifood systems has decreased significantly between 2001 and 2020, as shown by the FAO Agriculture Orientation Index (AOI) for Government Expenditures (see Section 1.10). At the same time, pervasive incentives for agro-industrial products that lead to land-use change and encroachment into forest ecosystems continue.[58]
g. Political and governance events	
Violence, conflict, human rights violations, civil unrest	Violent conflicts are on the rise. The sharp increase in acutely food-insecure populations in 2020 has been attributed to the devastating effects of conflicts and insecurity. Almost 100 million people were in crisis, or worse, in 23 countries/territories. Sustaining peace encompasses activities aimed at preventing the outbreak, escalation, continuation and recurrence of conflict, including by addressing root causes and moving towards recovery, reconstruction and development (see Section 1.5).
h. Protracted crisis	
Protracted crises	Protracted crises are where a significant proportion of the population is acutely vulnerable to death, disease and disruptions in livelihoods over a prolonged period of time.[59] In recent decades, increasing numbers of crises have evolved from catastrophic, short-term, highly visible events to more structural, longer-term situations resulting from a combination of many factors.[60] Today, most food crises are taking place in protracted crisis situations experiencing multiple interconnected shocks and stresses, combined with fragility. Almost a quarter of the world's population lives in countries and territories affected by protracted crises and conflicts.

Source: Authors' elaboration.

Stressors in agrifood systems

Stressors – also known as risk multipliers or aggravating trends – are processes or conditions, often related to development and inequality that influence the level of risk by contributing to or aggravating exposure and vulnerability, or by reducing capacities. The stressors in agrifood systems presented here aggravate risks and negative impacts from the shocks and stresses described in the previous section (see Table 1.10 for a summary of this section).

Table 1.10 Stressors affecting agrifood systems

STRESSORS	EXAMPLES AND RECENT TRENDS
Food insecurity, hunger and malnutrition in all its forms	Food insecurity, hunger and malnutrition in all its forms – undernutrition, including wasting and stunting, micronutrient deficiencies, overweight, and obesity – are problems experienced by every country today. Hunger is on the rise and this trend has been accelerated sharply by the COVID-19 pandemic. Two billion people suffer from micronutrient deficiencies and the number of adults who are overweight or obese is continuing to rise, putting them at high risk of developing non-communicable diseases – the top killers, globally – and making them more vulnerable to communicable diseases, as illustrated by the current pandemic. In addition, more than 3 billion people cannot afford a healthy diet (see the Introduction, Sections 1.1 and 1.7).
Food loss and waste	Food loss is the decrease in quantity or quality of food available resulting from decisions and actions taken by suppliers in food chains, excluding retailers, food service providers and consumers. Food waste refers to the decrease in quantity or quality of food available resulting from decisions and actions made by retailers, food service providers and consumers.[15] An estimated 931 million tonnes of food, or 17 percent of total food available to consumers in 2019, went into the waste bins of households, retailers, restaurants and other food services, according to United Nations research.[61] An estimated one-third of the food produced in the world for human consumption is lost or wasted during the production to consumption stages.[62] Three major types of footprints of food loss and waste are quantifiable: GHG emissions, pressures on land and pressures on water; these all have impacts on biodiversity.[63]
Consumption and nutrition patterns	Rise in incomes, population growth and urbanization contribute to changes in diets and consumption patterns, while pressuring agrifood system supply, distribution and waste management chains, and impacting negatively on health (see Sections 1.1 and 1.13).
Climate change	If not reversed, climate change is a threat multiplier and major driver of risks. However, to be tackled, the diverse expressions of climate change need to be understood, analysed and seen as a suite of shocks and stresses (refer to typology of extreme weather events and climate slow-onset events in Table 1.2) to be managed. The main climate change stressor considered here is linked to long-term global warming of the planet resulting from the increase of GHG emissions.
Demographic dynamics	Population growth, changes in population cohorts, migration and displacement (see Section 1.1).
Urbanization	Pressures on supply chains, land use and natural resources: change in food consumption patterns, loss of agricultural land to urban settlements, pollution of freshwater through poor treatment of greywater, management of waste, etc. (see Sections 1.1, 1.13 and 1.14).
Gender inequality	Women are key, but underrated, contributors to agrifood systems. They face inequalities in access to and use of resources, services and remunerative opportunities. Risks are not gender-neutral and may affect women and men in various and different ways. Given differentiated and socially constructed gender roles, and conditions of inequality, disasters may indeed exert a stronger socioeconomic impact on women than on men. The current social construction of gender roles in our societies and the conditions of inequality that this produces, causes a stronger socioeconomic impact on women due to the differentiated impact of disasters. This is particularly true for agriculture, where women already cope with more structural challenges, such as reduced access to land, resources and credit.[18] Rural women and Indigenous women, who are crucial for food supply and as custodians of natural resources, ancestral knowledge, seeds, cosmogonies and unique agrifood systems, are key actors in agrifood systems, yet they are underrepresented in decision-making bodies and are not properly considered in formulating policies and interventions. The exclusion of rural and indigenous women in the design, discussion, decision and implementation of policies and economic programmes is a source of underperformance of the measures, invisibility of stakeholders, loss of knowledge about unique agrifood systems and conflicts within agrifood systems and societies[64] (see Section 1.7).

Table 1.10 (cont.) Stressors affecting agrifood systems

STRESSORS	EXAMPLES AND RECENT TRENDS
Poverty and marginalization	Poor households are more likely to be exposed to risk, have higher vulnerabilities and less access to means to respond to current and future crises or manage multiple risks. Vulnerability does not necessarily equal poverty, yet evidence shows that it is generally the urban and rural poor – including smallholder and subsistence farmers, pastoralists, fishers and wage labourers – who bear the brunt of disasters.[18] In SSA, demographic growth, climate change, low manufacturing levels, and even premature deindustrialization, are paving the way for a massive increase in the number of informal, vulnerable and extremely poor workers, especially among young people. This is fertile ground for food crises, social unrest, violent conflicts and migration, as demonstrated in the Sahel and other regions around the world (see Section 1.5). The challenge is to find decent jobs for the 730 million people who will potentially join the labour force from 2020 and 2050, in addition to the 600 million currently making up the working-age population[65] (see Sections 1.1 and 1.7).
Technological innovations and digitalization	Potential challenges to smallholder farmers and food enterprises, such as overconcentration of market power among data and service providers (see Section 1.12); privacy and security concerns regarding agricultural data and techniques for data validation and storage; potential bias in data collection; the politics of data ownership and transparency; technology dependency and planned obsolescence; and, perhaps most importantly in terms of leaving no one behind, inequality of access to the technologies because of limited digital connectivity in rural areas and lower rates of Internet access among women compared with men. The most powerful applications require high levels of mobile coverage, Internet connectivity, skills and knowledge.[66] The Internet of Things (IoT) brings with it a dependency, which increases the potential of damage from cyberattacks and system failures (see Section 1.4).

Source: Authors' elaboration.

1.6.4 Future trends

The increase in risks and in interconnected and cascading crises present new challenges for agrifood systems and the whole of humanity. The level of insecurity and uncertainty is such today that it is difficult to be optimistic for the future. However, experience shows that risk management strategies (ranging from early warning systems, prevention, anticipatory action, risk-proofing infrastructure and nature-based solutions – including ecosystem-based adaptation, insurance and other risk transfer mechanisms) can contribute to build resilience capacities so that agrifood systems can be better positioned to prevent, anticipate, absorb, adapt and transform in response to shocks, stresses and stressors.

Scaling up on building up resilience contributes to reducing multiple risks and mitigating their impact. Hazard events will continue (volcanoes keep erupting, tectonic plates move, and industrial accidents occur as do extreme climate events). Yet, societies have the option to increase their risk management capacities to better deal with them. If risks are well understood, monitored, analysed, reduced thanks to investments that also mitigate their impacts as they limit the exposure, the vulnerability of populations, ecosystems and agrifood systems can be reduced.

Moreover, increased multi-risk management capacities for building resilience improve the handling of uncertainty as it emerges. Technological innovations, setting up early warning systems and modelling, including probabilistic analyses of different outcomes, help reduce the sphere of "unknown unknowns", strengthen the ability to prevent and anticipate unforeseen events, increase the preparedness to deal with them, absorb their impacts and adapt.

1.6.5 Summary remarks

Despite the growing mass of knowledge and experience accumulated and technologies developed by humanity, the world remains full of risks and uncertainties. In fact, uncertainty may have become the *zeitgeist* of a period marked by a human health crisis which exacerbates unfolding global emergencies associated with climate change, biodiversity loss, pollution, conflicts and the resulting increase of world food insecurity.

There are clear signals that uncertainty is growing. The cumulative impact of multiple risks and interconnected crises has turned into a major source of insecurity and uncertainty, and it may create conditions where cascading, cumulative and synergetic impacts have the potential to generate a snowball effect and lead to a tipping point, beyond which the world would enter unknown territory and massive global emergency.

However, as knowledge on key issues and their underlying processes improve, there is hope that their future evolution should be less prone to uncertainties, and that risks and impacts could be more precisely assessed, monitored, managed and prevented.

The past shows that partial or local quick fixes resulting from uncertain decisions and commitments, and free-rider strategies will not be up to the challenge. It clearly points at the need for a coordinated, systemic global response that addresses the four interconnected and unfolding human and planetary emergencies, where the transformation into inclusive, resilient and sustainable agrifood systems is part of the solution.

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1.7 Rural and urban poverty and inequalities (Drivers 7 and 8)

Societies are characterized by high levels of inequality in income; in job opportunities, in access to assets (including natural resources such as land and water) and to basic services; and in fiscal burden. More importantly, although human rights are universal, the rights of some groups are not respected, resulting in uneven enjoyment of entitlements and opportunities across countries and within societies. Such inequality and lack of respect of human rights, along with discrimination, results in situations of vulnerability and marginalization of some groups, leading to food insecurity and poverty. Indeed, large population segments live either on the edge or below the threshold of poverty, while a few make very significant profits, within and outside agrifood systems. Women, youth, migrant workers, the landless, pastoralists, small producers and Indigenous Peoples are most likely to fall into situations of vulnerability and discrimination, in ways that may not be captured by the standard measures of economic inequalities and poverty. For instance, in the case of Indigenous Peoples, the lack of recognition of and respect for their rights, and no compliance with Free Prior and Informed Consent,[ag] results in invisibility, marginalization, displacement and violence.

Rural areas are lagging behind, socially and economically. Despite great potential, in many instances, a high proportion of rural inhabitants live in poverty. Productivity and labour income in the agricultural sector is lower than the average income in other sectors, and it is characterized by higher gender imbalances. Many rural territories face a severe deficit in infrastructure, greater institutional weakness, poor access to basic services and natural resources, and an eroded social fabric. Overall, the number of food-insecure people is increasing and malnourishment is widespread, and there are significant risks for the most vulnerable to fall into poverty.

Globally, approximately 2.7 billion people (more than a third of humanity) derive their livelihoods from small-scale food production,[1] while at least 4.5 billion people, almost six out of ten people in the world, rely on agrifood systems for their incomes, including those employed in food value chains, those self-employed and family farm labour, and those living from informal, migrant and seasonal wage labour.[2] These groups are largely affected by poverty, with over 1.2 billion rural people living in moderate to extreme poverty.[3,4] This makes agrifood systems central to reducing poverty and, thus, to achieving SDGs 1, 2 and 10.

From the point of view of food consumption, the ability of the poor in both rural and urban areas to achieve nutritious and healthy diets depends on the availability and affordability of food. However, FAO, IFAD, UNICEF, WFP and WHO (2020)[5] state that "the cost of a healthy diet is much higher than the international [extreme] poverty line, established at USD 1.90 purchasing power parity (PPP) per day,"it is estimated that healthy diets are unaffordable for about 40 percent of the world's population, while around 20 percent cannot even pay for a diet that simply meets required levels of essential nutrients.[ah] Consequently, eliminating extreme poverty alone will not make healthy diets affordable for everyone.

Moreover, income and social inequalities directly affect the prospects of achieving sustainable agrifood systems. Inequalities undermine the capacity of the economic system to reduce poverty, and ultimately, they hinder growth itself.[7] As agrifood systems become increasingly complex and urbanized, the opportunities they generate risk excluding many of the rural poor because of the numerous structural constraints they face in accessing resources and services.

Although the 2030 Agenda for Sustainable Development is grounded on the principle of "Leave no one behind", in many instances, specific groups within societies, such as the elderly, children and youth, women, migrants and Indigenous Peoples, still confront high risks of

[ag] Free, Prior and Informed Consent (FPIC) is a specific right that pertains to Indigenous Peoples and is recognized in the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP).[86] It allows them to give or withhold consent to a project that may affect them or their territories. Furthermore, once they have given their consent, they can withdraw it at any stage. FPIC enables them to negotiate the conditions under which the project will be designed, implemented, monitored and evaluated. FPIC is not just the final result of a process to obtain consent for a particular project; it is also a process in itself, and one by which Indigenous Peoples are able to conduct their own independent and collective discussions and decision-making. FPIC is essential to guarantee the right to self-determined development.[87]

[ah] Herforth *et al.* (2020)[6] estimated that, globally, the cost of healthy diets was between USD 3.27 and USD 4.57 per person per day. They also estimated that meeting daily energy needs, using the most affordable starchy staple locally available, was USD 0.79 per day on average; and that the average cost of meeting essential nutrient requirements using the most affordable foods was USD 2.33 per day.

discrimination and marginalization that can place them in situations of vulnerability, inadequate access to entitlements and economic poverty. In some cases, they face damaging conditions, such as insecurity and violence. In the case of Indigenous Peoples, they are often subject to violence while defending their lands and territories. Indeed, the number of Indigenous People assassinated every year for defending human rights and the environment is growing.

An additional issue highlighted by the outbreak of the COVID-19 pandemic is the disparity of access to public health care services, as well as other publicly dispensed services, within and across countries. Taking into account these frequently unmeasured disparities may provide a more severe picture of current poverty levels. Furthermore, the pandemic, by exacerbating existing gender inequalities through, for instance, the proliferation of care and domestic work that limit women's participation in the labour market, has further squeezed incomes of already vulnerable people, pushing them in all likelihood below poverty and extreme poverty lines.[5] Because of their declining purchasing power, they may prioritize caloric intake, thus worsening their nutritional status.

As emphasized by several organizations, including the IMF and OECD, increased inequality can erode social cohesion, lead to political polarization, and ultimately, lower economic growth.[8,9] Worryingly, income inequality is growing. In Asia, for instance, despite the high economic growth over the past few decades (an average annual GDP per capita growth rate of 5 percent from 2000 to 2016), income inequality has risen, slowing progress in poverty reduction. The outbreak of the COVID-19 pandemic has exacerbated inequalities, as vulnerable people are suffering largely from loss of purchasing power as a result of loss of employment and other earning opportunities.[10]

In order to eradicate poverty and hunger and reduce inequalities, working towards sustainable agrifood systems will imply working for and with the poor.

This raises several questions, which are dealt with here or in other parts of this report:

- To what extent do the ways poverty is currently defined and measured reflect actual poverty levels and allow meaningful cross-country comparisons?
- How and tTo what extent and how does the lack of recognition of and respect ofor human rights create vulnerability that leads to poverty?
- Are there needs for new poverty metrics needed to measure poverty related to the likelihood toof falling into vulnerable situations, the lack of opportunities and levels of marginalization and discrimination?
- Are there trade-offs between rural and urban poverty, for instance, in terms of allocation of public investment, and economic orientations towards priority sectors?
- In retrospect, which factors have been the main causes of inequality within countries and across countries?
- How resilient is the progress made during recent decades oin reducing poverty and inequality during recent decades?

1.7.1 Recent trends

Trends in poverty

Measuring poverty. There is no general agreement on how poverty trends are best measured. The most common method for assessing poverty is based on a monetary approach that uses the level of income. An alternative has been to consider the multidimensional nature of poverty (see Box 1.19).

Box 1.19 Methods for measuring poverty

Traditionally, the measurement of welfare has been rooted in the concepts of income and consumption, which are related to the ability of households and individuals to purchase goods and services defined as essential for their well-being. The monetary approach to poverty measurement considers individuals as poor if their total income or consumption is below a certain monetary threshold – the poverty line.

This is the method that is employed most for monitoring poverty. It typically uses the international poverty lines periodically updated by the World Bank. These poverty lines are defined to guarantee comparability between countries, in that they represent the same purchasing power across them. This is achieved by converting a certain monetary standard to local currencies through purchasing power parity (PPP) indices.

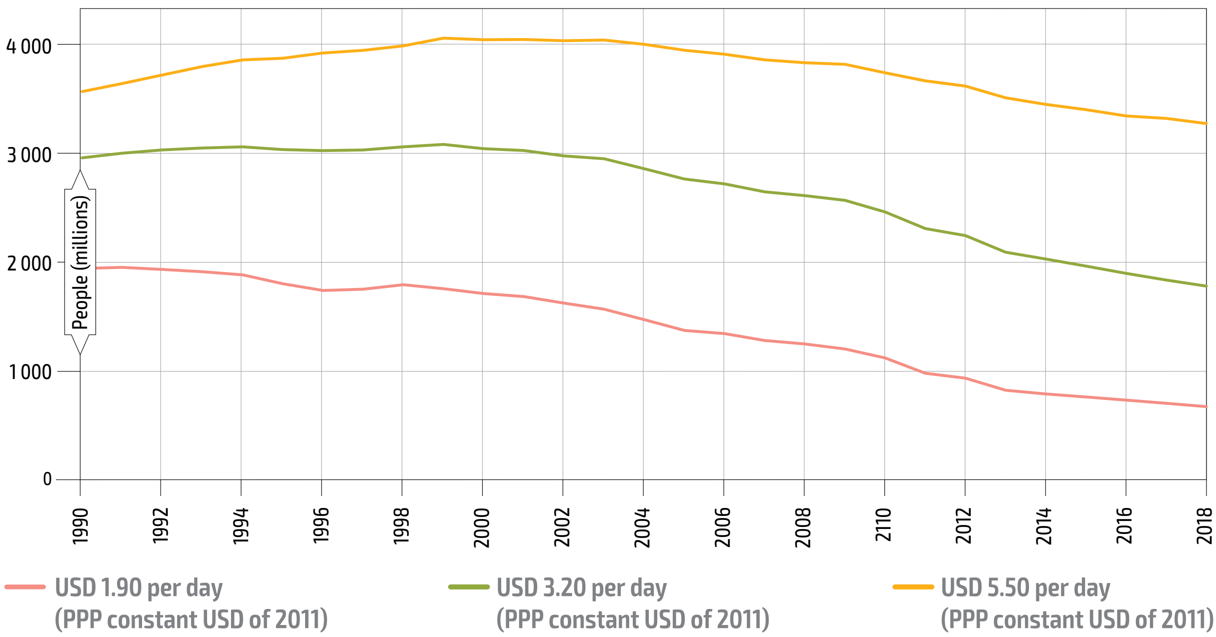
This monetary approach has its limitations, however. For example, the value of international poverty lines should ideally be adjusted using local PPP factors, capturing differences in purchasing power within countries, particularly between their urban and rural areas. However, most countries do not produce local PPP factors (important exceptions are China, India and Indonesia).

Amartya Sen's capability approach is probably the most widely recognized alternative to the monetary measurement of welfare. It establishes that welfare should be measured in terms of capabilities and, consequently, poverty should be thought of as "capability deprivation". Given the multiplicity of capabilities characterizing people's lives, this definition of welfare was translated into a multidimensional approach to poverty measurement. The most used measure for this purpose is the Global Multidimensional Poverty Index (MPI), periodically updated by the United Nations Development Programme (UNDP) and the Oxford Poverty and Human Development Initiative (OPHI). The MPI is used to compare poverty across countries according to the deprivations that people face simultaneously in health, education and living standards. The MPI's main limitation for cross-country comparisons is its more limited data coverage (in terms of countries and years).

The approach taken by the United Nations consists of using both approaches in a complementary way in monitoring SDG 1 (End poverty in all its forms and everywhere). With the support of OPHI, FAO developed a multidimensional measure of rural poverty, the Rural Multidimensional Poverty Index (R-MPI). This measure adds further dimensions and indicators to the Global MPI, with the objective of representing poverty in rural areas more accurately and consistently.

Before the outbreak of the COVID-19 pandemic, poverty was following a decreasing trend everywhere except in sub-Saharan Africa (SSA) and Near East and North Africa (NNA).[4] Between 1990 and 2018, the number of people living in extreme poverty (using the USD 1.90 a day poverty line) fell by more than 60 percent, below 700 million, around 9 percent of the global population (against around one-third of the population in 1990). During the same period, the number of people living below the USD 3.20 a day poverty line only fell by about 40 percent, while the bulk of those living below the USD 5.5 a day poverty line was only reduced by little more than 10 percent. In 2018, more than 40 percent of the world's population were living with less than this amount. This shows that although extreme poverty decreased, poverty is still the lot of a large share of the global population. Figure 1.33 illustrates clearly that poverty reduction has been slower in recent years.

Figure 1.33 Global number of poor people for different poverty lines (1990–2018)



Note: Poverty headcount ratio at USD 1.9, USD 3.2, USD 5.5 per day is the percentage of the population living on less than USD 1.9, USD 3.2, USD 5.5 per day at constant USD of 2011 in purchasing power parity (PPP).

Source: Authors' elaboration based on World Bank. 2022. DataBank | World Development Indicators. In: *World Bank*. Washington, DC. Cited 18 May 2022. https://databank.worldbank.org/source/world-development-indicators

Regional data shows that most of the poor now live in SSA and South Asia (SAS). SSA that despite undeniable progresses in the last decade, still present, by far, the highest prevalence of poverty under all international monetary poverty lines (Table 1.11 and Figure 1.34).

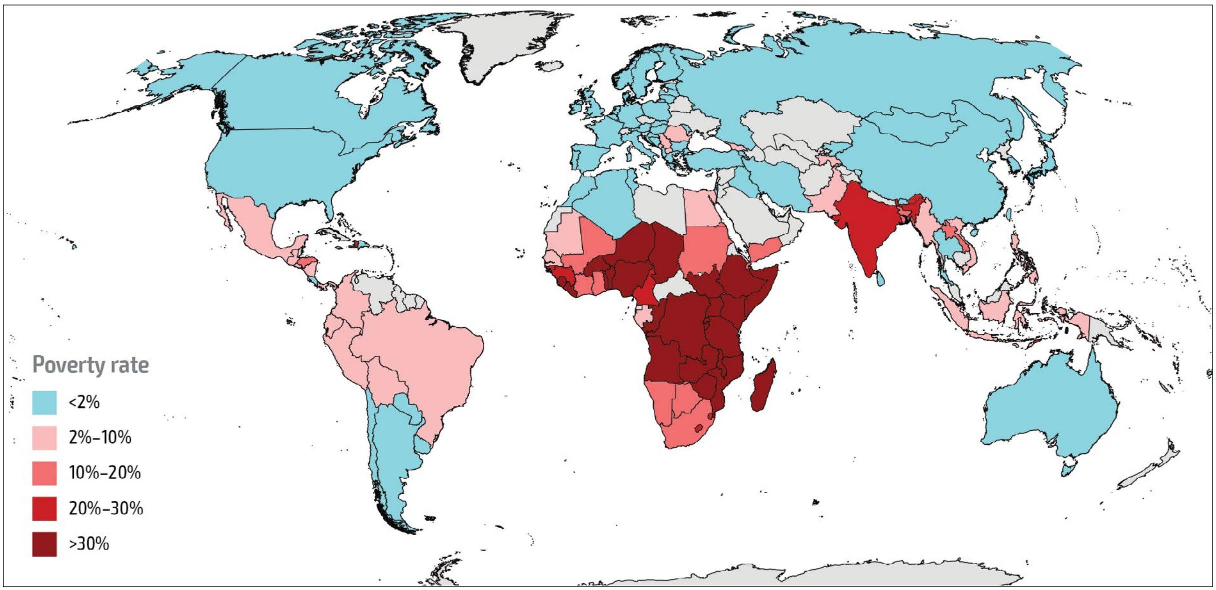
Table 1.11 Prevalence of poverty for different poverty lines by region (1990–2020, averages over ten-year ranges)

REGION	USD 1.9 PER DAY (PPP constant USD of 2011)			USD 3.2 PER DAY (PPP constant USD of 2011)			USD 5.5 PER DAY (PPP constant USD of 2011)		
	1990–2000	2001–2011	2012–2020	1990–2000	2001–2011	2012–2020	1990–2000	2001–2011	2012–2020
High-income countries	0.6	0.6	0.6	0.9	1.1	1.0	1.9	2.3	1.8
China	50.9	16.8	1.5	78.4	37.5	7.6	93.8	62.9	27.6
East Asia and the Pacific	34.8	15.1	4.1	63.8	42.4	20.1	81.9	67.7	46.3
Europe and Central Asia	12.6	9.5	0.6	28.8	19.0	2.3	46.5	35.6	8.7
Latin America and the Caribbean	13.6	8.4	4.3	26.8	18.8	10.9	56.2	37.6	25.7
Near East and North Africa	5.0	2.5	2.6	25.4	16.1	14.1	57.0	45.6	42.3
South Asia	41.8	28.7	19.3	78.2	64.1	57.2	94.3	89.6	85.5
Sub-Saharan Africa	56.6	49.8	40.6	77.4	74.0	67.3	90.1	89.2	86.1
World	**31.8**	**20.2**	**10.3**	**52.8**	**40.9**	**26.7**	**67.3**	**58.9**	**46.3**

Notes: Owing to missing data for many countries in many years, the prevalence of poverty for different poverty lines is calculated as averages over ten-year ranges. The results are related to 148 countries which shows at least one value in the considered decades.

Source: Authors' elaboration based on World Bank. 2022. DataBank | World Development Indicators. In: *World Bank*. Washington, DC. Cited 18 May 2022. https://databank.worldbank.org/source/world-development-indicators

Figure 1.34 Poverty rate at the USD 1.90 a day poverty line, at country level (average 2012–2020)



Notes: Poverty rate refers to those living below the USD 1.90 per day poverty line at constant USD of 2011 in purchasing power parity (PPP). This map represents the average of the poverty headcount ratio weighted by population between 2010 and 2020 for countries with at least one available observation in the considered period (148 countries). In case there were no observations available in the period 2012–2020, the value represented in the map corresponds to 2011. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties. Final boundary between the Sudan and South Sudan has not yet been determined. Final status of the Abyei area is not yet determined.

Source: Authors' elaboration based on World Bank. 2022. PovcalNet. In: *World Bank*. Washington, DC. Cited 16 June 2022. http://iresearch.worldbank.org/PovcalNet/povOnDemand.aspx

SAS hosts the majority of people living below USD 3.20 and USD 5.50 a day, while China was remarkably successful in reducing extreme poverty. At the higher monetary poverty line of USD 5.50 a day, just enough to afford a healthy diet, nearly half of the people in NNA, and almost a quarter of the people in Latin America and the Caribbean (LAC), are considered poor.

In SSA and SAS, the progress in the reduction of poverty at higher monetary lines (USD 3.20 and USD 5.50 a day) has been slower than against extreme poverty. This means that large parts of the population have escaped extreme poverty only narrowly and are at risk of falling back into it as a consequence of the COVID-19 pandemic or of the recent and emerging conflicts.[4]

SSA, together with SAS and NNA (mainly because of conflicts), are the regions that present the highest prevalence of multidimensional poverty (Table 1.12). The specific situation of SSA could at least be partially explained by the consequences of the slow structural transformation of the economy, characterized by a stable share of agriculture in the gross domestic product (GDP), and a relatively slow development of industry and services that do not generate sufficient employment and income opportunities (see Section 1.1).

Multidimensional poverty also appears to have decreased in most countries over the last 20 years: about sixty-five countries, home to 96 percent of the population of the 75 countries studied by OPHI and UNDP (2020),[11] significantly reduced multidimensional poverty.

Table 1.12 Multidimensional poverty: prevalence and number of poor by region (2018)

REGION	PREVALENCE (percent)	NUMBER (millions)
East Asia and Pacific	5.4	110.5
Europe and Central Asia	1.0	1.2
Latin America and the Caribbean	7.2	38.2
Near East and North Africa	15.8	53.0
South Asia	29.2	529.8
Sub-Saharan Africa	55.0	558.4
World	**22.0**	**1 291.1**

Notes: Global estimates cover 107 countries (28 low-income countries, 76 middle-income countries and three high-income countries) and 5.9 billion people. The prevalence refers to the latest survey data available for each country while the number of poor is obtained multiplying each country's prevalence with population data of 2018. The world's number is obtained here by summing up the regional figures. In the original source regional figures and world's one do not match probably due to rounding. No data available for China. High-income countries in this table, contrarily to the rest of the report, are included in their corresponding geographical region.

Source: OPHI & UNDP. 2020. *Charting pathways out of multidimensional poverty: Achieving the SDGs.* Oxford, UK and New York, USA.

Poverty is by far more rural than urban. Globally, the incidence of extreme poverty in rural areas is four times higher than in urban areas. It is also much higher among people working in agriculture than among those employed in other sectors. Extreme poverty has become more concentrated in rural areas in recent years. Indeed 80 percent of the extremely poor live in rural areas, even though the rural population represents only 48 percent of the total population.[4] Globally, poverty has proportionally grown more in rural areas, because it has declined faster in countries that are urbanizing rapidly than in those remaining rural. Multidimensional poverty is even more rural than income poverty: Of the 1.3 billion people who are multidimensionally poor worldwide, 84.2 percent dwell in rural areas.[11] Poverty is also particularly concentrated among Indigenous Peoples, although the definition of poverty and poverty dynamics for Indigenous Peoples in their communities requires further analysis (see Box 1.20).

Globally, agriculture is the main activity for 76 percent of the rural extreme poor.3 However, jobs generated by agrifood systems are not limited to agriculture. In West Africa, for example, 80 percent of the employment in the agrifood system is in agriculture, while 15 percent is in food marketing and 5 percent in food processing.[13, ai]

Many rural poor in low- and middle-income countries (LMICs) rely heavily on natural resources for their livelihoods and often live in areas where they have scarce access to basic services and support mechanisms. In LAC, forest-dependent people represented about 82 percent of the region's rural extreme poor,[14] while around 85 percent of pastoralists and 75 percent of agropastoralists were below the extreme poverty line, a population of several hundred million worldwide, and the vast majority in SSA.[15]

The poor in urban areas can count on a higher level of education compared to those in rural areas.[4] At the same time, they live in neighbourhoods characterized by better wages and more diverse employment opportunities. However, the urban poor face many specific challenges including degraded and risky housing conditions (especially in slums), low quality and very congested services; limited support from family and community networks; marginalization and strong inequalities; and exposure to crime and pollution.

Even though rural areas tend to be characterized by higher food insecurity at the global level,[16] the urban poor often face a difficult food environment, as their access to food is more dependent on income and put at risk by increases in food prices. In addition, the rise in overweight and obesity

[ai] In high-income countries, the picture is quite different: in the United States of America in 2019, for example, only 12 percent of employment in the agrifood systems was in farming, while it was nearly 60 percent in food services, 14 percent in food manufacturing and 14 percent in food stores.[12]

has been concentrated in urban areas,[17] where the poor are more exposed to unbalanced diets rich in fat, and sugary and processed products.

Box 1.20 Methods for measuring poverty

Although global data is lacking, anecdotal evidence and different reports from countries suggest that Indigenous Peoples are amongst the poorest in the world. Although over 80 percent of Indigenous Peoples live in middle-income countries, estimates suggest that, globally, 18.2 percent of Indigenous Peoples live on less than USD 1.90 per day, a large number compared to 6.8 percent of non-Indigenous Peoples.[88]

However, the impacts of monetary poverty depend on the location. Over 73.4 percent of the global indigenous population lives in rural areas, but there are substantial regional variations. for instance, in Latin America and the Caribbean and in North America, the majority of Indigenous Peoples live in urban areas.[88]

Indigenous Peoples in urban and peri-urban areas face levels of poverty similar to non-Indigenous Peoples. However, for Indigenous Peoples, poverty further compounds with discrimination and marginalization. These factors pave the way to labour exploitation, as revealed by an increasing number of studies on bonded labour and modern slavery, particularly in activities such as work on fishing vessels, domestic work, manufacturing and prostitution.[89]

On the other hand, Indigenous Peoples who live in their territories and rely on their own food systems and social relationships, although scoring as poor in terms of income, enjoy traditional safety nets built on the principles of solidarity and reciprocity that are common to most indigenous societies. Thus, despite their low monetary income and lack of access to basic public services and formal social protection, Indigenous Peoples enjoying their ancestral food and knowledge systems often claim to be rich, referring to the wealth of natural resources and the ecosystems that surround them where they live. Indeed, complex but effective governance practices ensure collective access to comunal resources. In addition, collective work and reciprocity help maintain the social fabric of the communities and ensure the wellness and livelihoods of all the members.[90]

Thus, poverty for Indigenous Peoples goes far beyond income or monetary poverty. It materializes as uncertainty over the tenure of their lands or even the lack of access to lands and territories which entail the impossibility to produce their food. Therefore, poverty is intertwined with the collective prosperity of the community, the solidarity and reciprocity ties and the health of nature.[91]

When applying the Food Insecurity Experience Scale (FIES) to measure the prevalence of food insecurity within indigenous communities, important differences emerge with respect to non-Indigenous Peoples. The appropriate unit of reference for assessing food insecurity cannot be the household or family but the collectivity. Some of the first anecdotal results from applying FIES in 18 indigenous communities in Northeast India, suggest that their levels of food security are better than other non-Indigenous Peoples in the region.

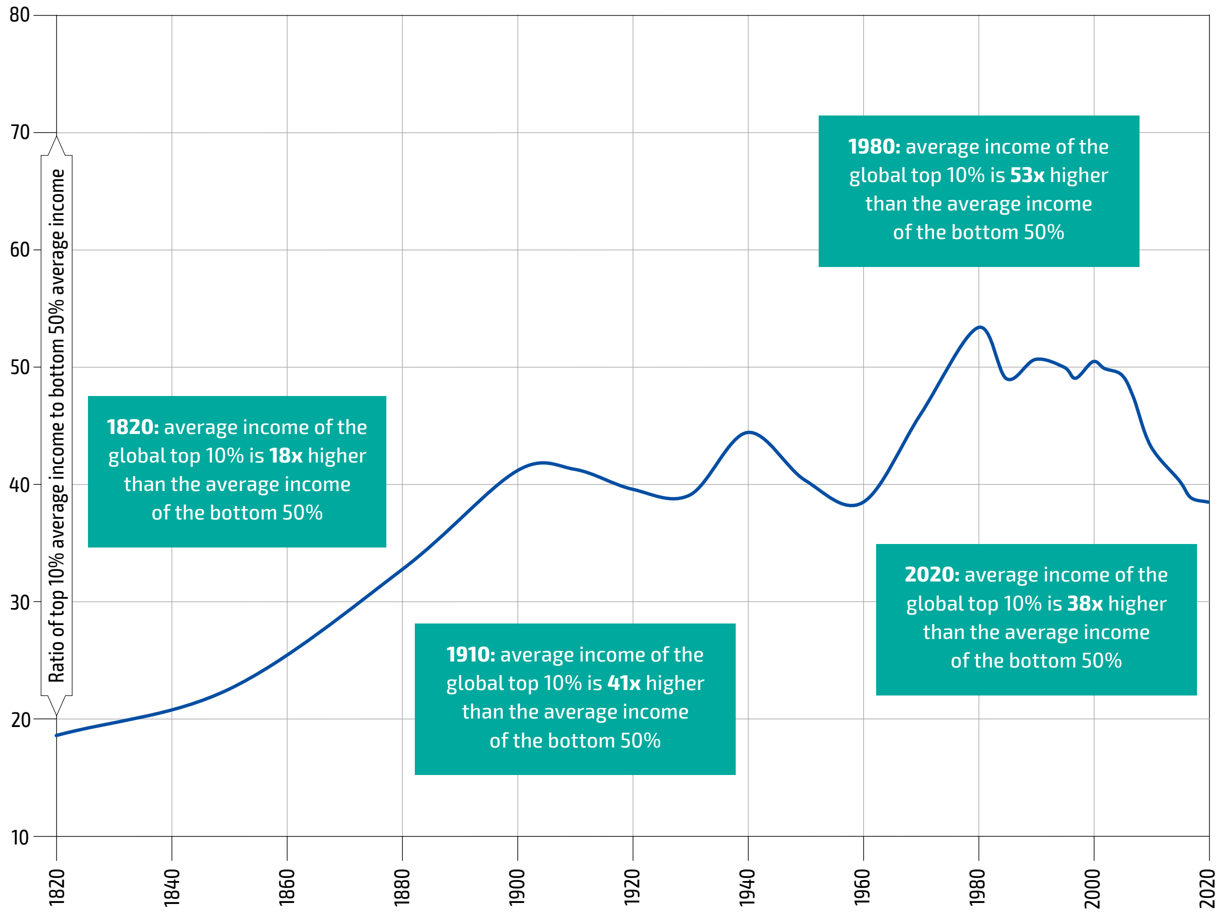
Consensus exists that Indigenous Peoples from across the world feel poor, destitute and vulnerable when they are not recognized, their rights are not respected, Free Prior Informed Consent (FPIC) is not applied and they cannot rely on their own knowledge, land and natural resources to maintain their ancestral food systems. Their poverty and food insecurity are rooted in discrimination, denied rights, lack of entitlements and opportunities, and can last generations.[90]

Trends in income and wealth inequality

There is general agreement that the current level of global inequality is unacceptable, denoting huge differences in the standard of living of people around the world.[18]

During the last 200 years, global income inequality, measured by the ratio of income of the top 10 percent over income of the bottom 50 percent, shows an abruptly increasing trend of inequality until the beginning of the twentieth century, stagnation until the 1960s and again rapid increase for two decades before a period of stabilization, followed by a decrease of income inequality since the start of the twenty-first century (Figure 1.35).[19]

Figure 1.35 Global income inequality: ratio top 10 percent/bottom 50 percent (1820–2020)



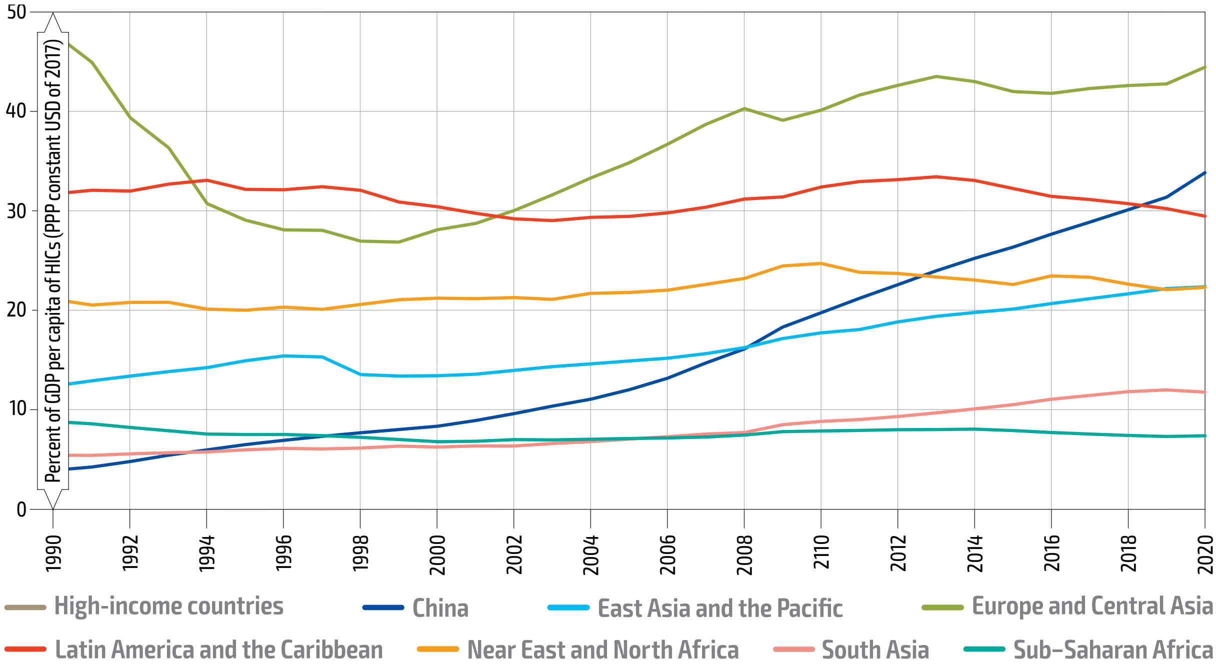
Note: Global inequality, is measured by the ratio between the average income of the top 10 percent and the average income of the bottom 50 percent (T10/B50).

Source: Chancel, L. & Piketty, T. 2021. Global Income Inequality, 1820–2020: the Persistence and Mutation of Extreme Inequality. *Journal of the European Economic Association*, 19(6): 3025–3062. https://doi.org/10.1093/jeea/jvab047

There is less of a consensus when it comes to recent observed trends. For some, conventional measures, such as the Gini index, indicate that global inequality decreased, essentially because of changes that occurred in China and India. Without including these two countries, global interpersonal income inequality in 143 countries was higher in 2015 than in 1988.[20] For others, the trend was towards less income inequality.[21]

Figure 1.36 illustrates the very varied relative evolution of income per capita in LMICs in the different regions compared to that witnessed in HICs. China, EAP to a lesser degree, and SAS in an even slower way, follow a positive converging trend showing a progressive increase of the share of their income per capita than that observed in HICs. NNA and LAC experience ups and down but they display a downward path during the last decade, while SSA definitely declines. Europe and Central Asia (ECA), appears to be stagnating after a big leap in the first decade of the century, following a significant drop in the aftermath of the end of the Soviet Union. Thus, in most cases, the convergence between LMICs on one side, and HICs on the other, is limited or non-existent. In addition for most LMICs regions the per capita income remains below (and mostly well below) a quarter of what it is in HICs.

Figure 1.36 Per capita income in low- and middle-income countries as a share of high-income countries by region (1990–2020)



Note: The percent of GDP per capita purchasing power parity (PPP) of high-income countries (HICs) is calculated by dividing the GDP per capita (in constant USD of 2017 PPP) of each region by the GDP per capita in the same unit of measure in HICs.

Source: Authors' elaboration based on World Bank. 2022. DataBank | World Development Indicators. In: *World Bank*. Washington, DC. Cited March 2022. https://databank.worldbank.org/source/world-development-indicators

A sizeable share of in-country income inequality results from the gap between rural and urban areas. A study on 65 low- and lower-middle-income countries found that around 40 percent of within-country inequality was owing to the difference in living standards between rural and urban populations.[22] In fact, location has a strong influence on poverty status and economic mobility and, in addition to income-related disparities, rural inhabitants face stark inequalities in access to adequate sanitation, health services, public infrastructure and documents of identification (which constrains participation in public programmes and services).[18]

Despite considerable problems with the availability of statistics, it is clear that wealth inequality showed increasing trends in the countries with data. In particular, wealth appeared to become more concentrated in China, Russian Federation and the United States of America and, to a more limited extent, in France and the United Kingdom of Great Britain and Northern Ireland.[23]

The COVID-19 pandemic's impact

The COVID-19 pandemic is reversing poverty and inequality trends. The increase in the number of the global poor because of the COVID-19 crisis points to a reversal of gains in global poverty reduction. Lockdowns and other measures to contain the spread of the pandemic caused a deep economic recession, and aggravated extreme poverty and food insecurity.

The World Bank estimates that the pandemic pushed a further 119 to 124 million people into extreme poverty in 2020,[24] while a group of United Nations agencies calculated that 161 million more people faced hunger in comparison to 2019 as a result of worsening purchasing power.[25]

The World Bank High-Frequency Phone Surveys reveal staggering proportions of households that reported a decrease in their income after the beginning of the COVID-19 crisis. In 24 out of the 30 countries with data, more than half of the national population declared a reduction in total income, ranging from 29 percent in Bulgaria to 85 percent in Senegal.[26] Different sources of income were impacted to varied extents. Non-farm family businesses have been the sources of income for which the highest proportion of households reported a deterioration, family farming being identified as the second most affected source, followed by remittances and wage employment.

The pandemic is partially changing the profile of the poor and increasing the share of the world's poor living in SAS and in urban areas, causing the world's poor to become more employed in non-agricultural activities and more educated, on average.[4] The new poor, more visible and probably more vocal, will likely divert attention away from chronic rural poverty for some time.

The current crisis also aggravates inequality, as it hits the most vulnerable harder. While wealthier people in high-skill service sectors were more able to work from home, poorer people were disproportionally exposed to the virus and economically more affected by restriction measures. In April 2020, the Inter-American Development Bank (IDB) rolled out an online survey in 17 countries in LAC, which provided evidence that households in low-income categories suffered more from job losses, business closures, income losses and hunger.[27] The effects of the pandemic were particularly severe for households dependent on informal employment, seasonal migration or mobile livelihoods in urban areas. Analysis shows similar trends (see Box 1.21). Moreover, the pandemic will also widen the gap between high-income and other countries, as the latter have fewer resources with which to confront the situation than the former.

Based on experience, it is expected that the COVID-19 crisis will likely generate a medium- to long-term vicious cycle between poverty and inequality,[28] demonstrating the fragility of results achieved over decades. In addition, the increased poverty and inequality brought about by the pandemic has the potential to undermine social cohesion, fuel nationalist and protectionist trends, and, in the worst cases, lead to unrest and violence.

The impact of the COVID-19 pandemic and associated lockdowns has not been gender-neutral, and has negatively affected women more than men because they are more vulnerable to employment loss, being generally more exposed than men to care burden and informal employment.[29] The income of women working in the informal sector fell drastically during the pandemic and many lost their jobs, in greater numbers compared to men.[30]

Several studies have also shown that declining incomes and food insecurity are possible causes of increasing domestic violence in periods of lockdowns (see, for example, Mittal *et al.* [2020][31]). The gender gap in the prevalence of moderate or severe food insecurity grew even larger during the pandemic. This prevalence was 10 percent higher among women than men in 2020 compared to 6 percent in 2019.[25]

As a vulnerable group, youth have also been strongly affected by the crisis, in particular in labour markets. Recent ILO-modelled estimates show that young workers (aged 15 to 24 years) incurred an employment loss of 8.7 percent in 2020, almost 2.5 times greater than for adult workers. Similarly, household surveys also show that many countries have experienced an increase in the rate of youths not in education, employment or training – mostly because of school closures – which can potentially affect their inclusion in educational systems and labour markets in the long term.[32]

Regarding Indigenous Peoples, on the one hand, those who relied on their own ancestral food and knowledge systems and applied traditional lockdownpractices coped better than other communities.[92] In these cases, Indigenous Peoples were able to maintain their food security and even supported non-Indigenous communities in need of food. Furthermore, Indigenous youth played a critical role in supporting networking and emergency response communications.[90,93] On the other hand, as available data show, Indigenous Peoples not living in their ancestral territories have been disproportionately affected, in part due to historic lack of access to health services.[94] In addition, Indigenous Peoples whose livelihoods are nomadic have seen their source of food and income shrink with the lockdown.[94] Several Indigenous Peoples experienced a surge in racial discrimination, either because they were held responsible for being patient zero, or as build-up of the discrimination they already face.[95] Furthermore, third parties took advantage of confinement measures to invade Indigenous Peoples' lands, provoking violence and forced displacement.[94,96,97] Unfortunately, responses to COVID-19 at the country level, including mitigation actions and economic assistance policies, were in many cases implemented with limited participation of Indigenous Peoples.[98] One of the few positive experiences from COVID-19, was the return of indigenous youth to their communities during the lock-down, which revitalized the transmission of oral knowledge in those communities.

Because of the pandemic, SDG 1 targets will likely not be met, unless a "poverty miracle" occurs – a scenario of unprecedented annual GDP per capita growth and a spectacular reduction in inequality in all LMICs (see Section 1.7.3).[33]

Box 1.21 Monetary poverty and inequality trends during the COVID-19 pandemic in Colombia, Costa Rica, Ecuador and Paraguay

Official information released by Colombia, Costa Rica, Ecuador and Paraguay on the impact of the COVID-19 pandemic shows that monetary poverty increased sharply between 2019 and 2020.

In Colombia, data indicate that poverty increased significantly in urban areas and decreased slightly in rural areas, bringing, , the prevalence of monetary poverty to similar levels in both rural and urban areas for the first time ever.

The same change was observed in Costa Rica, where rural and urban poverty levels have become almost equivalent. In Ecuador, poverty levels also increased faster in urban than in rural areas. In Paraguay, poverty remained nearly unchanged in rural areas while it worsened in urban areas.

Inequality in the distribution of income, measured by the Gini coefficient, increased in most of these countries during the pandemic. In Colombia, this was the case in urban areas, while there was no change in rural areas. In Costa Rica and Ecuador, inequality grew both in urban and rural zones. Paraguay stands out as the country where inequality in the distribution of income receded, particularly in rural areas.

Table A. Poverty and inequality before and during the COVID-19 pandemic

	COLOMBIA		COSTA RICA		ECUADOR		PARAGUAY	
	2019	2020	2019	2020	2019	2020	2019	2020
Poverty: prevalence (percent)								
National	35.7	42.5	23.9	30.0	24.8	32.1	23.5	26.9
Urban	32.3	42.4	22.7	30.0	17.1	24.8	17.5	22.7
Rural	47.5	42.9	27.2	29.9	41.3	47.7	33.4	34.0
Extreme poverty: prevalence (percent)								
National	9.6	15.1	6.7	8.5	8.9	14.6	4.0	3.9
Urban	**6.8**	**14.2**	**6.1**	**8.3**	**4.3**	**8.8**	**1.8**	**1.8**
Rural	**19.3**	**18.2**	**8.3**	**9.0**	**18.7**	**26.9**	**7.8**	**7.4**
Gini coefficient (0 to 1 range)								
National	**0.526**	**0.544**	**0.506**	**0.512**	**0.473**	**0.498**	**0.449**	**0.427**
Urban	**0.505**	**0.537**	**0.508**	**0.516**	**0.453**	**0.484**	**0.428**	**0.421**
Rural	**0.456**	**0.456**	**0.484**	**0.491**	**0.442**	**0.470**	**0.472**	**0.426**

Source: Authors´ elaboration based on information from national statistical offices.

1.7.2 Poverty, inequality and agrifood systems

How agrifood systems impact poverty and inequality

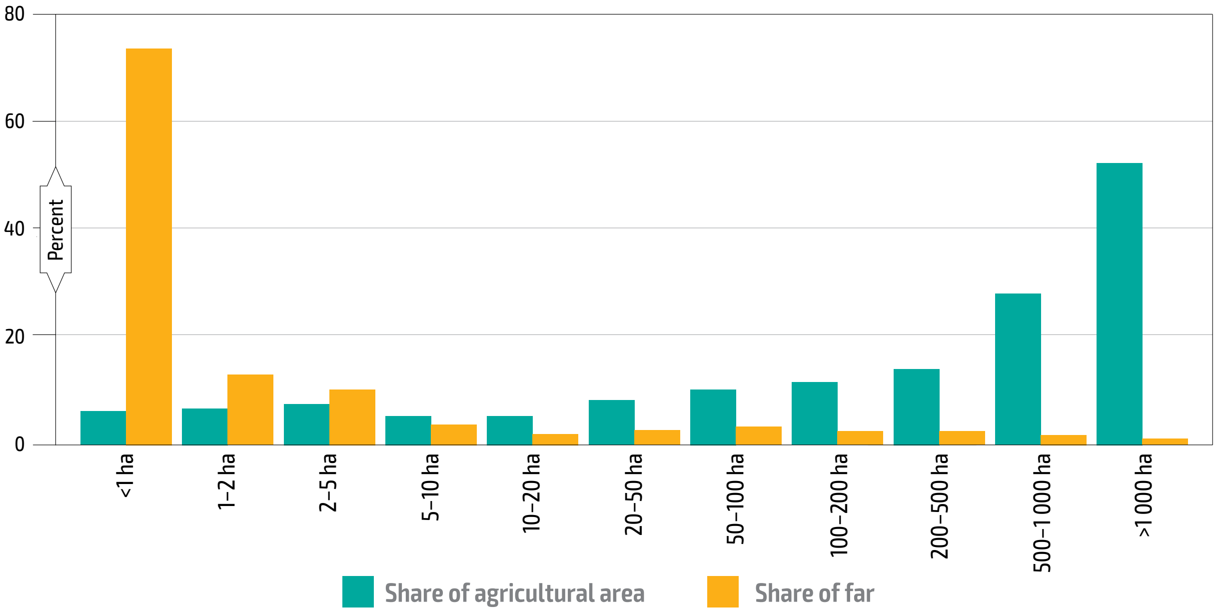
When agricultural growth is not inclusive of the poor and vulnerable, it generates poverty and inequality. As the complexity and global outreach of agrifood systems increases, new opportunities open up for small-scale and poor producers in urban, international, and quality-demanding food markets. At the same time, they face important challenges and risks of exclusion, as these markets require higher quality standards, and greater resources and capacities. The mode of operation of agrifood systems then tends to perpetuate poverty and inequality.

Inequality in access to land. As the basis for agricultural production, land is a central factor for wealth accumulation, power and influence in rural societies. Evidence shows that land has been increasingly concentrated in large farms and is unequally distributed, thus generating further inequality and poverty (see Section 1.12). In contrast, it has been established that land redistribution policies can play a fundamental role in poverty reduction and economic growth, as was the case, for example, in China, Thailand and Viet Nam.[34]

The most recent agricultural census and survey data available show that while small farms (of 2 hectares or less) represent 84 percent of the total number of farms in the world, they operate only 12 percent of agricultural land. In contrast, the 1 percent largest units (those of 50 hectares or more) manage more than 70 percent of the total land. Medium-sized units (between 2 and 50 hectares), which tend to be more market-oriented than smaller ones, hold the remaining 18 percent of farmland (Figure 1.37).[35] Moreover, in many countries, lower-income groups have access to land with lower productivity and greater vulnerability than average.[36]

The level of concentration of land varies, from country to country. For example, in LMICs (located primarily in EAP, SAS and SSA), smallholders operate about 30 to 40 percent of the total agricultural land.[35]

Figure 1.37 Worldwide distribution of farms and farmland by farm size class (various years)



Note: Various years from the more recent census rounds (1990, 2000 and 2010).

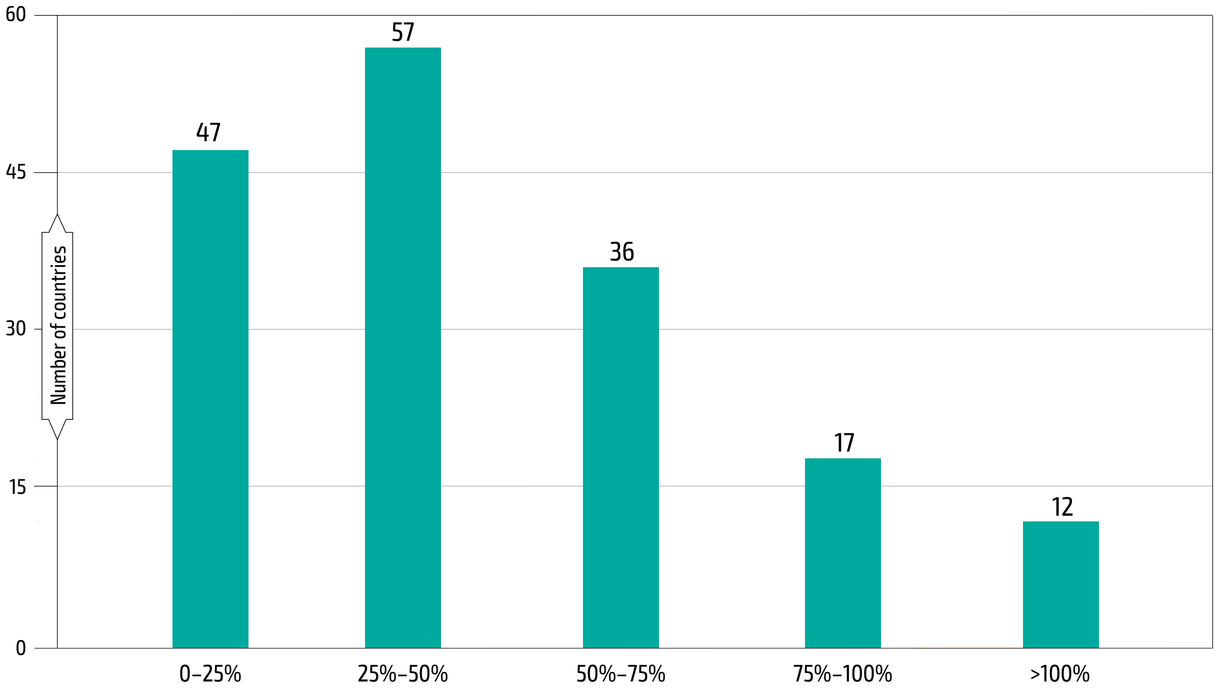
Source: Authors' elaboration based on Lowder, S., Sánchez, M.V. & Bertini, R. 2021. Which farms feed the world and has farmland become more concentrated? *World Development*, 142: 105455. https://doi.org/10.1016/j.worlddev.2021.105455

In some low-income economies, middle-sized farms have been gaining importance. In four sub-Saharan countries (Ghana, Kenya, Tanzania and Zambia), a growing share of land is being operated by medium-scale farms (defined as between 5 and 100 hectares). This trend can be partly explained by an increased interest of urban entrepreneurs and rural elites in the opportunities offered by a dynamic agricultural sector, and not by a better access to land by smallholders.[37] A similar evolution of average farm size has also been observed in several Asian countries,[38] including China.[39]

Low incomes. Promoting employment through agricultural development is often seen as an opportunity for job creation, income generation and poverty reduction. Yet, the advent of so-called "modern" agrifood systems may not be changing the nature of agricultural employment, mostly characterized by low productivity, low income and wages, as well as poor working conditions. While agricultural wage employment varies greatly – from casual daily work to agricultural employment in large plantations – paid workers in the rural sector usually obtain the lowest wages.[40]

When specific data are missing, one way of approaching agricultural income is to consider average GDP/person active in agriculture. It is generally found to be much lower than average GDP/person active in the economy as a whole. Figure 1.38 shows that among the 169 countries for which there were data available for 2017, 104 (62 percent) had an average agricultural value added per worker (agricultural labour productivity) less than half of the GDP per worker in the total economy (economy-wide labour productivity). In only 12 countries, the agriculture was higher than GDP/worker in the economy as a whole. When considering the rural population living in those countries, it appears that around 2.8 billion rural dwellers (or 70 percent of global rural population) live in countries where GDP/person active in agriculture was less than half of GDP/worker in the economy as a whole.

Figure 1.38 Ratio by classes between agricultural labour productivity and economy-wide labour productivity in different countries (2017)



Notes: The ratios refer to 169 countries for which all data needed were available in 2017. Calculations are based on agricultural value added and GDP at current prices.

Source: Authors' elaboration based on World Bank. 2021. DataBank | World Development Indicators. In: *World Bank*. Washington, DC. Cited 03 August 2021. https://databank.worldbank.org/source/world-development-indicators

This unfavourable situation affecting agricultural workers can possibly be explained by a combination of low productivity of labour (agriculture, in many parts of the world remains a very labour-intensive and low-capital activity), low prices of agricultural commodities,[41] and a generally weak bargaining position of farmers on markets.

Government policies used in implementing low food price policies and providing support to agricultural producers, particularly in HICs, but also increasingly in middle-income countries, have been penalizing peasants in LICs by putting them in an unfavourable competitive position (see Section 1.8).[42]

As complex agrifood value chains develop, the employment share in farming tends to decline, while its share in food manufacturing and services increases.[43] Data on wages paid for jobs in different parts of agrifood systems are not available globally. However, it is possible, for a few countries, to consider value added/workers in different parts of the agrifood system and compare them with value-added/workers in the economy as a whole. In the case of the United States of America, available data show that value added/worker was below 50 percent of the national average in all agrifood parts, but manufacturing (Table 1.13).

Table 1.13 Value added and employment in different subsectors of the agrifood systems, compared to the total economy – United States of America (2019)

SUBSECTORS OF THE AGRIFOOD SYSTEMS	VALUE ADDED (USD billion)	WORKERS (millions)	VALUE ADDED PER WORKER (USD)	INDEX TOTAL USA ECONOMY=100
Farming	136	2.6	52 300	50
Food services, eating and drinking places	544	13.0	41 800	40
Food, beverage and tobacco manufacturing	272	2.0	136 000	130
Food and beverage stores	136	3.2	42 500	41
Total USA economy	21 327	203.7	104 700	100

Source: Authors´ elaboration based on data published by USDA ERS. 2020. Ag and Food Sectors and the Economy. In: *USDA ERS*. Cited 18 August 2021. www.ers.usda.gov/data-products/ag-and-food-statistics-charting-the-essentials/ag-and-food-sectors-and-the-economy

Moreover, a large share of the labour force in LMICs is employed in the informal sector, work in poor conditions and in absence of adequate contractual arrangements. In some cases, this can be caused by the outsourcing of hiring processes that saves employers from meeting with labour regulations. In some subsectors, such as fisheries and forestry, labour may take place in very remote areas, making it harder for laws and regulations to be enforced.

Low income and poverty in rural areas are a major cause of child labour that, in many countries, is mainly an agricultural issue. Worldwide, 70 percent of child labourers are found in agriculture.[44] This amounts to approximately 112 million girls and boys. Over three-quarters of all children aged 5 to 11 years in child labour work in agriculture.

Agricultural employment is generally associated with low status in society, which can act as a social impediment to improving its conditions. Labour migration in agriculture is of particular concern, as migrant workers often do not benefit from decent living conditions at their work destinations and are not protected during travel from their places of origin to their destinations.[45]

Global agrifood value chains and exclusion of small-scale producers. The globalization of agrifood chains, characterized by consolidation of operations, increased power of retailers, progressive digitalization of procurement and quality-based competition, has significantly transformed agrifood systems, including the role played by small-scale producers.[46] Today, about one-third of global agricultural and food exports are traded within global value chains.[47] Through this process, retailers and supermarkets have grown larger, taking the lead of agrifood chains and linking daily grocery shoppers to farmers around the world. Power has substantially shifted in favour of global buyers vis-à-vis producers, in part because of diminished government capacities caused by structural adjustments and by the inflow of agrifood multinationals into producing countries.[48] Quality and price-based competition has soared in low-income countries, with imports offering goods often cheaper and of a higher quality than those domestically produced (see Section 1.12).[1]

As a result, only 36 percent of the value of food at global level is produced by smallholders (defined as farms of 2 hectares or less). In HICs and LAC, characterized by a strong presence of large farms, this share is much lower; while in China, most of the value of food production is generated by smallholders. Although smallholders play an important role in feeding the world, the risks are high of seeing them excluded unless specific policies in their favour are implemented, as many small producers in low-income countries (LICs) are being marginalized and bypassed by the ongoing process of change.[47] This contributes to maintaining large numbers of people in poverty and to perpetuating inequalities.

Poor producers lack required means to cope with natural resource degradation and climate change. The poorest groups in the world often depend directly on natural resources and the environment for their livelihoods (see Box 1.22). The impact of degradation of resources and climate change on agrifood systems hits them hardest, contributing to greater inequality.49 Repeated exposure to adverse weather events may affect willingness to invest in their farm. Mitigating and adapting to climate change is costly, particularly for farmers and rural populations. Adopting sustainable practices, as well as investing in risk management infrastructure, including for flood prevention and protection from extreme weather events, requires means that they do not have. To cope with climate change, small-scale farmers would need approximately USD 188 billion per year globally, with an additional USD 50 billion to cover non-agricultural expenses needed to sustain their overall livelihood strategies (health, education, housing and living standards).[50] This is more than twenty times the currently available resources.

Beyond the lack of sufficient funding, there is increasing concern that climate-financed projects generate more vulnerability across already fragile populations.[51] This is a consequence stemming from several factors involving inequalities in stakeholder participation, top-down design approaches, and donors' and governments' retrofitting of development agendas.[52] Access to social protection can foster sustained adoption of climate-smart practices.[53] However, mitigation projects still fall short of creating the necessary social and economic incentives for communities to adopt climate-smart practices and foster sustainability.[54] Finally, in many cases, these projects do not sufficiently address farming households' constraints, including time and resources used in their overall livelihood options, and their risk management strategies. The initial situation related to their access to adequate living conditions, infrastructure and social protection, will determine the extent to which farmers can embrace new practices, diversify their livelihoods and take risks.

Thus, the inability of poor producers to cope with climate change is likely to entrench many of them in poverty.

Box 1.22 Cocoa: a rapidly growing, unsustainable system generating poverty, inequality and environmental damage

Growth. Global cocoa bean production has grown from 1.7 million tonnes in 1980 to 5.6 million tonnes in 2019. Côte d'Ivoire (2.2 million tonnes) and Ghana (0.8 million tonnes) are the largest producers.[55]

Inequality. In 2017, raw or roasted exported cocoa beans had a combined value of USD 8.6 billion. In the same year, the chocolate industry, which is controlled by a handful of multinational companies (Mars Wrigley, Ferrero, Mondelez, Meiji, Hershey, Nestlé and others) and which consumed 43 percent of all cocoa, had a retail market value of USD 106 billion. This value is projected to reach USD 190 billion by 2026.[56] Based on these figures, it is clear that cocoa producers only acquire a small share of the value generated by the cocoa supply chain. An analysis of each stakeholder's share in the cocoa supply chain found that cocoa farmers were only receiving 6.6 percent of the price paid by consumers for chocolate,[57] although cocoa is its main ingredient.

Poverty and child forced labour. As a result, the majority of the 5 to 6 million cocoa growers are living in poverty: 70 percent of them were estimated to subsist on less than USD 2 per day.[57] A report commissioned by the United States Department of Labor found that, in 2018/19, 1.56 million children were engaged in child labour in cocoa production in Côte d'Ivoire and Ghana, 95 percent of whom were exposed to at least one component of hazardous child labour.[58] Moreover, it has been estimated that 13 700 adults and 16 000 children were engaged in forced labour between 2013 and 2017.[59] This situation has continued to perpetuate despite repeated efforts to combat child labour.

Environmental damage. Both Côte d'Ivoire and Ghana have seen their forests all but disappear to be replaced mainly by cocoa. In Côte d'Ivoire, more than 80 percent of the forests are gone, mostly following an illegal invasion by as many as a million landless people into national parks and other supposedly protected forests, mainly to grow cocoa.[60] In Ghana, from 1980 to 2010, about half of the country's forest area was lost, having been reduced from 8.8 million hectares in 1980 to only 4.9 million hectares in 2010.[61]

Poverty, inequality and the sustainability of agrifood systems

Poverty and unsustainable resource use. The capacity of agrifood systems to meet the objectives of food security, nutrition and environmental sustainability assigned to them, depends on the ability of farmers and consumers to access resources, and manage risk and uncertainty. This is intrinsically linked to how resources are distributed in a society. Policies, social structure and dynamics determine who has access to resources, employment opportunities and protection from risk, and who does not. Exclusion from certain categories reduces this capacity and overall social, economic and environmental sustainability.

Forests. Around two-thirds of bioenergy used worldwide involves the traditional burning of wood and other biomass for cooking and heating, much of which is unsustainably produced and inefficiently burned by poor population groups, affecting health and contributing to environmental degradation.[62]

LICs experienced both the largest annual net loss of forest area and annual net gain in agricultural area. This loss, predominantly resulting from the expansion of commercial farms, deprives forest communities, particularly the most impoverished, of plant and animal biodiversity that is often critical to their food security. In SSA, and tropical and subtropical Asia, subsistence agriculture also accounts for a considerable share of deforestation.[63]

Deforestation and forest degradation have repercussions for global food security. They are major sources of GHG emissions contributing to climate change, reducing options for breeding new crops and plant varieties that may allow food systems to adapt better to climate change,[64] and may be the cause of the occurrence of zoonoses (see Section 1.15).

Land. There is a clear spatial association between poor people and marginal land, as the prevalence of poverty is frequently substantially higher on degraded land than elsewhere. However, the causal link between poverty and unsustainable management of land resources is multifaceted and context-dependent. Poverty and land degradation are usually the result of a complex set of physical, social and economic processes that may themselves be linked spatially.[36] What is clear, however, is that their joint presence is a manifest symptom of a failing agrifood system that is unsustainable within its social, economic and environmental dimensions.

Poverty and inadequate nutrition. For the poor in both rural and urban areas, achieving nutritious and healthy diets is an everyday concern. Around 20 percent of people cannot afford a diet that meets required levels of essential nutrients. Twice that many people do not have the means to pay for healthy diets.[6]

Inadequate nutrition has consequences on economic performance. Some estimates fixed the economic cost of stunting at 13.5 percent of GDP per capita in low-income countries, because childhood stunting is associated with adverse outcomes throughout the life cycle. The process that causes stunting harms brain development, leading to lower cognitive and socio-emotional skills and lower levels of educational performance. Health problems, such as non-communicable diseases, are also more likely in later life, resulting in a reduced work capacity and higher health care costs.[65]

In urban areas, the poor do not have access to diets with fresh fruits and vegetables, tubers and legumes. Instead, they tend to consume larger amounts of sugars, fats, and highly-processed or ultra-processed food.[66] These types of food are convenient for them as they may have limited resources, such as household heating and cooking goods, access to safe drinking water and sanitation, but it increases the chances of chronic undernutrition, leading to higher overweight and obesity prevalence in future stages of life, along with their negative health consequences. This is particularly worrisome considering that an urban setting is where the majority of the countries' populations now live or will be living in the near future.[67]

Gender discrimination. Women are more food insecure than men in every region of the world, with the largest differences arising in Latin America. At the global level, and more markedly in Africa and Latin America, the gender gap in access to food is more pronounced in people living in rural areas.5 Women are also poorer than men, with the difference being the largest during their reproductive years, when their role in care and domestic responsibilities represents an added vulnerability factor. The gender gap in food insecurity and poverty is driven by underlying inequalities in access to resources, markets and economic opportunities.[68]

This situation seriously affects the performance of agrifood systems, as women are crucial actors in food production, preparation and distribution of food within the household, as well as of food processing and trading. In 2020, women represented over 37 percent of the world's rural agricultural labour force, a figure that reaches 48 percent in low-income countries.[aj] For FAO, there is a process of "feminization of agriculture" as the share of women in agricultural employment is growing in all low-income regions except EAP, where the lack of an upward trend reflects the fact that women already make up about 50 percent of the agricultural workforce. This evolution is because of men moving out from agriculture to higher-paying sectors or migrating to urban areas or abroad, while women are often left behind taking on new roles as primary food producers.[64]

Evidently, inequalities in access to productive resources, such as land and technology, experienced by women have a significant impact on the economic and social performance of agrifood systems.[70]

Indigenous Peoples. Over the years, Indigenous Peoples have shown that their relationship with Mother Earth has enabled them to generate food and preserve the world's largest biodiversity hotspots. However, their food and knowledge systems, their territorial management and governance practices are not well understood, resulting in their rights not being respected and in a lack of dedicated policies and programmes in support of their food systems.[90] Nineteen percent of the people who face extreme poverty worldwide are indigenous.[88] This economic poverty is in sharp contrast to the cultural and ecological richness of indigenous societies. Despite being the oldest existing societies on earth, Indigenous Peoples have struggled to be formally acknowledged and to have their rights protected by international legal frameworks. Although two major international frameworks do acknowledge and protect their rights (the 1989 ILO Convention 169[99] and the 2007 United Nations Declaration on the Rights of Indigenous Peoples, or UNDRIP).[86] Despite this recognition, Indigenous Peoples' views of the universe, time-tested practices of production and relational values continue to be excluded from science and policy.[100] Western scientific knowledge remains the dominant knowledge system that sets the prevailing standards for research and policy.[101] To trigger and accelerate transformative processes in which agrifood systems interact sustainably with broader socioeconomic and environmental systems, it is essential to ensure that Indigenous Peoples be recognised and fully and effectively participate in policymaking.

1.7.3 Future trends

Poverty

The contrast is striking between projections made before the occurrence of the COVID-19 pandemic and those made thereafter.

In January 2020, the Global Director of the Poverty and Equity Global Practice at the World Bank, while recognizing that the pace of global poverty reduction has slowed considerably, presented projections for the five countries in which half of the world's poor lived, that envisioned almost total eradication of poverty in India and Bangladesh, resulting in a reduction by half of poverty in the five countries. Globally, poverty was projected to virtually disappear in all regions but in SSA, where it was expected to increase slightly before starting to decrease to a little above 400 million people in 2030 (Figure 1.39).[73]

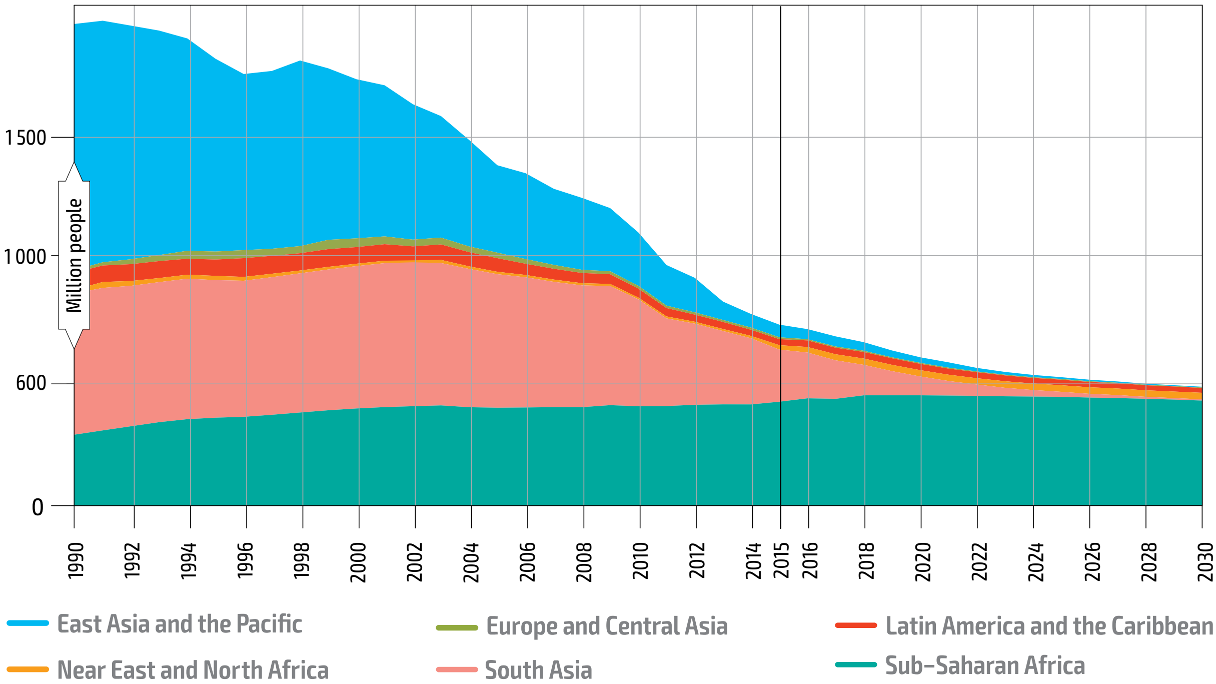
In 2020, well into the COVID-19 pandemic, the World Bank adjusted its projection and forecasted that the percentage of people living in extreme poverty would reach between 6.1 percent and 7 percent of the total population in 2030 (compared to 9.2 percent in 2017). This was far above the 3 percent expected before the pandemic, the number of extremely poor being projected to be 521 million to 597 million people (compared to the earlier estimate of 255 million).[4]

In 2021, World Bank analysts claimed that the consequences of the COVID-19 pandemic (economic downturn, loss of jobs and earnings) could impact the long-term trajectory of poverty reduction, especially in low-income countries,[74] and expect that climate change may push over 130 million into poverty by 2030 and cause more than 200 million people to migrate by 2050.[75]

Hoy and Sumner (2021)[76] believe that the SDG 1 on poverty is still achievable (or near achievable), under the demanding condition that "the impact of the pandemic on income poverty is addressed and countries are able to follow the most equitable growth pathway after the pandemic has abated".

[aj] Estimated based on ILO (2022).[69]

Figure 1.39 Extreme poverty by regions: historical (1990–2014) and projected (2015– 2030)



Note: The regions in this graph include all countries in those regions, including HICs, where applicable, contrarily to the other graphs of this report.

Source: Sánchez-Páramo, C. 2020. Countdown to 2030: A race against time to end extreme poverty. In: *World Bank Blogs*. Washington, DC. Cited 25 June 2022. https://blogs.worldbank.org/voices/countdown-2030-race-against-time-end-extreme-poverty

A similar conclusion is reached by UN DESA in a "miracle" scenario where annual average GDP per capita growth is fixed at 9.9 percent and cumulative change in income inequality is set at a 50 percent reduction by 2030. All other scenarios constructed show improvements compared to the situation at the end of the 2010s apart from the "pessimistic" alternative characterized by slow growth and greater inequality (Table 1.14).[33]

Table 1.14 Extreme poverty prevalence in 2030 according to various economic growth and inequality scenarios

SCENARIO	AVERAGE GDP PER CAPITA GROWTH	CUMULATIVE CHANGE IN INCOME INEQUALITY	SHARE OF POPULATION IN EXTREME POVERTY BY 2030					
	(percent)		(percent)					
	Developing countries		World	Africa	Asia	Land locked developing countries	Least developed countries	Small Island Developing States
Baseline	3.9	No change	7.6	26.4	3.5	28.0	36.6	8.2
Pessimistic	1.9	+25	12.9	37.9	7.7	38.9	47.0	15.2
Only growth	6.9	No change	6.1	21.6	2.7	21.7	31.3	5.8
Optimistic	6.9	-25	4.2	15.7	1.9	14.6	25.1	2.8
Poverty miracle	9.9	-50	2.7	9.4	1.4	5.8	16.8	0.3

Notes: The terms "developing countries" and "least developed countries" are quoted from the original source. They are used here just for the purpose of reference. Their use in this report does not imply any value judgement regarding the state of development of any country in those groups.

Source: United Nations. 2020. *The long-term impact of COVID-19 on poverty.* Policy Brief No. 86. New York, USA.

Addressing the issue of poverty and inequality from the climate perspective, Campagnolo and Davide (2019)[77] found that more stringent mitigation plans may increase poverty in LMICs by 4.2 percent, compared to the baseline scenario, with minor reduction in impact on inequality. Soergel *et al.* (2021)[78] found that climate policies consistent with a 1.5 °C global temperature target would push 50 million people into poverty by 2030, in addition to the 350 million projected in the trend scenario.

The disparity of these projections illustrates how dependent our views of the future are on recent occurrences and how vulnerable they are to events and crises whose eventuality is uncertain (see Section 1.6).

Inequality

As illustrated by Table 1.14, inequality is more often a parameter for characterizing poverty projection scenarios than a result. The variable used typically is annual percentage changes of the Gini coefficient, their plausibility being based on comparable data across countries over time.[79]

Existing efforts to project inequality trends have utilized, as explanatory variables, total factor productivity (TFP), education attainment at different levels of education, social public spending (education and health) and a general inclination towards progressive policies. Not surprisingly, these projections give very diverse results depending on the country considered.[80]

In the specific context of Hong Kong, analysts suggest that income disparity will be alleviated in the next 15 years, as a consequence of the increasingly equal spread of the level of schooling across the workforce.[81]

Starting from the ageing of world population (see Section 1.1) and the adoption of new automation technologies, a group of researchers forecasts rising inequalities through the loss of 20 to 25 percent of jobs, a loss hitting mostly middle- and low-income workers.[82]

Projections of inequality at country, regional and global level have also been carried out assuming alternative scenarios for the long-term future. They refer, for example, to the five alternative Shared Socioeconomic Pathways (SSPs) that have been developed by the Integrated Assessment Modelling community (IAMC) for the purposes of assessing future GHG emissions and the mitigation thereof, and used as reference in the assessment reports of the IPCC.[83, 84]

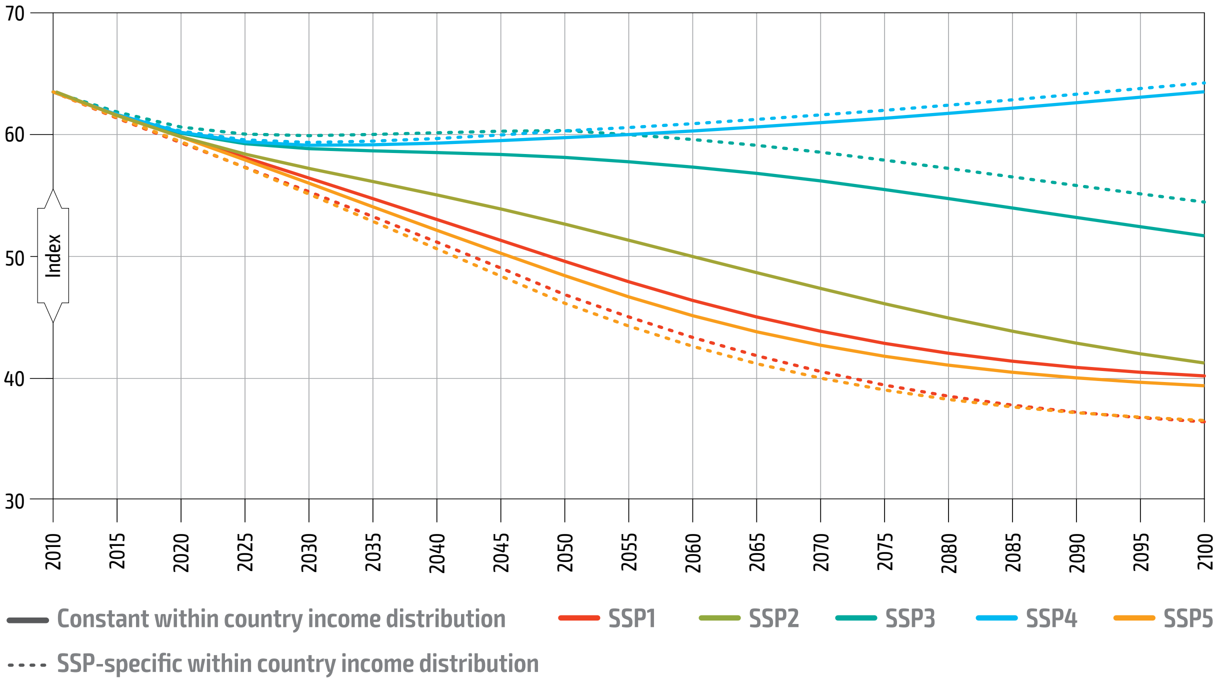
The five SSPs are characterized by different narratives regarding the within- and between-country income distribution, reflected in the different pathways for the Gini index. Results of projections at global level are shown in Figure 1.40.[ak]

SSP1 and SSP5 are predicated on robust and equitable growth across countries and would see the global Gini index dip below 40. SSP2, known as the middle-of-the-road scenario, would also see a steady decline in the Gini index to just somewhere above 40 by the end of the century. SSP3 and SSP4 are at the opposite end of the spectrum in terms of income convergence. SSP3 is characterized by slow per capita GDP growth and high population growth. There is a modest improvement in the global Gini index, but this represents to some extent shared sluggish economic growth. The SSP4 storyline is explicitly one with increased income inequality and this is reflected in a rising Gini index over most of the century. The core simulations, reflected in Figure 1.40 by the dotted lines, assume that the within-country income distribution will change according to the specific scenario narratives, compared with alternative simulations that assume no changes in the within-country income distribution with respect to the base year (2010), reflected by the solid lines. The projections for SSP2 are identical, as the narrative for this SSP explicitly assume that there will be no change in the within-country income distribution. In the case of SSP1 and SSP5, the assumption is that within-country inequality will decline and thus the dotted lines lye below the solid lines (lower overall inequality, reflected by a lower Gini index). On the other hand, under SSP3 and SSP4, the story lines suggest a deterioration of the within-country inequality. In these cases, the dotted lines reflecting both between and within-country inequality show a greater Gini index compared with the projections driven only by the between-country inequality.

[ak] The paragraphs on the projections of the Gini index benefited from important contributions by Dominique van der Mensbrugghe, Director, Center for Global Trade Analysis (GTAP) Department of Agricultural Economics Purdue University. Aggregated projections at regional level and by income groups are also available through the Data Dashboard of this corporate report. The reader can also refer to source of data referred to Figure 1.40.

It is interesting to note that all the SSPs but one (SSP4) project improvements in the overall income distribution, whether this is due to concurrent improvements in the within- and between-country distribution, as in the case of SSP1 and SSP5, or because the reduction of the between-country inequality more than offsets the increase of the within country inequality, as in the case of SSP3, or is sufficient per se to reduce the overall inequality, as in the case of SSP2. Furthermore, even in the "worst case" scenario (SSP4), at the end of the century the overall global inequality will barely reach the levels of 2010 (the base year of projections). Whether the SSPs actually reflect a wide range of plausible assumptions on possible futures regarding global inequality, is difficult to assess. In actual facts, SSPs have been shaped with the goal of investigating climate change implications of alternative socioeconomic pathways, rather than specific socioeconomic issues. Probably owing to this reason, the set of SSPs may not provide a scenario of significantly increasing global inequality in the long run with respect to the base period.[al]

Figure 1.40 Global Gini index projections for alternative futures under shared socioeconomic pathways (2010–2100)



Notes: The GINI index is a measure of the greater or lesser inequality in the way income is distributed across people. It varies between zero (perfect equality, each person receives the same income) and 100 (maximum inequality, all the income goes to one person). The five shared socioeconomic pathways (SSPs) are characterized by different narratives regarding the within- and between-country income distribution, reflected in the different pathways for the Gini Index. For each SSP, the solid line reflects the assumption that the within-country income distribution is kept constant as in the base year of the projections (2010) (proportional within-country income changes), while the dotted line reflect SSP-specific assumptions regarding within-country income distribution. For SSP2, the solid and dotted lines coincide as for this SSP, the narrative assumes no change in the within-country income distribution.

Source: van der Mensbrugghe, D. 2015. *Shared Socio-Economic Pathways and Global Income Distribution*. Center for Global Trade Analysis (GTAP) Department of Agricultural Economics Purdue University. https://gtap.agecon.purdue.edu/resources/download/7554.pdf

1.7.4 Summary remarks

The decreasing poverty and inequality trends have been reversed because of the COVID-19 pandemic, demonstrating the fragility of past achievements. Several traits of agrifood systems perpetuate poverty and inequalities: land distribution and access, low incomes resulting from low food price policies and exclusion of small producers from agrifood value chains. Moreover, smallholder farmers lack the means to cope with natural resources degradation and climate change.

[al] Updates of the Gini index projections are underway with updated income projections and improved income distribution functions. However, substantial changes in qualitative terms may not be expected.

In the case of SSA, significantly higher poverty levels than in other regions are probably a consequence of the slow structural transformation of the economy, characterized by a stable share of agriculture in GDP and a relatively slow development of industry and services that do not generate sufficient decent employment and income opportunities (see Section 1.1).

Poverty is also associated with deforestation and degradation of forests, and unsustainable management of marginal land. In addition, in urban as well as in rural areas, it is associated with inadequate nutrition. Women are poorer and more food insecure than men, while Indigenous Peoples are among the poorest population groups in the world.

There are high risks that the COVID-19 pandemic set off a medium- to long-term period during which its negative impact will continue to be felt in terms of poverty and inequality. Projections suggest that unless there is a “miracle” (unprecedented economic growth and spectacular reduction in inequality in all LMICs), SDG 1 targets are unlikely to be achieved.

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1.8 Food prices (Driver 9)

Real food prices have been significantly higher in recent years than 20 to 30 years ago, according to the FAO Food Price Index. Indeed, food is around 30 percent more expensive than in the 1990s.[am] This occurred despite the fact that current pricing mechanisms fail to capture the whole cost of food, including social and environmental externalities at all levels (full cost accounting). FAO's report, *The future of food and agriculture – Alternative pathways to 2050*,[1] highlights that if environmental costs were accounted for, food prices might increase, other things being equal, by 30 to 35 percent in the next decades. At a time when political and media attention is sensitive to the price of food, and policy-makers express concerns about the efficiency of agrifood systems, cheap, unhealthy, and socially and environmentally unsustainable food cannot be the solution.

The observed price trends raise some questions, including:

- Could this upward trend in prices illustrate the fact that the "green revolution" has exhausted its effects and new technologies are needed?
- To what extent could this price trend reflect that we are starting to pay the "cost of unsustainability" of current agrifood systems?
- Is a future scenario of significantly increasing food prices plausible? What factors could trigger such a scenario?

This section provides some pointers on how to address these questions. Additional elements to deal with these questions are provided in other parts of the report.

In market economies, prices are expected to provide signals that operators use to make efficient choices and take decisions that should maximize both individual and collective well-being. According to this conventional wisdom,[an] prices are determined by markets so as to balance demand and supply of a particular commodity, inform about the scarcity or abundance of goods, services and resources, and guide production decisions towards the most efficient utilization of resources and technologies. As such, they are important drivers of change in all sectors of the economy, including in food and agriculture.

In reality, however, prices are not explained by market forces only; they are the result of complex mechanisms influenced by policies (for instance, rules, regulations, subsidies and taxes) designed for achieving specific objectives, as well as by many other factors (e.g. imperfect or asymmetric information, institutions, technology, culture and habits) that result from the socioeconomic and political condition prevailing in a country at a given point in time (see Section 1.12).

Moreover, it is important to remember that there are major costs involved in food production that are reflected neither in production costs nor in prices, limiting the effectiveness of prices as indicators of the real efficiency of resource use and technologies. These costs that are invisible to the market – externalities[ao] – would, if they were accounted for and internalized (expressed in monetary terms), likely push food prices up and create incentives for reorienting food systems towards greater sustainability. They include environmental costs, e.g. the cost of greenhouse gas emissions causing climate change (see Section 1.16), loss of biodiversity and, more generally, natural resources degradation (see Section 1.14), as well as the cost of health impacts (see Section 1.15) and social costs. Several attempts have been made to estimate these costs.[3,4,5]

[am] As measured by the real FAO Food Price Index (FFPI). The FFPI is a measure of the monthly change in international prices of a basket of food commodities. It consists of the average of five commodity group price indices weighted by the average export shares of each of the groups over the 2014 to 2016 period.

[an] In its core, this wisdom is based on the neoclassical marginalist theory of perfect competition, as portrayed in almost all microeconomics textbooks.[2]

[ao] An externality is any action that affects the welfare of or opportunities available to an individual or group without direct payment or compensation, and may be positive or negative. The types of externalities encountered in the agricultural sector have five features: (1) their costs are often neglected; (2) they often occur with a time lag; (3) they often damage groups whose interests are not represented; (4) the identity of the producer of the externality is not always known; and (5) they result in sub-optimal economic and policy solutions.[3]

Recently, Hendricks *et al.* (2021),[6] in the Scientific Group of the United Nations Food Systems Summit, found that "food is roughly a third cheaper than it would be if these externalities were included in market pricing".

This section analyses trends in prices at three levels of food value chains: 1) global bulk commodity trade; 2) production; and 3) consumption.

1.8.1 Recent trends – global food prices

The conventional wisdom regarding the evolution of commodity prices is that they follow a long-term annual decline of around 1 percent in real terms, as compared to the prices of manufactured goods (Prebisch-Singer hypothesis).[ap] This secular trend has been explained by the low price and income elasticities of primary commodities, and by continuous technological development reducing demand for raw materials.[8] As stated in a document published by the United Nations Conference on Trade and Development (UNCTAD) and FAO:

> "Although there have been many attempts to test this hypothesis through econometric analyses, the significant variability in commodity prices makes it difficult to distinguish long-run from short-run behaviour. Ultimately, despite these mixed results, the hypothesis is generally accepted in many policy circles, and has influenced policymaking" (UNCTAD and FAO, 2017, p. 17).[8]

Figure 1.41 presents the long-term trend of global food prices as measured by FAO's Food Price Index, which is the result of the combination of prices of a basket of food commodities comprising cereals, vegetable oils, dairy products, meat and sugar, recorded at the stage of bulk food commodities being trade internationally.9 It illustrates that the real price index, which is the nominal price index deflated with the World Bank manufactures unit value index (MUV) evidently increases since the turn of the century.

Between 1961 and 1987, global food prices decreased progressively by around one-third, apart from a price hike observed during 1972–1976, which corresponds to the first oil shock. This period was followed by relative stability until the year 2000. Then, between the turn of the century and 2022, the real food price index almost doubled. This latter phase comprises the two successive 2008 and 2012 food price spikes and, another since 2020, linked to strong demand, weather uncertainties, macroeconomic conditions, COVID-19-related supply disruptions and recent and emerging conflicts.[10, 11]

The long-term (60 years) linear trend is still slightly declining but the second-degree polynomial trend that captures the price increase after the late 1990s, provides a much better fit (greater R^2) than the declining linear trend (see the note of Figure 1.41).

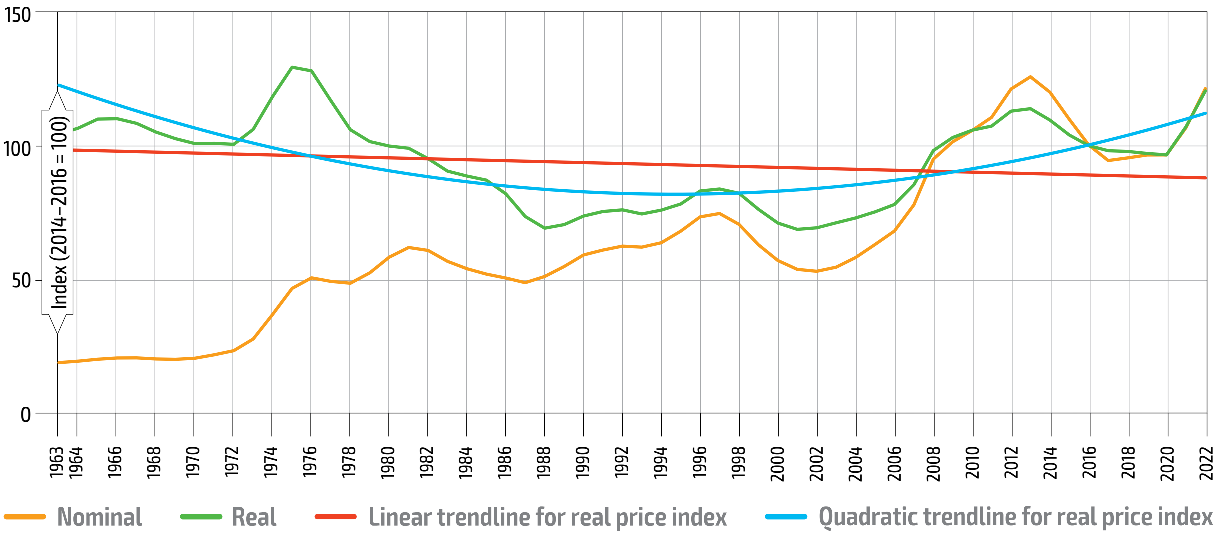
Figure 1.42 presents the monthly evolution of food price index, along with the five price indices corresponding to the groups of food commodities considered over the period from 1992 to 2022.

As can be seen from the graphs, while the price index of meat has been relatively stable over the period, growing only slowly after 2003, increase has been continuous for dairy prices, although in a very erratic way, with record peaks occurring late 2007 and early 2014.

In the case of cereals prices, the general trend has been upward (see the upward trend line in Figure 1.42). However, after the spikes of the first half of 2008 and 2011, prices receded and remained higher than before the crises, but soared again in 2020, 2021 and 2022. The prices of oils followed a similar pattern, although with greater degrees of variation and a historical peak in March 2022.

[ap] The Prebisch-Singer hypothesis applied to agriculture rests on the assumption that on the supply side, agriculture would not face diminishing returns to scarce resources, thanks either to abundant (virtually unconstrained) resources or to technological changes that would allow increasing the productivity of resources (or both), thus reducing marginal production costs. On the demand side, a relatively income-inelastic food demand in a context of income growth (Engel's Law) would entail a less than proportional expansion of food demand compared to manufactured goods. However, this hypothesis raised several controversies regarding, for instance, the non-food use of agricultural commodities that would weaken the Engel's Law argument, other forms of agricultural output diversification or the increasing resource degradation that boosts resource scarcity.[7]

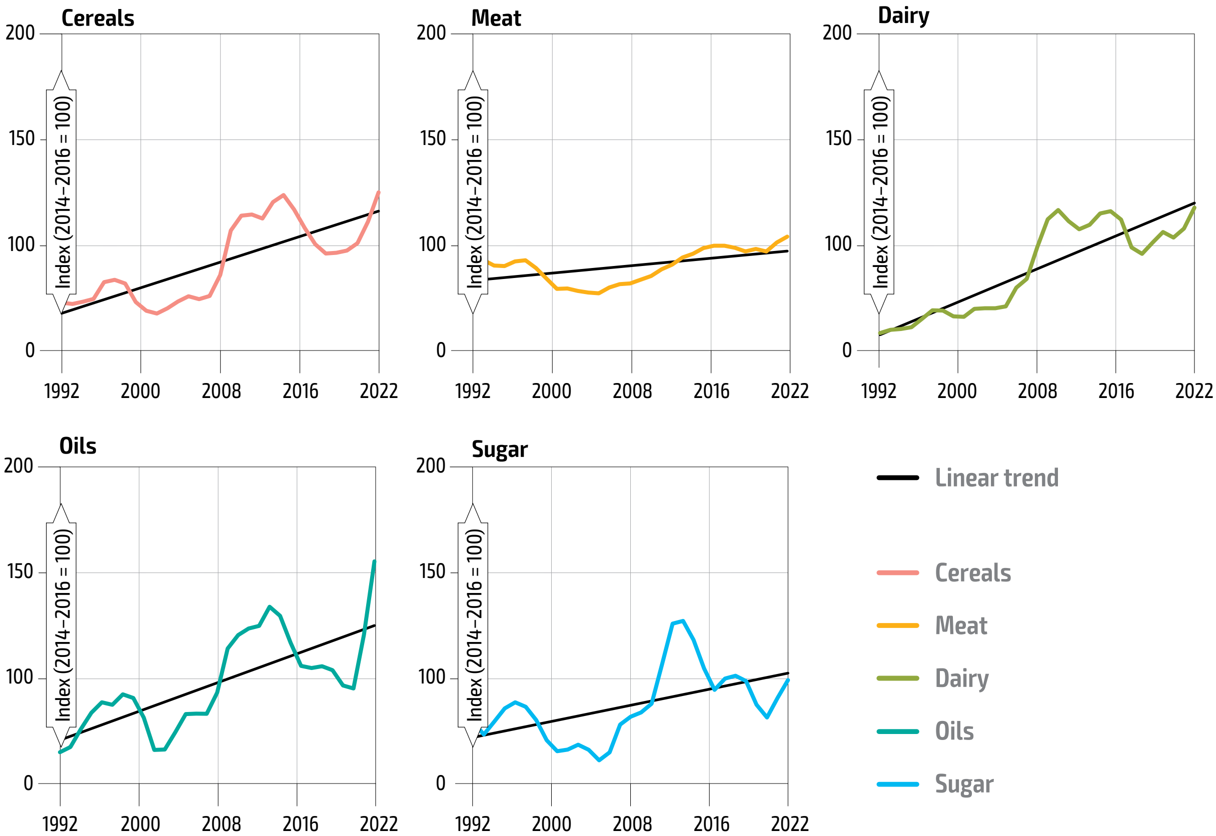
Figure 1.41 FAO nominal and real food price indices (1963–2022)



Notes: The FAO nominal food price index is calculated as the average of the price indices for five commodity groups weighted with the average export shares of each of the groups over 2014–2016. The FAO real food price index is calculated by deflating the nominal price index with the World Bank manufactures unit value index (MUV). Real price index, linear trend equation y = 441-0.174x (R^2 = 0.04); real price index, second order polynomial y = 1.58 * 10^5 - 158x + $0.0397x^2$ (R^2 = 0.49). Data for each year are calculated using a three-year right-aligned moving average.

Source: Authors' elaboration based on FAO. 2022. World Food Situation | FAO Food Price Index. In: *FAO*. Rome. Cited 18 May 2022. www.fao.org/worldfoodsituation/foodpricesindex/en

Figure 1.42 FAO real price indices for meat, dairy, cereals, oils and sugar (1992–2022)



Notes: The plots illustrate the mean of the monthly real price indices over each year. Data for each year are plotted using a three-year right-aligned moving average. Original data are provided at monthly level and aggregated with a mean over each year. The regional aggregation is then computed as average across countries in each region weighted by the gross production value.

Source: Authors' elaboration based on FAO. 2022. World Food Situation | FAO Food Price Index. In: *FAO*. Rome. Cited 16 May 2022. www.fao.org/worldfoodsituation/foodpricesindex/en

Several factors influence food prices. They include the availability of food (itself affected by technology, investment, weather conditions and stock levels), the way these products are used (for direct human consumption, to feed animals, or to make ethanol or diesel) and the manner in which food value chains and food markets are organized. In some cases, price movements may have been amplified by financial speculation, which seems to play a growing role in food commodity markets. This idea is supported by the fact that recent research found that co-dependency in price changes across commodities increased considerably after the 2008 financial crisis.[12]

As detailed here, the price crisis of 2008 illustrates how some of these factors, acting simultaneously caused a surge in food prices:

- The crisis followed a period of low investment in agriculture, an even decapitalization in high-income countries (HICs)[13] and two years (2005 and 2006) during which cereal production had declined, reducing the quantities in stock available to be mobilized to meet demand.[14]
- Higher oil prices and agrofuel support policies implemented by some countries provided incentives to use part of the so-called mixed agricultural commodities that can be either serve as food, feed or for making fuel, to manufacture more agrofuel, thus creating additional demand for agricultural commodities.[1,13,14]
- The reduction of poverty observed after the year 2000 (see Section 1.7) contributed to amplify the price rise by attenuating the downward adjustment of food demand. This occurred because, in a situation of higher food prices, poor consumers tend to cut substantially their consumption, while richer consumers are generally able to maintain their level of consumption by favouring food over other ways of spending their money.[13] As the proportion of poor had decreased, the depressing effect of higher prices on demand was lower, and it therefore did not drop so much but kept a strong pressure on prices.
- An analysis of diets during recent decades reveals a tremendous increase in consumption of animal products: between 1990 and 2018, meat consumption increased by almost 30 percent, a trend that had already impacted demand for agricultural commodities by 2007/08. Because of the low "feed-to-food" conversion efficiency, greater consumption of animal products implied an accelerated demand for feed (see Section 1.13), adding more pressure on food prices.
- Interestingly, markets are such that when the world prices rise, they are relatively well transmitted to national level, and when they decrease, the movement is only partially passed on, particularly in low- and middle-income countries (LMICs).[13,15] A similar asymmetry is observed between oil prices and food prices in the long-run, as food prices increase when oil prices rise, but do not fall back to their initial level when oil prices plummet.[16]

Moreover, climate change has proven to have a negative effect on yields and food supply, thus likely pushing up food prices and their variability,[17,18,19] and this might be amplified in the future as climate change accelerates (see Section 1.16), as natural resources degrade (see Section 1.14) and as risk and uncertainty increase (see Section 1.6).

From a structural perspective, the organization of the global food commodities market is dominated by a few, large multinational companies. They are the four historical so-called ABCDs[aq] who have long controlled the world grain trade,[22,23] and are increasingly operating at almost all stages of the value chain, from farm level up to food processing, with involvement in produce transport, storage and finance, in addition to international trade and in the procurement of agricultural inputs to contracted farmers. These companies also engage in speculation, rent-seeking and hedging in agricultural commodity markets.[24,25] Recently, these four majors have been facing new competitors, many originating from Asia,[ar] and this has strongly impacted their business.[20] Large manoeuvres are

[aq] Archer Daniels Midland (United States of America - annual revenue of USD 64.4 billion in 2020), Bunge (United States of America - annual revenue of United States of America 41.4 in 2020), Cargill (United States of America - sales and other revenues of USD 114.6 billion in 2020) and Louis Dreyfus Commodities (France - sales of USD 33.6 billion in 2020) (Macrotrends,[20] Craft[21] and corporate websites).

[ar] Wilmar (Singapore - revenues USD 50.53 billion in 2020), Olam (USD 35.8 billion in 2020) and COFCO International (USD 33 billion in 2020) (corporate websites).

frequent in the sector, with mergers and acquisitions changing the scene continuously.[24] Moreover, these large companies persist in diversifying their activities (see Section 1.12).[26]

These mega-firms are located at a strategic point in the global food system, between hundreds of millions of farmers, upstream, and billions of consumers, downstream of value chains. Their very existence, power and vertical control over value chains contribute to reducing market competition as they also strongly influence domestic markets of major food-producing countries. It is argued, in FAO's *The state of agricultural commodity markets 2020*,[27] that:

> "Traditionally, market concentration in value chains has been linked to collusive behaviour and market power. This increases prices for consumers (due to oligopoly rents) and lowers it for farmers (due to oligopsony rents), reducing welfare for both, and transferring gains to the large food processing companies and food retailers' although evidence of market power abuse remains scarce, also due to the difficulty and complexity to identify market power" (FAO, 2020, p. 62).[27]

However, where companies are able to set purchasing prices,[24] and thus increase their profits, the risk of creating larger wedges between farm gate prices and consumer prices increases.

1.8.2 Recent trends – producer prices

Producer prices, heavily affected by policies, have been promoting unsustainable agricultural practices globally and penalized producers in low-income countries (LICs). Figure 1.43 depicts the evolution of prices, expressed in constant USD 2015, paid to farmers for four major groups of agricultural products in six countries between 1993 and 2019.

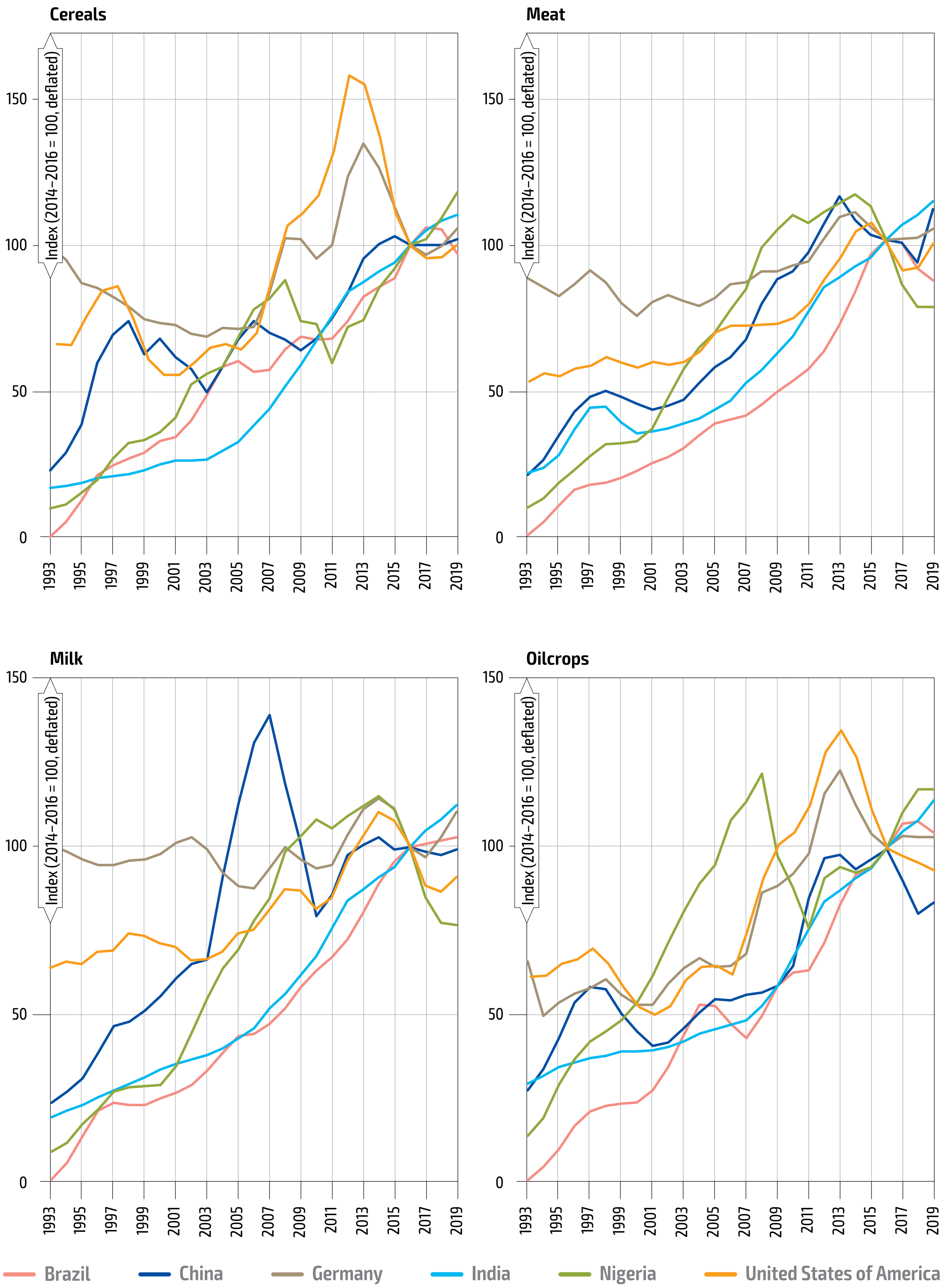
A general visual inspection of the different panels shows clear generalized upward trends for producer prices in the period considered. However, the diversity of shapes of the individual curves illustrates the variety of country-specific circumstances prevailing behind national boundaries in terms of the level of production achieved every year, trade policy and incentives provided to farmers in each country.

The importance of these incentives is critical: more than half of the huge amount of support given to farmers worldwide (almost USD 540 billion a year, or 15 percent of total agricultural production value, that would reach USD 1 800 billion by 2030, if past trends were to continue) is used for creating price incentives in a way that is unequal and harmful for the environment and human health. These incentives consist mainly of border measures (tariffs, quotas, export bans or subsidies) and price regulations (price fixation and market interventions). The remaining part of this support is predominantly made of fiscal subsidies to farmers (on outputs, inputs or factors of production), mostly linked to specific products, leaving approximately 20 percent only for funding general services or public goods for the agriculture sector.[28]

These incentives have been particularly significant in HICs (for example, in 2005, they represented more than 40 percent of total value of agricultural production in the European Union) and have been gaining importance in some middle-income countries (e.g. China, Indonesia and Türkiye) (Box 1.23). They are profoundly affecting choices made by farmers regarding what they should produce, with which technologies and inputs, by changing or complementing signals from prices, and have been putting peasants in low-income countries (LICs) at a disadvantage. The most supported goods include sugar, rice, meat and cotton, while the most penalized comprise bananas, sorghum, tea and cocoa beans.28

The subsidies provided in this way and the border measures adopted have been used to suppress food prices for consumers so as to be able to keep salaries low (see Section 1.2), but they have not proven sufficient for reducing the poverty prevailing among those earning their living in food systems (see Section 1.7). They have also been instrumental in avoiding political unrest in urban areas that, historically, has tended to occur when food prices rose, because of the importance of food in the budgets of poorer groups of the population.

Figure 1.43 Producer price indices for selected commodity groups in selected countries (1993–2019)



Notes: Data for each year are calculated using a three-year right-aligned moving average. The nominal producer price index is deflated with the GDP deflator (constant USD of 2015) available in the FAOSTAT database.

Sources: Authors' elaboration. Prices based on FAO. 2022. Producer Prices. In: *FAOSTAT*. Rome. Cited 4 June 2022. www.fao.org/faostat/en/#data/PP; deflators based on FAO. 2022. Deflators. In: *FAOSTAT*. Rome. Cited 4 June 2022. www.fao.org/faostat/en/#data/PD

Box 1.23 Support for agricultural producers across different country income groups

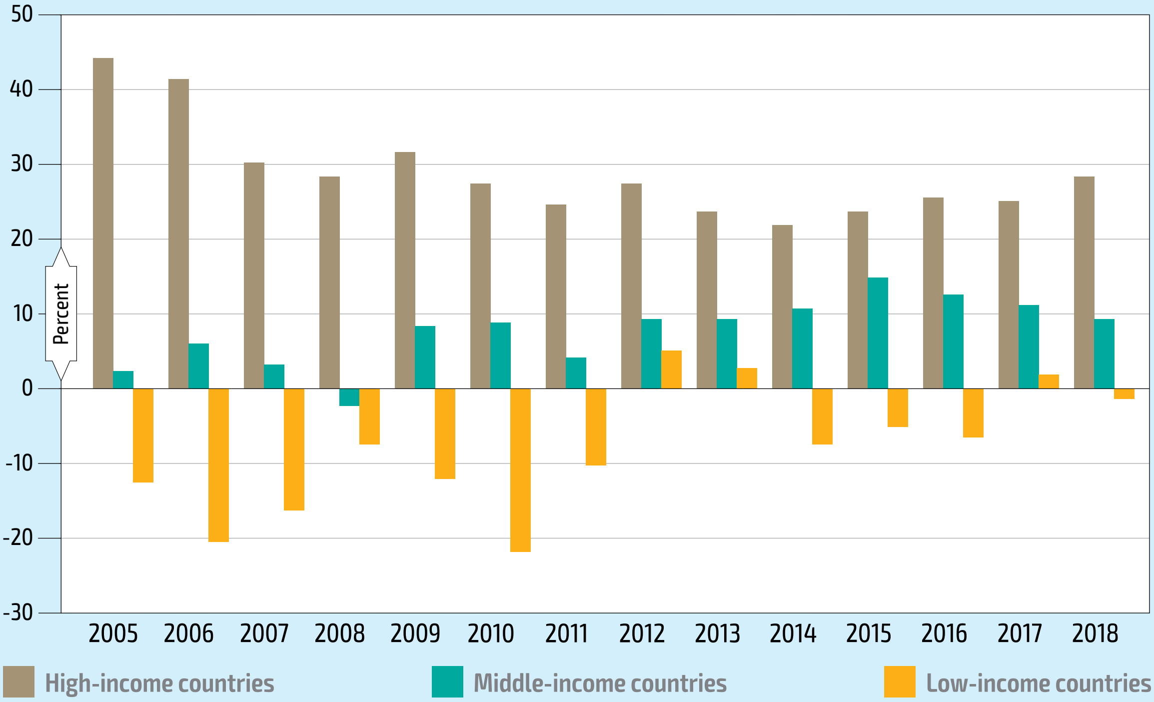
Support for agricultural producers varies significantly across country income groups. For example, food-importing countries often give stronger price incentives, especially for food staples, with the aim of shielding their weak domestic farming sector from international competition. Exporting countries tend to favour fiscal subsidies rather than price incentives. High- and middle-income countries, with a vibrant agriculture sector, have more scope for offering fiscal support compared to LICs, where resources are very scarce or are drained by other priority areas, such as national security or weather-related emergencies.

HICs provide considerable support to their agriculture sector. However, agricultural producer support, expressed as a share of the total value of production, has shown a downward trend in recent times, driven by attempts to repurpose support towards less environmentally and socially harmful policies (e.g. funding general sector services), and also because of the decreasing weight of agriculture in the overall economy of these countries. In 2018, support was provided predominantly through price incentives, followed by subsidies based on production factors (e.g. land) and input subsidies.

In **middle-income countries**, the average rate of assistance for agriculture rose since 2005, reaching a maximum of 14 percent of agricultural production value in 2015. However, the picture within these countries is heterogeneous, with countries adopting very different support profiles. In 2016–2018, support was mainly provided through price incentives, followed by input subsidies and subsidies based on production factors. In the case of India, subsidies on inputs did not come close to compensating for suppressed prices in 2018.

LICs, mostly found in SSA, are actually penalizing agricultural producers (with the exception of years 2012 and 2013). Their governments tend to limit producer prices, as a large share of their population is poor, and the affordability of food is a key concern. This policy results in a transfer of resources away from producers to consumers, who benefit from lower food prices. Certain governments, however, provide some input subsidies.

Figure A. Nominal rate of assistance as a percentage of production value by income level (2005–2018)

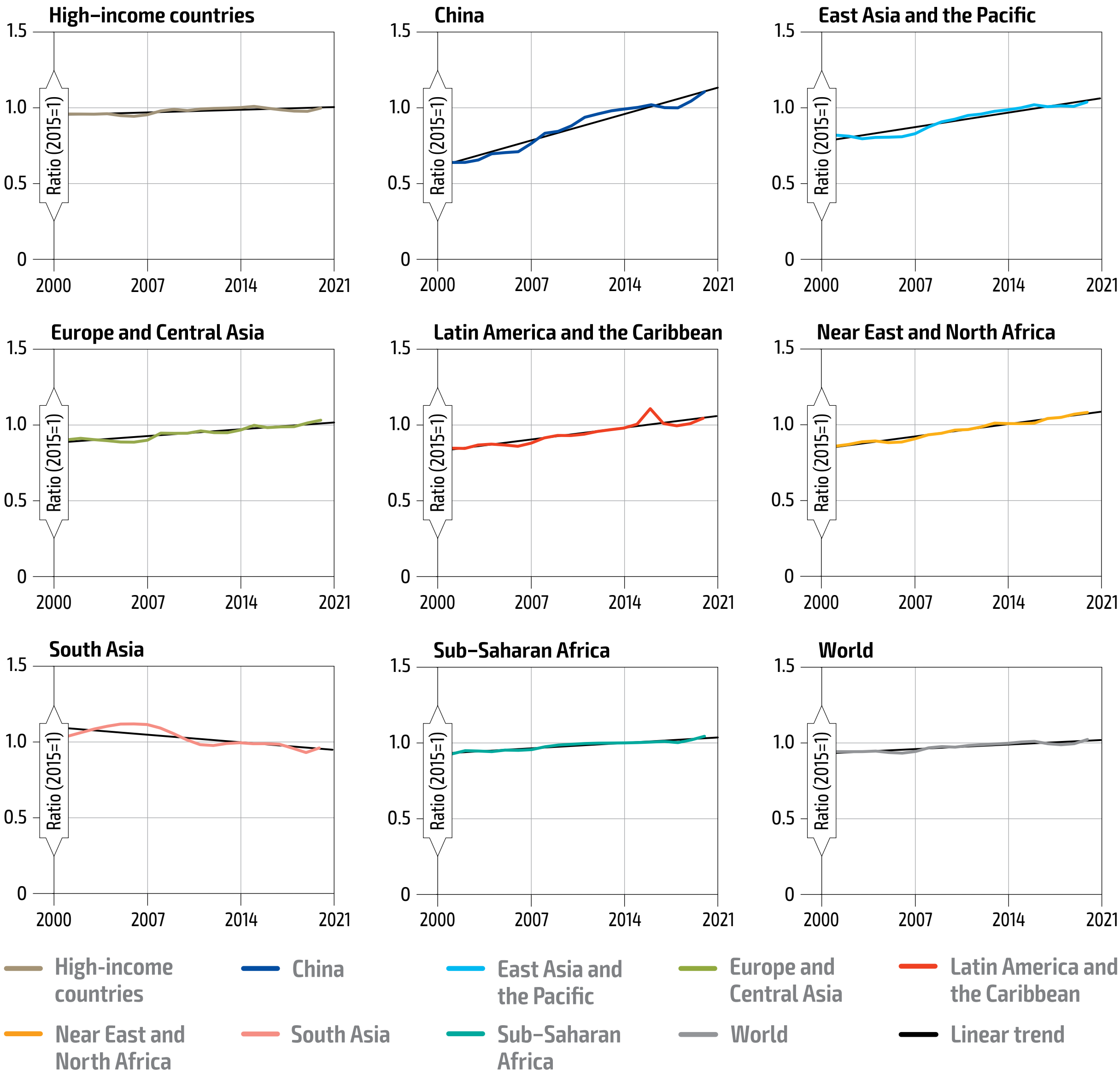


Source: FAO, UNDP & UNEP. 2021. *A multi-billion-dollar opportunity – Repurposing agricultural support to transform food systems.* Rome, FAO. https://doi.org/10.4060/cb6562en

1.8.3 Recent trends – consumer prices

Consumer prices of food have been increasing faster than the general cost of living in all regions but South Asia (SAS). Figure 1.44 shows that, at world level, on average, consumer food prices have risen faster than the general price index between 2000 and 2020. In China, the difference between the two is even higher as for the ratio of the two price indices shifted from close to 60 in 2000 to close to 110 in 2020, thus signalling that food prices almost doubled compared to all consumer goods. East Asia and the Pacific (EAP) follow a similar, although milder, trend. In contrast, food prices have decreased in SAS relatively to the general cost of living (mainly because of the evolution observed in India). HICs are where food prices have evolved almost at the same rate as the general consumer prices. The last two years analysed (2019 and 2020) show an acceleration of food price increase relative to the general cost of living, with significant differences among country groups.

Figure 1.44 Ratio between the consumer food price index and the general consumer price index by region (2000–2021)



Notes: Both the consumer price index for food and the general consumer price index are (2015=100). Their ratio is therefore 2015=1. The consumer price index by region is calculated as the average across the countries in each region weighted with the final consumption expenditure. Analogous calculation applies to the consumer price food index. The price index ratio for Latin America and the Caribbean does not consider Venezuela (Bolivarian Republic of) for the last years (2017–2021) because they are outliers whose reliability has to be carefully assessed.

Source: Authors' elaboration based on FAO. 2022. Consumer Price Indices. In: *FAOSTAT*. Rome. Cited 18 May 2022. www.fao.org/faostat/en/#data/CP

The variation of consumer food prices is mainly determined by the level of producer prices, costs and intensity of competition existing within the food supply chain (collection, transport, processing, storage and retail), taxes and subsidies, trade policy (openness, tariffs or subsidies) and exchange rate.

1.8.4 Future trends

In 2017, the projection by UNCTAD and FAO of future food price index envisioned an increase, for primary food, of 1.4 percent between 2010 and 2030, with marked disparities across regions. This modest projected increase, despite a growing projected demand for food resulting from population growth and higher incomes, is explained by a remarkable projected simultaneous increase of non-food commodities, manufactures and services, associated with higher incomes, and consistent with Engel's Law. The processed food price index, on the other hand, is projected to increase by 6 percent over the same period.[8, 29]

The *OECD-FAO Agricultural Outlook 2022–2031*[30] presents agricultural price projections that:

> "[…] result from the interplay of fundamental supply and demand factors under normal weather, macroeconomic and policy assumptions. Based on these fundamentals, the current price rally of agricultural commodities is projected to be temporary. While prices may remain high in the 2022/23 marketing year, they are expected to subsequently resume their long-term declining trend in real terms" (OECD and FAO, 2022, p. 19).[30]

As stated in the document, these projections assume:

> "[…] that yield growth in high-income countries will be based on better farm management practices, adoption of precision farming technology (namely optimization in the use of agricultural inputs such as fertilizer and chemicals) and improvements in cultivated varieties. [In LMICs,] yield growth is expected to come from the use of improved crop varieties, increased use of fertilizer and pesticides, as well as better farm management due to mechanization and improved agronomic skills acquired by farmers through education and extension services" (OECD and FAO, 2022, p. 47).[30]

The OECD and FAO also stress that uncertainties in the future mean that prices projections should be interpreted with caution:

> "The impacts of Russia's war against Ukraine on agricultural production in Ukraine and on agricultural trade, of climate change on agricultural productivity, of a higher incidence of animal and crop diseases and of weather variability on agricultural production, of changing consumer preferences and macroeconomic developments on demand, as well as the influence of domestic and trade policies, all heighten risks and create uncertainty" (OECD and FAO, 2022, p. 74).[30]

To deal with uncertainty, a partial stochastic analysis is conducted that simulates the potential future variability of main price determinants using past observed variability. Stochastic intervals for selected international reference prices by 2031, show, *inter alia*, a 75 percent interval of around 30 percent for vegetable oil, 20 percent for rice and 25 percent for butter, in nominal prices.[30]

Similarly, the Department of Agriculture of the United States of America forecasts virtually flat nominal farm prices for wheat, cotton and rice between 2021 and 2030, and declining prices for cattle and hogs, and stable for broilers.[31]

In contrast to these projections of relatively constant future prices, some experts see either price collapses or rises because of likely modifications in some market fundamentals.

One example is a major technological change, such as the development of precision fermentation, that, according to members of the Rethinks think tank, could lead to a significant decrease in animal protein prices (Box 1.24).

Box 1.24 An impending revolution: precision fermentation and the production of cheap protein could profoundly disrupt food markets

According to the Rethinks think tank, which analyses and forecasts the speed and scale of technology-driven disruption and its implications across society, we are at the dawn of a revolution that will shake up livestock farming.

With precision fermentation, the cost of producing protein could be 80 percent cheaper by 2030, and 90 percent cheaper by 2035. Furthermore, Tubb and Seba (2021)[32] state that future "food products [would] be higher quality and cost less than half as much to produce as the animal-derived products they replace".

Precision fermentation is a process for programming microorganisms to synthesize almost any complex organic molecule. Combined with an entirely new model of production (Food-as-Software), individual molecules engineered by scientists would be uploaded to databases that food engineers anywhere in the world could use to design products in the same way that software developers design apps.

Source: Authors' elaboration based on Tubb, C. & Seba, T. 2021. Rethinking Food and Agriculture 2020-2030: The Second Domestication of Plants and Animals, the Disruption of the Cow, and the Collapse of Industrial Livestock Farming. *Industrial Biotechnology*, 17(2): 57–72. https://doi.org/10.1089/ind.2021.29240.ctu

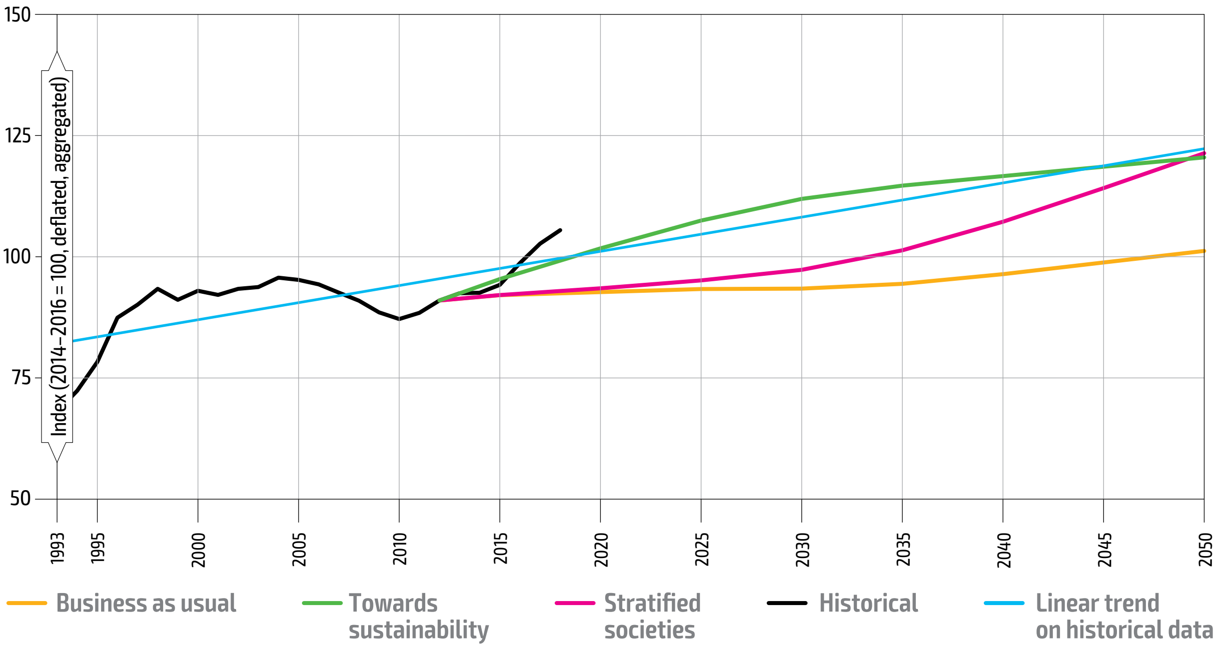
On the other side, with the growing importance of climate change on the global agenda, attempts have been made to project the possible impact of climate change on food production and prices. An IDS/GROW/Oxfam report, using the GLOBE model, assumes substantial reduction of production resulting in price increases for wheat, processed rice and maize of 28 percent, 31 percent and 33 percent, respectively, between 2010 and 2030, and 75 percent, 73 percent and 89 percent, each, between 2010 and 2030. These changes are largely attributed to rising land rents, land scarcity, greater competition between livestock and crop production, because of increased demand for meat, and lower agricultural factor productivity gains compared to industry. However, this study does not take into consideration possible improvements in land productivity.[33]

More recently, simulations of the impact of climate change on food security and food prices, and of climate change mitigation efforts on food prices, have envisioned varying levels of future price increases.[18, 19, 34, 35] In particular, the consequences of large-scale afforestation with the view of increasing carbon sequestration would imply considerably higher food prices.[36]

In 2018, FAO's Global Perspectives Studies team projected agricultural prices to 2050 in an environment of tightening of resources and climate change, using its Global Agriculture Perspectives System (GAPS) to simulate an interplay between adjustments in market supply and demand, along three scenarios (business as usual [BAU], towards sustainability [TSS] and stratified societies [SSS]). In the BAU scenario, prices remain fairly stable, before rising steadily between 2030 and 2050 (+13 percent), because of aggravating natural resource constraints and the effects of climate change. In the TSS scenario, prices increase rapidly from the start of the projection period as more sustainable agricultural practices are being adopted. Beyond 2030, prices evolve more slowly to reach a level 35 percent above the base year situation, as soil fertility and water quality are being restored and climate change impacts are mitigated. In the SSS scenario, prices also rise by 35 percent over the same period, as a result of more severe climate change effects on productivity, and greater production costs associated to scarcity of land and water resources (see Figure 1.45).[1] These projected prices to 2050 build upon an evident historical upward trend of producer prices (see the black line of the historical producer prices time series, expressed in constant USD of 2015 and the related linear trend line).

A very recent analysis of the impact of climate change on poverty found that food prices were the second-most influential channel leading to extreme poverty, after health. Estimates, based on the use of a model developed for the 2015 World Bank report *Shock Waves: Managing the Impacts of Climate Change on Poverty*,[37] show significantly higher food prices, particularly in SAS and Africa, with considerable cross-regional variations.[38]

Figure 1.45 Agricultural producer price index: historical (1993–2018) and projected (2012–2050)



Notes: Historical global producer price index (2014–2016=100) is plotted using a three-year right-aligned moving average. The historical global producer price index is calculated on the basis of national nominal producer prices indices for agriculture 2014–2016=100, deflated with the GDP deflator in constant USD of 2015 and averaged across countries by weighting with the gross value of agricultural production. Other aggregation methods could be applied when more detailed price-quantity data at national level are available. Projections by scenario are calculated as annual variations of projections by scenarios with respect to the base year (2012), as reported in FAO (2018).[1]

Sources: Authors' elaboration. Historical agriculture producer price index based on FAO. 2022. FAOSTAT. Rome. Cited 4 June 2022. www.fao.org/faostat; nominal agricultural producer prices based on FAO. 2022. Producer Prices. In: FAOSTAT. Rome. Cited 4 June 2022. www.fao.org/faostat/en/#data/PP; deflators based on FAO. 2022. Deflators. In: FAOSTAT. Rome. Cited 4 June 2022. www.fao.org/faostat/en/#data/PD. Projections are based on FAO. 2018. The future of food and agriculture – Alternative pathways to 2050. Rome www.fao.org/3/I8429EN/i8429en.pdf

1.8.5 Summary remarks

The review conducted in this section shows that there are clear signs that food prices are on the rise.

At the **global bulk markets level**, as illustrated by the FAO Food Price Index, the price of food has been increasing since the turn of the century. The ongoing degradation of natural resources (see Section 1.14), the impact of climate change on yields, crop suitability, pests and diseases, pollinators and other factors (see Section 1.16), climate change mitigation measures, and modifications in agriculture support policies mentioned earlier, all contribute to create uncertainty and tensions on supply that might push food prices up, if all other things remain unaltered. This movement would be amplified in the event that externalities were accounted for and internalized. Tensions could become even more critical if bioeconomy develops and a growing share of agricultural commodities is used to produce non-food goods (see Section 1.2), and if prices of energy continue to rise.

At the **farm level**, prices are strongly influenced by incentives and subsidies in HICs and middle-income countries, of which a substantial portion aims at keeping consumer prices low and giving a competitive advantage to agricultural goods produced locally. However, the recent trend, especially in high-income countries, has been to favour funding of general sector services and reduce measures that are harmful for human health and the environment.[28] This trend also affects protected or subsidized products and technologies emitting large amounts of GHG, creating negative externalities, and the cost of which are reflected neither in production costs nor in prices. This cost, if it were accounted for, would push food prices up and reorient food systems towards greater sustainability. Growing awareness of the consequences of climate change, loss of biodiversity and health impacts resulting from unsustainable agricultural practices, could lead to further cuts in incentives, possibly affecting adversely the supply of agricultural products and, ultimately, their price. This would appear likely unless there are ground-breaking technological innovations, perhaps funded in part by a repurposed reallocation of public resources that could alter this scenario.

At the **level of consumers**, food prices have followed a modest upward direction. The trend towards the consumption of resource-intensive foods reduces food systems efficiency (see Section 1.13), and tends to increase demand for agricultural products, adding to tensions on food prices. However, if the signs currently indicating some movement by consumers towards less resource-intensive dietary patterns with better nutritional and environmental outcomes are confirmed, and if this movement accelerates, it would considerably diminish demand and thus could modulate or even reverse food price trends.

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1.9 Innovation and science (Driver 10)

Several technologies currently applied in agrifood systems contribute to the degradation of natural resources. This is because of intensive production systems, which focus on the profitability aspects and neglect environmental ones. The latter are not reflected in the cost structure, as explained in the previous section. Harnessing science, technology and innovation will be key for making agrifood systems more efficient, inclusive, resilient and sustainable, and for achieving the Sustainable Development Goals (SDGs), or at least some of them.

Science-based transformations, including the emergence of innovative "systemic" approaches (e.g. agroecology, conservation agriculture and organic agriculture), digitalization, biotechnologies and others, raise opportunities to achieve,[as] in concert with all stakeholders, the dual aims of producing sustainably sufficient food and safeguarding the environment.

However, digitalization, biotechnologies and other innovations, while presenting an enormous transformative potential as they address all dimensions of sustainability, also carry risks and pose challenges, as highlighted in a recent report of the United Nations Secretary-General.[2] Indeed, they could be exploited in ways that reinforce and perpetuate inequalities, including market concentration, information asymmetry and exclusion of small-scale actors and already vulnerable populations, and contribute to the degradation of natural resources.

Research is ongoing in these fields on limits and potential drawbacks, to ensure that safety and acceptability aspects are adequately addressed. Among the issues being considered are the provision of gender-balanced access and proper inclusion of low-income countries (LICs) to avoid a technological divide whereby only rich nations take advantages of new solutions, as this might further exacerbate disparities in terms of productivity and market access.

Several questions arise in this context:

- How can digital technologies be integrated with, or favour, the implementation of "systemic" approaches such as agroecology, organic agriculture, agroforestry, etc.?
- To what extent are countries leading innovation processes affecting agrifood systems incentivized to spread knowledge and control over innovations?
- What plausible scenarios can be designed regarding the relationships between innovation processes and economic growth on one side, and across-country income distribution on the other?

Box 1.25 Innovation and science related terms

An **agrifood system** is a set of interlinked activities and related outputs that cover the journey of food from farm to table – including all the activities where food it is grown, fished, harvested, processed, packaged, transported, distributed, traded, bought, prepared, eaten and disposed of. It also encompasses non-food inputs, capital goods and services necessary to carry out the abovementioned activities. All the people involved, in such activities, are part of the system and key players. In the FAO Constitution, the term "agriculture" and its derivatives include fisheries, marine products, forestry and primary forestry products, as well as livestock.[3]

Innovation consists of doing something new and different, whether by solving an old problem in a new way, addressing a new problem with a proven solution, or bringing a new solution to a new problem.[4]

[as] FAO advocates for the leveraging of ecosystem services to complement external inputs. The overuse of external inputs increases the environmental footprint of food production – too much irrigation exerts more pressure on an already scarce resource just as too many pesticides and herbicides damage the environment, reduce biodiversity (which generates ecosystem services) and is prejudicial to human health. See, for instance, FAO's contributions through the "Save and Grow" paradigm and the International Panel of Experts on Sustainable Food Systems (IPES-Food, 2016)[1] report.

Box 1.25 (cont.) Innovation and science related terms

Agricultural innovation is the process whereby individuals or organizations bring new or existing products, processes or ways of organization into use for the first time in a specific context in order to increase effectiveness, competitiveness, environmental sustainability or resilience to shocks, and thereby contribute to food security and nutrition, economic development or sustainable natural resource management.[5]

In the context of agrifood systems, innovation refers to the process by which individuals, communities or organizations generate changes in the design, production or recycling of goods and services, as well as changes in the surrounding institutional environment, that are new to their context and foster transitions towards sustainable and resilient agrifood systems. Innovation also refers to the results generated by this process. Innovation includes changes in practices, norms, markets and institutional arrangements, which may foster new networks of food production, processing, distribution and consumption that may challenge the status quo.[6]

Cold chain is an uninterrupted series of activities, from the point where perishable products are produced to the point of consumption, along with associated equipment and logistics, which maintain a desired low-temperature range to preserve the quality and safety of the product throughout its shelf-life.

Science signifies the enterprise whereby humankind, acting individually or in small or large groups, makes an organized attempt, by means of the objective study of observed phenomena and its validation through sharing of findings and data and through peer review, to discover and master the chain of causalities, relations or interactions. It brings together, in a coordinated form, subsystems of knowledge by means of systematic reflection and conceptualization; and, thereby furnishes itself with the opportunity of using, to its own advantage, understanding of the processes and phenomena occurring in nature and society.[7] As stated by the Committee on Economic, Social and Cultural Rights, other systems of knowledge and ways of knowing coexist with science, including local, traditional and Indigenous Peoples' knowledge, which have an important role to play in the global scientific dialogue, which have an important role to play in the global scientific dialogue.[8]

Technology for sustainable agrifood systems can be defined as the application of science and knowledge to develop techniques to deliver a product or service that enhances the sustainability of agrifood systems.[9]

1.9.1 Innovations and agrifood systems

The need for innovations to transform dysfunctional agrifood systems. At the end of the Second World War, the world had to face an enormous challenge: feed a rapidly increasing population in countries devastated and fragmented by conflict. At that time, the food issue was seen from a production and productivity viewpoint: there was a need to produce, produce at any cost, sufficient food to satisfy a fast-growing demand, while contributing to overall economic development.

The solution found was a highly productive agricultural model that had the advantage of creating economic opportunities for other sectors, especially the chemical and construction sectors. This model rested on the intensive use of synthetic fertilizers and pesticides, manufactured by the chemical industry, and of improved seeds. It also required the building of infrastructure (roads, irrigation systems, silos, etc.) and the development of trade. Supported by huge public funding, it spread rapidly to replace in many parts of the world, within a few decades, traditional approaches to farming that had been developed by farmers over millennia.[10,11]

Today, there is growing evidence that this model generated a series of consequences that are now compromising the future of our agrifood systems. Current agrifood systems are responsible for 34 percent of total anthropogenic greenhouse gas (GHG) emissions,[12] and biodiversity is under severe threat.[13,14,15] Agricultural land is degrading and being eroded by cultivation practices,[16] while ore than 70 percent of freshwater withdrawals worldwide are for agriculture, which is also the primary source of nutrient runoff.[17] Moreover, 14 percent of the food is lost post-harvest up to (but not including) the retail level,[18] while 17 percent of total global food produced is wasted.[19]

From 1961 to 2018, agricultural land increased only by around 7 percent, while the world's cereal output rose nearly 3.3-fold and meat production 4.8-fold, essentially through intensification resulting in a 6-fold growth in fertilizer application over the period, and an almost doubling of the use of pesticides between 1990 and 2018.[20] In 2010, fertilizer-related emissions were estimated at 1.289 metric gigatonnes of CO_2, of which 94 percent is linked to nitrogen use. Expanding pesticide application has had detrimental effects on human and animal health, and contributed to the contamination of water resources and soils.[21] Today, 2.5 billion hectares of global agricultural land (i.e. 64 percent) is at risk of pesticide pollution by more than one active ingredient, while 31 percent is at high risk. Thirty-four percent of these high-risk areas are in high-biodiversity regions.[22]

It is therefore evident that many agrifood systems are dysfunctional and not fit-for-purpose. Inefficiencies in food and land-use systems are estimated to generate significant hidden costs of USD 12 trillion, outweighing a market value of USD 10 trillion.[23] To achieve the SDGs, agrifood systems must undergo a major transformation. This demands an increase in agricultural productivity and a simultaneous improvement in the economic, environmental and social dimensions of sustainability. In turn, this would entail recognizing that co-benefits, synergies and trade-offs exist among the three dimensions of sustainability. Science, technology and innovation have key roles to play in this change. Innovations needed are technological as well as social, policy, financial and institutional. They will have to be supported by a range of social, political and institutional factors and require well-functioning agricultural innovation systems, efficient research systems, extension and advisory services, along with appropriate mechanisms for bridging government, businesses, agricultural producers and consumers. In this endeavour, consideration of traditional knowledge and the transformative potential of Indigenous food and knowledge systems may help (see Box 1.26).

Box 1.26 Innovation potential of Indigenous Peoples' food and knowledge systems

Indigenous Peoples' territories are estimated to cover at least 28 percent of earth's terrestrial area and are home to 80 percent of remaining biodiversity of the world,[97] 36 percent of world's intact forests[98] and at least 24 percent of carbon terrestrial storage.[99] Indigenous Peoples' territories are also a major repository of in situ plant genetic material and agrobiodiversity critical for global agriculture and food systems.[100] The successful ecological stewardship of Indigenous Peoples' territories is directly linked to indigenous worldviews, knowledges, governance and food systems based in reciprocity and care.[101,102]

For centuries, through their territorial management systems, indigenous communities have nourished themselves. As recently confirmed by eight case studies, Indigenous Peoples' food systems: i) preserve and enrich their ecosystems; ii) are resilient and adaptive; iii) can broaden the existing food base with nutritious foods; and iv) are interdependent with language, traditional knowledge, governance and cultural heritage.[103] Indigenous Peoples' food and knowledge systems are multifunctional and holistic, generating food, medicines, shelter and energy, and supporting culture and social and spiritual manifestations. This multifunctionality is rooted in the understanding and engagement of food systems in their entirety, paying special attention to the relationships between the different elements of the ecosystem.

There is increased recognition at the global level of the role that Indigenous Peoples play in addressing the climate and ecological crises. Discussions at the recent climate[104,105] and biodiversity Conference of the Parties (COPs),[106] the Convention on Desertification as well as the United Nations Food Systems Summit, all recognize that Indigenous Peoples' territories, governance, knowledge and food systems contribute to climate regulation,[107] biodiversity conservation[108] and ecological restoration109 and provide hints for a sustainable future of all

Box 1.26 (cont.) Innovation potential of Indigenous Peoples' food and knowledge systems

agrifood systems.[100] For these reasons, at the 2021 United Nations Climate Change Conference (COP 26), the international community pledged USD 1.7 billion for Indigenous Peoples to protect and restore forests.[110] The potential of Indigenous Peoples' food systems for effective ecological restoration[111, 101] and biodiversity conservation is also confirmed by evidence from across the world.[112]

Indigenous Peoples' biocentric restoration: The core principles of Indigenous Peoples' food systems refer to a set of spiritual beliefs and credences regarding the origin of the universe (cosmogony) and customs, whereby humans are simply one component of the ecosystem, deserving respect alongside other (non-human) living entities.[100] Indigenous Peoples' food provision relies on both food generation (collecting food items naturally grown), and food production (food items produced with human intervention), mixed in variable proportions depending on specific communities, often combined with mobile livelihoods. The respect for all forms of life (biocentrism) informs practices of food generation, food production and natural resource management. Biocentric values radically differ from anthropocentric values. In anthropocentric food production practices prevailing worldwide, there is a conceptual hiatus between nature and humans, with human needs put first. The focus is on increasing food productivity and production; thus, performance indicators are largely based on quantitative metrics (tonnage, yields and other input-output ratios). Other aspects, such as impacts on biodiversity, climate, soil, water quality, and to some extent nutrition, have received so far less attention. Instead of biocentrism, anthropocentrism is more commonly associated with food-producing societies and linear value chains that seek specialization of tasks. In this sense, Indigenous Peoples' food and knowledge systems cannot be characterised according to dominant conceptualisations of agrifood systems that are presented as linear value chains.

To draw lessons from Indigenous Peoples' food and knowledge systems, FAO, in coordination with Indigenous Peoples' organizations, has been working on the Indigenous Peoples' Biocentric Restoration initiative. This initiative seeks models of inclusive restoration and conservation to conserve biodiversity and reduce GHG emissions. At the same time, the initiative promotes the preservation of Indigenous Peoples' traditional knowledge, sociocultural systems, beliefs regarding the universe (cosmogony) and governance systems.*

The role of Indigenous Peoples in combining traditional knowledge and innovation: The knowledge systems of Indigenous Peoples, mainly oral, are based on observation, know-how, local appropriate technologies, techniques, creation stories and ceremonial practices. Indigenous Peoples have demonstrated their capacity to innovate through time, to adapt to the ever-changing environmental conditions in their territories. Thus, innovation is not exogenous to Indigenous Peoples' traditional knowledge systems. Indigenous youth in particular, are combining their traditional values with current technologies to drive the urgent changes required by current generations to avoid a global race to the bottom implied by the progressive overexploitation of natural resources. For Indigenous Peoples this also means prioritizing intergenerational transfer of knowledge to preserve culture, languages and systems of knowledge before the oral traditions carried by the elders disappear. [100, 113]

Moreover, Indigenous Peoples' knowledge systems are associated with a bundle of rights, in particular the right to self-determined economic, social and cultural development as per the United Nations Declaration on the Rights of Indigenous Peoples,[114] and the right to FPIC[115] as per the ILO Convention 169.[116] The strict respect for these human rights; the acknowledgement of their intellectual property rights; the recognition of the collective, intergenerational, time-tested and experiential nature of their knowledge and practices; are all preconditions for the participation of Indigenous Peoples in co-creation processes related to the future of agrifood systems.

Box 1.26 (cont.) Innovation potential of Indigenous Peoples' food and knowledge systems

Indigenous youth navigate two worlds and face unique challenges. Especially due to current global trends of scarcity and degradation of natural resources, there are unprecedented rates of the loss of traditional knowledge as well as youth migration to urban centres. Indigenous women are holders of unique knowledge within their communities about seeds, edibles and medicinal plants, among others. The future of Indigenous Peoples' food and knowledge systems depends largely on the ability of youth to ensure the continuity of their ancestral practices, the preservation of their territories and the transmission of their language and knowledge systems, as well as to integrate such traditional knowledge with other forms of knowledge. Initiatives in this direction, such as the use of mobile applications, drones, Global Positioning System (GPS) and remote sensing technologies, in combination with indigenous knowledge, exist and should be upscaled.

Enhancing the potential of Indigenous Peoples' food systems through labelling and certification: Promoting, while preserving, specific high-quality products originating from Indigenous Peoples' food systems through labelling and certification schemes, and harnessing the opportunities of institutional and intercultural innovations, can help achieve many SDGs, especially considering the current process of decline and degradation of natural resources. SDG 1 and SDG 2 can be addressed by increasing incomes from indigenous foods. In many cases, women have a leading role in developing quality standards for indigenous food products, aligning with SDG 5. By being inherently tailored to Indigenous Peoples' values and aiming to overcome bureaucratic challenges faced in the current economic system, labelling and certification systems also have the potential to address SDG 10 for reducing inequalities. Further, labelling and certification systems allow consumers to make informed choices and can increase the preference and markets for sustainable products, in turn supporting SDG 12 for sustainable production and consumption. Finally, incorporating a basket of products and valuing Indigenous Peoples' territories through labelling and certification schemes can support SDG 15, for halting biodiversity loss and managing forests sustainably.

A recent publication by FAO, Alliance of Bioversity and the International Center for Tropical Agriculture (CIAT)117 on labelling and certification schemes for Indigenous Peoples' foods identifies eleven examples of innovative schemes implemented by Indigenous Peoples and practitioners in Africa, Asia, Latin America and the Caribbean and Oceania. They include territorial labels, geographic indications, participatory guarantee schemes, and one case study of community-supported agriculture. The research identified important factors leading to the success of different schemes, such as (i) leadership and ownership of Indigenous Peoples in the initiative; (ii) adequate support by external stakeholders, including public and private sector and universities; (iii) raising consumer awareness and education on indigenous food products via fairs, festivals and other platforms; and (iv) designing value chains and policies in a way that harmonizes local, domestic and international trade.

Despite the wealth of Indigenous Peoples' food and knowledge systems and their potential contribution to the transformation of agrifood systems everywhere, a number of drivers related to globalization affect the present and future of these systems. In particular, the lack of secure access to ancestral territories; encroachment into their territories; deforestation for agricultural expansion, dam and mining projects and other infrastructure development; illegal hunting and fishing as well as forced displacement seriously compromise the viability of these ancestral knowledge systems.103 Other global trends, related to trade, markets, monetization, regulations and mass media, are modifying Indigenous Peoples' food systems by introducing new opportunities, new products, new technologies and new livelihoods that are modifying the priorities, preferences and tastes of the members of the communities.

This include the cultivation of unsustainable high-value crops, unsustainable forestry and fishing practices, and over-exploitation of animal and plant species. For these reasons, in 2018,

Box 1.26 (cont.) Innovation potential of Indigenous Peoples' food and knowledge systems

the United Nations Permanent Forum on Indigenous Issues (UNPFII) recognized the urgent need to develop a universally recognized set of standards for engaging in conservation efforts on the lands and waters of Indigenous Peoples.

* The Indigenous Peoples' Biocentric Restoration approach and related projects undertaken so far are illustrated in the dedicated FAO web page: www.fao.org/indigenous-peoples/our-pillars/climate-change-and-traditional-knowledge/indigenous-peoples-biocentric-restoration/en

1.9.2 Recent trends

A fast-advancing field with immense promises and significant risks and controversies. In 2018, global investment in research and development (R&D) (including, but not limited to, the agricultural sector) represented 1.7 percent of gross domestic product (GDP), of which 80 percent is accounted for by ten countries.[24, at]

An analysis of output and impact of STEM[au] research over four decades provides, as Mishra and Wang (2021)[25] state, "clear indications of convergence among the high- and upper-middle-income countries across the STEM fields, but a widening gap is developing that segregates the lower-middle- and low-income regions from the higher-income regions" (Figure 1.46).

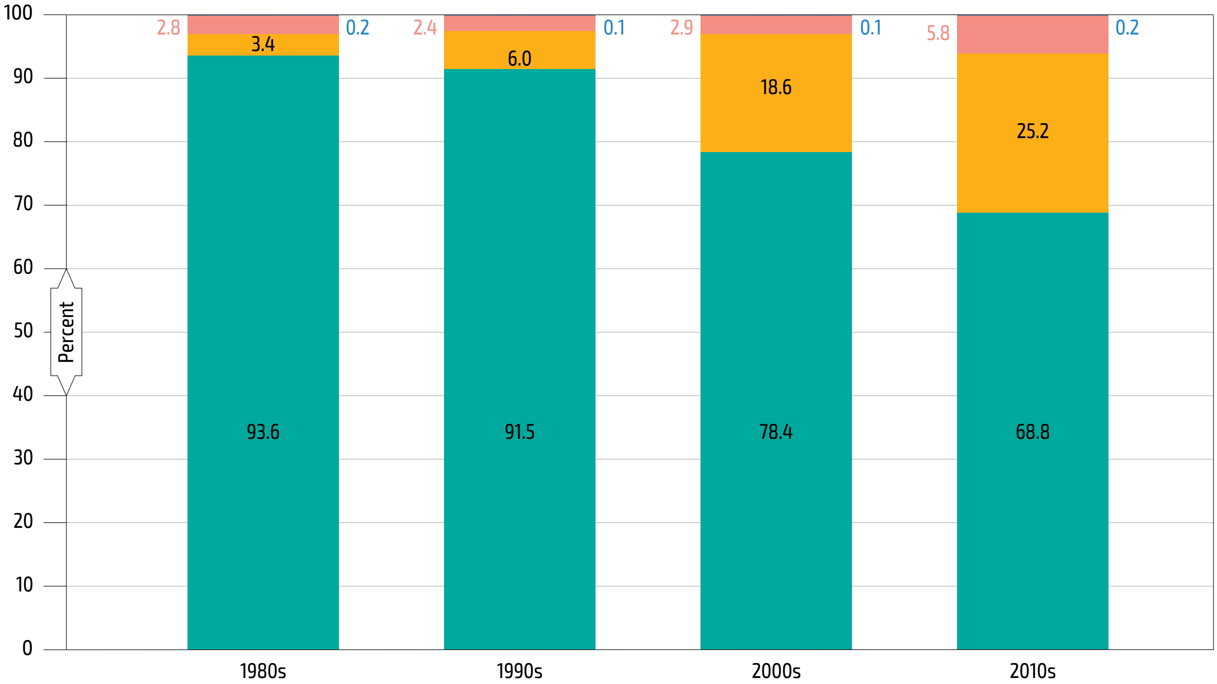
Although data on global public expenditure in agricultural R&D are limited and often outdated, some studies allow to infer that it is uneven across regions and, more specifically highly skewed by income level. However, it is claimed that in the last decades this expenditure grew faster in low- and middle-income countries (LMICs) than in high-income countries (HICs). Table 1.15 reports both public and private expenditure in 1981 and 2011, expressed in purchasing power parity (PPP) constant USD of 2011, both for LMICs and HICs. Once China is singled out, it appears that the share of expenditure of LMICs in total expenditure dropped from 38.9 percent in 1981 to 38.2 percent in 2011. Furthermore, the intensity of expenditure, for example, per unit of agricultural value added in HICs was in 2011 more than six times that of LMICs, not to mention the incommensurable difference between the expenditure per worker between HICs and LMICs in 2011 (more than 1 311 and 28 PPP constant USD of 2011, respectively). As there is compelling evidence that countries investing more in agricultural R&D achieve higher productivity growth, these figures may signal that the progress in productivity growth in LMICs faces serious hurdles.[26]

[at] United States of America (2.8 percent of GDP), China (2.1 percent), Japan (3.3 percent), Germany (3.3 percent), Republic of Korea (4.5 percent), India (0.7 percent), France (2.2 percent), United Kingdom of Great Britain and Northern Ireland (1.7 percent), Brazil (1.2 percent) and Russian Federation (1 percent). For sub-Saharan Africa (SSA), it was less than 0.4 percent.

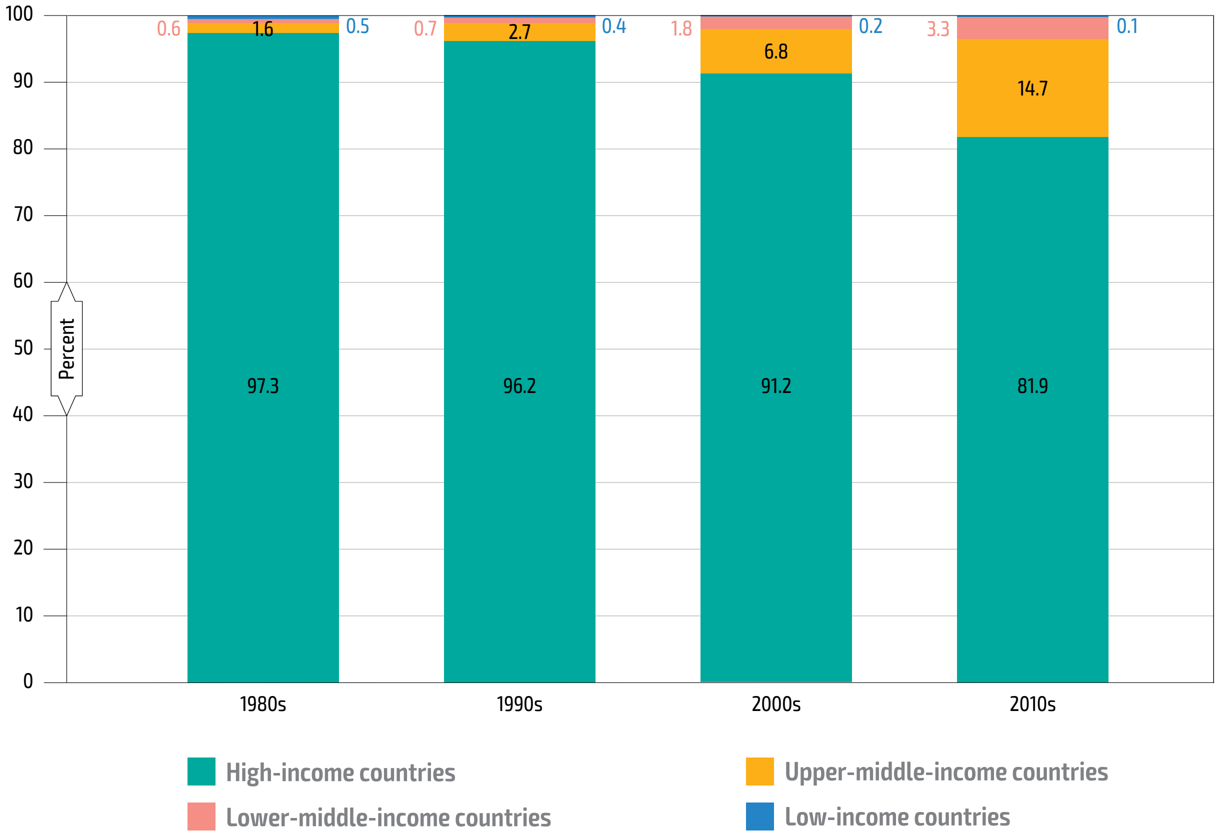
[au] STEM: science, technology, engineering and mathematics.

Figure 1.46 Publications and citations of research on science, technology engineering and mathematics (STEM) by income group and decade (1980s to 2010s)

a) Share of publications on STEM



b) Share of research citations on STEM



Note: STEM refers to science, technology, engineering and mathematics.

Source: Mishra, S. & Wang, K. 2021. Convergence and Inequality in Research Globalization. *Computer Science – Computers and Society.* https://doi.org/10.48550/arXiv.2103.02052

Table 1.15 Origin of public and private expenditure in agricultural research and development by region (1981 and 2011)

ORIGIN OF EXPENDITURE	PERIODS (million PPP constant USD of 2011)		AGRICULTURAL RESEARCH INTENSITY			
			R&D/agricultural value added		Cropland	Agricultural labour
			(percent)	(trend)	(USD/ha)	(USD per worker)
	1981	2011	2011		2011	2011
LMICs' public expenditure in agricultural R&D	8 932	23 939	0.51	↑	21.84	27.58
Out of which China	970	7 768	0.73	↑	46.94	39.56
HICs' public expenditure in agricultural R&D	11 522	18 426	3.25	↓	52.22	1 311.15
Global public expenditure in agricultural R&D	20 454	42 365	0.81	↓	26.83	46.49
Private expenditure in agricultural R&D	6 374	12 939	0.25	↑	8.19	14.20
Consultative Group for International Agricultural Research expenditure	158	707	0.01	↑	0.45	0.78
Total global expenditure in agricultural R&D	26 986	56 011	1.07	↑	36.47	61.47
Share of public expenditure in R&D in LMICs net of China in global public expenditure (percent)	38.9	38.2				

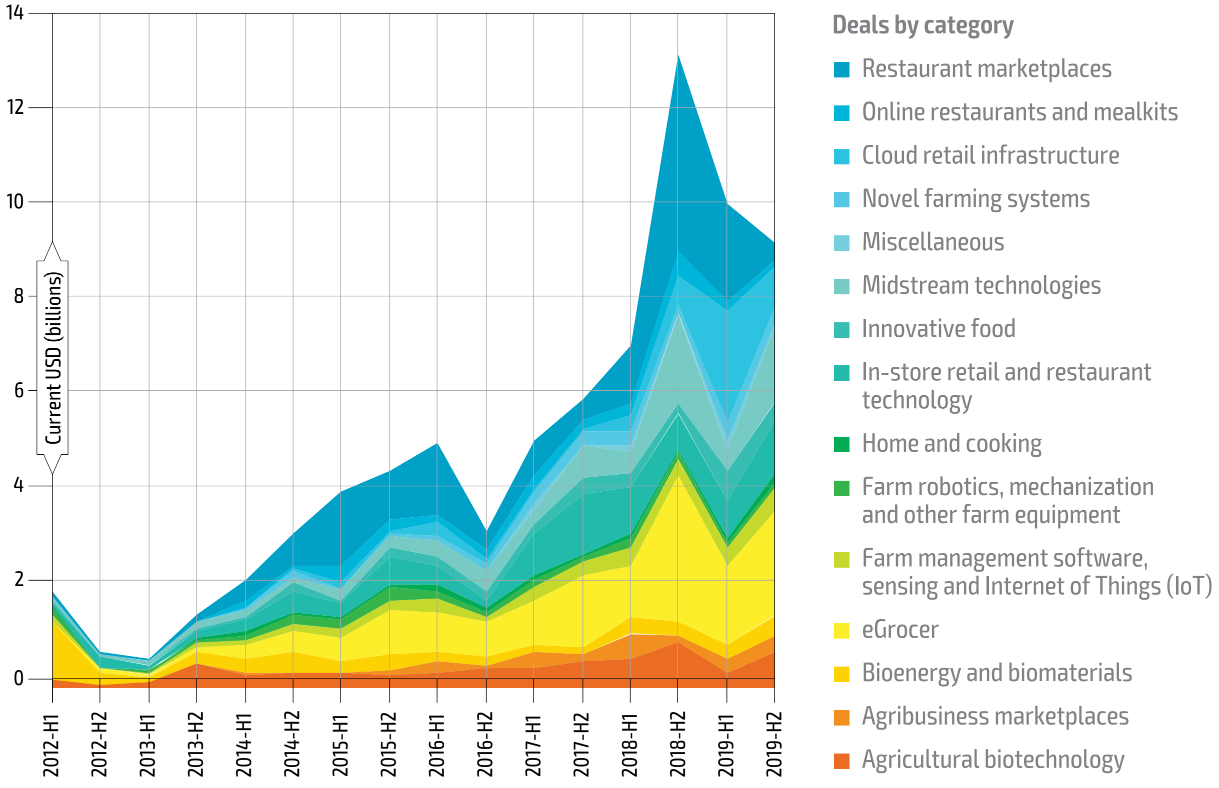
Notes: R&D refers to research and development. LMICs refer to low- and middle-income countries. They include the countries that in the original source are referred to as "developing" and "transition" countries. HICs refers to high-income countries. The trend for the share of expenditure in agricultural research and development in agricultural value added refers to the period 2001–2013.

Source: Authors' adaptation from Fuglie, K., Gautam, M., Goyal, A. & Maloney, W.F. 2020. *Harvesting Prosperity.* Washington, DC, World Bank.

On the other hand, private R&D spending on agricultural R&D (excluding R&D by food industries) accelerated as agricultural commodity prices began to rise in 2003, and climbed from USD 5.1 billion in 1990 to USD 15.6 billion by 2014, with five companies spending more than USD 1 billion per year.[27] According to AgFunder, a private advisor for agrifood investing companies, venture capital investments in agriculture and food technology have risen steadily (Figure 1.47), and in 2020, start-ups in the agrifood technology sector alone mobilized USD 26.1 billion, a 15.5 percent year-over-year increase.[28] Meanwhile, long-established, low-intensity, farm-level R&D continues (see also Box 1.34 in Section 1.10).

But it takes time before a scientific discovery translates into new technologies that enhance productivity and sustainability of agriculture at a sufficient scale: the lag is typically 15 to 25 years. Moreover, several of the innovations that are reviewed here have been the object of controversies that have hampered or prevented their wide adoption (depending on which viewpoint is taken). As an exhaustive listing of relevant technologies and innovations is beyond the scope of this report, a few indicative examples are provided below.

Figure 1.47 Global venture capital investment in agriculture and food technology by category (2012–2019)



Source: AgFunder. 2019. *AgFunder Agri-FoodTech. Year review 2019.* Investing Report. San Francisco, USA.

Biotechnologies

Huge potential; strong resistances. The promise of biotechnologies in the different areas of human endeavour, including food and agriculture, has been widely heralded in the last decades. Based on the definition of "biotechnology" in Article 2 of the Convention on Biological Diversity,[av] the term "agricultural biotechnologies" encompasses a suite of technologies from low-tech ones, such as artificial insemination, fermentation techniques, biofertilizers and nuclear techniques; to high-tech ones, involving advanced DNA-based methodologies, including genetic modification (GM), gene editing (see Box 1.27), whole genome sequencing (see Boxes 1.28 and 1.29) and multi-omics technologies.[30, aw] They have wide-ranging applications and possibilities including, *inter alia*, nutritionally enhanced and longer-lasting foods with diminished losses, reduction of allergens, monitoring of biodiversity, phytoremediation and improved soil health, efficient use of nutrients in animal feed, rapid diagnosis of diseases and development of vaccines,[31] and can enhance the use of neglected and underutilized species.[32]

Nuclear techniques have been employed to produce a broad range of improved crop varieties. For instance, new rice varieties obtained through mutation breeding are now planted on 15 percent of Viet Nam's rice area, and they have contributed to increased income, with government officials estimating that a USD 1 investment leveraged a USD 800 return.[33] The sterile insect technique has been used to eradicate the Mediterranean fruit fly. Over one trillion sterile insects have been released globally to help control major agricultural pests, including tsetse flies, screwworm and fruit flies.[34]

[av] Any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use.

[aw] "Omics" is the generic term for the study of large-scale data of a biological class, such as the total complement of genes or chemical metabolites present in an organism. Examples of omics technologies include metabolome, ionome, microbiome and phenome, as well as integrated informatics.[29]

Box 1.27 Gene editing technologies

Gene editing technologies, such as clustered regularly interspaced short palindromic repeats and their associated proteins, known as CRISPR-Cas, allow precise changes to be made in the genetic make-up of plants and animals. For example, they enhance the possibilities to breed, at reduced cost, crops with tolerance to abiotic stresses such as drought, flooding, high salt concentrations, nutrient deficiencies; with resistance to pests and diseases; and with preferential characteristics for harvesting. In livestock, CRISPR-Cas has allowed the development of cattle without horns and resistance to coronavirus in pigs.[42] In fisheries, a gene-edited tilapia has been developed with 70 percent improved fillet yield, a 16 percent faster growth and a 14 percent improvement in the feed conversion rate.[43]

However, gene editing can lead to off-target alterations in the genome. Additionally, there is no international consensus regarding if and how genome-edited organisms should be regulated, and whether their release should be regulated by the Cartagena Protocol on Biosafety to the Convention on Biological Diversity. In some countries, they are currently being regulated in the same way as genetically modified organisms (GMOs), while in others, they are treated as conventionally produced organisms.

Box 1.28 Digital sequence information/Genetic sequence data (DSI/GSD)

DSI/GSD do not have a universally agreed upon designation and definition. These refer to any kind of information that could be held by any existing or future database of the type collated by the scientific journal *Nucleic Acid Research*.[44] In addition to advancing discovery and development of new crop varieties and livestock breeds, examples of uses of DSI/GSD comprise monitoring and conservation of biodiversity (including species that might be illegally traded), disease diagnosis and prevention, supporting product labelling and certification schemes, and facilitating the design of new biofertilizers. While this type of information is stored in an estimated 1 700 publicly accessible databases and repositories globally, extensive technical, institutional and human capacity is required to fully exploit its innovation potential. Further, discussion on a multilateral framework for DSI has not reached a consensus for fair use and distribution of benefits, and access and benefit-sharing measures vary from country to country.

Box 1.29 Gene sequencing

Continuous advances in molecular biology and bioinformatics, increasing human and institutional capacities and significantly lowered costs for high throughput gene sequencing technologies are generating huge amounts of DNA sequence data, a great deal of which is now publicly available.

The 10 000 plant genomes sequencing project (10 KP) aims to sequence over 10 000 plants and eukaryotic microbes. Coupled with high-throughput trait discovery, genomic selection and phenotyping capabilities, limitations of conventional breeding can be overcome and development of improved and better-adapted crop varieties (including neglected and underutilized species) and livestock breeds can be accelerated.[45]

Genetically modified (GM) crops have been adopted for tolerance to biotic and abiotic stresses, higher yield, improved nutrition and decreased environmental impact associated with fertilizer and pesticide use.[ax] In 2019, 29 countries grew 190.4 million hectares of GM crops (an increase of approximately 112-fold from 1.7 million hectares in 1996), with the top five countries (Argentina, Brazil, Canada, India and the United States of America) planting 91 percent of the global GM crop area, and with only two traits, insect resistance and herbicide resistance, being used widely.[36] Genetically modified seed market analysts project a sales growth of more than 5 percent per annum to reach a value of more than USD 30 billion by 2026.[37]

A meta-analysis found that GM crops, on average, increased yields by 22 percent and reduced chemical pesticide quantities by 37 percent, with average profit gains of 68 percent for farmers adopting them.[38] The report *Genetically Engineered Crops: Experiences and Prospects*[39] observed that GM crops have generally had favourable, though heterogeneous, economic outcomes for farmers, depending on pest abundance, farming practices and agricultural infrastructure. No conclusive evidence of cause and effect relationships between GM crops and environmental problems were ascertained; similarly, no adverse impacts on human or livestock health were associated with GM crops. However, GM crops have been the object of a polarized scientific and policy debate, resulting in public backlash and political sensitivities because of contrasting perceptions regarding risks and benefits involved (see Table 1.16).

Table 1.16 The main terms of the debate on genetically modified organisms (GMOs)

POTENTIAL	RISKS AND CONCERNS
Increased yields	Replaces traditional varieties, favour monoculture and reduces agrobiodiversity, leading to greater vulnerability, and is supported by policies that ban exchange of traditional seeds.
Tolerance to biotic (pests and diseases) or abiotic (drought, high/low temperature, salinity, heavy metals, etc.) stresses	Developed and patented, based on the use of private appropriation of genes that have been selected by rural communities over centuries.
Possibility to enrich for improved nutrition	In the hands of an oligopoly of a small number of major multinational companies that control the market, and fix prices in a way that is conducive to an unfair sharing of benefits.
Reduced fertilizer and pesticide use	Contributes to building pesticide resistance, overuse of pesticide and environmental damage.
No conclusive evidence of cause and effect relationships with environmental problems. No proven effect on human or animal health	Obligation for farmers to purchase seeds every year and forbiddance to reuse grains from their harvest as seeds. This hampers access by poor farmers – particularly those producing for home consumption – who lack cash. Thus, their widespread use could aggravate inequality in rural areas.

Source: Authors' elaboration.

In addition, commercial use of GM trees has been authorized in two countries, Brazil and China,[40] while a fast-growing GM salmon was approved for commercial production in Canada and the United States of America.[41]

Microbes have always played an important role in agriculture – they have been utilized in fermentation and bioremediation, and applied as biopesticides/biocontrol agents, biofertilizers, biostimulants and probiotics.[31] Soil biodiversity drives many processes that produce food or purify soil and water. Soil microorganisms can improve nutrient availability, and nitrogen-fixing bacteria can minimize cost and dependence on synthetic nitrogen fertilizers, enhancing soil fertility and reducing GHG emissions. In addition, soil biodiversity can be a powerful tool in bioremediation of contaminated soils, contributing to the filtration, degradation and immobilization of target contaminants.[17]

[ax] For example, Bt corn and Bt cotton contain a few genes from *Bacillus thuringiensis* (Bt) that helps them to synthetize crystals proteins that are effective against European corn borer, rootworm, corn earworm, tobacco budworm and bollworm, without having any toxic effect on mammals.[35]

The microbiome, which refers to the combined genetic material of all microorganisms living in a given ecosystem, supports efforts towards systems approaches that inextricably link healthy soils to healthy plants and animals, to healthy diets in humans and to a healthy environment. Multi-omics technologies have significantly helped to understand the composition of microbiomes, their functions and networks of interactions.[46] Harnessing the microbiome offers comprehensive and innovative strategies to contribute to more diversified, efficient and resilient agrifood systems, improve soil carbon sequestration, and prevent and treat diet-related, non-communicable diseases. Microbiome science cuts across many technical disciplines and economic sectors, which adds to the complexity of the policy and regulatory dimensions that may affect it. Further work is needed to guide the translation of microbiome innovations from fundamental research to application, and to enhance regulation, standardization and management.[47]

Developments in **synthetic biology** have enabled precision fermentation that allows microorganisms to be programmed to produce almost any complex organic molecule, including growth factors for the production of cell-based meat. The cost of a single molecule by precision fermentation has fallen exponentially from USD 1 million/kg in 2000 to about USD 100/kg in 2019, but most of the companies in this sector are start-ups, so the speed of scale-up remains to be seen. Foods produced through precision fermentation are believed to be approximately ten times more efficient than a cow at converting feed into end products, translating to ten times less water, five times less energy and 100 times less land.[48]

Thirty-three percent of the world's croplands are allocated to livestock feed production, and the search for **alternative protein sources** is gaining traction in this domain. Numerous multinationals have made strategic investments in the use of microbial, insect and algal biomass as circular feeds in livestock, replacing conventional protein sources such as soy and fishmeal, with considerable potential to reduce GHG emissions.

Digital technologies

Exciting promises, mixed results. Digital technologies are rapidly changing our economies and societies. Even though agriculture is currently the economic sector with the lowest levels of digital technology adoption, emerging digital technologies appear to have tremendous potential to transform agrifood systems. There are high expectations that they could contribute to increasing agricultural production and productivity, and helping adapt to and/or mitigate the effects of climate change. Additionally, it is hoped that they could support early warning systems on plant and animal pests and diseases, bring about more efficient use of natural resources, reduce risk and improving resilience in farming, integrate small-scale producers into markets and reach consumers through e-commerce, thereby increasing efficiency in the design and delivery of agricultural policies.[49] They can drive down information and transaction costs, create jobs, change the nature of work and generate new income streams.

However, adoption of digital technologies by farmers is influenced by numerous factors and the benefits they obtain from these technologies vary widely,[50] and depend on which exact digital technology is applied (see Section 1.4.4).[51] It is more advanced in Northern America and Europe. In sub-Saharan Africa (SSA), they were estimated to reach up to 33 million smallholder farmers and pastoralists (i.e. 13 percent, mostly young people working in high-value chains) in 2018, and generate nearly USD 144 million in earned revenue annually, with the sector growing at about 44 percent per annum over 2015–2018 in terms of the number of farmers reached. Markedly, only 42 percent of farmers and pastoralists actually seemed to use the solutions they registered for with any frequency.[52]

Digital technologies can facilitate low-cost and continuous extension advice. For instance, Digital Green has produced and disseminated more than 5 000 locally relevant videos in over 50 languages in which farmers share knowledge on agricultural production practices. Mobile phone-based extension and price information systems in SSA and India have been estimated to improve crop yields by 4 percent, to increase adoption of recommended inputs by 22 percent and raise farmer profits.[53] Further examples of the impact of digital technologies on agrifood systems can be seen in Section 1.4 of this report.

FAO's eLocust3 records and transmits data in real time via satellite to map the movements of desert locusts across countries for early warning, forecasting and prevention efforts. The tool has been instrumental in the response to the desert locust crisis which has been ravaging areas throughout the Horn of Africa and, in conjunction with other operations, has avoided the loss of an estimated 2.3 million tonnes of cereal – enough to feed more than 15 million people a year.[54]

FAO is also developing and promoting open-source solutions for sustainable approaches. Recent digital solutions include the Hand-in-Hand Initiative, an evidence-based, country-led and country-owned initiative to accelerate agricultural transformation and sustainable rural development. It is supported by the Hand-in-Hand Geospatial Platform to guide food security investments and the Data Laboratory for Statistical Innovation, which combines big data and artificial intelligence (AI) for decision-making.[55]

Digital technologies can trigger major beneficial as well as damaging "disruptions" in agrifood systems. They can deepen the digital divide, serve to concentrate power, intensify vertical consolidation, increase energy costs, enhance data asymmetries and generate e-waste. The broad spectrum of digital technologies is along a continuum, requiring varying levels of mobile coverage, Internet connectivity, skills and knowledge. As opposed to 74 to 80 percent of farms of greater than 200 ha in size, only 24 to 37 percent of farms of less than one hectare in size have access to 3G or 4G services. In Africa, only 27 percent of women have access to the Internet and only 15 percent of them can afford to use it. As a result, small-scale rural producers, especially women in LMICs, have largely been left on the sidelines.[56] Additional issues relate to: scalability; privacy concerns, data ownership and control; vulnerability to cyberattacks; fewer unskilled jobs and replacement of human labour force with machines; dependence on a highly concentrated semiconductor economy; centralization of agricultural knowledge and homogenization of agricultural technology worldwide; and exclusion of the most vulnerable. The rapid progression of digital technologies also poses significant challenges for institutions to adapt, and a concerted action is required for them to develop and benefit society at large. The question of regulation, safeguards and ethics remains a serious issue with which even HICs are just beginning to grapple. Lastly, information and communication technologies are expected to become major energy users, with a potentially huge impact on greenhouse gas emissions.[57]

Renewable energy technologies

A very large number of people and businesses lack access to sustainable, reliable and affordable energy to produce, store, process and cook their food, resulting in significant food losses and emissions of GHG. Globally, agrifood systems consume about 30 percent of available energy, predominantly in the form of fossil fuels.[58] A third of agrifood system GHG emissions are from energy-related activities.[12]

However, farms generally have ways of generating their own renewable energy, in particular solar and wind energy, and by using residues of agrifood systems to produce biogas and biochar from biomass gasification. They can even earn possible additional income from the sale of excess energy to the energy grid.

FAO has developed an Energy-Smart Food (ESF) programme that aims primarily to ensure adequate access to sustainable, reliable and affordable energy in agrifood systems using a water-energy-food nexus approach. Major energy companies and development banks are now willing to collaborate with FAO to support sustainable clean energy use in rural areas of LMICs.

Geoengineering

A controversial technology aiming to limit global warming and control rainfall. Geoengineering involves large-scale manipulation of the Earth's environment that could be used to offset climate change (e.g. increasing the surface albedo to make the atmosphere reflect more sunlight and achieve rainfall management).

This technology mimics the cooling effect of large volcanic eruptions that project ash particles that reflect some incoming sunlight by injecting an aerosol into the stratosphere. At a cost of USD 2 billion to USD 10 billion, it could reduce both the temperature and precipitation anomalies at regional and subregional scales.[59] Solutions used include injecting sulphur aerosols into clouds or salt above oceans.[60, 61]

Technologies applied locally for rainmaking date back to the middle of the last century,[62] and current concerns are mostly over a large-scale application that could impact on regional and even global climate.[63] China, India and the United States of America have been accused of disrupting climate by cloud seeding,[ay] despite the moratorium decided upon during COP10 in Buenos Aires (2004).[68]

Geoengineering is the object of a fierce debate that was long dominated by opponents, but where supporters are gaining more influence. Major criticisms by opponents include that its expected results might reduce commitments to reduce GHG emissions (and that it may be driven by fossil fuel interests), that its use would have global transboundary effects and could create international tensions, as countries could accuse their neighbours of depriving them from "their" rain and demand compensation. This has led to requests for halting research and testing of the technology until there are clear rules for governing this activity and the means for controlling deployment.[59,63] On the other hand, supporters argue that these concerns call for more research and governance,[63] and some proposals are being formulated for this purpose,[69] while a group of countries, led by Switzerland, requested the United Nations Environment Programme (UNEP) to conduct a technology assessment of geoengineering – later withdrawn – with the objective to put the issue back on the agenda.[70]

Agroecological and other innovative sustainable agricultural approaches

Agroecology is a participatory and action-oriented approach that embraces three dimensions: 1) a transdisciplinary science; 2) a set of practices; and 3) a social movement. Agroecological approaches favour reliance on natural processes, limit the use of purchased inputs and promote closed cycles with minimal negative externalities. They also stress the importance of local knowledge and participatory processes that develop knowledge and practice through experience as well as more conventional scientific methods, and address social inequalities.[6] These approaches perpetuate a long-established process of farmer-led innovation through those like the FAO-developed Farmer Field Schools, where farmers and scientists cooperate.[71] Agroecological approaches recognize that agrifood systems are coupled social-ecological systems from food production to consumption and involve science, practice and a social movement, as well as their holistic integration, to achieve food security and nutrition.[6]

FAO elaborated and approved the 10 Elements of Agroecology as an analytical framework to support the design of differentiated paths for agrifood system transformation.[72] These ten elements are interlinked and interdependent, and include diversity, synergies, efficiency, resilience, recycling, co-creation and sharing of knowledge, human and social values, culture and food traditions, responsible governance, and circular and solidarity economy.

There are no generally agreed boundaries of agroecology. However, organic agriculture (see Box 1.30), permaculture,[73] conservation agriculture (see Box 1.31), integrated pest management,[74] the system of rice intensification (SRI)[75] and agroforestry,[76] are among the main approaches associated with agroecology, all of which have gained importance in recent years.

While there are instances of large-scale commercial farming following agroecological principles, most successful examples to date come from smallholder family agriculture,[77] and these examples have proved to be both productive and less damaging for the environment (greater water use efficiency, higher carbon sequestration and protected biodiversity)[78] and can lead to increased farmers' income.[79] In Cuba, approximately 300 000 small-scale producers use agroecological practices, and agroecological food production is estimated to contribute 60 percent of vegetables, maize, beans, fruits and pork consumed.[6] In the Indian state of Andhra Pradesh, the Community-Based Natural Farming Programme is scaling up agroecological practices, currently reaching 580 000 farmers across 3 000 villages. Independent assessments show reduction in production costs through integrated crop-livestock farming and system stability, resulting in higher net income for farmers, along with better soil and crop health, resilience, economic empowerment and dignity of labour.[80]

Agroecological practices can conserve biodiversity, reduce pests via biological controls, restore landscapes, provide ecosystem services and integrate crop-tree-livestock systems for better nutrient recycling aimed towards creating a circular bioeconomy. A Tool for Agroecology Performance Evaluation (TAPE) has been developed to assess the multidimensional performance of agroecology and is being tested in 29 countries globally.[81]

[ay] See, for example: zerogeoengineering.com (2020),[64] CNN (2020),[65] Current Science (2017),[66] GeoEngineering Watch (2015).[67]

Box 1.30 Organic agriculture

Organic agriculture is a production system that relies on ecosystem management and does not allow the use of synthetic chemical inputs (inorganic fertilizers and pesticides). It relies on ecological processes and natural sources of nutrients (such as compost, crop residues and manure). It has been considered as an environmentally friendly and economically viable alternative to conventional agricultural production. The benefits of organic agriculture include greater biodiversity, higher soil organic matter and improved soil properties. There is some controversy regarding the productivity of organic agriculture when compared with conventional agriculture. However, recent modelling studies suggest that organic agriculture with sufficient legumes in the crop mix could provide food in a sustainable way for more than 9 billion people in 2050 while reducing the negative environmental impact of agriculture.[6]

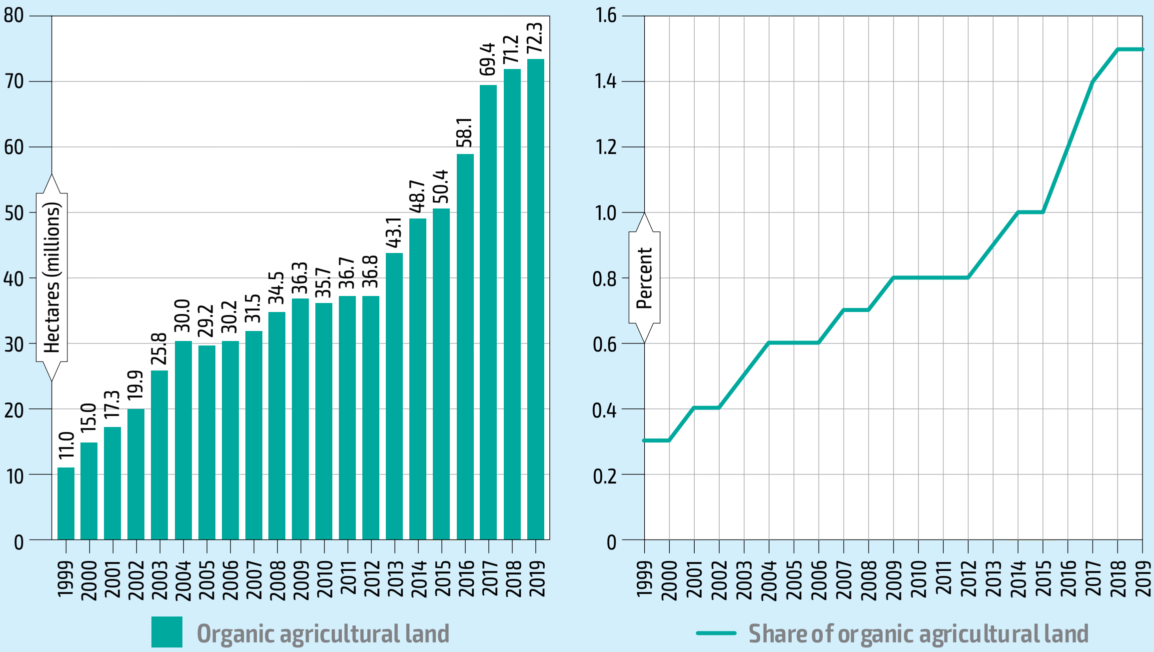
By 2020, 72 countries had fully implemented organic regulations with associated labels, certification processes and organizations, including participatory guarantee systems (locally focused quality assurance systems).[82]

In 2019, global organic agricultural area (including in-conversion areas) covered 72 million hectares or 1.5 percent of total agricultural area, and was used by about 3.1 million producers. This area increased six-fold between 1999 and 2019. In 2019, India, the United States of America and France were the countries where organic agricultural area grew most. The highest organic share of total agricultural land, by region, is in Oceania with 9.6 percent, followed by Europe with 3.3 percent and Latin America with 1.2 percent. In the European Union, the organic share of the total agricultural land is 8.1 percent.[82]

Figure A. Growth of area and share of organic agricultural land

a) Organic agricultural area

b) Share of organic agricultural area in total agricultural area



Source: FiBL (Forschungsinstitut für biologischen Landbau) & IFOAM (International Federation of Organic Agriculture Movements). 2021. *The World of Organic Agriculture 2021. Statistics & emerging trends 2021.* www.organic-world.net/yearbook/yearbook-2021.html

Total retail sales, according to the FiBL survey, amounted to over EUR 106 billion (equivalent to USD 119 billion). The largest single market was the United States of America, followed by the European Union and China.[82]

Box 1.31 Conservation agriculture

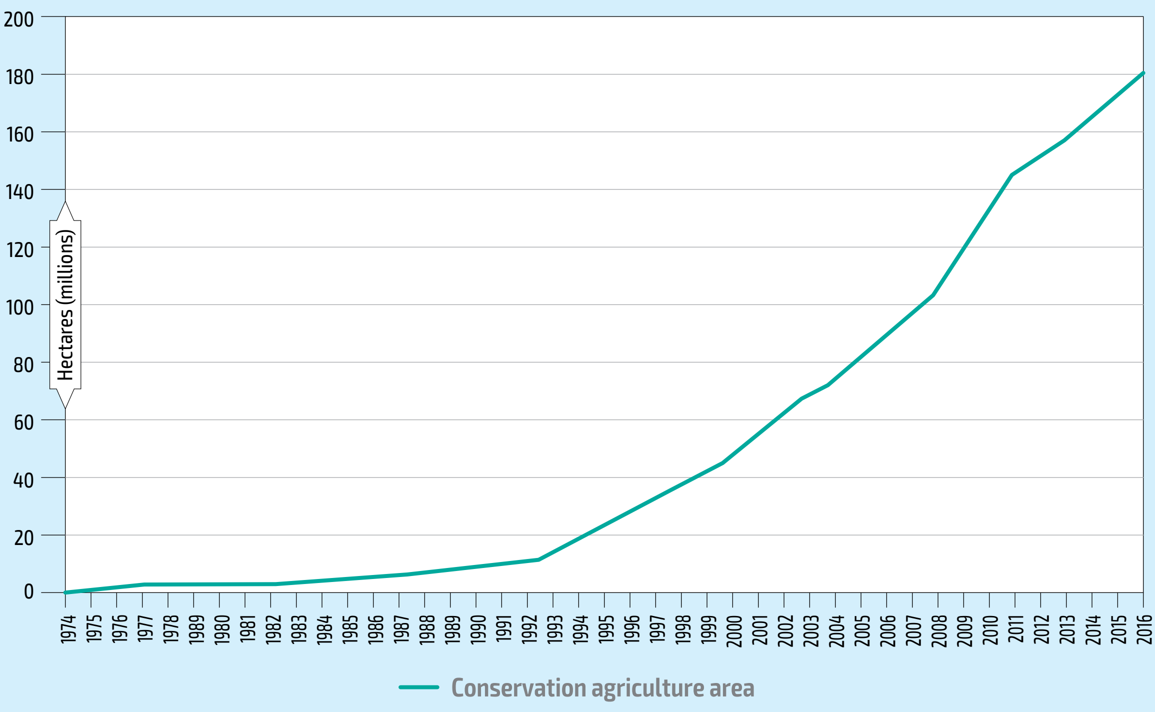
Conservation agriculture is based on three interrelated principles: 1) continuous no or minimal mechanical soil disturbance; 2) maintenance of a permanent biomass soil mulch cover on the ground surface; and 3) diversification of crop species (implemented by adopting a cropping system with crops in rotations, and/or sequences and/or associations involving annuals and perennial crops, and including a balanced mix of legume and non-legume crops). These three principles need to be respected simultaneously[83] in order to yield the full benefits of this approach.[84]

Conservation agriculture enhances biodiversity and natural biological processes above and below the ground surface. It facilitates good agronomy and improves overall land husbandry for rainfed and irrigated production. Complemented by other known good practices, including the use of quality seeds and integrated pest, nutrient, weed and water management, conservation agriculture is a base for sustainable agricultural production intensification.[83]

In South Asia, zero tillage with residue retention has been shown to have a mean yield advantage of around 6 percent, to provide farmers with almost 25 percent more income, to increase water use efficiency by about 13 percent and to reduce global warming potential by up to 33 percent compared to conventional agricultural practices.

The area covered by conservation agriculture grew from 106 million hectares in 2008/09 to 180 million hectares in 2015/16 in 78 countries (approximately 12.5 percent of global cropland). The largest extents of adoption are in South and North America, followed by Australia and New Zealand, Asia, the Russian Federation and Ukraine, Europe and Africa.[85]

Figure A. Global evolution of cropland area covered by conservation agriculture (1974–2016)



Source: Kassam, A., Friedrich, T. & Derpsch, R. 2018 Global spread of Conservation Agriculture. *International Journal of Environmental Studies*, 76(1): 29–51. https://doi.org/10.1080/00207233.2018.1494927

Additional innovative approaches for the transformation of agrifood systems include climate-smart agriculture, regenerative agriculture, agroforestry and controlled environment agriculture, among others (see Table 1.17), as well as integrated agro-aquaculture systems and integrated multi-trophic aquaculture.[86, 87]

Table 1.17 Comparison of different innovative approaches towards sustainable and resilient agrifood systems

CHARACTERISTIC	AGROECOLOGICAL AND RELATED APPROACHES					SUSTAINABLE INTENSIFICATION AND RELATED APPROACHES			
	Agroecology	Organic Agriculture	Agroforestry	Permaculture	Food sovereignty	Sustainable intensification	Climate smart agriculture	Nutrition sensitive agriculture	Sustainable food value chains
Resource efficiency									
Regenerative production, recycling and efficiency								No evidence	No evidence
Biodiversity, synergy and integration									
Resilience									
Economic diversification versus specialization									
Climate adaptation and mitigation									
Social equity/responsibility									
Knowledge generation and technology transfer									
Human and social values: equity									
Human and social values: Labour versus capital intensification									
Connectivity (value chains/circular economies) versus globalization									
Governance: rights, democratization and participation									

Note: The blue-scale intensity of the cells represents the evaluation of the HLPE based on the evidence about the approaches set out in Appendix 1 of the source below.

Source: HLPE. 2019. *Agroecological and other innovative approaches for sustainable agriculture and food systems that enhance food security and nutrition.* A report by the High Level Panel of Experts on Food Security and Nutrition. Rome. www.fao.org/3/ca5602en/ca5602en.pdf

Institutional innovations

In recent years, there have been several initiatives taken by businesses to gain credibility and consumer trust over the environmental, ethical or health properties of food. For example, more than 1 000 companies are working with the Science-Based Targets initiative (SBTi) to cut their GHG emissions in line with the Paris Agreement. The Consumer Goods Forum (CGF), a global network, has, as its ambition, the positioning of the consumer goods industry as a leader in tackling climate change, reducing waste and improving environmental stewardship in global supply chains. Such efforts have been supported by the multiplication of private ethical, social and governance (ESG) certification firms. Civil society organizations have been rather critical of these endeavours and Greenpeace has regarded them as being part of a green-washing operation.[88]

Producers, too, have been creating organizations to certify food products through participatory guarantee systems that use environmentally and ethically sound value chain approaches, and which promote short, domestic value chains, while ensuring transparency and trust between producers and consumers, fair compensation for the primary producers, conservation of agrobiodiversity and preservation of ancient techniques. One example is given by the 13 organizations of small-scale mountain producers from the Plurinational State of Bolivia, India, Kyrgyzstan, Mongolia, Nepal, Panama, Peru and the Philippines, operating under the Mountain Partnership Products initiative.

Similarly, the Fair Trade movement, a non-profit, multi-stakeholder association of three producer networks and 19 national Fairtrade organizations, has been benefiting small-scale producers (farmers and artisans), workers and consumers through standards, certification, producer support, programmes and advocacy. It has been associating producers and consumers in value chains that respect ten principles, including transparency and accountability, fair payment, no child or forced labour, no discrimination, protection of the environment and capacity building. The Fairtrade system involves 1.78 million farmers and workers and covers 2.3 million hectares of land. Since 2015, Fairtrade farmers and workers have received over EUR 500 million in Fairtrade Premium, and funding activities, such as farmers' trainings, student fellowships, building schools and wells in villages, and acquiring land for nurseries.[89]

Supply chains are also seeing technical innovations, such as the development of more efficient cold chains for perishables and sustainable packaging that maintain the quality, safety and nutritional value of products (with associated benefits in cutting food loss and waste), meet consumer needs and preferences, and reduce environmental impact (reusable, recyclable, biodegradable or compostable) (for more on global value chains, see Section 1.12).

Policy innovations

The challenge of facilitating adoption of new technologies and innovations, while also mitigating risks for disadvantaged market players, calls for policy innovation. With growing climate-, environment- and health-related concerns, policies have adjusted. In particular, government spending and tax/subsidy policies have been modified to produce more climate-, environment- and health-friendly incentives.

Typical examples of these shifts are fiscal policies promoting healthy diets, including "sin taxes", such as taxes on sugar-sweetened beverages (SSB), to reduce consumption and which have been enforced by more than 73 countries, especially during the last decade.[90] In Chile, implementation of the country's Law of Food Labelling and Advertising Purchases, on top of the SSB taxes, led to a significant decline in SSB purchases.[91] Conversely, subsidies for healthy foods can induce a 10 to 25 percent increase in consumption.[92] However, excessive reliance on taxes particularly hits the poor.

In recent years, cities and regions across the world are increasingly taking a leading role in building more sustainable, resilient and inclusive local agrifood systems. A broad range of stakeholders is mobilized and engaged through Food Policy Councils (FPCs) or similar mechanisms such as multi-stakeholder food forums/platforms, food policy networks, food boards, food coalitions, food partnerships and food labs, among others.[93]

In the process of policymaking, two innovations may be noted:

- The creation of citizens' conventions or assemblies made up by members drawn by lot to formulate policy proposals.[94] For example, this approach was used in France, Germany and Ireland on climate-related policies.
- The multiplication of legal actions referring to a country's fundamental law, or to its international commitments, to influence policymaking or corporate behaviour. These actions are usually initiated by civil society organizations to oblige governments to pass legislation or curb corporate activities.[95] Most of such actions have been related to health, climate or environmental issues.

Financial innovations

A growing share of agrifood R&D investment comes from private firms (see Section 1.10). The key to unleashing private and financial sector resources, especially in LMICs, is to address their concerns related to expected returns relative to perceived risk and uncertainty through innovative financial services and risk mitigation instruments. These include investment funds, loan guarantees and risk mitigation products such as index insurance, warehouse receipts systems and forward contracting.

The FAO–UNIDO (United Nations Industrial Development Organization) Accelerator for Agriculture and Agro-industry Development and Innovation (3ADI+) programme aims to facilitate the development of inclusive and sustainable agrifood systems that effectively link smallholders and larger farmers to the processing, value addition and end markets supplying higher value, nutritious and differentiated food, fibre, feed and fuel products to consumers.[96]

Blended finance, mixing public and private funds, has led to several innovative models. For instance, FAO launched the AgrIntel initiative with the European Union in 2018 to support efforts to crowd in private investment for small- and medium-sized enterprises (SMEs). IFAD's (International Fund for Agricultural Development) Adaptation for Smallholder Agriculture Programme (ASAP+) channels climate finance to small-scale producers and aims to bring 4 million hectares of degraded land under climate-resilient practices, and sequesters around 110 million tonnes of CO_2 equivalent over 20 years (see also Section 1.10).

Innovations as drivers of change

The technological, social, institutional, policy and financial innovations reviewed here have considerable potential to transform agrifood systems; however, they may also sometimes be a source of risk and uncertainty. Stand-alone interventions seldom achieve positive outcomes over multiple sustainability dimensions. An upscaling of portfolios of appropriate, complementary and synergistic technologies and innovations is needed to reach transformative solutions that result in better production, better nutrition and a better environment for a better life, while recognizing the importance of suitability to regional and local contexts. Technologies should not be seen as a substitute for a range of enabling social, political and institutional factors also required to make agrifood systems more just, sustainable and resilient.

1.9.3 Summary remarks

There is a need to innovate to help transform dysfunctional agrifood systems, as the current model generates a series of ills that are compromising the future. Anthropogenic GHG emissions responsible for climate change, loss of biodiversity, degradation of land and water and resources, and food waste are some of the negative impacts of how agrifood systems have been managed (see Sections 1.14, 1.15 and 1.16).

Science and innovation are fast advancing fields – the promise is immense, but there are also risks, as rapid developments can outpace the ability of societies to adapt, and existing socioeconomic inequalities and adverse environmental effects can be exacerbated. Eighty percent of global investment in R&D (including, but not limited to, the agricultural sector) is concentrated in ten countries. If past trends continue unaltered, large middle-income countries, such as Brazil, China and India, will likely play a greater role in innovation and science, aside from the HICs that dominate the field; whereas LICs, particularly in SSA, will be marginalized and remain "technology takers". This applies to STEM research in general, but also for research related to food and agriculture.

Biotechnologies have a huge potential and yet they are facing strong resistance, as are digitalization and geoengineering. Agroecological and other alternative, environment-friendly approaches also address social inequalities, as do some supply chain innovations. In the field of policy, innovations such as citizens' conventions or assemblies made up by members drawn by lot, or legal actions aimed at curving government policies, are becoming more numerous, but their impact has yet to be felt.

A major issue in the near future will be how and in which institutional framework are technologies and innovations to be governed, who will benefit from them and what will guide their regulation. In particular, how will the relative weight given to productivity, sustainability and inclusiveness be determined. In fact, the outcomes of the technologies and innovations listed in this chapter depend on the extent to which they address the needs of small-scale producers, whether civil rights are enforced, and an effective legal system ensures the respect of contracts as well as the protection of ownership (including intellectual property rights), and that society operates on transparent rules.

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1.10 Investment in agrifood systems (Driver 11)

The relative share of public expenditure in agriculture decreased significantly over the last 15 years, as shown by the FAO Agriculture Orientation Index (AOI) for Government Expenditures.[1] In many instances, priorities set by governments, particularly those of low-income countries (LICs), are not implemented because of insufficient public investment or low priority attributed to local food systems. Yet, FAO, in its *Strategic Framework 2022–31*,[2] identifies public investment as a critical driver of agrifood systems, directly affecting food and agricultural production, and distribution processes.

Beyond its importance as a standalone source of investment, public investment is also important as a driver of investment, including from private sources. It can mobilize private investment through several channels, including by providing long-term capital, setting up public goods and mitigating risk. The public sector also shapes the investment climate and investment decisions through policies and regulations.

This section aims to address several questions to understand better the current state of investment in agrifood systems and to identify trends, challenges and opportunities:

- What is the recent investment trend in agrifood systems? Is investment in agrifood systems contributing to reducing disparities among countries?
- What sources of investment complement public investment as a driver of sustainable agrifood system transformation?
- What is the role of foreign investment (both public and private) in agrifood systems?
- What does the analysis of investment tell us about the future of agrifood systems?

1.10.1 Investment in agrifood systems: definitions, classifications and trends

Definitions and classifications

Investment plays a central role in transforming agrifood systems. It is a critical driver for achieving and maintaining agrifood systems that are economically, socially and environmentally sustainable. Investment mobilizes capital for improving production, processing, services and related logistics processes over time. It differs from operating expenditure (e.g. applying fertilizer or sowing) in that it takes more than one year to generate returns, brings more than an immediate one-time gain and leads to capital accumulation (equipment, buildings, knowledge and trained people, etc.). Selected examples of investments include infrastructure such as dams, canals, markets, storage facilities and rural roads, farm buildings, logistics centres or food processing units, as well as improvements in land, establishment of perennial plantations, development of livestock herds, purchase of tools, tractors and of other machinery. Other examples include research and development (R&D) in agriculture and training and capacity building to generate knowledge, technologies and approaches that contribute to increasing productivity in the medium and long run, and enhance skills and competences of those working in the sector, and in legal and market institutions required for the effective operation of agrifood systems (see Box 1.32).

Beyond its amount, investment quality – including its composition and context – matters. Investing in certain activities and sectors will prove more productive than others, given the country context, risk level and implementation capacity. For example, returns to irrigation investments rank fifth out of six types of investments in China, fifth out of eight in India, and last out of four in Thailand.[3] In Indonesia, an analysis of total factor productivity growth in agriculture between 1975 and 2006 shows that it can virtually be explained in its totality by public spending in agricultural research.[4]

Investment can be classified according to its sources (see Figure 1.48). Typically, distinction is made between public and private, and domestic and foreign investment.

Box 1.32 Agricultural research, technology and extension services

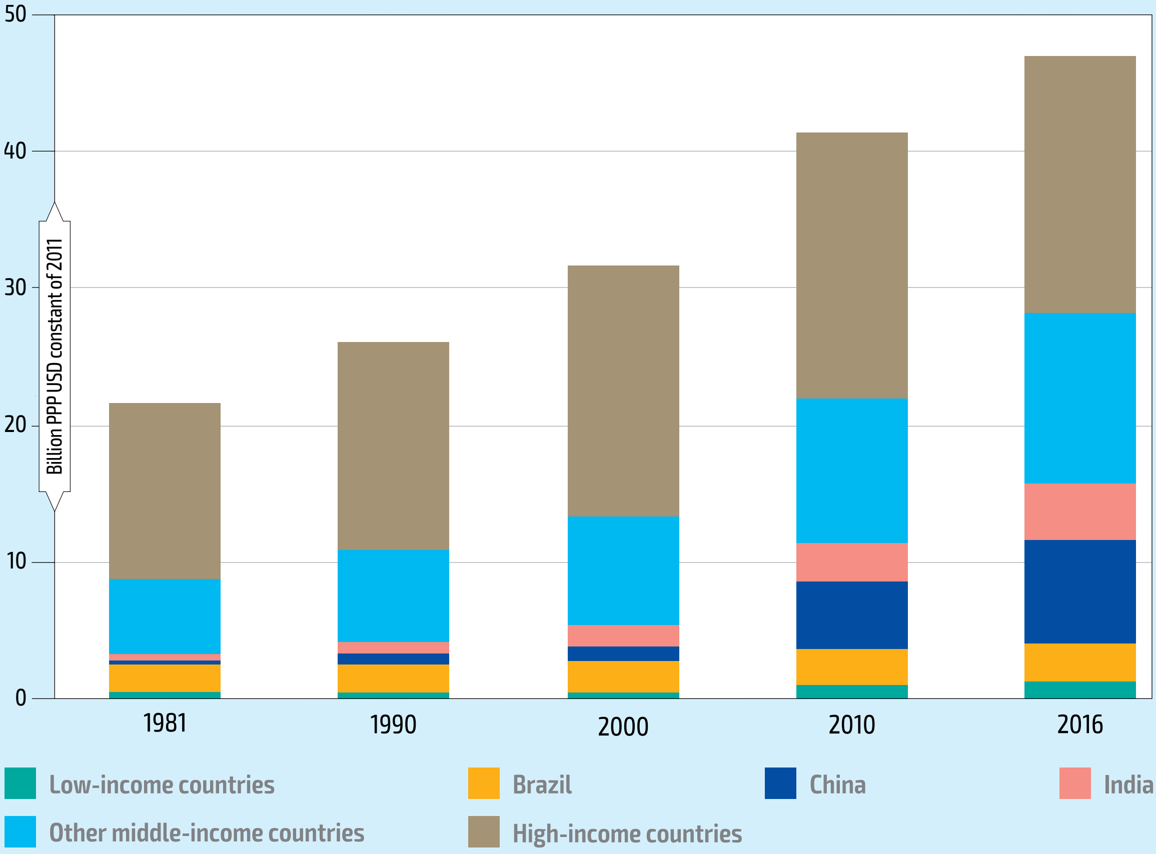
Agricultural research and extension services are a domain where public investment has a high potential for longer-term returns. The literature suggests that the returns to investment in agricultural research are considerable, with internal rates of return being higher than 20 percent.

For example, a compilation of 113 studies, published between 1975 and 2014 across 25 countries in SSA, highlights that internal rates of return to food and agricultural research conducted in or of direct consequence for SSA averaged 42.3 percent.[16] Microevidence also demonstrates the role of agriextension programmes in enhancing farm productivity and household income.[17]

FAO stresses that the dollar-for-dollar impact of R&D public spending on agricultural production is greater than the equivalent returns for public spending in activities such as irrigation or fertilizer subsidies, and is a higher performer in poverty reduction.[18]

Despite this evidence, investment in agricultural research grew only sluggishly in the 1990s. However, it increased by 50 percent between 2000 and 2016, mostly driven by China and other large middle-income countries (see Figure A), and the doubling of global investments by the private-for-profit sector. However, an analysis of the intensity of research investment, based on intensity index of the Agricultural Science & Technology Indicators (ASTI), indicates that the global gap in agricultural research investment was 34 percent of the world's attainable investment in 2016, ranging from 25 percent in HICs to 39 percent in LICs.[19]

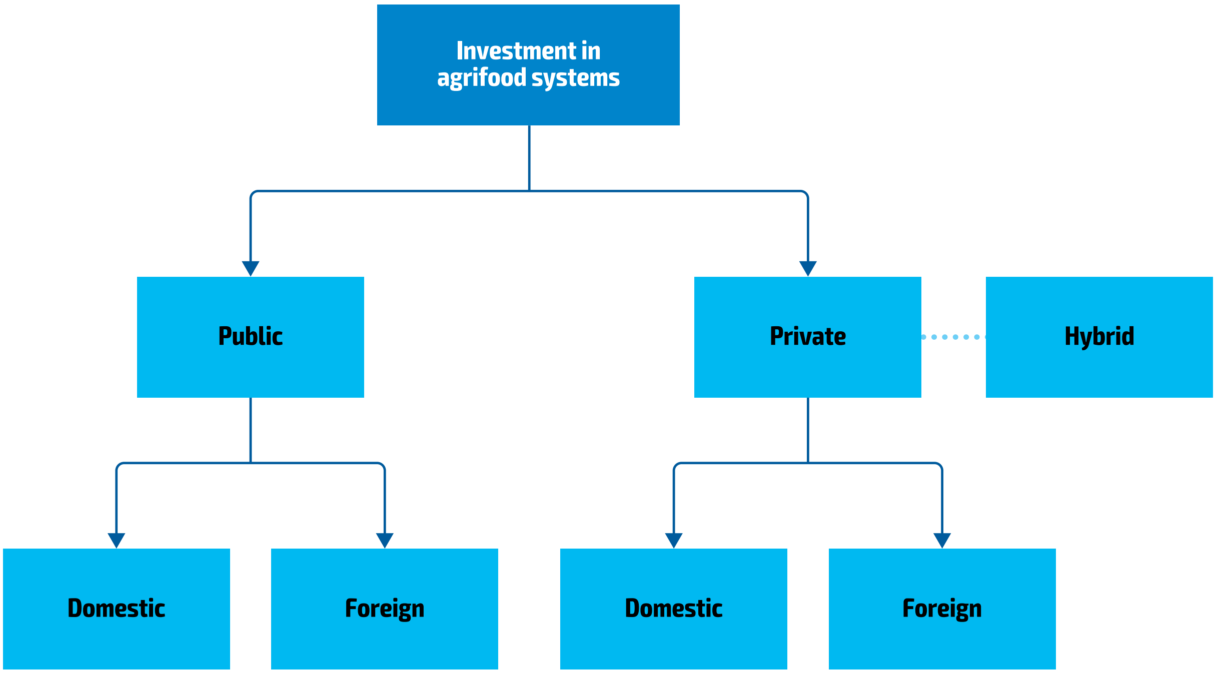
Figure A. Agricultural research spending by income group and selected countries



Notes: The private-for-profit sector has not been taken into account for the total due to lack of available data. Income groups were based on the situation in 2019. Data include estimated spending for various (short) timeframes for various countries. See ASTI website for more information on data sources and estimations by country.

Source: Beintema, N., Nin Pratt, A. & Stads, G.-J. 2020. *Key trends in global agricultural research investment.* Washington, DC, ASTI (Agricultural Science & Technology Indicators) by IFPRI (International Food Policy Research Institute).

Figure 1.48 Sources of investment in agrifood systems



Source: Authors' elaboration based on Mutambatsere, E. & Schellekens, P. 2020. *The why and how of blended finance. Recommendations to Strengthen the Rationale for and Efficient Use of Concessional Resources in Development Finance Institutions' (DFI) Operations.* Washington, DC, IFC (International Finance Corporation) and World Bank; FAO. 2012. *The State of Food and Agriculture 2012. Investing in agriculture for a better future.* Rome. www.fao.org/3/i3028e/i3028e.pdf

Domestic public investment corresponds to the investment part of government expenditure. Domestic private investment is made by local private operators (farmers and companies). Foreign public investments are investments funded by foreign public sources, such as multilateral and bilateral donors and Development Finance Institutions. Investments by foreign private investors (including financial firms), and the share of international remittances channelled for investment purposes, make up foreign private investment.

Recently, a third, hybrid, category of investment, has gained importance. One example of this is blended finance, a combination of private and public funds, grants and loans to make projects financially viable and/or financially sustainable.[5] The Organisation for Economic Co-operation and Development (OECD) defines blended finance as the strategic use of development finance for the mobilization of additional finance towards sustainable development in "developing countries" with additional finance referring primarily to commercial finance.[6, az] Though blended finance has been used for decades, interest in it has grown since the adoption of the Addis Ababa Action Agenda of the Third International Conference on Financing for Development in 2015. Critics argue that blending operations have been concentrated on certain sectors, lack incentives for pro-poor investments, focus on middle-income countries, and exhibit poor ownership and accountability.[7] However, blending represents an option for mobilizing private investment in agrifood systems.

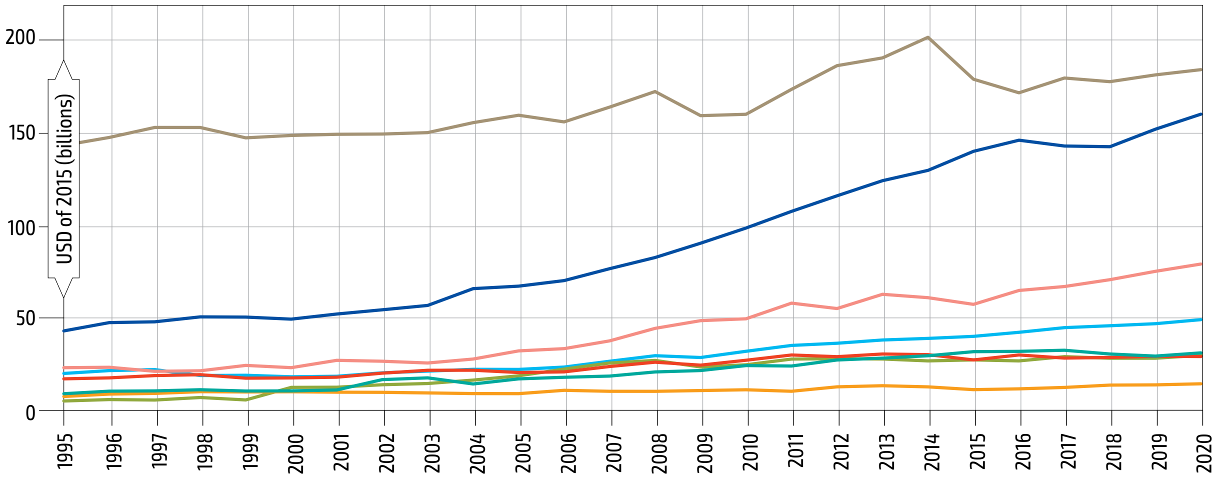
Data challenges hinder the analysis of investment, particularly because of insufficient and incomparable data across categories. Further, the data are limited in scope, may not always distinguish between investment and expenditure, vary in quality and coverage and may not be comparable across stakeholders. These challenges are especially pronounced in regions like sub-Saharan Africa (SSA), for which the demand for the concerted mobilization and coordination of public and private investment is particularly important. Strengthening data and analysis in processing (industry) and service segments of agrifood systems is particularly important for the mobilization of investment needed to drive inclusive, value-added and job-creating downstream growth.

[az] The term "developing countries" is quoted here as it is in the original source. Its use in this report is for purposes of reference only and does not imply any value judgement on the development conditions of any of the countries implicitly or explicitly included in this category.

Trends in gross fixed capital formation in agriculture, forestry and fisheries

In 2020, gross fixed capital formation in agriculture, forestry and fisheries totalled USD 577 billion (in constant USD of 2015). Of this, around USD 183 billion (32 percent) were in high-income countries (HICs), USD 159 billion in China (27 percent), 79 billion (14 percent) in South Asia (SAS), while, in all other regions, it was less than 10 percent of the total (see Table 1.18a). Thus, close to 60 percent of the total was taking place in HICs and China. Overall, investment in agriculture, forestry and fisheries (gross fixed capital formation) has been increasing. A look at growth rates shows that it is in SAS where investment grew fastest over the period, followed by China and SSA. In Near East and North Africa (NNA), investment has only grown marginally. In HICs, a limited investment growth occurred due to setbacks in 2009 and 2010, in the aftermath of the financial crisis, and again in 2015, as displayed in Figure 1.49.

Figure 1.49 Agricultural gross fixed capital formation by region (1995–2020)



Notes: Agriculture definition comprises agriculture, forestry and fishing.

Source: Authors' elaboration based on FAO. 2022. Capital Stock. In: *FAOSTAT*. Rome. Cited 18 May 2022. www.fao.org/faostat/en/#data/CS

When this level of investment is considered in per capita terms (see Table 1.18b), regional disparities are striking. In 2020, HICs are, by far, the countries where investment in agriculture per inhabitant is highest, despite the sluggish growth in the last two decades highlighted above. Per capita investment in HICs exceeds by close to 40 percent that of China, it is more than two times the world average and that of East Asia and the Pacific (EAP) and Europe and Central Asia (ECA), it is almost three times that of Latin America and the Caribbean (LAC), four times that of SAS and NNA more than five times that of SSA. In addition, there is to note that SSA is the only region where per capita gross fixed capital formation in agriculture has declined since 2010.

HICs tend to reinvest more of their resources in productive assets. The average agricultural investment ratio (gross fixed capital formation as a share of value added in agriculture that is reinvested in new fixed assets), is about 16 percent on average globally. This ratio is the highest in HICs (29 percent) and lowest in the NNA (9 percent). HICs have always devoted a larger share of investment to agriculture in total investment than the weight of the sector in gross domestic product (GDP), while it is the reverse in low- and middle-income countries (LMICs). Agriculture in HICs is significantly more capital-intensive than in LMICs, as it requires four units of capital to generate one unit of value added, compared to around 1.5 in LMICs. This highlights the fact that producers in HICs, on average, tend to reinvest more of their assets for productive purposes than those in LMICs. However, capital intensity in agriculture is now growing fast in ECA and China, accompanied, as a consequence, by a rapid decrease of the share of labour employed in agriculture[8] (see Section 1.12).

Table 1.18 Total gross fixed capital formation and per capita gross fixed capital formation (agriculture, forestry and fishing) by region (2001–2020)

a) Gross fixed capital formation

REGION	GROSS FIXED CAPITAL FORMATION (million constant USD of 2015)			CUMULATED GROWTH RATE OVER THE PERIOD (percent)	
	2000	2010	2020	2000–2010	2010–2020
High-income countries	147 645.4	158 947.0	182 761.4	7.7	15.0
China	49 606.4	98 241.9	159 005.3	98.0	61.9
East Asia and the Pacific	18 837.3	32 441.5	49 329.1	72.2	52.1
Europe and Central Asia	13 181.6	25 245.1	30 294.2	91.5	20.0
Latin America and the Caribbean	18 227.8	27 663.9	29 636.6	51.8	7.1
Near East and North Africa	10 840.4	11 904.0	15 092.1	9.8	26.8
South Asia	23 699.2	49 790.5	79 010.1	110.1	58.7
Sub-Saharan Africa	11 303.7	24 817.0	31 598.6	119.5	27.3
World	**293 341.7**	**429 050.8**	**576 727.4**	**46.3**	**34.4**

b) Gross fixed capital formation per capita

REGION	GROSS FIXED CAPITAL FORMATION PER CAPITA (constant USD of 2015)			CUMULATED GROWTH RATE OVER THE PERIOD (percent)	
	2000	2010	2020	2000–2010	2010–2020
High-income countries	138.2	138.9	152.0	0.5	9.4
China	38.4	71.8	110.5	86.7	54.0
East Asia and the Pacific	35.5	53.8	72.9	51.4	35.6
Europe and Central Asia	35.6	66.5	75.8	86.9	14.0
Latin America and the Caribbean	37.0	49.4	51.1	33.6	3.4
Near East and North Africa	38.8	35.7	38.1	-7.8	6.6
South Asia	17.0	30.4	42.6	78.3	40.2
Sub-Saharan Africa	17.9	30.1	29.3	68.0	-2.8
World	**48.5**	**62.6**	**75.6**	**29.2**	**20.7**

Sources: Authors' elaboration. Gross fixed capital formation based on FAO. 2022. Capital Stock. In: *FAOSTAT*. Rome. Cited 8 May 2022. www.fao.org/faostat/en/#data/CS; population and employment based on FAO. 2022. Annual population. In: *FAOSTAT*. Rome. Cited 8 May 2022. www.fao.org/faostat/en/#data/OA

1.10.2 Public investment in agrifood systems

Domestic public investment

Data on government agricultural investment, intended in a strict sense as public capital expenditure in agrifood systems, is scattered across countries and periods. In addition, the concept of investment per se may include items that are not necessarily classified as capital expenditure. For example, the report *Achieving zero Hunger – The critical role of investments in social protection and* *agriculture*[9] broadened the concept of investment to include expenditure in social protection. The assumption is that social protection policies, if properly designed, may allow poor people not only to immediately increase their well-being, but also to save and improve household assets, health, education and other immaterial capital, including human capital. Thus, the extent to which social protection expenditure may be considered an investment in agrifood systems depends on the targeted areas (whether rural or urban), targeted people (whether related to agrifood systems such as small-scale farmers or food processors) and, more in general, whether they are expected to impact in the medium to long run on agrifood systems.

Definitely more information exists on government expenditure (current plus capital). Unfortunately, government expenditure include items that cannot be considered investment per se.[ba] In addition, government expenditure includes various forms of support to agriculture that not necessarily favour sustainable development (see Sections 1.3 and 1.8 on repurposing agricultural support).

Despite all the caveats above, inspecting public expenditure in agriculture allows gaining a general view of the extent to which governments commit to allocate money to agriculture that is invest in a loose sense.[12] Indeed, Although the proportions of the investment and recurrent expenditure may vary considerably, it is generally taken as an indicator of public involvement in agriculture and as a proxy for public investment.[13]

Globally, government expenditure on agriculture, forestry and fisheries (GEA) as a share of total government expenditure has remained broadly steady at around 2 percent between 2001 and 2020.[14] At the regional level, in SSA, during 2008, owing to the food price crisis, the GEA peaked at more than 3 percent. However, much of this increased spending was allocated to input subsidies and food assistance programmes, with uncertain impacts on material and immaterial assets.[15] Since then, GEA's share has fallen below 2.5 percent until 2020, albeit with some subregional differences. In any case, it remained well below the 2003 Maputo commitment of 10 percent (see Box 1.33).

Box 1.33 Public expenditure in food and agriculture in sub-Saharan Africa

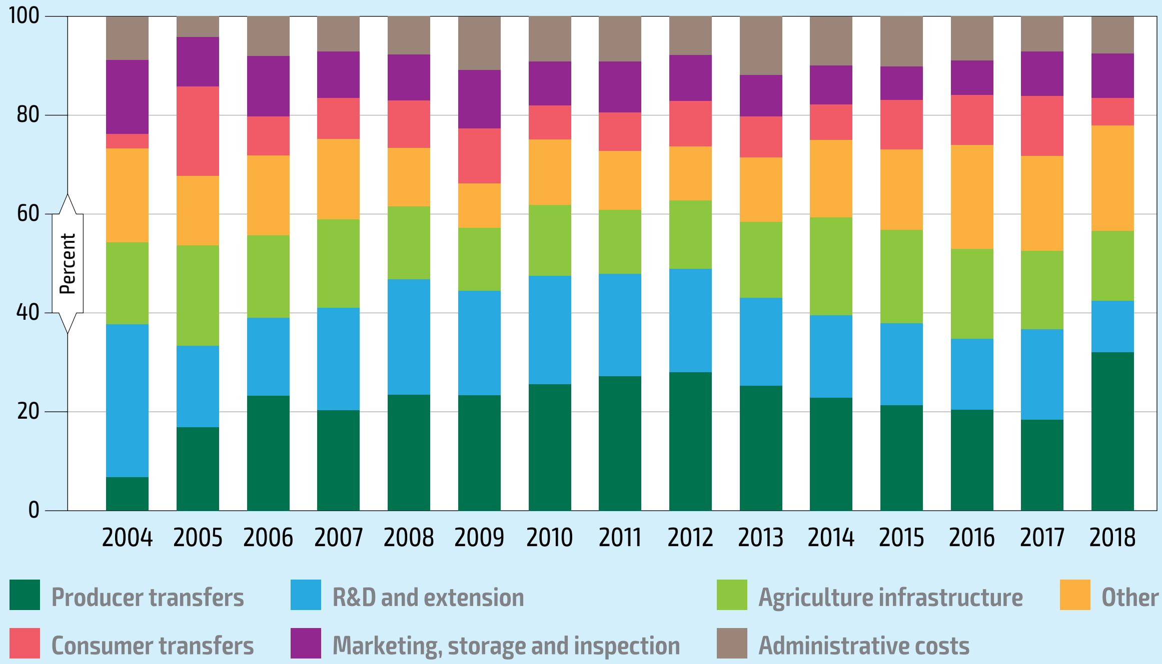
Public expenditure on agriculture remains low in sub-Saharan Africa (SSA). Eighteen years after the 2003 Maputo Declaration, in which African governments committed to dedicate more than 10 percent of their public expenditure to agriculture and rural development, only very few countries in the continent have reached this target. In the thirteen countries analysed by FAO's Monitoring and Analysis of Food and Agricultural Policies (MAFAP) programme, only one (Malawi) consistently met the 10 percent threshold of public spenfing on food and agriculture, while the average public spending onfood and agriculture for the 13 countries represents around 6 percent over the 2004–2018 period analysed.

Most of the expenditure carried out so far covers subsidies, which have been found to lead to mixed outcomes. In the countries analysed by MAFAP, the main uses of public expenditure for food and agriculture have been for: transfers to producers (mostly through agricultural input subsidies); R&D and extension, agricultural infrastructure (mainly irrigation); and transfer to consumers (through social protection programmes such as cash transfers and school feeding) (see Figure A).

[ba] For instance, according to the metadata note in FAOSTAT on government expenditure in agriculture forestry and fisheries, this item includes: administration of agricultural affairs and services; operation or support of programmes or schemes to stabilize or improve farm prices and farm incomes; or operation or support of programmes or schemes to stabilize or improve farm prices and farm incomes; which cannot be considered investment per se.[10] This may limit the use of this variable as a proxy to monitor public investment in agriculture as part of the Sustainable Development Goals (SDGs) Target 2.a: Increase investment, including through enhanced international cooperation, in rural infrastructure, agricultural research and extension services, technology development and plant and livestock gene banks in order to enhance agricultural productive capacity in developing countries, in particular least developed countries.[11]

Box 1.33 (cont.) Public expenditure in food and agriculture in sub-Saharan Africa

Figure A. Trends of expenditure shares over total expenditure on food and agriculture (13 MAFAP countries, 2004 to 2018)



Source: Pernechele, V., Fontes, F., Baborska, R., Nkuingoua, J., Pan, X. & Tuyishime, C. 2021. *Public expenditure on food and agriculture in sub-Saharan Africa: trends, challenges and priorities*. Rome, FAO. https://doi.org/10.4060/cb4492en

The analysis shows that, on average, 21 percent of budgets were not spent, suggesting that large financial commitments are not sufficient to enable a country to transform its agriculture sector. Implementation is equally important. This is particularly true for donor-funded expenditures, where the share of unspent funds was found to be substantially higher (at around 40 percent).

The MAFAP analysis showed that higher spending per capita is associated with better agricultural outcomes (proxied by technical efficiency). Beyond a certain level, however, this relationship becomes weaker, with a possible saturation point. The majority of African countries are well below this point, indicating underfunding in the agriculture sector.

Countries that allocate larger shares to input subsidies were found to fare worse in terms of agricultural outcomes than those spending more on consumer transfers (i.e. cash transfers and food aid programmes), R&D and extension services. The negative effect of overinvesting in private goods, such as input subsides, seems to be particularly harmful for countries at more advanced stages of agricultural transformation.

It is by far China, SAS and EAP that allocated the highest share of government expenditure on agriculture throughout the last two decades, with shares exceeding 6 percent in some instances. LAC lagged behind with shares below 2 percent while HICs have so far allocated shares close to 1 percent, along a declining trend in the period considered (see Table 1.19).

Overall, if China is singled out, the global trend in the last decades is downward sloping as it is in most regions.

Furthermore, the share of GEA in total government expenditure remains far below the share of agricultural value added in GDP as reflected by the AOI for GEA.

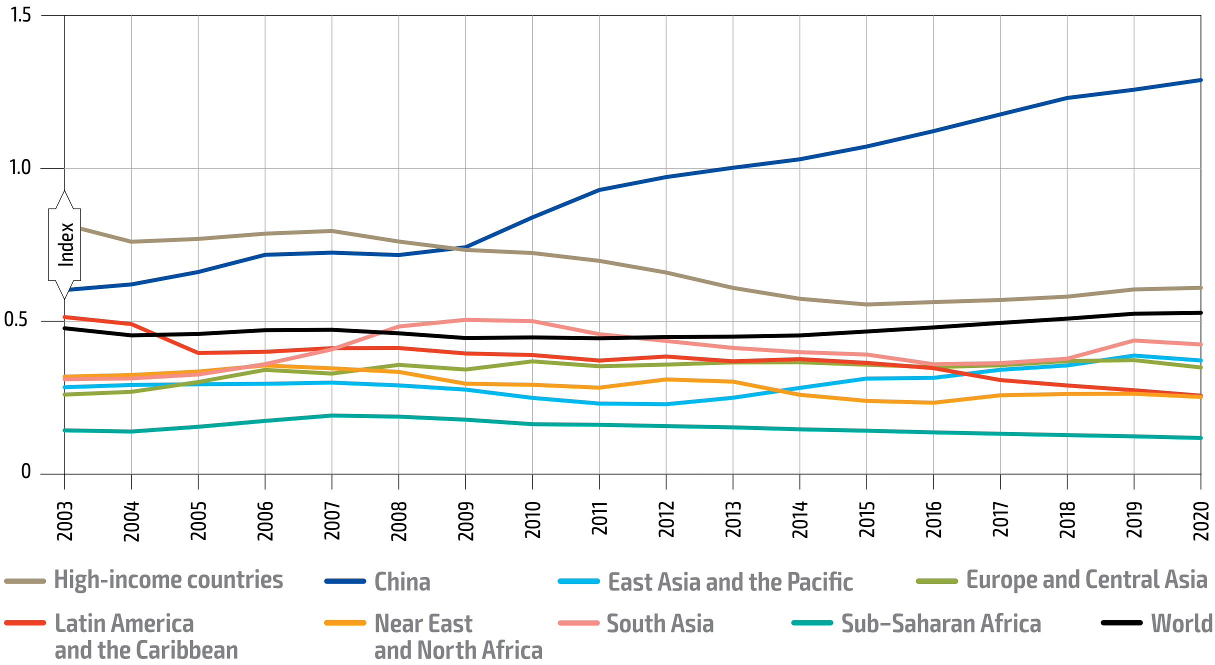
When the AOI for GEA, defined as the share of GEA in total government expenditure divided by the share of agricultural value added in GDP,[1] is greater than 1, the agriculture's weight in government spending is more than agriculture's share in GDP. Conversely if it is less than 1, it denotes an underspending. Figure 1.50 highlights the evolution of the AOI between 2001 and 2020, by region. Globally, in this period, the AOI remained at around 0.50. This means that GEA is roughly half of what it would be if it were commensurate to the weight of the agricultural sector in the economy.

Table 1.19 Share of government expenditure in agriculture by region (2001–2020)

REGION	SHARE OF AGRICULTURE IN GOVERNMENT EXPENDITURE (percent)				
	2001	2005	2010	2015	2020
High-income countries	1.4	1.1	0.9	0.7	0.7
China	8.1	8.6	9.1	9.9	9.6
East Asia and the Pacific	3.6	3.5	3.1	4.3	4.1
Europe and Central Asia	2.5	2.3	2.1	2.2	1.7
Latin America and the Caribbean	2.2	2.1	1.9	1.7	1.3
Near East and North Africa	3.2	3.5	2.6	2.5	2.7
South Asia	6.9	6.3	8.1	6.5	6.6
Sub-Saharan Africa	2.8	2.8	2.7	2.3	2.3
World	**1.7**	**1.5**	**1.7**	**2.1**	**2.2**

Sources: Authors' elaboration. Government expenditure based on FAO. 2022. SDG indicators In: *FAOSTAT*. Rome. Cited 30 June 2022. www.fao.org/faostat/en/#data/SDGB and selected unpublished background data in such dataset.

Figure 1.50 Orientation index of government expenditure in agriculture by region (2003–2020)



Notes: "Agriculture" includes forestry and fisheries. "Government" refers to general government, including all the government levels in each country, when data are available. The Agricultural orientation index of government expenditure in agriculture (GEA) is calculated as GEA/government expenditure (economy-wide) divided by value added in agriculture/GDP (share of agricultural expenditure divided by the share of value added).

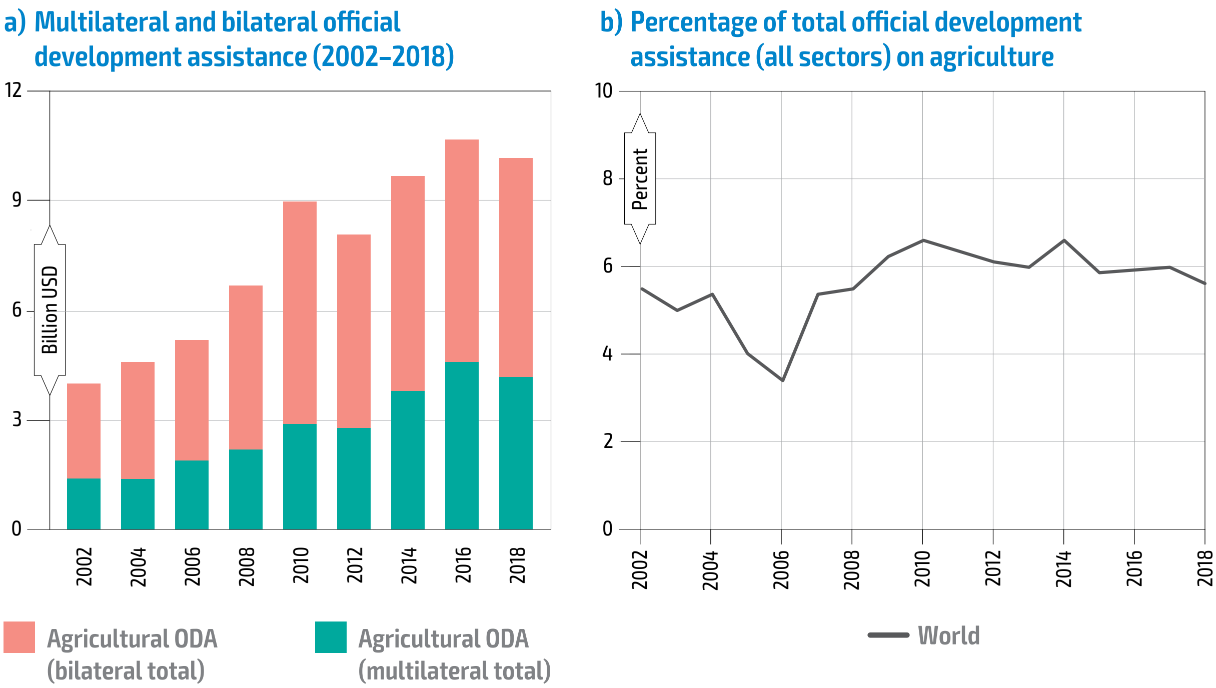
Sources: Authors' elaboration. Government expenditure based on FAO. 2022. SDG indicators In: *FAOSTAT*. Rome. Cited 30 June 2022. www.fao.org/faostat/en/#data/SDGB and selected unpublished background data in such dataset.

Among regions, SSA definitely displays the lowest AOI, well below 0.2 during the whole period and following a downward trend. This highlights that, on average, in SSA governments typically underspend on the agriculture sector. This underexpenditure is likely to impact on the future performances of SSA, particularly as it also affects public expenditure in agricultural research, a domain where LMICs dramatically lag behind HICs (see Box 1.32). To some extent, this consideration may also apply to LAC, whose AOI follows a declining trend since 2001. When it was 0.47 to reach a low 0.22 in 2020. Conversely, China and EAP follow an upward trend, with China exceeding 1 in the last decade. Overall, if China is singled out, the AOI for GEA globally follows a significantly decreasing pattern in the period.

Foreign public expenditure and investment

Public funds from countries, channelled as bilateral or multilateral assistance, also play an important role in agrifood systems investment. Total Official Development Assistance (ODA) in agriculture, forestry and fishing increased by over 156 percent between 2002 and 2018, standing at USD 10.2 billion in 2018 (Figure 1.51). Africa and Asia have been the main recipients of these funds.[20] At the same time, the share of agriculture, forestry and fisheries in total ODA declined since 2008. In 2018, this share was 5.2 percent, the lowest since 2008.

Figure 1.51 Official development assistance for agriculture by all official donors



Sources: Authors' elaboration. Panel a) based on Eber-Rose, M., Laborde, D. & Murphy, S. 2020. *Ending Hunger Sustainably: Trends in official development assistance (ODA) spending for agriculture*. Ceres2030. Panel b) based on OECD. 2022. Aid (ODA) by sector and donor [DAC5]. In: *OECD.Stat*. Paris. Cited 15 June 2022. https://stats.oecd.org/viewhtml.aspx?datasetcode=TABLE5&lang=en

Despite its importance as a source of investment, particularly for LICs, ODA remains modest relative to agricultural output. For instance, African countries received USD 4.5 billion in 2018. While this was almost three times the region's public expenditure on agriculture, it represented less than 1.3 percent of Africa's agricultural GDP. In addition, the high amount of ODA, compared to domestic public expenditure, may also involve conditions for recipient governments on strategies to be followed that may shape domestic policies.[21,22]

From that perspective, the priority given to leveraging private finance, in the wake of the Addis Ababa Third International Conference on Financing for Development, and the resulting growing share of blended finance in ODA that concentrates more on sectors such as infrastructure, banking and financial services, and on middle-income level countries, may deflect ODA from crucial investments required to eradicate poverty in LICs,[23] including investment in agrifood systems.

The role of public expenditure, investment and policies in shaping private investment

The rationale for public investment is to provide public goods, address externalities, create incentives through subsidies or co-funding to leverage and orient private investment.[24] Country-level evidence supports these arguments around the public sector's role. For instance, in China, a strong commitment to agricultural research and complementary rural investments triggered productivity gains in agriculture after the 1980s.[25] In Nepal, investments in roads and bridges moderated food price levels and volatility.[26]

The overall policy and regulatory environment, along with investment in public goods, shape the level and effectiveness of private investments.[18] Government policies, including foreign direct investment (FDI) rules, property rights, access to banking, labour regulations, taxation, and patent regimes, shape the quantity and allocation of private investment.[27]

Reciprocally, domestic public investments and policies are influenced by the aim of attracting greater private investment. They often comprise specific investment support measures such as investment facilitation (including online), investment promotion and information dissemination, incentives for investment that target certain sectors, or simplified administrative procedures. There are also special policy measures around FDI, such as negotiating international or bilateral investment agreements, providing incentives for foreign investors, relaxing rules and regulations, and facilitating flows, including profit repatriation. In India, for example, the Department of Industrial Policy and Promotion allows 100 percent FDI in agriculture under the automatic route for selected activities, although challenges stemming from uncertain property rights and contract farming can deter investments.[28]

Beyond policy support to attract greater amounts of FDI, public policies also play a role in shaping the composition of investment. For example, the *Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests in the context of National Food Security* (VGGT)[29] contains provisions to guide responsible foreign investment. Policies around land ownership and titling also affect investment in agrifood systems. For instance, studies found that secure land tenure encourages farm-level investment in West Africa and enhances market access in Chad.[30,31] Studies also support the argument that secure land rights can increase farmers' incentives to make long-term investments, such as in land and water management.[32]

1.10.3 Private investment in agrifood systems

Private investment is the most important source of investment in agrifood systems, and within private sources, farmers themselves are first in the field of production, while private companies are the main actors in value chains. On-farm investment in agricultural capital stock is more than three times as large as all other sources of investment combined.[18]

Sources of finance for private sector investments are expanding and diversifying, particularly in value chains. Sources include own savings, local and international banks, value chains actors (agricultural dealers, services providers and fintech companies), impact investors, development financing institutions, private sector foundations, and agricultural investment funds. Increasing private sector investment and associated financing requires identifying and understanding market failures currently leading to the suboptimal private provision of goods and services needed to achieve key development goals.[33,34]

Various constraints hinder private investment in agrifood systems including agricultural and other risks, cost of capital, volatile prices, inconsistent application of policies and inadequate public goods. For instance, agriculture is exposed to weather shocks and natural hazards. Agricultural prices are volatile and market failures and inadequate provision of necessary public goods deter many private investors from operating in agrifood systems. Often, after accounting for transaction costs, risks, many private investors may not find it economically viable to invest in the sector.

Commercial bank credit to agriculture

The banking system is an important source of financing for agrifood systems, though its importance varies by country. Outstanding loans by private or commercial banks to producers in agriculture, forestry, and fisheries (including farming household, cooperatives, and agri-businesses) was USD 808 billion in 2020 (in constant USD of 2015). This figure has increased by around 8 percent between 2010 and 2020. However, there are large differences in the dynamics of credit provision across regions. Compared to 2010 in 2020 credit dramatically dropped ECA and NNA (minus 87.8 and 73.5 percent respectively), while it largely grew in SSA (+404.3 percent) but also in China, EAP and LAC. Despite the dramatic increase over the period considered, credit in SSA remains still quite limited compared to other regions. It is also worth noting that in 2020 two-thirds of the global credit to agriculture were provided in HICs and China (see Table 1.20).

Table 1.20 Credit to agriculture, forestry and fishing (2010–2020)

REGION	AMOUNT OF CREDIT (millions constant USD of 2015)		VARIATION (percent)
	2010	2020	2010–2020
High-income countries	424 726	358 970	-15.5
China	120 062	179 204	49.3
East Asia and the Pacific	25 941	42 521	63.9
Europe and Central Asia	34 614	4 239	-87.8
Latin America and the Caribbean	16 417	24 861	51.4
Near East and North Africa	31 305	8 294	-73.5
South Asia	87 901	171 476	95.1
Sub-Saharan Africa	4 541	22 904	404.3
World	**745 510**	**808 233**	**8.4**

Note: Last year available for China is 2018.

Source: Authors' elaboration based on FAO. 2022. Credit to Agriculture. In: *FAOSTAT*. Cited 20 June 2022. www.fao.org/faostat/en/#data/IC

Smallholder investment

Self-financing by farmers is the largest sources of investment in agriculture.[18] It often relies on informal means, particularly in LICs. More than 90 percent of the 608 million farms globally are family farms, and 84 percent of these farms comprise less than two hectares of land.[35] On-farm investments by smallholders are the most critical component of agricultural investments for ensuring food security and poverty alleviation. However, smallholder investments are constrained by several factors, including low savings rate, difficult access to credit and uncertain property rights. Further, a caveat here is that some of the credit obtained by smallholders may be used for other purposes than investment.

Smallholders often invest in agrifood system mobilizing funds from informal sources such as savings groups, credit cooperatives and village savings associations. In 2015, about 30 percent of SSA smallholders and 25 percent of smallholders in South and Southeast Asia reported borrowing from informal and community-based institutions (various FinScope surveys, 2015), similar to Latin American smallholders.

Private investment in value chains

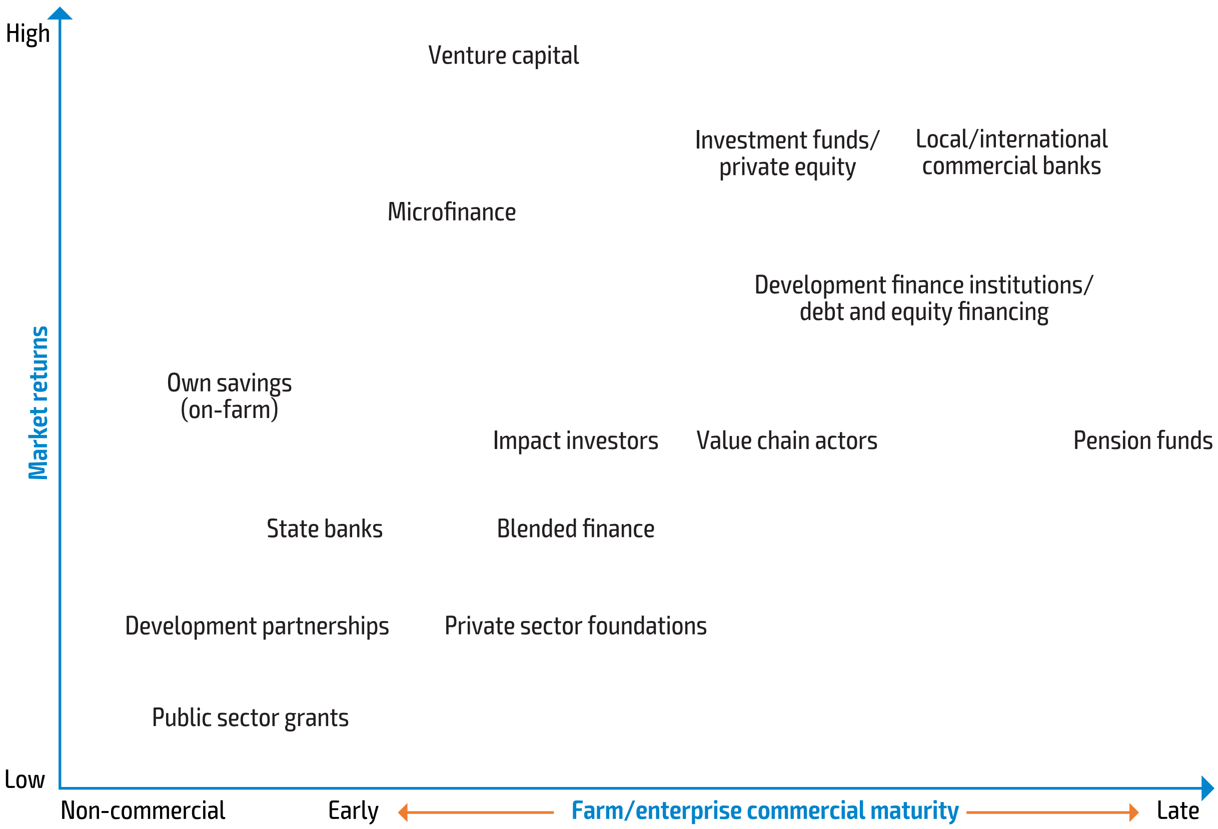
Investment in agrifood value chains has been growing, and the share of private investors has increased. Investments in value chains comprise those in wholesale and processing companies, food design, marketing and packaging, logistics, food distribution and retailing, along with AgTech (mechanization and automation, seeds and agrochemicals, biomaterials, and big data and its applications). Investments in transport, storage (including cold chains) and market infrastructure, as well as in electrification and communication are also fundamental, particularly when they are combined as they are essential for ensuring market access.[36]

Agrifood value chains have been evolving rapidly and gaining more attention around measuring financing. Value chain activities have been shifting, in part due to rapid changes occurring both upstream (technological and commercial) and downstream segments (urbanization and evolution of diets– see Section 1.14). In addition, food is being increasingly commercialized and businesses along the value chain are increasingly integrating (see Section 1.13). Along with these changes, there is greater interest in understanding better how investments take place along these value chains, a relatively understudied topic in the past due to the complex and cross-cutting nature of these value chains. As a result of these transformations, the intermediate part of value chains that is placed between agricultural production and consumption has progressively been capturing a greater share of value added generated within agrifood chains and attracting a growing volume of investment.[37]

Until the 1980s, in Asia and Africa, most of these changes – and related investments– were in the hands of the public sector. Later, with liberalization and the dismantling of parastatals, activities and investments became largely private[37, 38] except possibly for infrastructure where the public sector and, to some extent, public-private partnerships represent the bulk of investment.

Figure 1.52 shows the main actors of private investments in value chains, mapped according to the level of expected market return and the maturity of targeted enterprises. It illustrates that many of the new investors mentioned earlier are market-driven actors attracted by high profits. This carries the risk of creating a chasm between capital intensive, market-oriented commercial farms, on the one hand, and small farms with little surplus and limited investment capacity, on the other, with the possibility of public policies and investments geared towards commercial agricultural production and value chain promotion being incoherent with policies and investments aiming to reduce poverty and food insecurity.[39]

Figure 1.52 Landscape of financing entities for private sector actors in agrifood value chains



Note: Financing entities (lenders) are ranked by the rate of returns on loans they expect (y-axis – market returns) and maturity of the loans they provide (short-term versus long-term reimbursements, x-axis, early versus late maturity).

Source: World Bank. 2018. *Future of Food: Maximizing Finance for Development in Agricultural Value Chains.* Washington, DC.

The figure also highlights private financial actors entering the sector, such as pension funds, specialized investment funds, endowment funds and impact investors. These actors operate along with pre-existing private corporations and traders, and public organizations. They utilize a diversity of instruments and channels, including private equity, venture capital, private debt or green bonds and digital finance. Global commercial banks have continued to make up a large share of credit to agriculture, but various reports predict a growing share of investments for newer actors (see Box 1.34).[40] A large number of these new operators are based in the HICs of Northern America, Europe and to a more limited extent Asia.

Box 1.34 New investors and instruments: institutional investors

Between 2004 and 2020, the number of investment funds focusing on farmland and food production has grown from 7 to 300. Overall, in 2019, there was USD 121 billion worth of assets held by private institutional sources in food and agriculture. Of this, asset managers held 89 percent of funds, agribusinesses accounted for 4 percent, sovereign wealth funds accounted for another 4 percent and pension funds held 2 percent.[41]

Venture capital investment in agrifood systems is also playing an increasing role, particularly in the R&D area. In 2020, venture capitalists invested about USD 4.8 billion into the food and agriculture sector in Q1 and Q2, compared to the total funding of USD 7 billion in 2019.[42]

Investment of small- and medium-sized enterprises (SMEs) in value chains

Investment of SMEs in agrifood value chains is constrained by access to credit, particularly in SSA. Due to their disaggregated nature, it is hard to quantify investment by SMEs in agrifood systems. Across SSA, however, nearly three-quarters of SMEs in agriculture lack enough access to finance and the capacity to manage loans. The annual gap between capital supply and demand has been estimated at USD 65 billion a year for sub-Saharan SMEs alone.[43]

Surveys of SMEs in LICs list access to finance among the top challenges; banks find it riskier to lend to agri-SMEs. In Lesotho, where only 40 percent of SMEs have access to formal financial services, half of SMEs report securing credit as their primary difficulty.[44] The conditions are comparable in other African countries. In South Africa, 47 percent of SMEs are access to formal financial services, but 22 percent can also access savings via alternative formal non-bank institutions. An analysis conducted in East Africa covering lending data from commercial banks, non-bank financial companies and global social lenders revealed that risk in lending to agricultural SMEs is twice as high for bank lending to agri-SMEs relative to other sectors and that operating costs are also higher – the combined effect is returns are 4 to 5 percent lower for banks in their agri-SME lending relative to other sectors. Lending to agri-SMEs in many parts of Africa is considered unprofitable for loans of USD 25 000 to USD 50 000, because of below market rate returns and prohibitive management costs.[43]

Foreign direct investment (FDI)

FDI is relatively low in food and agriculture, compared to other sectors, and mostly linked to exports. Data on FDI in agrifood systems remains scarce and inconsistent across sources. The limited data suggest that FDI remains relatively small in the food and agriculture sector when compared to other sectors such as industry and services,[45] and despite the high hopes reflected in the substantial amount of literature produced on FDI and its potential role. This low share (6 percent and 0.5 percent of total FDI Stock respectively, for food and beverages and agri-based goods) can probably be explained by the low export intensity of food and agriculture (exports as a share of total industry output) that are of 35 percent and 14 percent, on average, for food and beverages and agri-based goods, respectively, compared to around 80 percent in industries like electronics, machinery or textiles.[46]

Multinationals play a key role in driving FDI, including across value chains and subsectors in food and agriculture. FDI has been predominantly directed to global value chains where trade is a driving force and often involves mergers and acquisitions through which multinational corporations penetrate particular countries and become key players. Within agrifood systems, a large share of FDI goes to food processing, driven by large food and beverage corporations. The services sector (wholesale and retail trade, transport and logistics, various business services, as well as investment and holding companies) also attracts a large share of FDI.[45] However, data on cross-border mergers and acquisitions indicate a rapid growth of over 300 percent in the food, beverage and tobacco industries between 2019 and 2020.[47]

Within agrifood systems, foreign investment in land and its impact is a controversial topic. On the one hand, FDI in land is seen as a source of capital and transfer technology from HICs to the host country, which can contribute to increased production and, possibly, employment creation. On the other hand, there are concerns around foreign ownership of domestic land and its impact on local communities and food security, inclusive development, sustainability and growth.

Impact investments

Agriculture captures a small but growing share of impact investments. Impact investments consist of financing companies, organizations and funds that aim to generate a measurable, beneficial social or environmental impact alongside financial returns; they are currently used primarily in HICs, but are growing in emerging economies. Socially responsible (SRI) and environmental, social and governance (ESG) investing are two main approaches to impact investing.

Agrifood systems represent about 9 percent of the assets under management by impact investors globally, according to the Global Impact Investment Network.48 In a recent survey, the aggregate size of current assets of impact investors is small compared to other financial flows in the sector, but is rapidly growing. The future growth potential for impact investing is significant. A study found that focusing on green investments, including decarbonization in agriculture, could generate about USD 1 trillion in investment opportunities and support over 40 million direct new jobs.[49]

1.10.4 Future trends

In 2018, FAO explored alternative pathways to 2050 through three scenarios that envisioned different future trends for investment in food and agriculture.[50] Table 1.21 summarizes their main characteristics.

Table 1.21 Main characteristics of investment in the three scenarios in FAO's report *The future of food and agriculture – Alternative pathways to 2050*

SCENARIO	SUMMARY DESCRIPTION	INVESTMENT TRENDS
Business as usual (BAU)	The economy develops according to socioeconomic, technological and environmental patterns that fail to address many challenges for food access and utilization, as well as for sustainable food stability and availability, despite efforts to achieve SDG targets.	Foreign investment continues along the North–South axis, following historical trends and with current levels of impact on economies and societies.
		Credit policies have no particular interest in innovative, sustainable enterprises, and public investment remains modest as per current trends.
		The adoption of conservation practices stagnates, as do investments in R&D for agriculture in LMICs.
		Innovation is generated through high investments in research following historical trends, with a reduced role of the public sector.

Table 1.21 (cont.) Main characteristics of investment in the three scenarios in FAO's report *The future of food and agriculture – Alternative pathways to 2050*

SCENARIO	SUMMARY DESCRIPTION	INVESTMENT TRENDS
Towards sustainability (TSS)	The economy develops along virtuous social, environmental and economic dynamics that ensure fairly generalized equity in terms of access to basic services and sufficient, safe and nutritious food mostly produced with environmentally sustainable methods. Comparatively more resource-efficient food production systems and inclusive societies imply lower challenges for achieving SDG targets and beyond 2030.	Foreign investment is higher than in the BAU scenario, with positive impacts on local incomes. Domestic savings increase and help to finance investments in innovative technologies such as precision agriculture and applied robotics.
		Public investment focuses on R&D that stimulates technical progress on sustainable and pro-poor policies. Strong internal redistribution reduces inequality and eases access to food for the poor.
		Widespread conservation practices and increased R&D investments lead to a sharp decrease in greenhouse gas (GHG) emissions
		Massive investments enable increasing proportions of the world's energy needs to be satisfied by renewable sources.
		Extreme poverty reduction targets are achieved by 2030 as a result of pro-poor investments.
		Investments improve food storage and processing, and speed up technological transition to sustainable production processes.
		Boosted investment ensures the transition towards a more sustainable use of natural resources and effective climate change mitigation.
Stratified societies (SSS)	The way the economy develops structures societies in separate layers. Self-protected elites use their decisional power primarily to protect their position and interests. They do not feel the urgency to conserve natural resources or mitigate climate change. Simultaneous increased poverty, food insecurity and poor nutrition lead to the over-exploitation of natural resources and unmanaged agglomerations. Both equity and sustainable production are more seriously challenged than under the BAU scenario.	Foreign investment in LMICs is higher than in BAU, but with limited impact on local incomes.
		Public investment is limited and flows to non-sustainable practices that favour both fossil fuels use and the elite.
		Highly unequal investments in human capital, know-how, physical and financial assets, generated by disparities in incomes and saving potential as well as uneven opportunities to invest, lead to increasing inequalities both among and within countries.
		Limited investments flow to R&D and the intensive use of chemicals and land in agriculture, as well as fossil fuels economy-wide, contribute to very high levels of GHG emissions.
		Little investment is made towards water use efficiency.

Source: Authors' elaboration based on FAO. 2018. *The future of food and agriculture – Alternative pathways to 2050*. Rome. www.fao.org/3/i8429en/i8429en.pdf

1.10.5 Summary remarks

Investment plays a central role in driving change in agrifood systems. It has been growing, particularly after the 2008 food price crisis, evolving rapidly and engaging new private actors such as pension funds, specialized investment funds, endowment funds and impact investors, in addition to pre-existing private corporations, traders and public organizations operating in the sector. Hybrid mechanisms, such as blended finance, that strategically utilize public funds to attract private investment are playing an increasingly important role in agrifood systems investment.

At the same time, there remain considerable disparities across countries. For instance, per capita investment in HICs was five times larger than in SSA in 2019. As a result, more than half of the overall investment is taking place in HICs and China.

Public investment in agriculture mainly aims at enhancing productivity, funding critical public goods, reducing poverty and food insecurity, and facilitating and shaping private investment. The proportion of public resources allocated to the sector is usually less than the sector's weight in the economy. A share of public finance is increasingly used for blended finance to support private enterprise development.

FDI is low in agrifood systems, relative to other sectors, and mostly linked to exports, but it has boomed during the COVID-19 pandemic. In contrast, self-financing remains the largest source of investment for farmers, and smallholders rely often on informal providers such as savings groups, credit cooperatives and village savings associations, particularly in LMICs.

Beyond agriculture, the development of global value chains has attracted a growing volume of investments, predominantly private, boosting the emergence of a myriad of SMEs. However, evidence suggests that investments by national agrifood systems actors in downstream segments of value chains is lacking, reducing their productivity and competitiveness. This has huge potential impacts on value addition, job creation with upstream and downstream multiplier effects in the agrifood system and related sectors.

If past trends continue, private investment in agrifood systems will continue to make up the bulk of total investments in the sector. This will help meet the growing capital needs of agrifood systems. It could, however, penalize smallholders, the poorest of who may become increasingly marginalized, if there are no funds mobilized to meet their investment needs and allow them to benefit from the development of agrifood systems. More than ever, public action and investment are critical in catalysing the mobilization of financing to provide indispensable public goods, an incentivizing environment, and ensure that investments made are both inclusive and sustainable.

NOTES – SECTION 1.10

1. **FAO.** 2022. Sustainable Development Goals | Indicator 2.a.1 - The agriculture orientation index for government expenditures. In: *FAO*. Rome. Cited 12 May 2022. www.fao.org/sustainable-development-goals/indicators/2a1

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1.11 Capital and information intensity of production (Driver 12)[bb]

With mechanization and digitalization, capital and information intensity of production is increasing in almost all sectors, including in food and agriculture. While this process contributes to raising overall productivity, it also raises concerns about the level of employment, both in rural and urban areas. A report of the United Nations Secretary-General, issued in January 2020, states that:

> "The manufacturing sector has traditionally absorbed excess labour freed by agricultural development […] however […] the manufacturing, agrifood and service sectors are themselves undergoing capital intensification through the adoption of information technologies (robotics, digitalization and artificial intelligence) that reduce the need for workers" (United Nations, 2020, p. 16).[2]

Increasing capital intensity in the downstream segments of food value chains limits labour demand in processing and distribution, other things being equal. In addition, the mechanization and digitalization of primary production lowers the entitlement to profits of those farmers who do not appropriate the new capital assets, for lack of access to finance, training and other means to increase their human capital. However, although the progressive spread of new technologies is likely to increase profitability, require new professional profiles and create new job opportunities, it is most probable that the net job balance will be negative. Thus, increasing capital and information intensity of food production may further contribute to urban migration. Moreover, the level of employment and other earning opportunities found in urban areas will determine the levels of poverty and food security experienced by these migrants.

This section explores possible implications for agrifood systems, employment and natural resources pose by the changing intensity of capital and information in agrifood and economy-wide processes. Here, capital intensity will be understood either with respect to output or in relation to other inputs, and in particular, labour. For example, a greater value of capital equipment relative to the amount of labour (the capital-labour ratio) indicates a greater intensity of capital use.

With this in mind, questions considered here, or in other parts of this report, include:

- How might capital and information intensity of production affect income and wealth distribution in the future?
- Is a jobless growth or a jobless structural transformation plausible? To what extent might digitaliza-tion, automation or robotization affect labour demand and wages in agrifood systems and economy-wide?
- To what extent might capital and information intensity dynamics in agrifood systems influence the future use of natural resources?
- What plausible scenarios can be built regarding capital and information intensity of production pro-cesses, as well as capital and information ownership, across countries?
- How can investment in human capital, as the body of productive knowledge and the physical and mental conditions that make people act to take part in productive activities, contribute to addressing the risk of job losses?

Agrifood systems are highly heterogeneous, spanning multiple sectors of the economy. They include age-old operations like land preparation, crop management, harvesting, post-harvest handling, primary and secondary processing, and, more recently, tertiary processing, such as preparing and distributing pre-packaged meals.

Each stage in agrifood value chains involves multiple technologies and inputs ranging from labour, simple implements such as hoes and loppers, physical structures such as canals or storage facilities, machines and means of transport, seeds, agrochemicals, water, power and so on. They also rely on non-market inputs, such as sunlight, soil biota, pollinators and pest predators.

[bb] This section and related Annex 2 draws upon Kemp-Benedict and Adams (2021).[1]

An enormous amount of tacit knowledge – knowledge that is uncodified and learned through experience – can be found across agrifood systems. Formal knowledge is also employed, encompassing agronomy, husbandry, soil science, biochemistry, food science and others. Finally, there is information, which is distinct from knowledge. Contemporary agrifood systems abound with remotely collected information about soil and weather conditions, markets and storage capacity that can help producers to improve output, cut costs and gain price advantages through planting and harvesting decisions, or through arbitrage opportunities (see Section 1.4).

Within the agrifood system, any sufficiently isolated unit must cover its costs with its revenues. For that reason, the main strategy for raising profitability is to reduce costs. One way to achieve this, in the longer run, is to reduce the amount of an input required for production through technological change. This can be achieved by introducing a new and more efficient piece of machinery or other physical change, but also through improved procedures using the producer's existing physical capital stock. Yet other ways of reducing input prices include convincing suppliers to charge a lower price in exchange for a guaranteed market, or lobbying the government for subsidies. Labour costs might be reduced by employing a vulnerable workforce with weak bargaining power (e.g. marginal groups or migrants).

This section discusses the following components of agrifood systems: agriculture (land preparation, planting, tending and harvesting); pre-processing (post-harvest handling, transportation and storage); and processing (food processing and packaging). Other components, such as wholesale and retail trade, will not be discussed.

The above questions will be addressed with a focus almost exclusively on conventional notions of economic development. Annex 2 provides a subset of the mathematical models used in the literature dealing with this topic.

1.11.1 Recent trends: productivity and distribution

Capital and labour productivity

The link between income distribution and technological change is a long-standing focus of research in economics. In conventional economics, technological possibilities, combined with profit-maximizing behaviour of firms, are believed to determine income distribution (see Sections A and C of Annex 2). The model of directed technological change itself,[3] offers an explanation for why technological change proceeds in one direction or another, biased towards saving labour or saving capital. In that model, changing costs of inputs lead "technology monopolists" to focus their inventive energies on producing machines to save on one input relative to another. In this way, income distribution helps to determine productivity growth. Similarly, a separate class of theories of technological change explains how income distribution influences the pace and direction of technological change and vice versa (see Section B of Annex 2), combining an explanation for how income distribution determines productivity growth rates with a variety of mechanisms through which productivity growth leads to changes in income distribution, with the outcome depending on comparative bargaining strength.

The implication of these theoretical traditions is that **the relationship between income distribution and the pace and direction of technological change flows in both directions.** Subject to the caveat that some inputs tend to be substitutes (e.g. machines as replacements for human labour and animal traction), while others are complements (e.g. machines require fuel), the tendency is for a rising cost share of one input to induce a subsequent rise in the productivity growth of that input. Nevertheless, in practice, much analysis considers one direction of influence: from technology to income distribution.

It is difficult to measure capital and information intensity. The first of the two questions posed above, regarding changes in intensity, is asking about productivity change, either for an individual input or with respect to another input. For example, the capital-labour ratio, equal to the labour productivity divided by capital productivity, is a measure of capital intensity vis-à-vis labour. There are serious problems with measuring capital as it is highly heterogeneous. In the case of information, there is no intrinsic measure, and the recommended assessment of information intensity was qualitative rather than quantitative,[4] despite several methods proposed in the literature.[5,6]

More recently, a review of the literature, identified a number of characteristics of information value, including its quality, structure, diffusion, infrastructure and utility.[7] Given the current state of the art, "information intensity" will be treated as a metaphor, while "capital intensity" will be treated as a measurable (although problematic) quantity.

"Capital deepening". The long-run historical pattern has been the substitution of labour and animal traction with machines, a process known as "capital deepening".[8] This process leads to a steadily rising capital-labour ratio. Labour and capital productivity trends can be computed using national accounts data from the Penn World Table 9.1.[9,10] For this section, time series have been constructed for average productivity for the current high-income countries (HICs) and middle-income countries.[bc]

In HICs, applying a structural break-finding algorithm to the time series gave break dates of 1963, 1972 and 2007 for labour productivity,[bd] as shown in Figure 1.53. The first date was the start year for a rapid period of post-war growth in several HICs, and which accelerated, passing from 2.7 percent per year to 3.9 percent growth per year. The other two dates marked decelerations, to 1.9 percent per year after the first oil crisis, and to 1.0 percent per year after the Global Financial Crisis. The net result has been a substantial slowing of labour productivity growth in HICs. Part of the evidence behind the hypothesis is that the HICs may be facing "secular stagnation".[13]

For the middle-income countries, labour productivity fell, on average, over the tumultuous 1950s. This was a period of independence movements – India and Pakistan gained independence in 1947, Ghana and Malaysia in 1957 – and the first years of the People's Republic of China. Subsequent to that period, the twenty years between 1960 and 1980, and the twenty-three years between 1981 and 2004, saw almost identical average growth rates of 2.8 percent per year and 2.7 percent per year, respectively. The difference was a drop in the level of labour productivity following the 1980s debt crisis. After 2005, average labour productivity growth accelerated to 3.8 percent per year. The result is that after the first oil crisis, today's middle-income countries began to converge slowly on the HICs. The convergence became much more rapid after the 2007 crisis – but still far too slow to close the gap in the coming decades.

Labour-saving technological change. In contrast to labour productivity, in virtual exponential growth, capital productivity remains within a comparatively narrow range. This means that technological change is "directed" or "biased" towards labour-saving innovation. As can be seen in Figure 1.54, in the HICs, capital productivity tends to be relatively stable. Nevertheless, there was a sharp and persistent drop in capital productivity between 1970 and 1981. Aside from some modest deviations, average capital productivity was nearly constant from 1950 to 1970 and from 1982 to 2017, but fell by about 0.2 percentage point per year from 1971 to 1981. These patterns and the associated break dates are distinct from those for labour productivity. Furthermore, both showed a decline: slowing labour productivity growth and lower capital productivity.

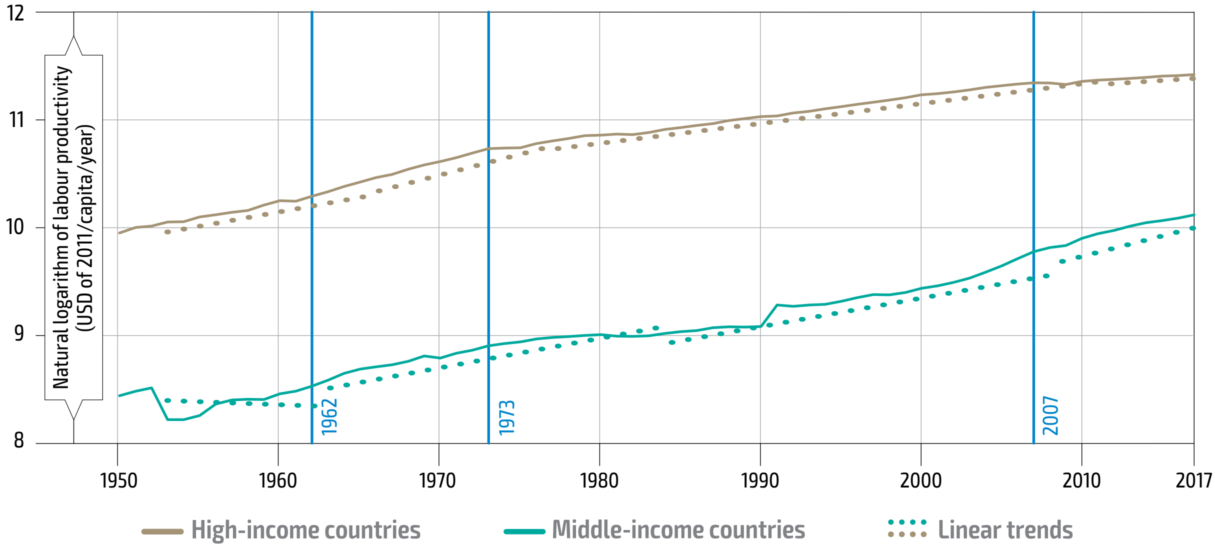
Sharing the benefits of higher productivity in HICs: a matter of power. When the fall in capital productivity first started, unions in HICs were comparatively strong, and real wages continued to rise in line with labour productivity growth. As a result, the wage share was constant as therefore was also the profit share. This meant that returns to investment, which are roughly proportional to the product of capital productivity and profit share, began to fall. Subsequently, unions were weakened, real wages began to stagnate, and the profit share began to rise. The result has been continuing low capital productivity, but with profit rates returning to their earlier levels. While the trigger may have been changing technological potential,[14] leading to declining capital productivity, the response can be explained from a political economy perspective: firms and governments actively sought to weaken unions. The delayed return to prior profit rates through a rising profit share may be indicative of a shift from fixed markup pricing policies, which leaves the wage-profit distribution unchanged, to target-return pricing policies, which leads the profit share to vary inversely with capital productivity, although both strategies can be found, along with others,

[bc] In this section "middle-income countries" refer to lower-middle-income and upper-middle-income countries as per the classification of countries based on the World Bank Country Groups of 2021 (available at http://databank. worldbank. org/data/download/site-content/CLASS.xlsx).

[bd] The R package strucchange[12] version 1.5–2. For presentational clarity, a maximum of three break dates was specified for each series.

in business surveys.[15] Target-return pricing, combined with cost share-induced technological change (outlined in Section B of Annex 2) can be shown to lead to a constant capital productivity as a long-run tendency, the pattern observed in HICs.[16] Cost share-induced technological change also suggests that a falling wage share will lead to slower labour productivity growth, consistent with the trend shown in Figure 1.53.

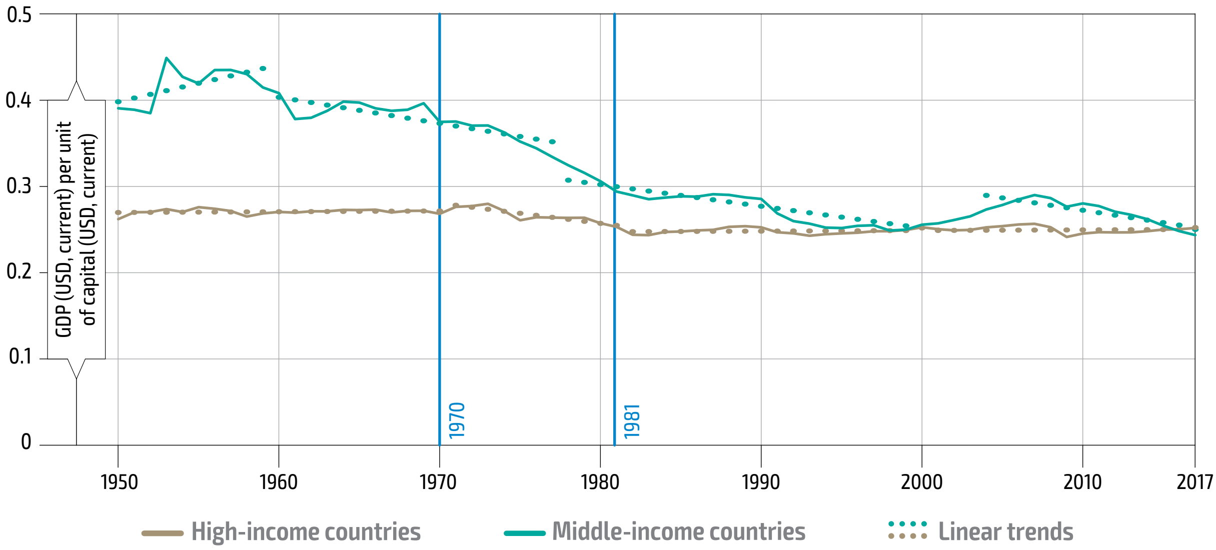
Figure 1.53 Labour productivity for high- and middle-income countries (1950–2017)



Notes: Trends between structural breaks are indicated by dotted lines. Labour productivity is calculated as number of workers divided by gross domestic product (GDP) expressed in USD constant of 2011. Middle-income countries refer to lower-middle- and upper-middle-income countries as per the classification of countries based on the World Bank Country Groups of 2021 (available at http://databank.worldbank.org/data/download/site-content/CLASS.xlsx).

Source: Based on data from Groningen Growth and Development Centre. 2021. *PWT 9.1 Penn World Table version 9.1.* Groningen, The Netherlands, University of Groningen. Cited 18 May 2022. www.rug.nl/ggdc/productivity/pwt/pwt-releases/pwt9.1?lang=en with structural break dates for the high-income country time series.

Figure 1.54 Capital productivity for high- and middle-income countries (1950–2017)



Notes: Trends between structural breaks are indicated by dotted lines. Labour productivity is calculated as number of workers divided by GDP expressed in USD constant of 2011. Middle-income countries refer to lower-middle- and upper-middle-income countries as per the classification of countries based on the World Bank Country Groups of 2021 (available at http://databank.worldbank.org/data/download/site-content/CLASS.xlsx).

Source: Based on data from Groningen Growth and Development Centre. 2021. *PWT 9.1 Penn World Table version 9.1.* Groningen, The Netherlands, University of Groningen. Cited 18 May 2022. www.rug.nl/ggdc/productivity/pwt/pwt-releases/pwt9.1?lang=en with structural break dates for the high-income country time series.

In middle-income countries, there are opposing trends for labour and capital productivity. In contrast to the HICs, the break dates for capital productivity in middle-income countries are nearly identical to those for labour productivity, and the trends are opposite. The phenomenon of opposing trends for labour and capital productivity in middle-income countries is consistent with a rising capital-labour ratio, in which the productivity of labour is augmented by machinery. Thus, falling capital productivity, when accompanied by rising labour productivity, is not inherently problematic. Moreover, as with agricultural productivity growth, rising labour productivity growth in any sector provides a surplus and frees up labour to be used for other productive activities. The post–1959 patterns are therefore characteristic of the conventional view of economic development.

Convergence of capital productivity and its implications. The overall pattern shown in Figures 1.53 and 1.54 is of productivity convergence between today's middle-income and HICs. Convergence of capital productivity is effectively complete – albeit on average across a large and heterogeneous group of countries – while labour productivity features a large and slowly closing gap. This has substantial implications. Investors tend to demand higher profit rates from middle-income countries because they perceive them to be riskier than HICs. In the past, that could be accomplished by having comparatively higher capital productivities. However, as capital productivities of middle-income countries converge on those of the HICs, the only way to achieve higher returns is to keep the wage share low. That means that real wages must be low relative to labour productivity, as explained in Section B of the Annex 2. However, as Figure 1.53 shows, labour productivity in middle-income countries remains well below that of HICs. The implication is that, to offer competitive rates of return, firms in middle-income countries must keep their wages low, both as a share of the total and in absolute terms.

Labour productivity and employment. Growing labour productivity means that more can be produced with the same number of workers. Equally, it means that fewer workers are needed for the same level of output. Which outcome prevails – expanded opportunities or shrinking employment – depends on the potential to expand production.

For countries that have exited the lower-income bracket, labour is comparatively expensive, so there is always pressure to reduce labour costs, often through a mix of low wages and labour productivity. Yet, if the country can find a sufficiently large market for its products, then incomes per person can rise.

In agrifood systems, inputs other than labour are highly relevant

Land and agricultural inputs also matter. Land is constrained, and land rents can be substantial, so output per unit land area has long been a critical productivity indicator, to the extent that it is identified with the otherwise generic term "agricultural yield". Manufacturing costs of synthetic fertilizers and other inputs tend to rise and fall with fuel costs, while fuels are an input in themselves. For this reason, agricultural profits tend to be highly sensitive to energy prices. Rising competition for water resources is leading to calls for increased water productivity growth, or increasing "crop per drop",[17,18] although the economic incentives for farmers can be weak.[19]

The World Bank identified total factor productivity (TFP) as the major component of productivity growth in agriculture.[20] The authors carried out a growth accounting exercise (see Sections A and B in Annex 2), and noted that average productivity growth can arise from reallocation towards more productive farms; increasing productivity on existing farms; and entry and exit of farms. This motivated their list of policy drivers, which included research and development (R&D); and enabling environment for innovation and technology adoption; "factor market" reforms (that is, wages and rents); and nonfarm employment growth. Pre-processing technologies can be energy-intensive, particularly if goods must be chilled or frozen. For food processing, energy is also an important input, as is the cost of the agricultural feedstock itself.

The cost of information technology is driven by factors outside of agrifood systems. Information intensity is not only a poorly defined concept, but also changes if the cost of information technology is driven by factors outside of the agrifood system. While the value of information may be elusive, an important subset of digital technologies has been developed to support "precision agriculture", where innovations provide farmers with high-resolution data regarding their crops or livestock in an effort to enable better decision-making.[21, 22, 23] As costs fall, it becomes easier to justify investments in such technologies, despite the lack of an agreed measure of the value of information. Nevertheless, these technologies carry risks (see Section 1.4). Moreover, farmers are typically required to pay significant sums of money for these services, while the service provider is able to collect high-precision data on specific fields and farmer operations free-of-charge that can be used for further R&D.

Jobless growth and automation

Agrifood 4.0. An important hallmark of the twenty-first century is the increasing ubiquity of new science-based technologies and their application in an ever-wider variety of human activities. The agrifood sector is no exception and has recently entered an era referred to by many scholars and practitioners as "Agrifood 4.0", where automation and digitalization stand poised to radically transform the sector and the daily lives of those who participate in it (see Section 1.9).

It is important to note that automation and digital technologies are not wholly distinct categories of technologies. On the one hand, automated technologies represent a progression of prior forms of agricultural mechanization, in particular, the use of robotics' tools to create more advanced machinery that operates on the basis of user inputs. Automation is especially well-suited to routine tasks which involve limited variation,[24, 25] such as ploughing fields or spraying chemicals. On the other hand, digital technologies include those which generate, store or process data.

What is the effect of automated and digital technologies on labour in agrifood systems? As structural transformation occurs, the key question is whether these technologies are *labour-replacing* or *labour-augmenting* and in what ways.[24] In the former case, the increasing adoption of new technologies may in all likelihood eliminate employment opportunities. For labour-enhancing technologies, it is also necessary to consider precisely how the roles of labourers may change. Deschacht[25] notes that labour-enhancement can be deskilling, wherein job roles which formerly had a wide variety of complex tasks are replaced by low-skilled repetitive tasks, such as machine operation or upskilling, or where low-skilled repetitive tasks are replaced by high-skilled ones requiring creativity and problem solving. Such changes are sometimes referred to under the broad heading of "human capital" (see Box 1.35). In the event both deskilling and upskilling occur in parallel, there is a risk of skill polarization, possibly contributing to increases in inequality as available roles diverge. Moreover, it is essential to recognize how these trends may vary across contexts or have unequally distributed effects, whether positive or negative.

A key factor is the extent to which various tasks are indeed automatable. Research on the computerization of various job roles has suggested that some segments of the agrifood sector may be more susceptible to these changes than others: jobs that involve non-routine tasks or tasks that cannot be expressed in a checklist form are more difficult to automate than others, suggesting that positions like agricultural inspector or some kinds of farm labour may be susceptible to automation.[26]

Gainers of and losers to automation and digitalization. To the extent that automation and digitalization are labour-enhancing, particularly in cases where labour shortages persist, scholars have suggested that wages for those labourers who are not displaced may increase as demand for their skills increase,[25] or as they are able to negotiate a share of the increased income associated with higher productivity. In an era of data-driven agricultural practices, farm labourers with a high degree of data literacy and experience with these technologies stand to gain, while others may have to move out of the sector.[31, 32, 33]

Smallholder farmers are less likely to invest in automation and digitalization. Another relevant consideration is the prospects for and likely experiences of different countries with automation and digitalization in the agrifood sector. While the vast majority of research to date has focused on automation in HICs, and disproportionately the United States of America, the effects of automation and digitalization on low-income countries (LICs) are likely to be distinct. On the one hand, automated technologies tend to be most successful at routine tasks with low levels of variability, and benefit substantially from economies of scale. For smallholding farmers in LICs, the infrastructure and production scale that would justify heavy investment in automation is lacking, so substantial automation and digitalization are unlikely, at least in the short term.[34]

Box 1.35 Human capital

The term "human capital" was first proposed by Schultz,[27] who was explicitly interested in the value of education. While acknowledging that education can be "consumed" for its own sake, he argued that it also has a quality of "investment", in which current expenditure contributes towards the building of a productive asset that can provide a stream of income in the future. He noted:

> "Since it becomes an integral part of a person, it cannot be bought or sold or treated as property under our institutions. Nevertheless, it is a form of capital if it renders a productive service of value to the economy" (Shultz, 1960, p. 571).[27]

While the initial focus was on formal education, human capital has taken on broader connotations. Lall notes that industrial production requires:

> […] skill, know-how and organisation in almost every function, from the shopfloor, via supervision and technical work to engineering, innovation, procurement, employee relations and marketing (Lall, 1998, p. 13).[28]

He identifies two kinds of human capital formation: **skill development**, acquired from both industry-specific education and informal training; and **technological capability formation**, which comes from engaging with technologies in practice, whether as in formal R&D efforts or through informal learning.

Cañibano and Potts (2019)[29] argue that human capital should be thought of in evolutionary terms as knowledge networks in which people are embedded. This viewpoint aligns well with the notion of systems of innovation, which rely on continually transforming networks of explicit and tacit knowledge.[30]

Some varieties of endogenous growth models explicitly include human capital as a factor of production (see Section C in Annex 2). Such models justify expenditure on formal education in terms of its social return. Yet, for agrifood systems, Lall's skill development and technological capability formation are arguably the more relevant concepts. While formal education is a component of skill development, much of the human capital in his framework is built through learning networks.

1.11.2 Future trends

How might capital and information intensity of production affect income and wealth distribution in the future?

A matter of policy. The influences go in both directions: technology and productivity change affects income and wealth distribution, and income distribution influences the pace and direction of technological and productivity change. The answer to the question depends on price and wage setting policies. Those policies, in turn, are influenced by political economy considerations, such as political influence and bargaining power. As live information about agrifood systems becomes more readily available and cheaper, it can be expected to be used to a greater degree to lower costs. The cost savings could be shared between profits and wages, but might be taken entirely in the form of profits, depending on the bargaining power of workers and their ability to monitor the firm's income.

In agrifood systems. Improvements and cost reductions in digital technologies and data collection are driven by forces lying outside of agrifood systems proper. In contrast, innovations in technologies specific to agrifood sectors are driven by processes within those sectors, and in particular, cost reduction and the push to expand markets. In LMICs, abundant labour tends to keep rural wages low, which also puts a floor on urban wages. Labour costs are therefore not as influential as they are for HICs. Moreover, firms in LMICs must learn about technologies with less access to information about them than their HICs competitors. For these and other reasons, technologies tend to be modified and adapted when they are imported by LMICs.[30,35]

When LICs raise their productivity and production levels and attain middle-income status, their low-wage sector shrinks, raising the bargaining power of low-wage workers. Rising incomes and living standards thus create pressure to raise wages. However, as discussed above, comparatively higher risk ratings means that wages must be kept low to attract investment, creating an incentive to restrain wage growth.

Moreover, if capital intensity is raised through foreign direct investment (FDI), then some of the profits, and perhaps some of the wages, will be remitted abroad. If production takes place in free trade zones, then taxes on profits and foreign workers' wages may be lower than for domestic enterprises. There is thus an international dimension to income distribution.

What scenarios can be built regarding capital and information intensity of production processes, as well as capital and information ownership across countries?

Capital-labour ratios in agrifood systems are likely to continue to grow in middle-income and HICs, across all components – namely, agriculture, pre-processing and processing. In contrast, persistent challenges within LICs in financing investment and providing employment will probably continue to keep both labour productivity and capital-labour ratios low. Low wages reduce the pressure on labour-saving innovation, so that innovations focus more on saving on costly or scarce inputs, for example, by improving water use efficiency. That can drive up yields, providing more farmer income. For LICs, focusing on the food processing sector using domestic products can offset processed food imports and add employment and income along agrifood value chains, while providing an opportunity to build national innovation systems.[36]

Countries that are able to shift into the middle-income level can increase their domestic savings and attract more foreign investment. This process can drive accelerating growth, allowing those countries to expand more rapidly. However, rapid growth can increase the risk of external debt and vulnerability to changes in the exchange rate. If capital is financed through FDI, then some profits will be remitted to foreign owners. The country can still benefit through employment and by linkages to domestic producers, but at least part of the ownership would be held abroad.

As information technologies drop in price and become more available, middle-income countries can increasingly take advantage of them, thereby increasing information intensity. However, again there is a risk – that the companies providing the information technologies can aggregate data across their networks for their own purposes. Farmers and agrifood businesses will have access to data about their operations, but the data will be held by a third party.

To what extent might capital and information intensity dynamics in agrifood systems influence the future use of natural resources?

Natural resource use depends on both intensity and scale of production. For agriculture, natural resource inputs include land and water, both of which might be governed by a set of traditional or formal rights, and might be priced in markets. Other crucial inputs, including soil biota, sunlight, pollinators, predators of pests, and so on, are not priced. For inputs that are priced, the cost may not be large enough as a share of the total to drive innovation that reduces resource use (see Section 1.8). Nevertheless, even in the absence of a price system, or with comparatively low prices, the pressure of sharing finite resources can drive efficient use. Unlike traditional resource management schemes that increase local resource productivity, increasing capital and information intensity tends be associated with expanding scale. In both cases, manufactured technologies are used to lower unit costs. The savings can be converted into some mix of lower prices and higher profits. Resource intensity per unit of output might fall, but total resource use will typically increase; where resources are locally constrained, an expanding enterprise can establish branch operations in new locations or implement outgrower schemes.

The implication is that increasing natural resource efficiency does not, in itself, reduce global pressures on resources. This suggests the need to limit commercial access to natural resources, for example, by protecting them outright or through pricing schemes. In either case, resource prices are likely to rise, which can shift the focus of innovation towards improved resource efficiency or towards the development of alternative resources. One consequence is that the cost of agrifood products would likely rise. To the extent that rising prices erode the real purchasing power of wages, natural resource protection may, in the first instance, have adverse distributional impacts, disproportionately impacting LICs. However, that is not a reason not to protect natural resources, which is necessary for sustainable production and consumption; rather, it calls for accompanying policies that anticipate and offset the adverse impacts.

To what extent might digitalization, automation, or robotization affect labour demand and wages in agrifood systems and economy-wide?

Is a jobless growth or a jobless structural transformation plausible? The key question is one of cost and technological possibility. Continuing efforts in automation and digitalization are lowering the cost. As technical hurdles are overcome, it can be expected that routine jobs that are currently carried out by hand will be done by machine, including harvesting, inspecting, sowing, milking and land preparation. However, technologies carry their own burdens of maintenance and upgrading; none of which is costless.

In LICs where labour costs are low, it can be expected that automation, at least, will lag. However, the availability of robust and low-cost sensors may make some kinds of digitalization attractive even in these countries.[37,38]

Economy-wide, automation and digitalization can be expected to support the continuation of the long-run trend of labour productivity growth in manufacturing. That growth has powered economic expansion, but today is associated with “premature deindustrialization”,[39] and a shift in the locus of manufacturing production to LICs as incomes rise.[40]

How can investment in so-called “human capital” contribute to address the risk of job losses? To the extent that longer-term transitions to higher levels of automation and digitalization occur, skill development for the resulting data-oriented roles can help to protect at least some on-farm employment. Moreover, agriculture involves tacit knowledge that cannot easily be replaced by machines. Even with robotic self-milking machines, which allow cows to voluntarily choose milking times, one farmer who had benefited from increased milk yields noted that, “It makes good cowmen better and bad cowmen worse”.[41]

Nevertheless, as with any labour-saving innovation in agriculture, some jobs will simply be displaced.[42] To some extent, the new technologies will increase demand for non-farm employment within the agrifood sector, but the question of how to absorb displaced agricultural labour is not a new one. The difference is the rapidity with which the change might occur. A critical observation is that formal schooling offers, at best, a partial response to the challenge. To master new technologies, it is necessary both to gain direct experience with them and to enter into global networks where information about the technologies is shared.

1.11.3 Summary remarks

The long-run historical pattern has been one of “capital deepening”, as labour was substituted by machines. This resulted in a growth of labour productivity and a progressive convergence of middle-income countries on HICs. In contrast, capital productivity evolved only narrowly in HICs and fell in middle-income countries. This implied that investors tend to demand higher profits rates from LMICs by keeping wages low.

Economic transformation has always been socially dislocating,[43] and new technologies promise to accelerate the dislocation by automating jobs that had until now been irreplaceable.

Those technologies can reduce resource use, including land, water, agrochemicals and other inputs, but if they at the same time open up new market opportunities, the increased efficiency can be partially or wholly offset by increased production. Therefore, protecting natural resources for a sustainable future cannot be left to productivity growth alone.

With the development of automated and digital technologies, low-skilled routine jobs are being replaced by high-skilled, problem-solving jobs. There will be gainers and losers, as farm labourers with a high degree of data literacy and experience with these technologies stand to gain, while others may have to move out of the sector. The risk is high, at least in the short term, that smallholder farmers will not invest in these new technologies.

Abundant labour in LICs is likely to continue keeping wages low, which implies weak incentives for raising labour productivity. In those cases, working with farmers to reduce their costs and improve yields, in order to boost income, can help generate the resources for transformation.

Meanwhile, investment in food processing offers a traditional route for an agriculturally dominant economy towards manufacturing. Contemporary development strategies urge the simultaneous development of high-technology, export-oriented sectors financed through FDI. For those investments to be transformative, countries should use them to benefit labourers requiring skill development and technological capability formation.

The concept of "information intensity" remains ill-defined, but rapidly falling costs for robust sensors may make digital technologies available even in LICs. The concern is that the associated data will typically be stored by a firm that can then make use of the data to increase its own revenue.

Between foreign ownership of capital and foreign (or at least off-farm) ownership of data, technological change can shift patterns of ownership and control over resources.

NOTES – SECTION 1.11

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1.12 Market concentration of food, and agricultural inputs and outputs (Driver 13)

Market concentration of food, and agricultural inputs and outputs represents a challenge for the resilience, equitability and sustainability of agrifood systems. According to a report by International Panel of Experts on Sustainable Food Systems (IPES-Food), there are unprecedented levels of market concentration throughout global agrifood systems.[1] A few companies control seeds, chemicals, pharmaceuticals, machinery, fertilizers, livestock genetics, food processing and commodity trading, and have potentially gained "market power". A recent United Nations Conference on Trade and Development (UNCTAD) report highlights that:

> "Increased market concentration and rising mark-ups have become commonplace across many sectors and economies, with rent-seeking behaviour dominating at the top of the corporate food chain" (UNCTAD, 2018, p. iv).[2]

At the global level, there is an increase in market concentration in various domains, such as: crop seeds, agricultural chemicals, veterinary pharmaceuticals, agricultural machinery, fertilizers, livestock genetics, fishing rights, food processing and commodity trading. Large proportions of goods and services in these domains are being produced by a few leading firms. Land concentration associated to lack of land-use regulation also affects access to resources. This puts rural, local and low-income countries (LICs) at risk and increases their dependency on external actors. The COVID-19 pandemic is exposing the weaknesses arising from such concentrations.

Several issues/questions can be raised in this context:

- What is the magnitude of market concentration and what factors have triggered market concentra-tion on the input and output sides?
- To what extent has market concentration fuelled income asymmetries and power disparities among market actors?
- What governance mechanisms could allow for control of market concentration?

This section addresses some of these questions. Others are addressed in other sections of the report.

1.12.1 A changing economic system

The world economic system has undergone fundamental changes in recent times. International trade has boomed in an unprecedented way over the last seven decades, creating new structures adapted to a new context, and modifying the mode of operation of markets and of the economy, more generally. This movement has led to a greater concentration of activities within a limited number of economic giants (a handful in certain fields) present and active across borders. It has also profoundly altered the way private companies interact, compete and cooperate. These major changes occurred throughout the world economy, affecting all sectors, including food and agriculture.

The current digital revolution (see Section 1.4) is still transforming radically the functioning of the economy. And its progressive penetration in the food and agricultural domain is likely to reorganize the sector still further.

Between 1991 and 2018, agricultural exports increased in value by 320 percent, twice as fast as total production, in current terms. Over the same period, exports which represented 24 percent of the value of agricultural production in 1991, reached 40 percent in 2018.[3]

This spectacular growth was simultaneous with the development of a global food system where primary production, processing and consumption of a particular good may be taking place in different parts in the world. This new globalized system saw the progressive establishment of transnational value chains with the aim to rationalize and reduce uncertainties in dealing with a variety of economic actors spread throughout the world.[4] This transformation was facilitated by a gradual removal of barriers to trade and investment.[5]

The emergence of global value chains has been occurring together with a growing importance of product and process standards, because of the strict food safety requirements of importing countries. This has contributed to a greater concentration of activities in the hands of a limited number of enterprises.

Concentration has taken place horizontally through mergers and acquisitions among firms operating at a particular stage of food value chains (input provision, primary production, processing, retailing and catering). This has been largely propelled by economies of scale and the drive towards developing market power, rents-seeking and gaining the capability of raising prices.

A novel way of concentration gradually emerged that occurs vertically along product-specific value chains, as maintaining product and process standards became increasingly the responsibility of private firms themselves, through the development of private standards promulgated and executed by businesses, individually or collectively. This vertical integration, governed by a lead firm in which explicit inter-firm coordination and quality assurance substitute earlier coordination by the market,[6] brought about a new form of economic power, with the lead firm also driving product differentiation and innovation within a given global value chain, and defining conditions of chain participation.[7]

With the liberalization and development of trade, the advent of transnational lead firms was facilitated, including some originating from emerging countries,[8] adding to those pre-existing firms that were, at least in part, a heritage of colonial times.

All these changes – the evolution of the level of concentration and modification of interrelations within global value chains – are difficult to detect and analyse as data often only becomes available with a considerable time lag,[9] and internal processes are less visible to outside observers, including researchers.[10]

1.12.2 Horizontal concentration at various stages of food and agricultural value chains: some facts and figures

Horizontal concentration traditionally refers to the share of a market in the hands of the biggest companies, and the assumption is that the larger the share held by a firm, the greater its market power.

There is a general agreement that horizontal concentration has been observed at all levels of value chains, from agricultural input provision, agricultural production and food processing to retail and catering.6 Global bulk commodity trade, however, has seen an opposite movement.

Statistical evidence on the market share of various companies is rare, partial and decreasingly meaningful as, over time, most of the businesses operating in the food and agriculture domain have activities throughout value chains.

Concentration in agricultural inputs

For most inputs, more than half of the market share is in the hands of a small number of companies. In the late 1980s, the top 20 seed companies accounted for 90 percent of global sales. By 2002, this number had fallen to seven, despite the fact that, in the mid-1980ss, agrochemical and agrotechnology corporations made their entry into the sector.[11] Just ten firms,[be] by 2011, weighed 75 percent of the seed market.[12]

Agrochemical companies had been attracted by the success of hybrid crops in the 1960s and 1970s and complementarities between seeds and other inputs, while agrotechnology firms developing genetically modified products, saw seed corporations as a channel for distributing their new products. This brought enterprises like DuPont, ICI, Elf-Aquitaine, Monsanto, Rohm and Haas, and Unilever into the seed business.

Another proof of concentration within the seed sector is the large proportion of plant varieties owned by just a handful of transnational seed companies.[6]

By 2013, six corporations accounted for 75 percent of the global agrochemical market,[bf] 63 percent of the commercial seed market, and more than 75 percent of all private-sector research

[be] Monsanto, DuPont Pioneer, Syngenta, Vilmorin, WinField, KWS, Bayer Cropscience, Dow AgroSciences, Sakata and Takii & Company.

[bf] BASF, Bayer, Dow, DuPont, Monsanto and Syngenta. The agricultural research and development budget of these firms was estimated at 20 times bigger than the total expenditure of the Consultative group on international agricultural research expenditure(CGIAR) on crop-oriented research/breeding and 15 times bigger than the crop science research budget of the Agricultural Research Service of the US Department of Agriculture.[13]

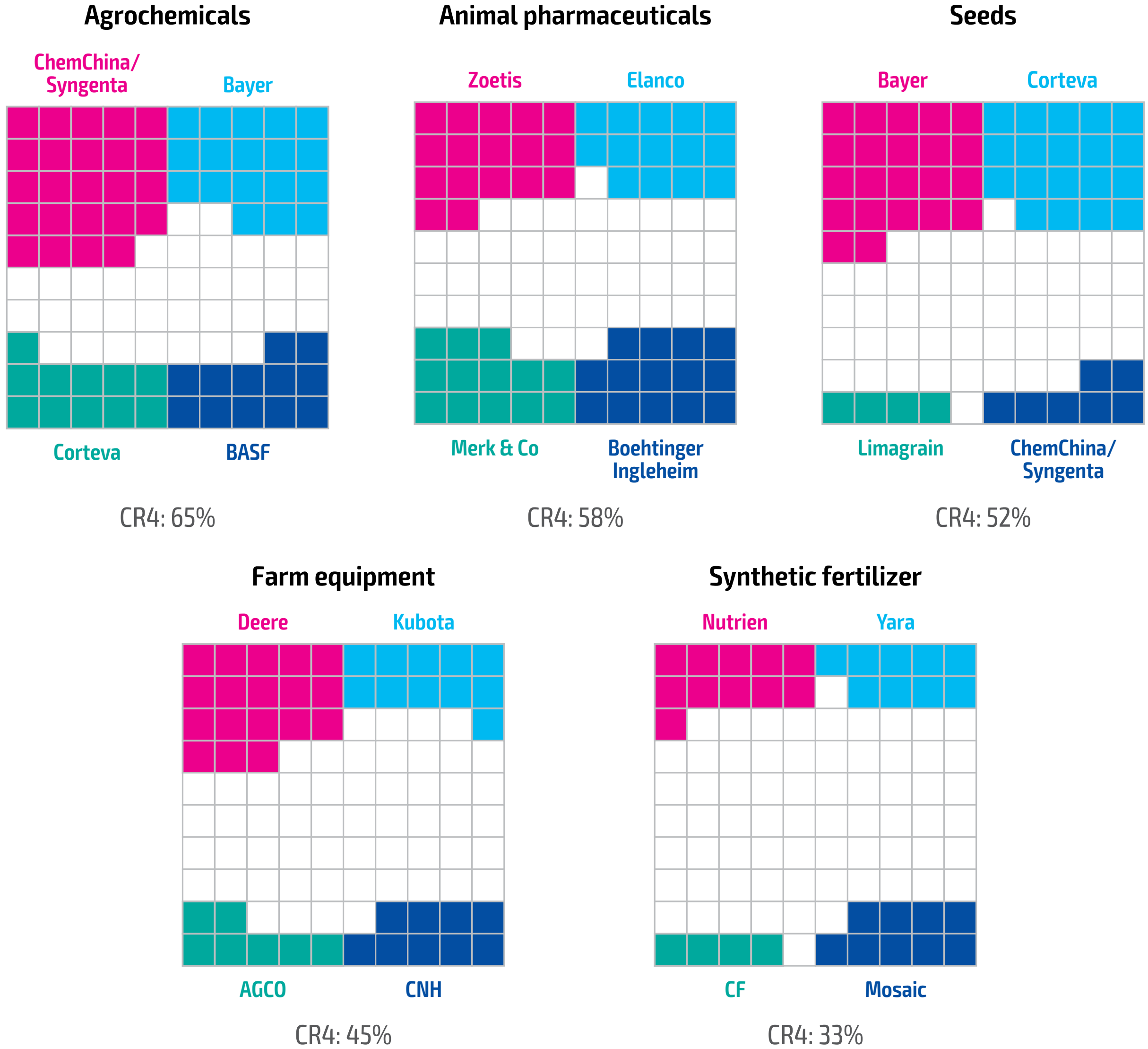
in seeds and pesticides.[13] In 2020, the four top agrochemical firms (ChemChina/Syngenta, Bayer, Corteva and BASF) weighed 65 percent of the market.[14]

In recent years, there have been major merger and acquisitions in the agrochemicals-seed area, the largest being the USD 130 billion Dow/DuPont merger of 2017,[bg] the USD 66 billion merger of Monsanto and Bayer in 2018 and the purchase of Syngenta by ChemChina for USD 43 billion in 2017. In 2021, the Chinese state-owned Assets Supervision and Administration Commission approved the ChemChina Sinochem merger to create the world's biggest producer of chemicals.

However, with the recent development of gene editing technologies that reduce tremendously the cost of developing crop varieties, new and smaller companies (including start-ups) could shake up the sector (see Section 1.9).

Levels of concentration comparable to those seen for seeds and agrochemicals are also found in the farm equipment business (45 percent for Deer, Kubota, CNH and AGCO), animal pharmaceuticals (58 percent for Zoeetis, Elanco, Merck & Co. and Boehringer Ingleheim), while fertilizer is much more diffuse globally (only 33 percent for Nutrient, Yara, Mosaic and CF)[14] (Figure 1.55).

Figure 1.55 Four-firm market concentration (CR4) for seeds, agrochemicals, farm equipment, synthetic fertilizers and animal pharmaceuticals (2020)



Source: Hendrickson, H., Howard, P.H., Miller, E.M. & Constance, D.H. 2020. *The food system: concentration and its impacts. A Special Report to the Family Farm Action Alliance.* http://dx.doi.org/10.13140/RG.2.2.35433.52326

[bg] Resulting DowDuPont was later dissolved, in 2019, and split into three companies: DuPont, Dow and Corteva.

The concentration process has also been ongoing at the national level in the decades before and in the aftermath of the new century, as illustrated in the case of the United States of America (Table 1.22).

Table 1.22 **Market share of the four largest companies for inputs and machinery manufacturing in the United States of America (1977 and 2012)**

INPUTS AND MACHINERY MANUFACTURING COMPANIES	MARKET SHARE (percent)	
	1977	2012
Nitrogenous fertilizer manufacturing	34	69
Phosphatic fertilizer manufacturing	35	88
Pesticide manufacturing	44	57
Farm machinery	46	61

Source: Carstensen, P.C., Lianos, I., Lombardi, C., MacDonald, J.M. & Moss, D.L. 2016. *Competition law and policy and the food value chain.* On-Topic l Concurrences N° 1-201. https://discovery.ucl.ac.uk/id/eprint/1478197/7/Lianos_03percent20concurrences_1-2016_on_topics_lianos_et_al.pdf

Concentration in agricultural production

Concentration of agricultural production is not a general phenomenon worldwide. It is higher in high-income countries (HICs), while in low- and middle-income countries (LMICs) a large mass of increasingly fragmented family farms coexists with giant farms. In fact, the relevant literature indicates a contrasted evolution: in HICs, average farm sizes have increased (see Box 1.36), while in low-income countries, they have tended to fall (see Box 1.37). In Brazil and the United States of America, for example, both very prominent countries in terms of agricultural production, large farms have been taking over a growing share of agricultural land. In the United States of America, the share of land held in farms with more than 2 000 acres (809 hectares) jumped in 40 years from 15 percent to 37 percent, with most of the additional land coming from mid-sized farms, and with the largest cattle on feed and pork producers having nearly 1 million animals.[14] The same trend is observed in major European agricultural producing countries.[15]

This view needs, however, to be somewhat qualified as it is too schematic. For example, in a number of countries in Africa, there is evidence that medium-scale commercial farms have been gaining importance, as a result of urban-based professionals, entrepreneurs or civil servants acquiring land, encouraged by the rapid development of land rental, purchase, and long-term lease markets, and of the expansion of some small-scale farms.[16,17]

Box 1.36 **Example of concentration in a high-income country: livestock production in the United States of America (1987 to 2012)**

The United States of America is a good example in showing how the size of farms has been increasing in HICs. In little over 50 years, the United States of America lost one-third of its farms. As a result, the median farm size in cropland more than doubled between 1982 and 2012. It grew even more rapidly with regard to livestock farming.

As can be seen in Table A, livestock production saw a significant concentration between 1987 and 2012, while the size of livestock farms became larger. Midpoint-sized poultry farms more than doubled the number of broilers they produced. Over the same period, the size of milk cow herds for midpoint farms multiplied tenfold and the number of hogs produced increased by more than 30 times. This took place concurrently with the adoption of new intensified production methods, which have considerable animal and human health consequences (see Section 1.15).

Box 1.36 (cont.) Example of concentration in a high-income country: livestock production in the United States of America (1987 to 2012)

Simultaneously, the number of farms decreased drastically, particularly for pig production, in which the number of farms dropped by almost 75 percent.

Table A. Structural change in livestock production in the United States of America (1987 and 2012)

ITEM	1987	2012
Median farm sizes		
Broilers (annual sales/removals)	300 000	680 000
Cattle feeding (annual sales/removals)	17 532	38 369
Pigs (annual sales/removals)	1 200	40 000
Milk cows (herd size)	80	900
Number of farms with:		
Contract broiler production	22 000	15 830
Cattle feeding	112 109	77 120
Pigs	243 398	63 246
Milk cows	202 068	64 098

Note: The median size of farm is the farm size for which half of the farms are larger farms, and half are smaller.

Source: Carstensen, P.C., Lianos, I., Lombardi, C., MacDonald, J.M. & Moss, D.L. 2016. *Competition law and policy and the food value chain*. On-Topic l Concurrences N° 1-201. https://discovery.ucl.ac.uk/id/eprint/1478197/7/Lianos_03%20concurrences_1-2016_on_topics_lianos_et_al.pdf

Box 1.37 Example of fragmentation in a middle-income country: evolution of landholdings in India between 1976–1977 and 2015–2016

Data from successive agricultural censuses in India show the fragmentation of agricultural landholdings.

Table A illustrates how the number of marginal and small farms increased respectively by 125 percent and 75 percent over four decades, while the number of semi-medium farms first grew before decreasing after the mid–1990s. Meanwhile, the number of medium and large farms fell respectively by 32 and 66 percent over the whole period.

Interestingly, the reduction of the number of medium and large farms did not imply a growth in size and greater concentration of land. In fact, their average size even slightly decreased to remain near 6 hectares for the former and just above 17 hectares for the latter category. This suggests that medium and large farms actually were fragmented into smaller units, whose share of total land grew over the period (Figure A).

This evolution can probably be linked to the slow structural transformation and urbanization taking place India and the densification of rural areas to a level similar to that observed in urban areas (see Section 1.1 and Section 1.2).

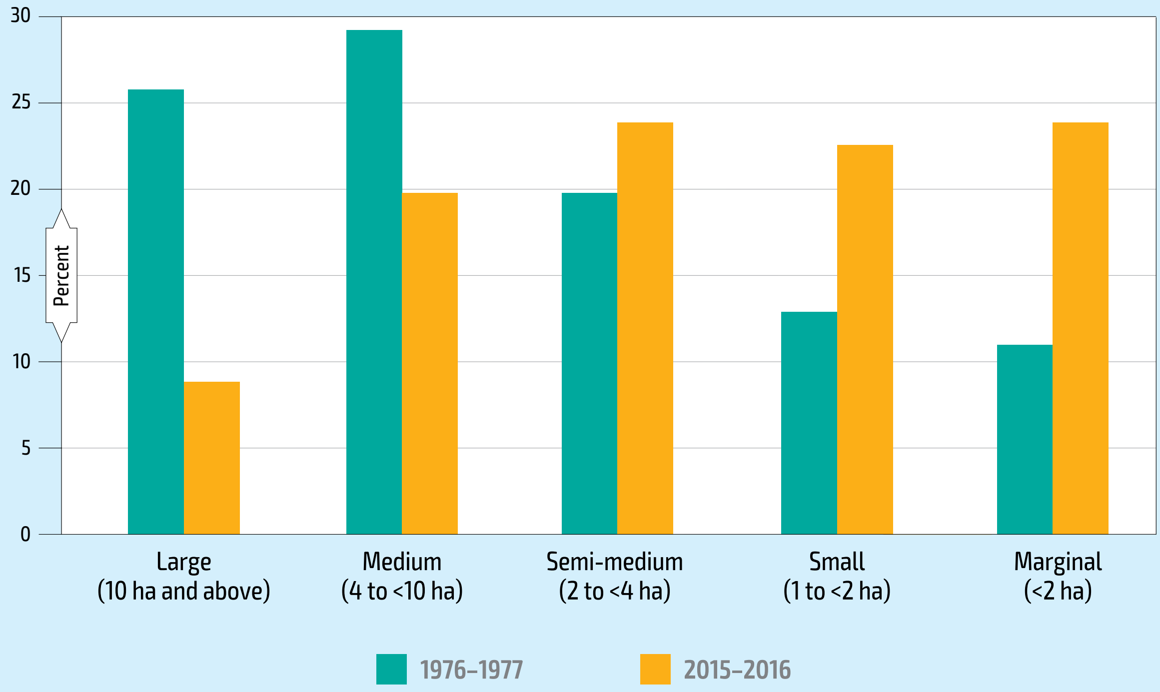
Box 1.37 (cont.) Example of fragmentation in a middle-income country: evolution of landholdings in India between 1976–1977 and 2015–2016

Table A. Evolution of landholdings in India between 1976–1977 and 2015–2016

NUMBER OF HOLDINGS	1976–1977	1995–1996	2015–2016
Marginal farms	44 523 000	71 179 000	100 251 000
Small farms	14 728 000	21 643 000	25 809 000
Semi-medium farms	11 666 000	14 261 000	13 993 000
Medium farms	8 212 000	7 092 000	5 561 000
Large farms	2 440 000	1 404 000	838 000
Operated area (ha)			
Marginal farms	17 509 000	28 121 000	37 923 000
Small farms	20 905 000	30 722 000	36 151 000
Semi-medium farms	32 428 000	38 953 000	37 619 000
Medium farms	4 628 000	41 398 000	31 810 000
Large farms	42 873 000	24 160 000	14 314 000

Source: Government of India. 2020. *All India Report on Agriculture Census 2015-16.* Department of Agriculture, Cooperation & Farmers Welfare Ministry Of Agriculture & Farmers Welfare. New Delhi. https://agcensus.nic.in/document/agcen1516/ac_1516_report_final-220221.pdf

Figure A. Evolution of the share of land occupied by different farm categories in India between 1976–1977 and 2015–2016



Source: Authors' elaboration based on Government of India. 2020. *All India Report on Agriculture Census 2015-16.* Department of Agriculture, Cooperation & Farmers Welfare Ministry Of Agriculture & Farmers Welfare. New Delhi. https://agcensus.nic.in/document/agcen1516/ac_1516_report_final-220221.pdf

Concentration in agriculture has also taken place through what is referred to in the literature as "land-grabbing". Following the 2007–2008 food price crisis, governments, using sovereign funds or public enterprises, as well as private investment funds, acquired agricultural land in LICs, particularly in Africa. The former were aiming to secure supply of food for their populations, the latter sought to invest in the new and rapidly expanding market of land and water rights resulting of the commodification of natural resources.[18] The estimates of the size of this phenomenon range from 42 million hectares within a year[19] – twice the area of France's farmland or two-fifths of all the farmland of the European Union – to a much more modest 30 million hectares, for which a deal was concluded and for which 6 to 13 million ha are actually in production on land that was earlier being used largely by commercial and smallholders farms. A predominant share of production on the land involved is for export (oil palm, rubber trees, sugar beet and sugar cane, and pineapple) and is connected to large private businesses in HICs or emerging countries with a dynamic agricultural sector.[20]

Another spectacular process of concentration in agricultural primary production has been the development of mega-farms or agroholdings in Eastern Europe, South America, China and countries of the Former Soviet Union. These production units operate on huge tracts of land (often several hundreds of thousands of hectares) and raise very large number of animals.[21] These mega enterprises seem to challenge the general belief that large-scale farming is only viable under special conditions, and suggest that the need for supervision of labour has been compensated by an increased use of innovative technologies and corporate-style organizational architecture.[22] Examples include 80 agroholdings in Ukraine that farm around 6 million hectares, 38 mega-farms in the Brazilian Cerrado cultivating grain and oilseed on 3.5 million hectares, a Chinese firm in the United States of America producing an estimated 18 million pigs (9 percent of total production).[21]

Concentration in international commodity trade

Global bulk commodity trade has been dominated by a few large multinational companies: the four historical so-called "ABCDs"[bh] that, along with being involved in commodity trade, operate at almost all stages of the value chain from farm level up to food processing, with participation in produce transport, storage and finance, as well as in trade and in the procurement of agricultural inputs to contracted farmers. These companies also engage in speculation and hedging in agricultural commodity markets.23 They may deal indirectly in those activities through affiliates or, increasingly, through other firms (wholesale traders, importers and exporters) with whom they have arrangements or contracts, while not participating in their capital. This allows them to integrate and play a central role in selected value chains in a very flexible manner and at a minimal risk, as they can withdraw at any time and at very low cost.24 Moreover, this modality has the advantage of being able to escape the scrutiny of national regulating authorities.

Recently, the four majors have been facing new competitors, many originating from Asia (e.g. Wilmar (Singapore), Olam (Singapore) and COFCO International (China), and this has strongly impacted their business.[25] Large manoeuvres are frequent in the sector, with mergers and acquisitions changing the scene continuously.[23] Moreover, these large companies persist in diversifying their activities.[1]

These mega-firms are located at a strategic point in the global food system, between hundreds of millions of farmers, upstream, and billions of consumers, downstream of value chains. Their very existence, power and vertical control over value chains contribute to reducing market competition as they also strongly influence domestic markets of major food-producing countries.[23] It will be seen later, that they have, however, to deal with mighty partners.

National level wholesale trade: in most African countries, markets remain relatively fragmented

Information on the level of concentration of agricultural wholesale trade at national level is generally rather insufficient. A recent study conducted for the European Commission found that wholesale is usually less concentrated than retail and comparable to processing, in selected European Union Member States (see Box 1.38). The CR4 varies from around 10 percent in Bulgaria to approximately 30 percent in Finland and Sweden.[26] Figure 1.56a shows, relatively flat lines, denoting that different turnover size classes of wholesalers capture similar shares of the market, with the exception of the category of those with more than EUR 350 million turnover in some countries.

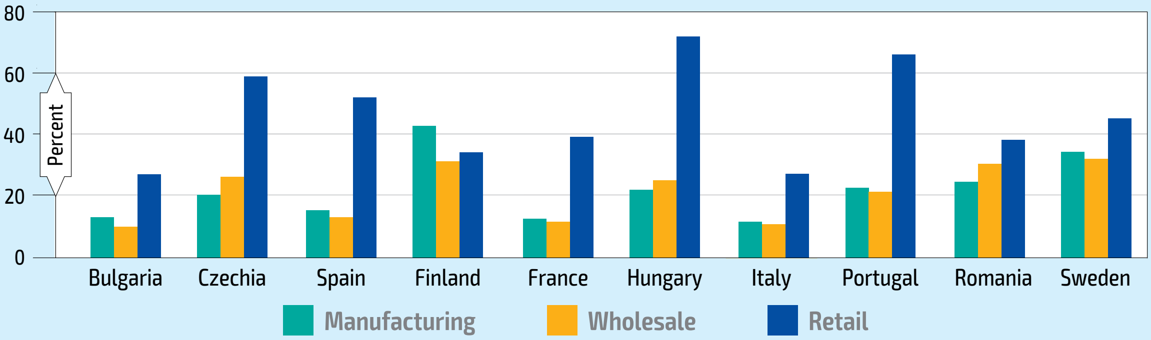
[bh] Archer Daniels Midland (USA), Bunge (USA), Cargill (USA) and Louis Dreyfus Commodities (France).

Box 1.38 Concentration of the food sector in selected European Union Member States: a comparison among manufacturing, wholesale and retail segments

In their recent work for the European Commission on market power in the food industry in selected European Union Member States, Nes, Colen and Ciaian[26] found that concentration was generally significantly higher in retail than in food manufacturing or wholesale.

The top four companies represented between 25 percent and 70 percent of the total market share in retail.For manufacturing, their share was around 10 percent in countries such as Italy, France, Spain and Bulgaria, but close to or more than 40 percent in Romania, Sweden and Finland). In the case of wholesale, the share hardly reached 30 percent in one country (Finland) and remained at around 10 percent in countries like France, Italy and Spain (Figure A).

Figure A. Concentration ratio for the top four firms in food manufacturing, wholesale and retail in selected European Union Member States (2016)



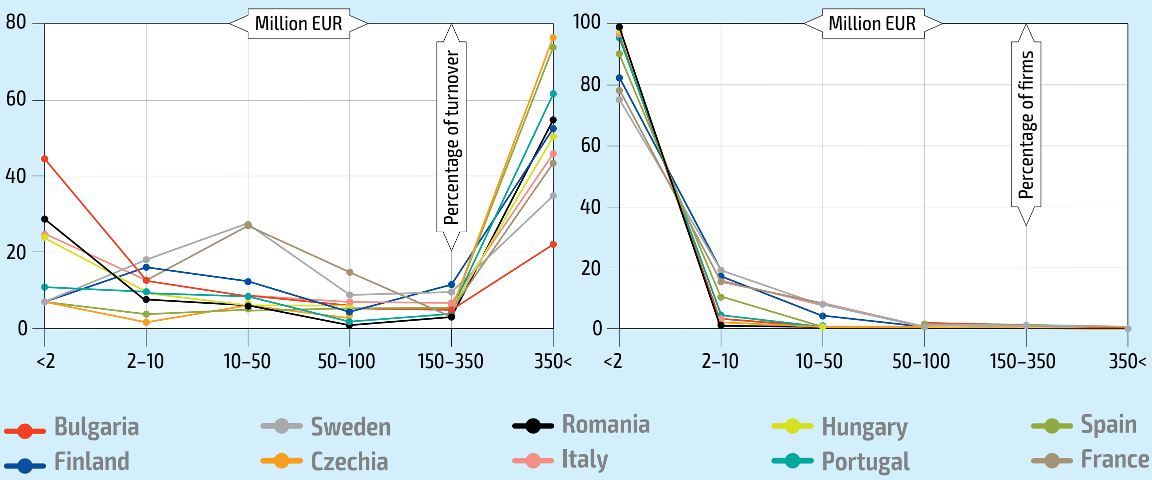
Source: Nes, K., Colen, L. & Ciaian, P. 2021. *Market power in food industry in selected EU Member States.* Brussels, European Commission, Joint Research Centre. https://data.europa.eu/doi/10.2760/63613

In retail, small outlets with less than EUR 2 million turnover, represented more than 80 percent of the number of firms and less than 40 percent of turnover, while the small number of companies with more than EUR 350 million turnover weighed from 20 percent to almost 80 percent of total turnover, depending on the country. Concentration, however, varied greatly depending on the food product and country considered.

Figure B. Distribution of turnover and firms in the retail sector by turnover size class in selected European Union countries (2016)

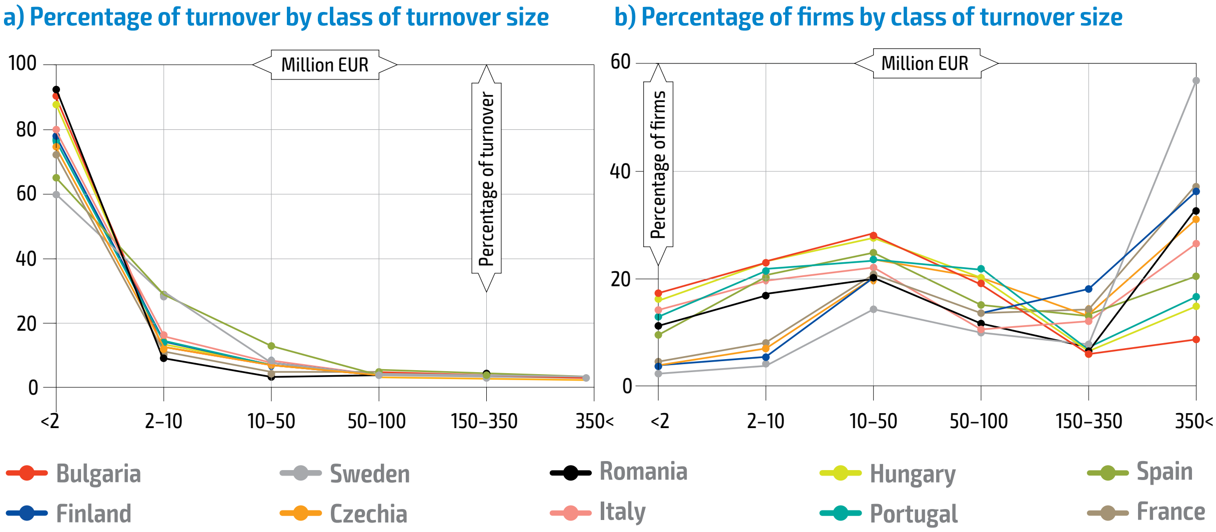
a) Percentage of turnover by class of turnover size

b) Percentage of firms by class of turnover size



Source: Nes, K., Colen, L. & Ciaian, P. 2021. *Market power in food industry in selected EU Member States.* Brussels, European Commission, Joint Research Centre. https://data.europa.eu/doi/10.2760/63613

Figure 1.56 Distribution of turnover and firms in the wholesale sector by turnover size class in selected European Union countries (2016)



Source: Nes, K., Colen, L. & Ciaian, P. 2021. *Market power in food industry in selected EU Member States.* Brussels, European Commission, Joint Research Centre. https://data.europa.eu/doi/10.2760/63613

In Africa, with the ongoing urbanization process, wholesale trade of agricultural commodities is developing, and a growing share of local production is moving to supply goods to expanding urban areas. Current agricultural markets remain rather fragmented and segmented, often because of a lack of proper transport infrastructure, and they involve large numbers of collectors and wholesalers. However, as infrastructure improves, markets become more integrated.[27] In South Africa, food and agroprocessing markets show a high level of concentration (Hirshman-Herfindahl Index of more than 2 800) comparable to what can be observed for the most concentrated markets in the European Union (oils/fats, beer and malt).[28]

Concentration in food processing and catering

At the global level, food industries are dominated by giant enterprises that often combine agricultural production and trade, as well as food processing and services (Table 1.23).

Table 1.23 Top ten food giants (2019)

	COMPANY	REVENUE (USD billion)	HEADQUARTERS	MAIN ACTIVITIES
1	Cargill	115	USA	Production, trading, processing
2	Nestlé	90	Switzerland	Food and beverages
3	PepsiCo	64	USA	Soft drinks, snacks
4	Archer Daniels Midlands	61	USA	Commodities trading and wholesale, insurance, processing, feed, food additives, ethanol
5	Sysco Corp.	55	USA	Processing, distribution, catering, food-related hardware
6	JBS	49	Brazil	Meat processing, ranching, meat packing and trade
7	Bunge	42	USA	Grain and sugar trading, processing, food services
8	George Weston	38	Canada	Industrial bakeries, grocery
9	Tyson Foods	38	USA	Poultry, eggs, catering, grocery
10	Mars	35	USA	Confectionery and snacks

Source: Levin, N. 2019. 10 Largest Food Companies in the World. In: *Larget.org*. Cited 18 May 2022. https://largest.org/food/food-companies

At the country level concentration varies depending on products and location. There are signals that food processing is also concentrating among a few major players, but the speed and level of concentration achieved vary according to the products. Beer in the United States of America, for example, has seen less concentration recently, mainly because of growing competition from craft breweries.[14]

Tables 1.24 and 1.25 show changes in the level of concentration observed in livestock slaughtering and in processing of selected food products in the United States of America.

Table 1.24 Market share of the four largest slaughtering companies in the United States of America (1980 and 2012)

SLAUGHTERING SUBSECTORS	MARKET SHARE (percent)	
	1980	2012
Steer and heifer slaughter	36	85
Pig slaughter	34	64

Source: Carstensen, P.C., Lianos, I., Lombardi, C., MacDonald, J.M. & Moss, D.L. 2016. *Competition law and policy and the food value chain.* On-Topic l Concurrences N° 1-201. https://discovery.ucl.ac.uk/id/eprint/1478197/7/Lianos_03%20concurrences_1-2016_on_topics_lianos_et_al.pdf

Table 1.25 Market share of the four largest firms in selected food processing subsectors in the United States of America (1977 and 2012)

SELECTED FOOD PROCESSING SUBSECTORS	MARKET SHARE (percent)	
	1977	2012
Fluid milk processing	18	46
Flour milling	33	50
Wet corn milling	63	86
Soybean processing	54	79
Rice milling	51	47
Cane sugar refining	63	95
Beet sugar	67	78

Source: Carstensen, P.C., Lianos, I., Lombardi, C., MacDonald, J.M. & Moss, D.L. 2016. *Competition law and policy and the food value chain.* On-Topic l Concurrences N° 1-201. https://discovery.ucl.ac.uk/id/eprint/1478197/7/Lianos_03%20concurrences_1-2016_on_topics_lianos_et_al.pdf

Concentration at the retail level

Retail is the stage where the biggest corporations operate. Table 1.26 lists the major players and illustrates their financial strength.

Companies at this level of the food chain have a size and financial power far greater than any of the champions at other levels of the food system (Figure 1.57), but for most of them, food only constitutes part of the goods they are retailing.

With the mergers that took place since 2016, the proportions across the steps of the food value chain seen in Figure 1.57 remain comparable. In 2020, Walmart, the largest retailer, had an annual turnover approximately five times that of Cargill and ChemChina/Syngenta, the biggest actors in the food industry and in seeds/agrochemicals, respectively, and more than ten times that of Bayer/Monsanto.

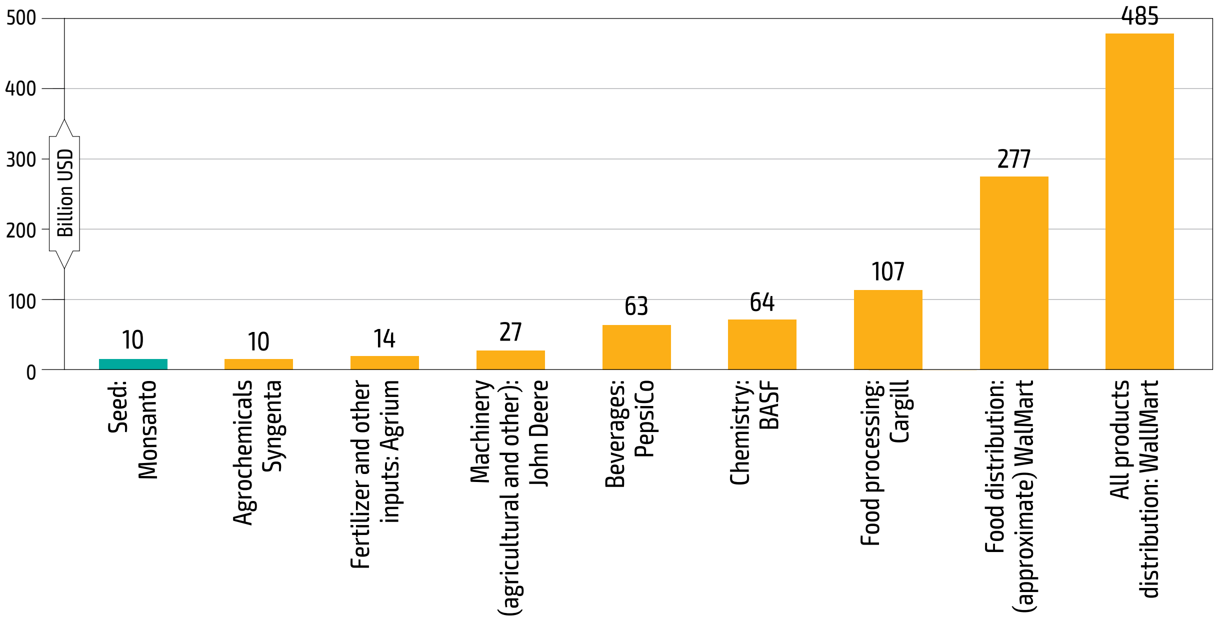
Table 1.26 Top ten retail global giants (2020)

	COMPANY	REVENUE (USD billion)	HEADQUARTERS
1	Walmart	553	USA
2	Amazon	322	USA
3	Costco	161	USA
4	Walgreens Boots Alliance	139	USA
5	The Kroger	127	USA
6	The Home Depot	112	USA
7	JD	86	USA
8	Tesco	83	UK
9	Carrefour	81	France
10	Target	63	USA

Notes: 12 months trailing data as of 3 August 2020. USD are expressed as current USD.

Source: Johnston, M. 2020. 10 Biggest Retail Companies. In: *Investopedia*. Cited 18 May 2022. www.investopedia.com/articles/markets/122415/worlds-top-10-retailers-wmt-cost.asp

Figure 1.57 Size of the largest company at each step of the food value chain (2016)



Source: Bonny, S. 2017. Corporate Concentration and Technological Change in the Global Seed Industry. *Sustainability*, 9(9): 1632. https://doi.org/10.3390/su9091632

Retail is the part of the food system that has been experiencing two major revolutions over the last four decades that have had and will have considerable implications for the mode of operation of food systems throughout the world. The first one is well advanced and under threat of the next major reshuffle caused by the second.

The first revolution, which developed in the wake of department and chain stores as a symbol of capitalist abundance in the West in contrast with socialist scarcity in the East, is the rise of **supermarkets**. Hamilton (2018)[29] states that these have been high-performing tools emerging "in tandem with a state-supported process of industrializing agriculture" and, by the mid-twentieth century, exercising "extraordinary power within the American economic scene". A decade or two later, supermarkets sprouted up in Europe, and during the 1990s, they spread throughout the world, often with the help of foreign direct investment (FDI), as profits for companies were much higher abroad than at home. For example, Carrefour earned 29 percent of its profit from its South American stores that represented only 13 percent of its global sales, and imposed new commercial requirements and rules of the game that substantially restructured supply chains in the subcontinent.[30]

Supermarkets centralized procurement, revolutionized retail procurement logistics technology, imposed private standards, relied on contractual arrangements with producers and suppliers, diffused innovation throughout supply chains, generating economies of scale and, finally, by applying thin margins on very large volumes of goods, made efficiency gains that led to reduced consumer prices.

By the early years of this century, supermarkets represented the lion's share of retail food consumption in HICs for packaged food, and a variable portion in other parts of the world: 75 percent in Brazil, 10 percent in the Plurinational State of Bolivia, 55 percent in South Africa and 5 percent in Nigeria.[31] The emergence of supermarkets not only impacted the way food is produced (technologies, norms and preference for larger farmers), they also tended to impose an external food culture (selling low-nutrition, ultra-processed, convenience food manufactured by transnational food companies), took over local distribution, undercutting local vendors, and wiped out traditional markets by lobbying for food safety and sanitation regulations unsuited to local pre-existing markets.[32]

The second revolution, represented by the irruption of **digital technology** and the emergence of the **platform economy**,[33] has started to bite deeply into supermarket quasi-monopolies. The COVID-19 pandemic accelerated this process by creating a boom of food orders and providing strong incentives for retailers to venture into the digital market or create their own digital platforms. Successive lockdowns have pushed previously reluctant consumers to become platform clients, and they may have succeeded in shifting the retail and catering sectors towards more digital transactions.[34] Supply chain actors expanded the use of new delivery methods such as "click and collect" services and on-line sales. Farmers started harnessing digital technologies and platforms to sell their produce directly to consumers. Restaurants switched to providing take-out and delivery services, with some offering grocery-like services (e.g. selling meal kits rather than prepared food).[35]

Digital platforms make purchasing goods easier for clients. They are powerful engines of innovation, far beyond their weight in the economy, if measured in terms of gross domestic product (GDP). They can be considered much like quasi-markets, where products or services can be traded in the same way as information and data.[33] They implement new and disruptive business models, lower the cost of interacting and transacting, and are challenging competitors on markets.[36] On the negative side, there is evidence that online food delivery platforms encourage consumption of highly processed foods and unhealthy meals.[37]

The growing importance of digital platforms was at least in part confirmed in January 2021 by a nationwide study conducted in the United States of America that pinpointed Amazon as the preferred retailer for consumers – the top retailer, Walmart, being ranked only 14th.[38] Nevertheless, it is yet too early to imagine the full impact this new revolution will have on the level of concentration within food retail, and its effect is likely to be felt throughout food systems (see Section 1.4).

1.12.3 Vertical concentration in food and agricultural value chains, and its implications for the exercise of power within the sector

Vertical concentration refers to processes that have been taking place along global value chains that emerged in recent decades. The originality of global value chains is that their existence creates a link between successive markets that hitherto had been relatively independent, and sets them within a larger context with its specific objectives and rules.

The establishment of global value chains went along with a growing importance of the role played by services, mainly trade, transport, financial and business services. They contribute approximately 25 percent (for agricultural exports) to 35 percent (for food exports) of value added generated along a value chain.5 Spatially, these chains were progressively centralized around three major hubs: the United States of America in Northern and Central America, China in Asia, and Germany in Europe.[5]

The advent of global value chains

The advent of global value chains further spurred concentration, particularly with regard to handling issues of food safety and sustainability and the creation of private standards for addressing food safety and sustainability within global value chains.

The emergence of cross-border value chains and the resulting increased distance between producers and consumers triggered concern about food quality and safety. This has led to the expansion of national and international regulations regarding consumer protection, food safety and quality, such as rules imposing traceability of food and feed, at all stages of production, processing and distribution (e.g. European Union Regulation 178/2002287, World Trade Organization sanitary and phytosanitary standards and Codex Alimentarius).[39]

It also caused a shift from product standards enforced at borders towards systematic controls over production and processing standards, and the emergence of private standards to complement mandatory public norms. This change meant a move away from inspection and testing of products towards quality assurance based on risk management and process controls to satisfy the demand of global buyers.6 These tasks are generally carried out by a lead firm that takes up the responsibility of governing a particular global value chain.

Gradually, along with food safety and standards and under consumer pressure, sustainability also became a concern. This led to new standards as well as companies' rating and certification processes,[bi] often inspired by ethical, social and governance (ESG) criteria. It also justified the creation of associations grouping multinational companies such as the 4C Association for coffee; the World Cocoa Foundation; the Sugar Association; the Roundtable on Sustainable Palm Oil (RSPO) for palm oil; and several others.

The presence of a lead firm governing the global value chain so that it meets the requirements of global buyers often leads to concentration at other levels of the chain in search of more efficient coordination. For example, during the 1970s, the fast-food giant McDonald's, reduced the number of its domestic suppliers of ground beef in the United States of America from 175 to just 5. This brought about deep modifications in the structure of the beef-processing industry in the country and it is seen as one of the main drivers of concentration.[6]

More generally, the way concentration spreads in global value chains is that of a ripple effect. The emergence of large firms at one level of the chain often triggers more concentration at other levels. For example, a large processing plants will seek to push its suppliers to increase their size, as coordination of a small number of large suppliers is much easier and less costly than dealing with a large number of small suppliers.[6]

1.12.4 Major implications for governance, power, competition and innovation

The notion of power, competition and innovation have to be reconsidered in light of the new context created by global value chains and digital technology. In this context, lead firms have a role in the governance of economic entities that cut across interlinked markets that pursue their specific objectives, impose their rules and may not even always be selling any of the products on the markets concerned.

Implications for governance

Concerns about food safety, quality and sustainability standards, as well as the development of services, had several important consequences that led to a new type of concentration that is more difficult to measure than market concentration, as it is expressed in terms of concentration of power in the governance of global value chains.

The role of global buyers in those value chains has become prominent as they are the ones who are directly in touch with consumers, and know their requirements regarding food quality and sustainability. But they also understand requirements in terms of customization and specifications of goods, as well as the volume, speed and reliability of deliveries for those who supply them.

[bi] For example the Dow Jones Sustainability Index, Vigeo Eiris, MSCI, CDP, Forest rating, Rainforest Alliance and UTZ Certified.

The complexity of the problem to be solved and of the risks incurred means that relying on tacit coordination through markets is no longer sufficient, and explicit coordination of firms is required, through direct exchanges of information among companies involved. This further strengthens the position of influence of the lead firm responsible for constructing and coordinating a value chain able to, as Humphrey and Memedovic (2006)6 put it, "deliver what is required by global buyers and food safety regimes" that exercises vertical coordination and drives product differentiation and innovation; in other words, a firm that governs the value chain. This centralized mode of coordination can facilitate the faster application of better practices and the adoption of new technologies, prompting productivity gains.[40] At primary production level, contracts are tools frequently used to impose a standardized production process (see Box 1.39).

Box 1.39 Concentration of the food sector in selected European Union Member States: contractual arrangements in the livestock subsector

In the European Union, the poultry and pork industries rely heavily on production contracts between farmers and integrators. The integrator provides farmers with feed, veterinary services and young livestock (chicks or feeder pigs) and collects the mature animals at the end of a production cycle, while the farmer provides housing, equipment, utilities, labour and management. The integrator decides on the inputs used and on a technology that meets the needs of clients in terms of the attributes consumers want. In this system, the farmer is a simple executor.

Farmers are paid a fee for services rather than a price reflecting the animal's market value. Hog farmers are usually paid an amount per animal or per animal space, and they may receive premiums or be charged deductions tied to performance, based on mortality and feed conversion.

Production contracts reduce some of the risks that an independent farmer would normally ,face, such as the risks of price fluctuations for feed or livestock. They also shift some production risks, like the risk of disease, to integrators.

Contracts create dependence of farmers on integrators: farmers need to renew their contracts with the integrators (the contracts often being of a rather short duration), as they have made long-term investments in animal housing. This puts them in a weak position that results in low fees, particularly when there is only one integrator in the neighbourhood.

Source: Carstensen, P.C., Lianos, I., Lombardi, C., MacDonald, J.M. & Moss, D.L. 2016. *Competition law and policy and the food value chain.* On-Topic l Concurrences N° 1-201. https://discovery.ucl.ac.uk/id/eprint/1478197/7/Lianos_03%20concurrences_1-2016_on_topics_lianos_et_al.pdf

Implications for power, competition and innovation

Traditionally, increased concentration is associated with less competition, as the larger firms are expected to concentrate market power to their benefit, and be capable of fixing the price of a given good.

However, in reality, in complex value chains where exchange between large food manufacturers and retailers, such as supermarkets, involves thousands of differentiated products, and where consumers purchase a basket of food items from a large network of shops spread over a large territory, the market power of big players appears to be less than what could have been anticipated. However, this is true if one referred only to the high level of concentration of agricultural and food markets at different levels of the value chain. In fact, mechanisms operating within value chains are challenging standard views, as firms internalize the long-run implications of pricing decisions they make, and as various actors within the chain (e.g. food manufacturers and retailers) countervail each other's market power.[9]

Another traditional view arising from empirical work conducted in the past century is that the greater the level of competition and number of firms present in a market, the greater productivity growth within the sector, as companies are expected to be forced to innovate in order to survive and develop.[41]

Today, however, giant digital platforms that are in a dominant, if not almost monopolistic position, continue to innovate.[36] They have created zero-price markets,[bj] and multi-sided platforms,[bk] that give them great flexibility and ability to tap into new markets, adding more and further diversified products, and engaging in cross-market activities. They become "gatekeepers", structure digital markets, conglomerated power in various markets, thus gaining a strategic position.[44] They operate as walled gardens, establishing several lock-in effects, setting standards, defining codes of conduct, and barriers to market entry, thus dictating who will be able to act on that market, when, and under what conditions.[33]

By treating more favourably some of their customers over others, they may have exploitative effects.[45] By establishing themselves as indispensable intermediaries between businesses and consumers, they create dependence, as there are no comparably effective alternative options for businesses to reach their clients (and vice versa). This creates a power imbalance, quite different from traditional market power imbalances, that may put them in a position to extract excessive profits, and impose unfair terms and conditions.[46]

Another difference, compared with earlier conditions, is that with the irruption of digital platforms, prices of goods sold are no more the main source of profit for firms. Digital attention markets,[47] along with asset valuation, become key sources of wealth.[48] This explains why some tech companies see their stock exchange value boom while they do not make commensurate profits in their daily operations.

Therefore, power resides no longer in the faculty to compete on markets, to influence others' behaviour or obtain a favourable outcome from a bargaining process, or even to exclude competitors from a market. Rather, it lies in the capacity to attract consumers and businesses to a single platform, to change technology and create new products or scarcities, and obtain the cooperation of both clients and businesses by providing them with something they consider to be indispensable (e.g. access to potential clients or vital information on their specific interests or behaviour). An indicator of this power is, among others, the number of direct relations established with companies and number of clients attracted, as well as the capacity to observe others without them knowing, and learn better and faster about them than anyone else.[33, 44]

Social implications: inclusion and exclusion

Conventional wisdom has been that foreign direct investment (FDI) and transnational enterprises involvement would contribute to economic development in the host country by bringing more capital, new technology, skills and knowledge. The evidence, however, is weak and damaging effects of foreign investments have been highlighted, as they have been blamed for encouraging a race to the bottom and "miserizing growth" by worsening workers' conditions.[7]

The increasingly drastic standards applied in global value chains raise barriers to entry and are responsible for making them more exclusive, particularly where governments scale back their support to smallholders and firms streamline operations to enhance competitiveness.[49] As noted earlier, large food manufacturers and supermarkets often seek to work directly with a small number of preferred, mostly big, suppliers capable of meeting their stringent requirements. This excludes and marginalizes smallholders unable to comply with standards,[7] or are producing too little to justify being dealt with. This process could be reversed at least in part, particularly in HICs, as a result of the "consume local" movement that was boosted by the COVID-19 pandemic.[50]

1.12.5 Concluding remark

Recent history of the food and agriculture sector has been that of concentration. Large corporations have emerged at every level of the food systems, from agricultural inputs provision to food retail.

[bj] The zero-price effect is a phenomenon whereby the demand for a good, service or commodity is significantly greater at a price of exactly zero compared to a price even slightly greater than zero, as consumers do not simply subtract costs from benefits, but instead they perceive the benefits associated with free products as higher.[42]

[bk] Multi-sided platforms: platforms that enable interactions between two or more sides (e.g. Airbnb, eBay, Uber, etc.).[43]

In agriculture proper, farms have grown in HICs, while in LMICs, a mass of nearly 600 million increasingly fragmented smallholders coexists with mega-farms.

The spectacular growth of international trade in agricultural commodities has led to new forms of organization. Global value chains structure the world food economy and have become major suppliers of food and agricultural products around the planet, governed by powerful lead firms that define private production and processing standards to meet consumers' requirements.

With the advent of supermarkets, during the twentieth century, and now of digital platforms whose role in food has been accelerated by the COVID-19 pandemic, new forms of economic power are concentrating in a handful of corporations that cut across interlinked markets. Innovations such as zero-price markets, multi-sided platforms, attention markets and big data analysis create new opportunities for concentrating economic power and accumulating wealth.

The consequence of this evolution has been to exclude and marginalize tens of millions of smallholders unable to comply with standards or who produce too little for large corporations to be bothered to deal with them.

If past trends continue, there will be further concentration in food systems, and more smallholders will be excluded and pushed towards urban areas throughout the world, particularly in LMICs.

Further concentration of power within food and agriculture is likely to lock the world in the current technological path that has proven to be unsustainable. Large global corporations will accumulate sufficient knowledge and information to be in a position to decide and impose what consumers will eat in the future.

The "consume local" movement that was boosted during the COVID-19 pandemic might, if it is confirmed and gains further strength at the global level, change radically this perspective by creating an alliance of consumers and producers able to take the lead in piloting the food systems through a transition towards greater sustainability.

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1.13 Consumption and nutrition patterns (Driver 14)

With the acceleration of dietary transitions among many low- and middle-income countries (LMICs) towards higher consumption of resource-intensive foods and Western-style diets,[bl] underpinned by demographic, socioeconomic and political drivers, two major interrelated challenges will need to be faced in the coming decades: 1) malnutrition in all its forms (undernutrition, micronutrient deficiencies, overweight and obesity); and 2) the (un)sustainability of agrifood systems.

While the underlying causes of malnutrition are complex and multifaceted, diets remain one of its major direct causes. Recent research shows that unhealthy diets top the list of the main risk factors for the global burden of disease.[1] On the one hand, the food produced exerts enormous pressure on the environment and natural resources, while, on the other, people working in primary production or food services face low incomes and food insecurity (see Sections 1.7, 1.14 and 1.16).

The need to shift diets and consumption patterns towards those that can address simultaneously malnutrition, social and environmental concerns, i.e. sustainable healthy diets,[bm] is more pressing than ever. Achieving such diets not only requires that the "right food" is produced, available and affordable, but also that multiple and long-lasting changes are made to consumer behaviours.[3]

Consumers are increasingly making complex choices about the sustainability, nutritional content and safety and of what they eat. It may be that consumers actually hold the power to shift demand towards more environmentally and socially responsible, and nutritious foods. Provided the right mix of information, support and regulation is in place, this movement may lead to deep changes in production systems. For instance, FAO in 2018[4] states that "Carbon labelling could help shape consumer preferences, contributing to the transition to a low-emissions economy. This would require an internationally recognized approach in setting the related standards".

The *Global Sustainable Development Report 2019*[5] recalls that building sustainable food systems and healthy nutrition patterns to accelerate progress towards the Sustainable Development Goals (SDGs) requires collaborative action by various stakeholders, including consumers.

Some questions can be raised in this context:

- To what extent can consumers contribute to the transitioning of agrifood systems towards sustainability?
- What future scenarios look plausible regarding the role of consumers in shaping sustainable agrifood systems?

To address the above questions, this section analyses recent trends in food consumption and explores causal factors of change.

1.13.1 Recent trends

Changes in dietary patterns over time, regional differences and driving factors

Dietary patterns have been changing throughout history.[6] The hunter-gatherer diet was based on plants and low-fat wild animals. It corresponded to short life spans because of infectious diseases and other natural causes. After the advent of agriculture, the dietary pattern was less varied and was predominantly made up by cereals. Recent times have brought other eating habits, sometimes characterized by fewer starchy staples, more fruit, vegetables and animal protein or, in others, patterns richer in fat (coming especially from animal products), sugar and processed foods, and poorer in fibre, while people's physical activity reduced, on average. The latter has been associated with the emergence of illnesses such as diabetes, hypertension, cardiovascular diseases and some cancers. Finally, a more desired pattern, characterized by reduced consumption of fat and higher consumption of fruits and vegetables, has begun to appear in some contexts.

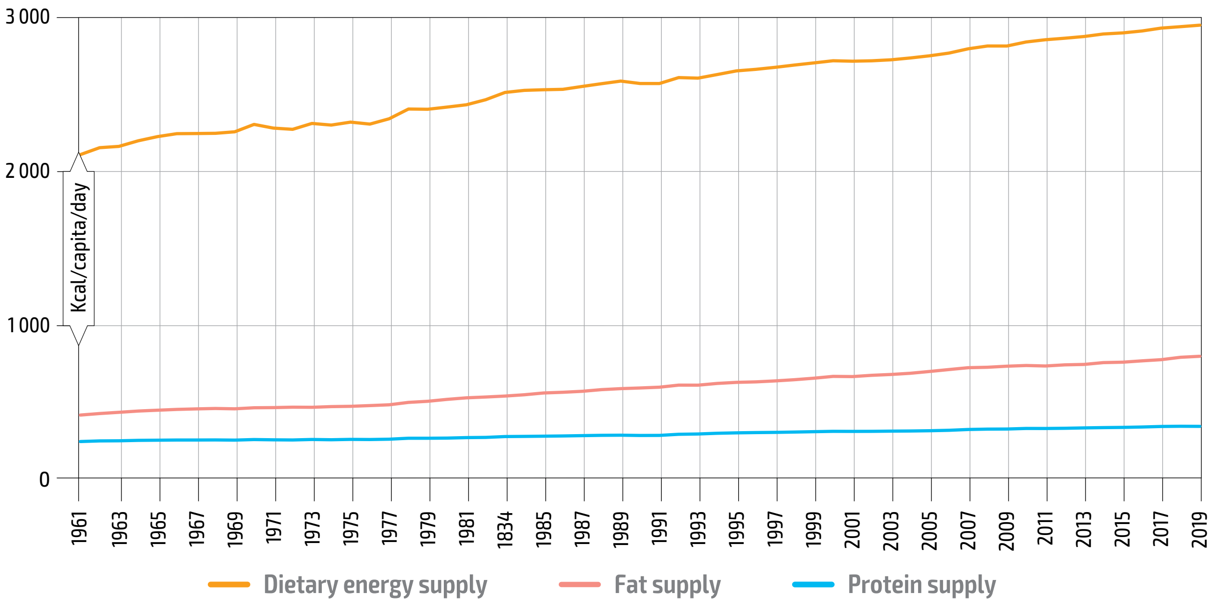
[bl] Characterized by high energy, fat, protein, sugar and salt, and low fibre and micronutrient-rich foods.

[bm] FAO and the World Health Organization (WHO) define sustainable healthy diets as "Dietary patterns that promote all dimensions of individuals' health and well-being, have low environmental pressure and impact, are accessible, affordable, safe and equitable and are culturally acceptable".[2]

The dietary energy supply (DES), that is, the daily supply of calories per capita, is an important indicator for assessing the evolution of the national, regional and global food situation. It is based on data from the FAO Food Balance Sheets, and documents shifts in the quantity and composition of food supply over time. On some occasions, it is used as a proxy for consumption.

Figure 1.58 shows DES trends worldwide, highlighting an increase of around 40 percent from 1961 to 2019. In the same period, the contribution of fats and proteins to DES rose respectively by around 75 percent and 32 percent. FAO's data also show that global average per capita availability of animal-based protein grew by 67 percent, while that of plant-based protein grew by only 19 percent over the same period.

Figure 1.58 Global per capita dietary energy supply and energy from fats and proteins (1961–2019)



Sources: Authors' elaboration based on FAO. 2022. Supply Utilization Accounts. In: *FAOSTAT*. Rome. Cited 9 June May 2022. www.fao.org/faostat/en/#data/SCL; FAO. 2022. Suite of Food Security Indicators. In: *FAOSTAT*. Rome. Cited 9 June May 2022. www.fao.org/faostat/en/#data/FS

Yet, these trends have not been consistent across different regions and periods. Table 1.27 shows that, for example, the DES for China more than doubled between 1961 and 2019, with the fastest growth being observed before 1991. This allowed China, which had the lowest DES in 1961 to almost catch up with high-income countries (HICs). Near East and North Africa (NNA) registered a significant increase (+51.7 percent), until 1991 but shows a non-marginal decrease (-11.1 percent) between 1991 and 2019, East Asia and the Pacific (EAP) and Latin America and the Caribbean (LAC) saw a moderate but regular rise. In both South Asia (SAS) and sub-Saharan Africa (SSA) instead, DES levels grew only modestly before 1991 to then increase their growth between 1991 and 2019.

The *2016 Global Food Policy Report*[7] estimated that, already in 2009, the average DES exceeded average daily energy requirements in more than 60 percent of countries and territories.

Behind this general increase in DES, there have been changes in food consumption patterns, shaped by a number of factors that interact in a complex manner, including income, prices, demographic changes, urbanization, trade, individual preferences and beliefs, cultural traditions and social norms, and modifications of lifestyle.

Among these factors, rising incomes have been proven to play a major role. For instance, based on data from 120 countries, analysis shows that when gross domestic product (GDP) per capita increases, meat intake first grows until it reaches a maximum and then decreases, while diets become more diversified and fruit and vegetable consumption rises.[8] During the last four decades, some populous countries in EAP and LAC, in particular, have experienced rapid economic growth that resulted in massive changes in their social structure and the emergence of middle classes that consume increased quantities of highly resource intensive foods, such as meat and dairy products.

Table 1.27 Dietary per capita energy supply by region (1961–2019)

REGION	DIETARY ENERGY SUPPLY (kcal/capita/day)			CUMULATED GROWTH RATE OVER THE PERIOD (percent)	
	1961	1991	2019	1961–1991	1991–2019
High-income countries	2 858.2	3 281.9	3 471.9	14.8	5.8
China	1 438.9	2 444.1	3 340.1	69.9	36.7
East Asia and the Pacific	1 840.6	2 194.4	2 441.5	19.2	11.3
Europe and Central Asia	2 969.5	3 578.0	3 310.7	20.5	-7.5
Latin America and the Caribbean	2 249.1	2 679.3	3 031.1	19.1	13.1
Near East and North Africa	1 909.3	2 896.1	2 573.3	51.7	-11.1
South Asia	2 024.3	2 267.7	3 347.0	12.0	47.6
Sub-Saharan Africa	2 041.1	2 227.3	2 825.2	9.1	26.8
World	**2 114.1**	**2 580.4**	**2 963.0**	**22.1**	**14.8**

Note: Dietary energy supply (DES) is calculated using three-year averages to reduce the impact of possible errors in estimated DES, due to the difficulties in properly accounting of stock variations in major food items.

Source: Authors' elaboration based on FAO. 2022. Supply Utilization Accounts. In: FAOSTAT. Rome. Cited 9 May 2022. www.fao.org/faostat/en/#data/SCL

The four following tables illustrate how the supply of four food groups has evolved between 1990 and 2019 in different regions. Cereal supply per person increased by around 52 and 24 percent in EAP and SAS, respectively. It grew, but more slowly, in China, HICs, LAC and SSA, while it decreased in NNA and Europe and Central Asia (ECA) (see Table 1.28).

Table 1.28 Cereal supply per capita by region (1990 and 2019)

REGION	CEREAL SUPPLY PER CAPITA (kg/capita/year)		CUMULATED GROWTH RATE OVER THE PERIOD (percent)
	1990	2019	1990–2019
High-income countries	118.0	128.1	8.5
China	171.2	201.7	17.8
East Asia and the Pacific	148.5	226.9	52.8
Europe and Central Asia	240.8	167.1	-30.6
Latin America and the Caribbean	121.2	135.9	12.1
Near East and North Africa	218.1	213.3	-2.2
South Asia	154.8	191.8	23.9
Sub-Saharan Africa	122.7	137.8	12.3
World	**148.5**	**174.7**	**17.6**

Sources: Authors' elaboration. Data for 1990 are based on FAO. 2022. Food Balances (-2013, old methodology and population). In: *FAOSTAT*. Rome. Cited 22 June 2022. www.fao.org/faostat/en/#data/FBSH; data for 2019 are based on FAO. 2022. Food Balances (2010-). In: *FAOSTAT*. Rome. Cited 22 June 2022. www.fao.org/faostat/en/#data/FBS

Meat supply per person almost tripled in China, more than doubled in ECA and EAP, almost doubled in LAC, significantly increased in NNA but stayed steady in SSA at around 15 kilograms per capita in 2019. In HICs, meat supply per person barely increased, as these countries may have entered what has been called the "second nutrition transition".[8] Globally, meat available per capita grew by more than a third (see Table 1.29).

Table 1.29 Meat supply per capita by region (1990 and 2019)

REGION	MEAT SUPPLY PER CAPITA (kg/capita/year)		CUMULATED GROWTH RATE OVER THE PERIOD (percent)
	1990	2019	1990–2019
High-income countries	82.7	90.2	9.1
China	26.5	63.4	139.2
East Asia and the Pacific	14.3	30.8	115.4
Europe and Central Asia	26.8	57.2	113.4
Latin America and the Caribbean	41.5	75	80.7
Near East and North Africa	18.2	26.8	47.3
South Asia	5.0	6.5	30.0
Sub-Saharan Africa	14.5	15	3.4
World	**31.5**	**43.1**	**36.8**

Sources: Authors' elaboration. Data for 1990 are based on FAO. 2022. Food Balances (-2013, old methodology and population). In: *FAOSTAT*. Rome. Cited 22 June 2022. www.fao.org/faostat/en/#data/FBSH; data for 2019 are based on FAO. 2022. Food Balances (2010-). In: *FAOSTAT*. Rome. Cited 22 June 2022. www.fao.org/faostat/en/#data/FBS

Similarly to what is observed for meat, the quantity of milk available per person dramatically increased in China and, to a much lesser extent, in SAS, ECA and LAC. However it decreased in EAP, NNA and SSA. In addition, also HICs display shrinking supply per person. It is noticeable that, globally, the per capita supply of milk stayed substantially steady (see Table 1.30).

Table 1.30 Milk supply per capita by region (1990 and 2019)

REGION	MILK SUPPLY PER CAPITA (kg/capita/year)		CUMULATED GROWTH RATE OVER THE PERIOD (percent)
	1990	2019	1990–2019
High-income countries	205.3	169.4	-17.5
China	6.2	23.3	275.8
East Asia and the Pacific	9.8	7.4	-24.5
Europe and Central Asia	145.4	166.8	14.7
Latin America and the Caribbean	92.8	107.6	15.9
Near East and North Africa	55.0	35.2	-36.0
South Asia	54.3	71.5	31.7
Sub-Saharan Africa	28.0	21.8	-22.1
World	**70.0**	**70.7**	**1.0**

Sources: Authors' elaboration. Data for 1990 are based on FAO. 2022. Food Balances (-2013, old methodology and population). In: *FAOSTAT*. Rome. Cited 22 June 2022. www.fao.org/faostat/en/#data/FBSH; data for 2019 are based on FAO. 2022. Food Balances (2010-). In: *FAOSTAT*. Rome. Cited 22 June 2022. www.fao.org/faostat/en/#data/FBS

Lastly, the supply per person of fruits and vegetables globally grew the fastest among the four groups of food items, pushed by a dramatic increase in China, SAS and EAP, and, to a lesser extent, inLAC. On the contrary, in SSA, it barely increased while in HICs and ECA, it decreased (see Table 1.31).

Table 1.31 **Fruits and vegetables supply per capita by region (1990 and 2019)**

REGION	FRUITS AND VEGETABLES SUPPLY PER CAPITA (kg/capita/year)		CUMULATED GROWTH RATE OVER THE PERIOD (percent)
	1990	2019	1990–2019
High-income countries	208.3	188.8	-9.4
China	118.3	482.9	308.2
East Asia and the Pacific	92.9	147.1	58.3
Europe and Central Asia	304.2	252.4	-17.0
Latin America and the Caribbean	127.6	165.4	29.6
Near East and North Africa	205.6	236.2	14.9
South Asia	72.5	133.1	83.6
Sub-Saharan Africa	94.9	108.6	14.4
World	**127.7**	**220.6**	**72.7**

Sources: Authors' elaboration. Data for 1990 are based on FAO. 2022. Food Balances (-2013, old methodology and population). In: *FAOSTAT*. Rome. Cited 22 June 2022. www.fao.org/faostat/en/#data/FBSH; data for 2019 are based on FAO. 2022. Food Balances (2010-). In: *FAOSTAT*. Rome. Cited 22 June 2022. www.fao.org/faostat/en/#data/FBS

Urbanization and per capita income increase appear to act as an accelerator of the nutrition transition from cereals towards meat and fruits and vegetables. As compared to their rural counterparts, urban households spend a lower share of their income on cereals, fats and oils, but a higher percentage on meat, dairy and fish (see Section 1.1).

This transition goes along with an increasing availability and consumption of cheap, industrially processed foods (also known as ultra-processed foods)[9] that are high in salt, sugar and fat. Recent research has been carried out to quantify the magnitude and distribution of this increase. For instance, based on sales data from 80 countries, a research study estimated that, between 2002 and 2016, the volume of sales per capita increased in all regions, except in Western Europe, Northern America and Oceania, with the highest increases in EAP, NNA and SAS. However, in 2016, the total volume of sales of ultra-processed foods per capita was still highest in Northern America and Oceania.[10] Trends are different for beverages. Moreover, a recent systematic review of 99 studies evaluated actual consumption of ultra-processed foods, finding a high variability in terms of the percentage of energy provided by such foods. Highest consumption estimates were found in the United States of America and the United Kingdom of Great Britain and Northern Ireland, while the highest variability within a country was found in Brazil.[11] Financial crises such as that of 2007–2008 tend to accelerate this process, including among low-income groups of people.[12]

The safety and quality of diets have also suffered changes, because of the non-compliance with good agricultural or production practices or from pollution. Some research studies have shown that diets increasingly contain pesticide residues,[13] antibiotics[14] and microplastics[15] as a result of agricultural technologies or water pollution.

Changes in the past decades have not been limited to what people eat, but also to how people consume foods, including a substantial increase in people eating away from home, loss of conviviality, fast-paced consumption, and changes in ways and methods of how people procure and pay for food, to name a few.[16,17] Further, the COVID-19 pandemic has brought significant changes to consumption and diet patterns, and to people's food behaviours.

The impact of dietary shifts on nutritional and environmental outcomes

Globally, changes in dietary patterns, underpinned by the above-mentioned drivers, have contributed to a modest reduction in child stunting and, to a certain extent, in undernourishment. However, after decades of decline, the trend reverted. The COVID-19 pandemic has exacerbated further the situation, with an estimated global range between 720 and 811 million people facing hunger in 2020. Moreover, around 3 billion people do not have regular access to safe, nutritious and sufficient food. Simultaneously, adult obesity keeps rising and child overweight levels have not yet reached a plateau.[18]

Poor diets are the leading risk factor for deaths in most countries, causing an estimated 11 million deaths and 255 million disability-adjusted life years (DALYs).[19] An increased risk to non-communicable diseases is also associated with high consumption of meat, processed meats and sodium,[20] as well as industrially processed foods. However, the evidence available still needs corroboration and to be interpreted with caution.

Moreover, the shift towards resource-intensive foods has also had a huge impact on the environment.[20, 21, 22, 23] Research shows broad inefficiencies in energy and protein conversion rates from feed to food (Table 1.32). Beef, for example, has one of the lowest "feed-to-food" conversion efficiencies. Only 1 percent of gross cattle feed energy and 4 percent of ingested protein are transformed into human-edible calories and protein. Other foods of animal origin also have low conversion rates. These rates may, however, vary depending on the production system being considered.

Table 1.32 Feed-to-food conversion efficiencies in percent (units of edible output per units of feed input)

FOOD	PERCENT OF CALORIES	PERCENT OF PROTEIN
Beef	1	4
Sheep	1	3
Farmed shrimp	7	15
Milk	7	16
Pork	10	15
Poultry	11	20
Farmed Finfish	12	18
Egg	13	25

Source: Based on WRI (World Resources Institute). 2019. *World Resources Report. Creating a Sustainable Food Future: A Menu of Solutions to Feed Nearly 10 Billion People by 2050.* Washington, DC. https://files.wri.org/d8/s3fs-public/wrr-food-full-report.pdf

Conversely, there is a significant difference in the pressure exerted on natural resources by animal-based compared to plant-based foods, as well as in their contribution to greenhouse gas (GHG) emissions. For instance, the most land-demanding items are beef, lamb, mutton, coffee and cheese. For freshwater, the most requiring productions are farmed prawns, farmed fish, tomatoes and cheese, while the highest GHG emitters are coffee, beef, prawns, and lamb and mutton.[24]

Researchers have argued that the impacts of animal products can markedly exceed those of vegetable substitutes, as meat, aquaculture, eggs and dairy use around 83 percent of the world's farmland and contribute 56 to 58 percent of food's GHG emissions, despite providing only 37 percent of our protein and 18 percent of our calories. They also report that the effects of the lowest-impact animal products exceed on average those of substitute vegetable proteins in terms of GHG emissions, eutrophication, acidification (excluding nuts) and, frequently, land use. These differences are likely to hold in the future unless technological changes disproportionately target animal products.[24]

The evolution in dietary patterns have largely contributed to the global increase of GHG emissions and, unless mitigation measures and technical efficiency improvements are implemented, emissions will continue to further build up in the future. It is good to keep in mind that, already now, croplands and grazing lands are estimated to occupy more than a third of the Earth's surface,[25] that agriculture uses 70 percent of all freshwater resources, and that it has led to the pollution of surface water and groundwater, and created dead zones in oceans because of the excessive application of fertilizers in some regions.[21]

Dietary patterns linked to better nutritional and environmental outcomes

In the last decade, there have been noteworthy attempts to model future alternative diet scenarios and their potential impacts on various sustainability outcomes (mainly nutrition/health and environment).[21,26,27]

For instance, moving from a Western-type diet to one that excludes animal products would contrib-ute to improve health outcomes and reduce premature diet-related mortality in various contexts. It also has a transformative potential, reducing by more than 75 percent the land used for food, including a 19 percent decrease in arable land. In addition, it would reduce by half food-induced GHG emis-sions, acidification and eutrophication, and cut scarcity-weighted freshwater withdrawals by 19 percent for a 2010 reference year.[28] The International Panel on Climate Change (IPCC) reports that adopting a sustainable diet has the potential to reduce global GHG emissions by 0.7 to 0.8 gigatonnes of CO_2 per year.[29]

The evidence is not limited to modelled future scenarios. Together with other low resource-intensive consumption patterns, the Mediterranean diet, for example, has been promoted as a model of a healthy and sustainable diet, as it has been documented to diminish pressure on the environment in various countries.[30,31]

Dietary change therefore appears to be capable of delivering environmental benefits on a scale not achievable by production alone with the introduction of new technologies, including digitalization of agriculture (see Table 1.7 in Section 1.4). In the absence of such shift in food consumption, many of the environmental impacts of food are expected to worsen, especially as demand for resource-intensive foods, such as meat and dairy, increases and the global population grows.

However, despite the encouraging results of several studies, there exists uncertainty about the magnitude of the dietary changes that could take place, because of the different economic, social and cultural barriers that constrain consumer behaviour and demand.[32]

1.13.2 Consumption and nutrition patterns and agrifood systems

Now that the potential that diet change represents for bringing agrifood systems onto the path of sustainability is well established, it is necessary to analyse whether consumers can really be credible agents of this transformation. Researchers and decision-makers are divided on the subject.

On the one hand, some claim that consumers hold the power to shift demand towards environmentally and socially responsible and nutritious products, mainly through their choices and their ability to select what they eat, but also by taking a greater part in food governance.[33] Others go all the way to promote an "alternative hedonism", where consumers experience both a sense of morality and pleasure concurrently.[34,35]

On the other hand, there are those who put forward that, despite some exceptions, consumers are mostly passive or have not been in a position to shift demand significantly towards better nutrition and sustainability outcomes.[34] Furthermore, they claim that most people have not yet internalized environmental sustainability and that the concept of sustainability is understood differently among countries, which poses an additional challenge.

Although the complexity of the realities concerning consumer behaviour and consumer demand has been emerging,[bn] has been increasingly acknowledged,[37] it is still not adequately factored into

[bn] It is important to clarify what constitutes consumer demand and consumer behaviour. Consumer demand is understood as the collective ability to acquire a food product or service. Consumer behaviour, on the other hand, is defined as the actions or decisions made by consumers at the societal, household or individual levels, on what, where and how they procure, use and dispose of food and feed others (considering gender, age and social factors), as well as the actions to promote changes in their food environments.[36] Not all changes in consumer behaviour will translate into a significant shift in demand.

many interventions and evaluation designs.[38] For instance, many studies are framed on specific theories of behaviour that are not reflective of modern, complex choice realities or account for the fact that food consumption and diet are made up by numerous interactions. Many interventions are still assuming that improvements in knowledge, or changes in attitudes and beliefs, will automatically lead to concrete changes in behaviours, while evaluators often use outcomes and indicators that are not feasible or realistic.

The examples presented below (see Table 1.33) highlight such complexities and illustrate further the consumer perspective. They examine positive changes and how these interact with food supply and the food environment.

Table 1.33 Selected demand-side policy measures to influence consumer behaviour and consumer-driven efforts and approaches

DEMAND-SIDE APPROACHES	CONSUMER-DRIVEN EFFORTS AND APPROACHES
• Financial measures to discourage, restrict or incentivize selected choices. • Food environment strategies to influence and guide consumers: – nudges and choice of architecture – sustainability labelling (i.e. eco-labelling) • Information, communication and education measures.	• Consumer-driven behaviour changes (at the individual level). • Positive deviants, influencers and agents of change. • Consumer advocacy and activism. • Consumer movements and trends. • Formal consumer associations/groups/bodies.

Source: Authors' elaboration.

Demand-side approaches to influence consumer behaviour

In recent years, several types of demand-side policies have been adopted by governments, with the intention of influencing consumer behaviours and ultimately demanding better human and planetary health.

Financial measures to discourage or incentivize choices. Taxes and subsidies have been increasingly used by governments to address health, environmental and inequality goals.

Food taxes are intended to provide consumers with an economic and rational decision-making justification for change. The underlying assumption is that higher prices, sometimes coupled with the cognitive effect of the tax highlighting the seriousness of the issue, will lead to lower consumption of the taxed foods, and in some cases, to industry reformulation.[39]

Over the past few years, the motive for implementing food taxes, such as the sugar-sweetened beverages tax, has been primarily for obesity and non-communicable diseases prevention. This has resulted in some reductions in sales and consumption.[40] More recently, such taxes have been proposed to serve broader sustainability purposes.[41] Even the sugar-sweetened beverages tax has been rethought for serving environmental goals, because of the impacts associated with their production, transformation and distribution, including packaging and transportation.[42]

However, critics have pointed out that such taxes can have adverse food security effects in lower-income households.[39]

Alternatives have been proposed to mitigate the potential inequality effects of taxes, such as combining them with subsidies for fruits and vegetables, while avoiding subsidizing energy-dense products; reducing the supply cost and increasing consumer acceptability of more sustainable sources of protein; allocating the revenue from taxes to social protection programmes; and targeting meat products with the highest GHG emissions.[43, 44, 45, 46, 47]

It is nonetheless worth noting that all these fiscal measures are the result of a highly political endeavour that can be further jeopardized by a limited consumer acceptability, and putting too much value on taste, convenience and price, especially when resources (time and financial) are insufficient, as is the case of low-income families with young children.[48, 49] Other key challenges include complexity of their design, economic and governance contexts, industry opposition, and the lack of empirical explanations of the changes of consumer behaviours.[50, 51]

Based on lessons learned from the implementation of sugar-sweetened beverage taxes, these should not be planned as stand-alone policies, but rather used in tandem with other behavioural change initiatives.[44, 47, 50, 52] Research also recommends taxes to be coupled with interventions at the individual and community levels that target known personal and sociocultural barriers of high-consuming groups.[53]

Food environment strategies to influence and guide consumers

Nudges and choice architecture interventions rely on automatic and intuitive decision-making processes in habitual circumstances. Nudging strategies alter aspects of the choice architecture, usually at the time and place of food selection in order to make healthier or more sustainable food choices easier, more appealing, timely and normal.[54, 55] They can have a significant effect on desired, specific behaviours particularly when considering food choices, albeit with different degrees of effect.[56] For example, reducing meat portion sizes, providing meat substitutes with complementary information materials, and manipulating the sensory properties of meat or meat alternatives, were associated with a reduced demand for meat.[57]

From an ethical point of view, nudges may in some cases reduce the personal sense of agency and control of consumers to understand how their actions contribute to health and sustainability issues.[47] It has been recommended that nudging be accompanied by well-designed education programmes so that "nudged consumers" are conscious of the types of interventions that are being applied and that they are capable of identifying them.[58]

Food labelling (e.g. eco-labelling, nutriscore, front-of-pack). Food labels have emerged as a scheme to provide consumers with information about the nutrient composition and the environmental or social features associated with the production of a food item.[54] Currently, there are a variety of labels available in the market, either addressing a single issue (e.g. carbon footprint, nutrient composition, workers' conditions) or multiple concerns (e.g. animal welfare and local production). They may enable consumers to recognize the origin, carbon footprint and production methods of specific foods.[59]

The Italian innovative small-scale approach SANI (Italian for "healthy"), for example, introduced a series of nutrition and sustainability labels (carbon footprint) to characterize specific local products of the Mediterranean diet. These labels were designed with easily distinguishable colours and icons, and equipped with a quick response (QR) code to provide consumers with real-time information about a given item's nutrition and sustainability properties. Further, the labels were promoted via novel marketing channels and through meetings among an active network of partners. Altogether, this led to a significant increase in SANI-labelled product sales.[60]

Indigenous Peoples face significant challenges to access markets for commercializing their food and produce. As is the case with other rural and local people, Indigenous Peoples have minimal opportunities to capture a share of the final consumer price as, along the market chain, they are highly dependent on intermediaries and players who have more information and bargaining power than them. The lack of labelling and certification, fluctuating supply, the organoleptic characteristics of their products, and lack of market information add to issues of remoteness, marginalization and language and communication barriers. As Indigenous communities increase their linkages to markets, labelling and certification become a priority if the quality of their products has to be recognized by consumers. Indigenous youth are also working on reducing the length of the market chain by using cell phones and the internet to link urban consumers with community production.[86]

Limitations of this approach in steering consumer demand towards nutritious and more sustainable foods include low visibility and understanding in real life situations; difficulty for consumers to digest information on the implications of their food choices; and the fact that exposure to information may not bring about behaviour change, especially in a retail environment, where buyers make a large number of decisions within a relatively short time span. Even if consumers notice the labels and make an effort to understand them, they may make wrong inferences about the true meaning of their features.[61, 62] Positive sustainability features can be traded off against other criteria such as price, taste, brand, use-by-date, quantity, and even the healthiness of a food product, which consumers may not want to compromise on.[61, 63, 64]

Sustainability labels are important, but unless complemented by educational interventions (such as integrating competences related to the comprehension and use of food labels in the school system), their role will be limited in helping consumers become aware and skilful on how to use them as part of their normal food shopping practices.[64]

Information, communication and education. Several measures ranging from information dissemination and communication campaigns (e.g. Meatless Mondays, text messages or TV shows) to long-term educational interventions (e.g. school food and nutrition education, community-based nutrition education programmes and cooking programmes), have been implemented with the aim to raise awareness, empower and encourage consumers to improve their food choices.[65]

Weak assumptions of how behaviour change occurs are still very prevalent in research and programme design. It is commonly thought that the provision of generic information will lead to long-lasting behavioural change. This has led to an overestimation of effects of stand-alone media campaigns and dissemination of information materials.[36] At the same time, the amount of competing dietary advice and information makes it very difficult for consumers to discern evidence-based claims on nutrition and environmental sustainability.

In contrast, characteristics of interventions that have shown effectiveness include being grounded on consumers' barriers, priorities, as well as on what influences their diets, and being of an adequate dose and duration for the intended change. Interventions ought to involve direct experiences where consumers can strengthen their skills and sense of agency to own the change, and have the capacity to share and propagate it. Other key principles of effect include being rolled out alongside interventions of the food environment that make the desired behaviours feasible to maintain.[36]

A good example is the integration of holistic and competence-based food education programmes into national primary and secondary curricula which has the potential, together with enabling school food environments, to foster food competent, resilient, critical and proactive food citizens.[36]

It is therefore necessary to promote long-term education interventions and other strategies that have a solid evidence foundation, are context-specific, address major determinants of food behaviour, and are adequately combined with other financial and food environment policies.[65,36]

Consumer-driven approaches

Individual consumer behaviours and political participation. Some examples of "sustainably conscious" consumer behaviours include shopping mostly seasonal or fair-trade foods, reducing purchase of ultra-processed foods, spending more time on cooking, supporting small-scale farmers, choosing free-range eggs, or doing composting at home. These types of behaviours often arise in those with strong health-oriented goals or ethical stances, and in believers of individual responsibility, and who at the same time have the access, financial means and time to maintain them.[34,66]

Shifts in social norms, widespread collective practices (e.g. buying seasonal food in Mediterranean countries) and facilities (e.g. fruit and vegetable stands, free compost containers), health scares and warnings (e.g. BSE - bovine spongiform encephalopathy in meat, dioxin in poultry), alerts to major social or environmental issues (poverty, climate change or loss of biodiversity), access to know-how and basic food skills are also key facilitators for consumer uptake of more sustainable behaviours.

Box 1.40 showcases a concrete case of transformation of consumer behaviour that led to a measurable impact on demand and supply.

Unfortunately, not all behaviour changes in individuals translate into significant collective impact on consumption patterns and demand. Aside from evident structural obstacles and resource limitations (i.e. physical and economic access), it is difficult to capitalize on what exactly drives such changes for scaling up. For instance, there is interplay in consumer goals, as they may engage in practices thought to be environmentally conscious for reasons other than environmental concerns, such as status, health, emotion or distress over animal suffering.

Additionally, even if consumers believe that how they eat has a significant impact, there is still a lot of complexity to navigate through. For instance, apart from a few straightforward practices (e.g. eating less red meat and reducing food waste), individuals have difficulty in evaluating the real environmental impacts of their choices.[24]

Box 1.40 How consumers have shaped the meat market in the United Kingdom of Great Britain and Northern Ireland

In October 2015, the World Health Organization published a report[67] announcing that the consumption of processed meat is "carcinogenic to humans" and that eating red meat is "probably carcinogenic to humans".

Shoppers in the United Kingdom of Great Britain and Northern Ireland reacted quickly to this information and media attention. Sales of bacon and sausages fell by GPB 3 million in the two weeks following the publication of the report. In 2016, meat sales were down by GPB 300 million and, as communicated by the specialized media,[68] this was attributed to the health warning linking processed meat to cancers. Meanwhile, consumers chose fish as a substitute to meat, moving sales up by GPB 30 million in the same year. This trend continued well into 2019.

According to the United Kingdom National Diet and Nutrition Survey,[69] red and processed meat consumption in the country dropped by nearly 30 percent in a decade, from 2008/09 to 2016/17.

Besides modifications in individual behaviour, consumers frequently influence change through their civic responsibilities by, for instance, advocating and voting for local or national political candidates according to their food policy or environmental proposals, or by supporting petitions.

Positive deviants, influencers and agents of change. They are consumers who regularly adopt behaviours that are supportive of good nutrition and are environmentally conscious. They can cast an influence on others to follow, including by acting as role models. In terms of positive deviants, these have been well documented for practices concerning nutrition of young children in low-income contexts, even though there is yet an important uncertainty regarding its potential for promoting sustainability-related practices.

The concept of "influencer" is currently mainly associated with social media. However, in a broader sense, influencers are those who exert an influence on others to change behaviours through a variety of channels and settings, including within their own families, schools or communities. There are many examples of influencers having reached a large number of online followers. They involve food journalists, chefs promoting plant-based diets or youths supporting a zero-waste lifestyle.

Currently, social media plays a critical role in shaping consumer opinions, attitudes and purchasing decisions.[70] Much has been discussed on the part of youth-led and social media-driven efforts for change, even though little has been studied and published on their actual impact, particularly with regard to modification of food habits (beyond enhanced awareness and intention to change), and ultimately, on consumption patterns. On the other hand, much research has focused on the results of the promotion by social media of highly processed foods and other behaviours that are not conducive to adequate nutrition or that have led to the creation of a "homogenized consumption", described as degrading the environment. In some cases, efforts have led to enacting policies (e.g. ban of digital marketing of food products with high content in fat, sugar or salt).[71]

Some of the main challenges that may impair a wider impact of social media influencers centre on the sheer amount of information that consumers are bombarded with, and which is most often conflicting and competing with more credible and science-based information. Moreover, the low level of critical food and media literacy among populations, as well as the fact that when reaching a substantial following, many influencers may be approached by commercial interests (e.g. for endorsing certain brands or promoting specific food products), constrains the potential for achieving impact. In addition, the attitude-action gap acts as a barrier, along with the fact that consumers have to make competing choices in their everyday life on how to best allocate their time and financial resources.

Consumer advocacy and activism. Consumer advocacy and activism seek to bring about change on a particular issue or set of concerns. This may involve organizing rallies or protests, boycotting certain food products or brands, or creating petitions aimed at passing or blocking legislation, or for ending problematic industry practices.[72]

The main requirements for successful consumer activism and advocacy efforts include having a clear and attainable goal, attention from mainstream media, contexts in which protesting is politically enabled, alliances with established movements, and use of emotional and motivational content.[73]

On the other hand, there are significant challenges that impair large-scale and durable gains from consumer activism. They comprise the long road towards actual change, coordination failure, dependence on resources and an interest in maintaining pressure,[74] a focus on single issues, and dangers of polarization. The effectiveness of various conventional and emerging forms of consumer political participation within the nexus of food, nutrition and sustainability has yet to be properly studied.

Consumer movements and trends. Slow Food, organic food, ethical consumption, community-supported agriculture, community gardens, fair trade,[bo] and zero food waste, are a few of the most popular food movements and trends around the globe. They aim at making significant changes in demand or production, or are challenging or disrupting current market dynamics when the goods supplied conflict with consumers' higher-order values.[75] Interestingly, several among them seek to bridge the gap opened over time, with urbanization, between rural producers and urban dwellers, and intend to create some form of coalition. In many cases, government indifference and a declining confidence in public institutions have prompted these movements, motivating and empowering consumers to take action.[34]

The Slow Food movement, for example, began in the 1980s mostly driven by a few activists wanting to defend regional traditions and good food. Over three decades, it has evolved to embrace the Right to Food in its broader sense (recognizing the interconnections between diet, environment, people, politics and culture). Today, Slow Food is a global movement, involving thousands of projects and millions of people in more than 160 countries in an intimate relation between consumers and producers, and focusing on enacting change at the local level.[76]

Key success factors of the most important food movements and trends include a deep engraining into people's core values that become powerful triggers for action, strong leadership, cooperation from local government structures and, in some instances, robust engagement and buy-in from producers.

However, the impact, size and duration of such movements are hampered by factors such as having considerably less power than entities with political or economic interest to maintain the status quo, competing values and constraints among consumers, the wide range of possible issues to be addressed, shortage of resources and lack of regular access to communication channels. In some instances, emerging positive trends have been piggybacked by market operators such as large retail chains.

Formal consumer associations and bodies. The purpose of these groups or bodies, generally, is to ensure that consumers are aware of their rights (e.g. right to safe food, right to be informed about various characteristics of products) and that they are able to exercise them. They have a wide range of functions including monitoring consumer rights, denouncing instances of non-compliance with key regulations, such as clear labelling or marketing restrictions, demanding accountability from private companies and government, and influencing policy and industry practices. For example, despite major barriers and leverage from food businesses, *El Poder del Consumidor* in Mexico has been successful in influencing several pieces of legislation and public policy, particularly the promotion of a tax on sugar-sweetened beverages, guidelines for items sold in schools and composition of certain food products, such as juices and breads. They have also played a key "watchdog" role by denouncing multiple instances of deceptive food product advertising.[77] In some

[bo] A distinctive feature of the fair-trade movement is that it goes beyond health and environmental concerns to emphasize the socioeconomic well-being of those working within the food sector (particularly poorly paid worldwide), including their living conditions, income and human value.

contexts, consumer associations have resorted to legal actions when collective consumer rights had been gravely violated, such as in cases of food poisoning or false health claims.

As with diet patterns, many of these consumer-driven efforts have adapted and responded to various issues that have arisen during the COVID-19 pandemic, for instance, grassroots organizations buying fresh foods from stallholders and distributing to those in need, or activism to push governments to ensure free and nutritious school meals during the holiday breaks. Whether these efforts are sustainable over time, and whether they can enact change at scale, is yet to be determined.

1.13.3 Future trends

In 2018, FAO explored alternative pathways to 2050 through three scenarios that envisioned different future patterns in food consumption.[78] Table 1.34 summarizes their main characteristics of the three scenarios regarding food consumption. Box 1.41 illustrates how the gross agricultural output could evolve in the three scenarios to accommodate such food demand together with the non-food demand of agricultural goods.

Table 1.34 Main consumption characteristics of the three scenarios in FAO's report *The future of food and agriculture – Alternative pathways to 2050*

SCENARIO	CONSUMPTION TRENDS
Business as usual (BAU)	This scenario assumes a continuation of historical trends of food preferences.
	In HICs, as incomes rise, consumption of animal-based food is reduced, giving way to micronutrient- and vitamin-rich foods such as fruit and vegetables.
	In LMICs, staple foods still play an important role in food preferences, especially in the first half of the projection period. During the second half, these countries start adopting similar patterns to those of HICs.
	Overweight, obesity and diet-related non-communicable diseases continue to increase worldwide following historical patterns. In HICs, this is mainly because of greater consumption of processed food, while in LMICs, this is because of lower incomes that do not allow consumers to switch to higher quality and more nutritious food.
	Food waste at the consumer level is assumed to reproduce past proportions in all regions under this scenario.
Towards sustainability (TSS)	In this scenario, there is a reduced preference for animal-based foods and vegetable oils and fats, especially in HICs. Consumers are assumed to be more educated, on average, and better informed about the health and environmental impacts of excessive consumption of animal proteins, particularly meat.
	Dietary shifts towards more fruits and vegetables and less animal protein imply lower malnutrition, including less child and adult obesity.
	In this scenario, consumers are more concerned about food waste.
Stratified societies (SSS)	In this scenario, because it is characterized by lower incomes, consumer preferences are more oriented towards staple foods.
	Preferences for animal products remain important in HICs as well as in several LMICs, not only because of higher incomes but also on the grounds that they are less likely to be educated on the negative health and environmental implications of excessive meat consumption.
	The shift to more consumption of animal products and foods rich in fat and sugars, combined with urban sedentary lifestyles, will further increase the risks of overweight and obesity compared with the two other scenarios.
	For these same reasons, consumers also waste a larger proportion of their food.

Source: Based on FAO. 2018. *The future of food and agriculture – Alternative pathways to 2050.* Rome. www.fao.org/3/i8429en/i8429en.pdf

Box 1.41 Global agricultural gross production value under alternative future scenarios

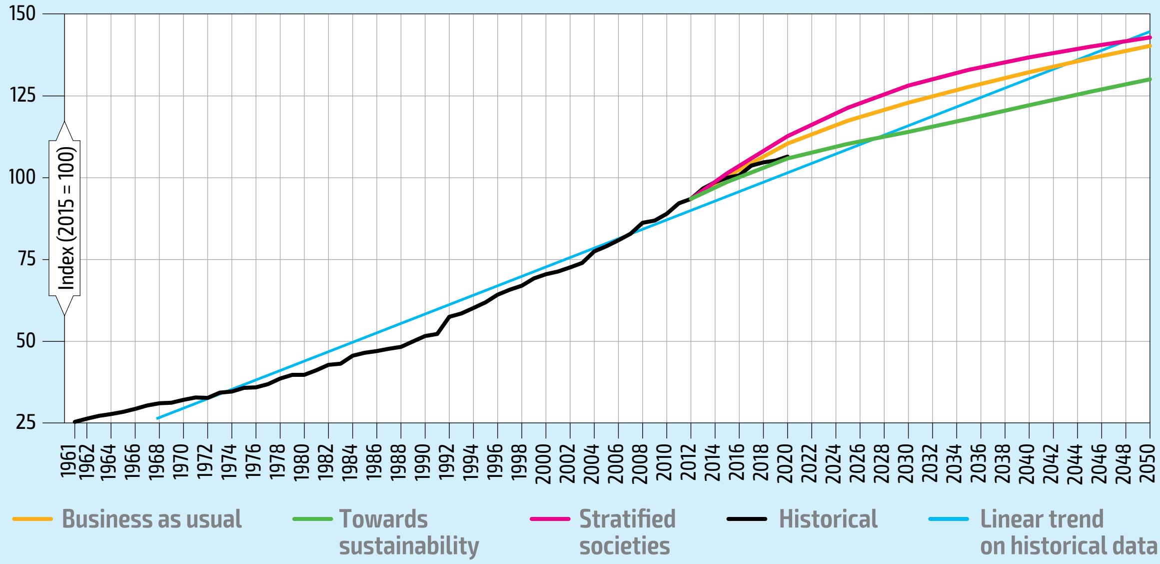
Future agricultural supply will respond to demand from growing populations, increasing per capita incomes and changing consumer preferences. According to the alternative scenarios illustrated in Table 1.34, future agricultural supply may expand to varying degrees, depending on how these drivers evolve and interplay. Although each scenario assumes the same demographic patterns (UN medium-term variant), agricultural output exhibits different dynamics as it is influenced by the other determinants.

Under the "business as usual" (BAU) scenario, global gross agricultural output (in terms of value) is projected to grow by around 50 percent between 2012 and 2050, with marked differences across regions.*

The "towards sustainability" (TSS) scenario presents lower levels of agricultural production compared to BAU (a 40 percent increase between 2012 and 2050 as opposed to 50 percent), mostly due to diminished demand for livestock feed due to a reduction of animal-based foods, specifically in HICs, and lower food loss and waste. As a consequence, globally, pressure on natural resources is relatively lower than in BAU, although in SSA the gross agricultural output keeps growing as per capita income and population rises, and there is there good potential to expand yields and agricultural land.

On the other hand, the "stratified societies" (SSS) scenario presents a greater expansion of gross agricultural output worldwide compared with BAU (a 53 percent increase by 2050). This larger expansion is due to greater food loss and waste and to relatively higher food demand, particularly for animal products in HICs and China, which in turn generates larger demand for feed. Marked regional differences are also observed for SSS compared to BAU. The output expands more in HICs and China and less in LMICs, with SSA and SAS projected to lag behind. Limited expansion in these regions combined with population growth poses important challenges for food security and nutrition.

Figure A. Global agricultural gross production value: historical (1960–2020) and projected (2012–2050)



Notes: Linear trend on historical data: y=-2.83 +1.45x; R^2 = 0.98. Historical gross production value (index 2014–2016=100) is plotted using a three-year right-aligned moving average. The historical gross production value index is calculated on the basis of the gross production value in constant USD of 2014–2016. Projections by scenario are calculated as annual variations of projections by scenarios with respect to the base year (2012), as reported by FAO in 2018.[78]

Sources: Authors' elaboration. Historical gross production value based on FAO. 2022. Value of Agricultural Production In: *FAOSTAT*. Rome. Cited 29 June 2022. www.fao.org/faostat/en/#data/QV; projections are based on FAO. 2018. *The future of food and agriculture – Alternative pathways to 2050*. Rome. www.fao.org/3/I8429EN/i8429en.pdf

Box 1.41 (cont.) Global agricultural gross production value under alternative future scenarios

Overall, the projections depicted in Figure A reflect the assumption that the demand for agricultural products, and related supply, will increase, but its increments will be decreasing. That is, it will not follow a linear pattern such as the one represented by the historical linear trend line. This pathway reflects the assumption that the global agricultural gross production value may essentially follow food demand. Assuming an increasing role of agriculture in providing raw materials or energy would lead to different long-term patterns of the global agricultural gross production value (see Section 1.2).

* The findings of this scenario are compatible with previous FAO projections published in 2017.[79]

The International Panel of Experts on Sustainable Food Systems (IPES-Food) and Action Group on Erosion, Technology and Concentration (ETC) consider two contrasting scenarios at the horizon 2045:[80]

- **Scenario 1 (agribusiness as usual)** is a techno-based view of the world in which "advances in digitalization, automation, synthetic biology, and molecular technologies […] prove irresistible to panicking policymakers". To cope with "climate change, environmental breakdown, and pandemics wreaking havoc on food systems" they are lured into a world where synthetic proteins are grown in petri dishes, artificial intelligence manages food production and consumption, novel ultra-processed foods are invented and geoengineering becomes the rule to control the climate and decide on weather, and where governments hand over the "keys of the food system … to biodigital megacorporations, data platforms, and private equity firms".[80]
- **Scenario 2 (civil society as unusual)** is a civil society-led world guided by the concept of food sovereignty and built on ongoing indigenous struggles against colonization to the anti-globalization movement, where "territorial markets […] continue to grow in the wake of COVID-19 […] short supply chain initiatives blossom, community and household food production grows, and producer and consumer cooperatives boom". Ethical, organic and local purchasing develops while "vegetarian and flexitarian diets – adopted by as many as 80 percent of people in previously high-meat consuming (wealthier) population groups." By 2045, urban farms supply around 25 percent of the world's small livestock products, fruits and vegetables and "up to half of the food industry's offering is fairly traded". True cost accounting helps consumers to make the difference between "business-as-usual corporations […] firms with a sustained commitment to corporate responsibility […] and sustainable, cooperative enterprises".[80]

Other authors emphasize the continuation of the strong trend that sees a reduction of time spent in preparing food. Ready-to-consume, hyper-processed convenience food, sophisticated cooking robots, mass collective catering, e-commerce, m-commerce and food delivery leave more time available for work and leisure.[81]

Observers expect a growing importance of foods such as insects, algae and mushrooms and a development of plant-based diets,[82, 83] as well as of enriched or fortified food in protein, vitamins and other micronutrients through biomolecular technologies, including genetic engineering.

Other authors project personalized nutrition, "precision nutrition", "individualized nutrition", or "nutritional genomics" to gain importance, with the view of customizing food to cater to the needs of individuals or groups of individuals with similar characteristics (e.g. genetic straits, health condition or level of physical activity), described by data from biosensors and other technologies, with the objective of preventing chronic diseases.[84] Food printing is seen as a key means for delivering this type of individualized food.[85]

1.13.4 Summary remarks

With the acceleration of dietary transitions among many LMICs towards higher consumption of resource-intensive foods and Western-style diets, two major interrelated challenges lie ahead for the coming decades: malnutrition in all its forms (undernutrition, micronutrient deficiencies, overweight and obesity) and the (un)sustainability of agrifood systems.

The consumption of more meat and dairy products, processed food and beverages rich in salt, fat and sugar, contributed to higher rates of adult obesity and greater incidence of non-communicable conditions that lower global life expectancy. Simultaneously, the number of chronically undernourished people increased.

The growing consumption of food of animal origin reduces efficiency of food systems, because of low energy and protein conversion rates from feed to food. It also generates high emissions of GHG and puts pressure on natural resources.

Dietary patterns with better nutritional and environmental outcomes are possible, and they have an enormous transformative potential for agrifood systems that deliver environmental benefits on a scale not achievable by producers with the introduction of new technologies, including digitalization of agriculture.

There are signs that consumers might hold the power to shift demand towards more environmentally and socially responsible and nutritious products. Some have started to adopt alternative behaviours, swayed by influencers, activists or consumer movements and associations. Many believe, nevertheless, that using this power will require guidance and financial incentives by public authorities.

A significant proportion of the consumers likely to adopt sustainable food behaviours are highly educated, live in urban areas and have the means and access to alternative pathways, but a majority of vulnerable consumers are left out of this movement if they are not provided support.

Some approaches have been successful in enacting collective change in food consumption by directly influencing people's behaviours and shifting demand for certain foods. They require a mix of coordinated policies, a variety of behavioural change initiatives (e.g. nudges, food labelling, information and education) as well as support to consumer-driven actions undertaken by individuals and groups. It is particularly essential to avoid oversimplifying the issue by making the assumption that improvements in knowledge or changes in attitudes and beliefs will automatically lead to concrete changes in behaviours, and by neglecting major structural, power and political challenges that compromise change scale-up.

If past trends in food consumption continue, the risk is high that the impact of agrifood systems on climate change and natural resource degradation will further increase. There are, however, indications that these trends could be overturned, and that consumers may adopt dietary patterns with better nutritional and environmental outcomes.

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1.14 Scarcity and degradation of natural resources (Driver 15)

Land, water, soil and biodiversity, are progressively degrading. Water scarcity, land degradation, soil nutrient depletion, extensive deforestation, overexploitation of marine resources and pastures and pollution at all levels raise serious concerns, not only for food and agriculture systems, but also for the achievement of the Sustainable Development Goals (SDGs). The recent report from United Nations Environment Programme (UNEP), *Global Environment Outlook*,[1] for instance, states that:

> "Inefficient or unsustainable farming systems are often associated with environmental and soil degradation and biodiversity loss and an increase in crop specialization and distribution can raise the risk of poor harvests" (UNEP, 2019, p. 11).[1]

Available and accessible natural resources per capita, including land and water, are among the most important bottlenecks for agrifood systems. For example, although East Asia and the Pacific (EAP) region accounts for more than half (56 percent) of the world population, the region covers less than one quarter of global land area. Demographic growth, urbanization and industrialization are increasingly subtracting precious natural resources from the agricultural sector. In Latin America, natural resources have been damaged by the development of productive activities related to agriculture and food systems. Sub-Saharan Africa (SSA) is experiencing the same situation of severe degradation of natural resources, water scarcity in dryland areas of the Sahel and the Horn of Africa, as is also Southern Africa. Massive deforestation also proceeds, linked to the extension of agricultural land, the exploitation of mining resources, infrastructure works such as hydroelectric dams or roads, urbanization and excessive logging. Competition over progressively scarce natural resources contributes to fuel conflicts which undermine livelihoods, food security and nutrition.[2] Similarly, across many regions, the agricultural sector is being deeply affected by the increase in frequency and intensity of extreme weather events that generate significant production costs and compress margins.[bp]

These factors raise some important questions:

- How have interactions between agrifood systems and natural resources evolved in recent decades?
- Are there agrifood systems that may be more sustainable and resilient and that could inspire the transformation of other agrifood systems?
- How can food be produced and generated with reduced environmental impact and GHG emissions?
- What are the implications of degradation of natural resources for the future of agrifood systems and the production processes underpinning them?
- What scenarios are plausible regarding degradation of natural resources and their relationships with technologies for agrifood systems?

This section addresses some of these issues. Others are addressed in the other sections of the report.

1.14.1 Trends in natural resources

Throughout the world, there are signs of increasing scarcity and degradation of natural resources. This exacerbates competition over natural resources and contributes to spark conflicts which undermine livelihoods, food security and nutrition.

[bp] Full cost accounting of natural resource use and degradation, while engendering shifts in prices, may positively impact natural resource use, greenhouse gas (GHG) emissions and biodiversity. The Internal Expert Consultation of the Corporate Strategic Foresight Exercise highlighted this as an important domain to be further explored.

Land area and quality are decreasing

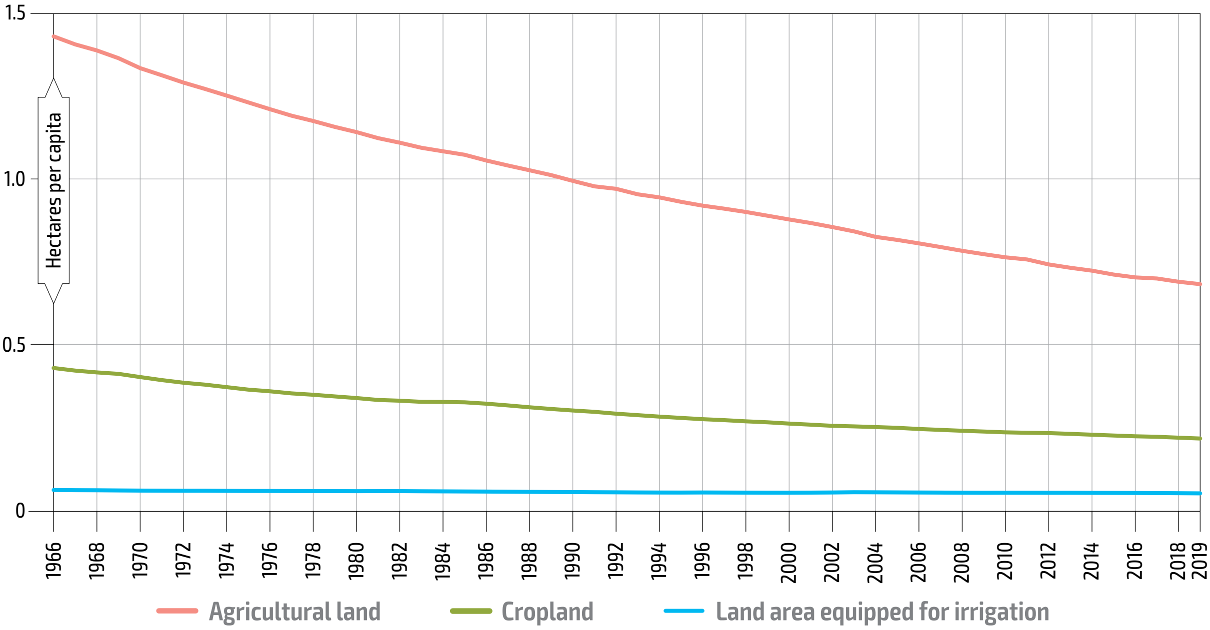
The amount of land per person available for agriculture is continuously decreasing. Worldwide agricultural land accounts for around 37 percent of land area.[bq] Between 1961 and 2019, agricultural land increased by around 6 percent (283 million hectares) to reach 4.75 billion hectares.

Most of this land was gained at the expense of forests. Some area was also lost as it became unsuitable for agriculture because of unsustainable agricultural practices, natural degradation or urban expansion, and the development of infrastructure and extractive industries.

Over the same period, cropland grew by 15 percent (205 million hectares), on area previously occupied by forests or grassland, reaching 1.56 billion hectares, while land area equipped for irrigation more than doubled to come to more than 340 million hectares.[3]

The amount of agricultural land and cropland available per person fell significantly over this period, as population increased from 3.1 billion to 7.7 billion people.[4] As for land area equipped for irrigation per person, in 2019 it reached 85 percent of what it had been in 1961, despite considerable investments (Figure 1.59).

Figure 1.59 Global per capita agricultural land, cropland and land equipped for irrigation (1966–2019)



Source: Authors' elaboration based on FAO. 2022. Land Use. In: *FAOSTAT*. Rome. Cited 18 June 2022. www.fao.org/faostat/en/#data/RL

Huge discrepancies exist across regions, as can be seen from Table 1.35, but the reduction in agricultural land witnessed at the global level is confirmed everywhere.

Between 1961 and 2019, agricultural land used per person globally dropped by 1.5 to around 0.6 hectares. In 1961, in all regions but China and SAS, it was above 1 hectare with much higher values in SSA and LAC (more than 4 and 2.6 hectares, respectively). In all regions, by 2019 it dropped to around 1 hectare per person or less in all regions, with greatest drop being observed in SSA.

Also cropland globally dropped in the same period by around 50 percent. Already in 1961, the area per person in China was the lowest (less than 0.2 hectares/capita). By 2019, it had fallen by around 40 percent, to less than in any other region.

[bq] FAOSTAT provides the following definitions for selected land categories: a) land area: country area excluding area under inland waters and coastal waters. b) Agricultural land: land used for cultivation of crops and animal husbandry. The total of areas under "Cropland" and "Permanent meadows and pastures". c) Land used for cultivation of crops: the total of areas under "Arable land" and "Permanent crops". d) Arable land: the total of areas under temporary crops, temporary meadows and pastures, and land with temporary fallow. Arable land does not include land that is potentially cultivable but is not normally cultivated. e) Land area equipped for irrigation: land area equipped with irrigation infrastructure and equipment to provide water to crops, which are in working order. The equipment does not have to be used during the reference year.

Land area equipped for irrigation per capita globally dropped by around 15 percent. It was highest in the Near East and North Africa (NNA) in 1961 (more than twice than the world average), but by 2019, it dropped by almost half. In the meantime, in Europe and Central Asia (ECA), it increased by close to 40 percent, this reaching the same level as NNA.

The declining amount of land per person has been in part compensated by a more intensive land use: the number of crops harvested on the same land has increased (cropping intensity) and so have yields. Intensification has been taking place through the adoption of multiple cropping made possible by irrigation, as the share of land equipped for irrigation passed from around 12 percent of cropland in 1961 to 22 percent in 2019, through a greater application of agrochemicals and the use of improved crop varieties.

Table 1.35 Change in per capita agricultural land, cropland and land area equipped for irrigation by region (1961–2019)

a) Agricultural land, per person

REGION	AGRICULTURAL LAND (PER CAPITA) (ha/capita)		CUMULATED GROWTH RATE OVER THE PERIOD (percent)
	1961	2019	1961–2019
High-income countries	1.69	1.00	-40.8
China	0.51	0.37	-27.5
East Asia and the Pacific	0.97	0.37	-61.9
Europe and Central Asia	2.32	1.53	-34.1
Latin America and the Caribbean	2.55	1.03	-59.6
Near East and North Africa	1.99	0.51	-74.4
South Asia	0.45	0.15	-66.7
Sub-Saharan Africa	4.09	0.92	-77.5
World	**1.56**	**0.68**	**-56.4**

b) Cropland, per person

REGION	CROPLAND (PER CAPITA) (ha/capita)		CUMULATED GROWTH RATE OVER THE PERIOD (percent)
	1961	2019	1961–2019
High-income countries	0.49	0.29	-40.8
China	0.16	0.09	-43.8
East Asia and the Pacific	0.3	0.18	-40.0
Europe and Central Asia	1.08	0.59	-45.4
Latin America and the Caribbean	0.46	0.27	-41.3
Near East and North Africa	0.51	0.15	-70.6
South Asia	0.36	0.12	-66.7
Sub-Saharan Africa	0.62	0.22	-64.5
World	**0.47**	**0.22**	**-53.2**

c) Land area equipped for irrigation, per person

REGION	LAND AREA EQUIPPED FOR IRRIGATION (PER CAPITA) (ha/capita)		CUMULATED GROWTH RATE OVER THE PERIOD (percent)
	1961	2019	1961–2019
High-income countries	0.04	0.05	25.0
China	0.07	0.05	-28.6
East Asia and the Pacific	0.04	0.04	0.0
Europe and Central Asia	0.05	0.06	20.0
Latin America and the Caribbean	0.03	0.04	33.3
Near East and North Africa	0.11	0.06	-45.5
South Asia	0.07	0.06	-14.3
Sub-Saharan Africa	0.01	0.01	0.0
World	**0.07**	**0.05**	**-28.6**

Source: Authors' elaboration based on FAO. 2022. Land use. In: *FAOSTAT*. Rome. Cited 6 July 2021. www.fao.org/faostat/en/#data/RL

The quality of agricultural land is degrading, resulting in loss in ecosystem services, biodiversity and productivity. Land degradation is a global pervasive and systemic phenomenon that can take many forms. These include erosion, reduction of biological activity, depletion of organic matter and of carbon stored in the soil, nutrient imbalance, waterlogging, soil compaction and soil sealing, salinization and sodification, acidification and pollution. It results in a substantial loss of both biodiversity and ecosystem services.[5]

According to the *Status of the World Soil Resources Report*,[6] the majority of the world's soil resources are in only fair, poor or very poor condition. Human-induced land degradation observed in almost all inhabited parts has damaged 33 percent of soils, of which approximately half is moderately to severely degraded. Both drylands and humid areas are affected, although drylands tend to be more badly degraded. Estimates are that 75 percent of wetlands has been lost.[5]

The main direct drivers of land degradation are expansion of crop and grazing lands into native vegetation through deforestation, unsustainable agricultural and forestry practices, climate change and, in specific areas, urban extension, and the development of infrastructure and of extractive industry. Increased human pressure also translates into frequent fires, overgrazing and the introduction of invasive species.

Processes involved in land degradation are often the result of a cascading set of interactions. For instance, removal of vegetation through overgrazing may exacerbate soil erosion, and losses of soil organisms and soil organic matter. In combination, these impacts change soil fertility, water infiltration and the water-holding capacity of the soil. The combined effect leads to reduced net primary production, loss of biodiversity and reduced resilience of the landscape when environmental changes occur.[5]

The soil plays a critical role in supporting plant growth by providing water and nutrients. These functions require maintenance of soil's physical structure, a wide range of soil organisms and the prevention of pollution that can result from applications of chemicals.[5]

Erosion. It is generally claimed that 80 percent of agricultural land and from 10 to 20 percent of rangelands suffer from severe erosion.[5] Soil erosion is defined as the net long-term balance of all processes that detach soil and move it from its original location through three major pathways: water, wind and tillage.[7]

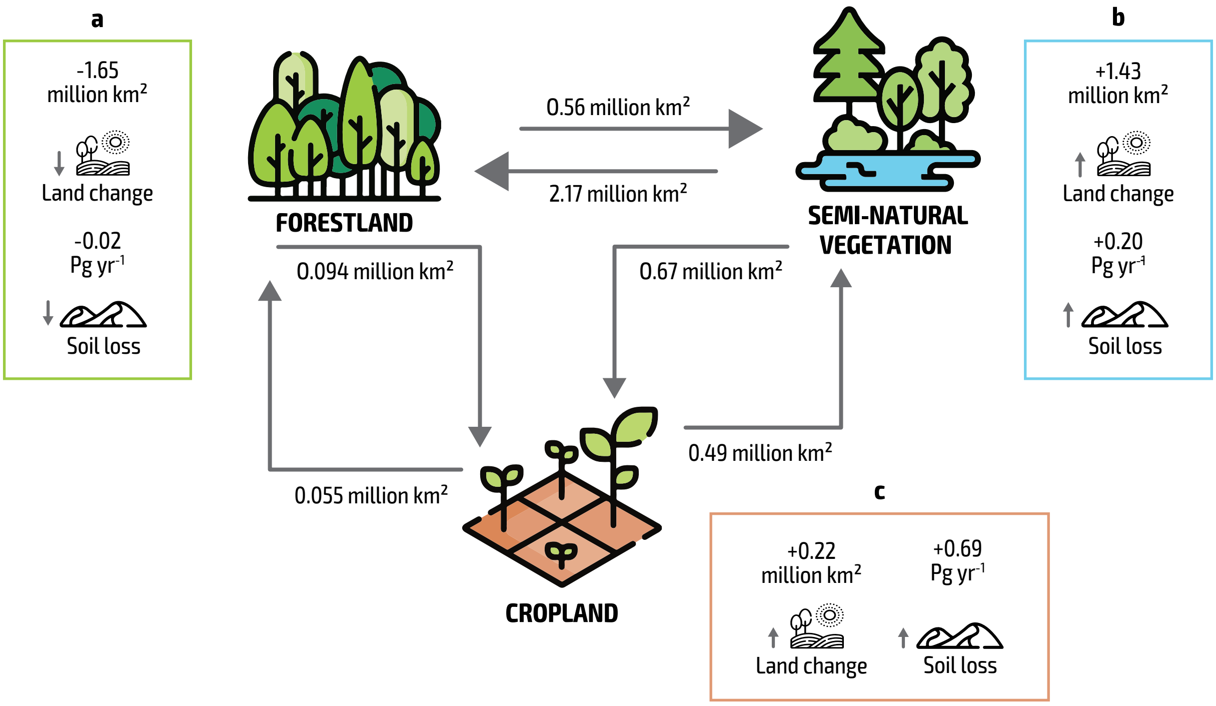
Through modelling, it was estimated that worldwide, soil erosion carries away around 35 billion tonnes of topsoil every year with an area-specific soil erosion average of 2.8 tonnes/ha/year. The amount of topsoil lost was calculated to have grown by 2.5 percent between 2001 and

2012, mainly because of change in land use. The area exceeding the tolerable loss rate was lowest in Oceania (0.8 percent) and highest in South America (8.3 percent). The global erosion rate for cropland (12.7 tonnes/ha/year) is 77 times higher than for forest (0.16 tonnes/ha/year) and seven times higher than other natural vegetation (1.84 tonnes/ha/year)[8] (Figure 1.60).

Erosion is a source of concern as it significantly reduces crop yields and the soil's ability to store and cycle carbon, nutrients and water. Some areas may, however, benefit from deposits brought from elsewhere by erosion. The erodibility of soils is linked to characteristics such as topography, vegetation and physical, chemical and biological attributes of the soil. It also depends on agricultural technologies and on the presence of anti-erosion measures.

Soil organic carbon loss is a key indicator of degradation. At the global scale, soils are the main terrestrial reservoir of carbon and therefore have a major influence on the concentration of carbon dioxide (CO_2) in the atmosphere. They contain 3.3 times the size of the atmospheric carbon and 4.5 times the size of carbon in living organisms.[9] Globally, the primary driver of soil organic carbon loss is land-use change. A 2014 meta-analysis of publications showed that soil organic carbon stocks decreased at 98 percent of sites by an average of 52 percent in temperate regions, 41 percent in tropical regions and 31 percent in boreal regions.[10] Increasing land-use intensity and associated soil organic matter loss are placing the highest pressure on soil biodiversity, and numerous studies report that soil biodiversity declines as a result of the conversion of natural lands to agriculture and of agricultural intensification. Soil organic carbon is the main indicator of soil health, and responsible for many soil functions that provide essential ecosystem services.

Figure 1.60 Land-use changes and their effects on soil loss



Notes: The circular forms refer to the three major land use and land cover groups obtained from the combination of the MODIS MCD12Q1 land cover type (International Geosphere Biosphere Programme [IGBP] system), global forest change maps, and cropland extend and harvested area statistics extracted from FAOSTAT database. The arrows indicate the amount of land use and land cover change between 2001 and 2012. Insets a–c demonstrate the net change of the land surface and soil loss measured in terms of Permanent grassing (Pg) (billion tonnes/year).

Source: Borrelli, P, Robinson, D.A., Fleischer, L.R., Lugato, E., Ballabio, C., Alewell, C., Meusburger, K., Modugno, S., Schütt, B., Ferro, V. *et al.* 2017. An assessment of the global impact of 21st century land use change on soil erosion. *Nature Communications*, 8(2013). www.nature.com/articles/s41467-017-02142-7

According to the Global Soil Organic Carbon Map,[11] around 680 gigatonnes of carbon are stored in the top 30 cm globally, with a considerable fraction stored on croplands. Sustainable soil management, including mulching, planting cover crops, judicious fertilization and moderate irrigation are therefore of key importance to contain the carbon in the soil. From that perspective, it was observed that croplands can lose 50 percent or more of the soil organic carbon compared to natural habitats, and many forms of land degradation have negative impacts on soil organic carbon.[5]

Soil salinization and sodification are major degradation processes threatening ecosystem services.[6] They are recognized as being among the most important problems at a global level for agricultural production, food security and sustainability in arid and semi-arid regions.[12,13]

Globally, soil salinity is a long-standing problem, and it is increasing, mostly in irrigated areas in drier regions. According to available information, over 1.1 billion hectares of soils are affected by salinity and sodicity, of which about 60 percent are saline, 26 percent sodic and the remaining 14 percent saline-sodic.[14] The most concerned regions are ECA, NNA and Australia.[14] An estimated 76 million ha of mostly irrigated land has actually been lost to salinization.[5] This corresponds to an area larger than all the arable land in Brazil.

Soil salinization is often caused by poorly managed irrigation or fertilization, or through saline water intrusion from sea, river, groundwater or mining. In these instances, soils undergo a rapid decline in health, losing their capacity for biomass production, natural filtration, carbon sequestration and other necessary ecosystem functions.[14]

Soil acidification results from the excessive application of fertilizers and from atmospheric pollutants. It is affecting soils in Northern America, Central and Northern Europe and Southern China.[5]

Diffuse pollution. Agricultural soils are also affected by pollution for which it is difficult to determine the exact, specific origin of the contaminants involved, and the number of contaminants released. Sources of diffuse soil pollution are, in order of decreasing importance: industries, mining, waste treatment, agriculture, fossil-fuel extraction and processing, transport emissions and human settlements. Pesticides utilized in agriculture put at risk up to 64 percent of global agricultural land (approximately 2.5 billion hectares).[15] Almost one-third (31 percent) of agricultural land is deemed at high risk of pesticide pollution.[16] Among these dangerous areas, about 34 percent are in high-biodiversity regions, 5 percent in water-scarce areas and 19 percent in low- and middle-income countries (LMICs).[17] The use of agricultural pesticides is also associated with environmental harms and health risks (see Section 1.15).

The worrying trends of degradation of land and soil described here are a threat to the world's capacity to produce food for its population in the future. This degradation is pervasive and systemic. It is negatively impacting the well-being of at least 3.2 billion people and is a major factor of species extinction, costing more than 10 percent of the annual global gross product in loss of biodiversity and ecosystem services. It has irreparable consequences on human and ecosystem health.[5] As mentioned earlier, it is often found to be a consequence of the agriculture production technologies used (agricultural intensification, use of pesticide, reduced protection of soils by vegetation, etc.).

This implies that more consideration will need to be given to adopting more sustainable production technologies that preserve soil and land resources (see Table 1.36 for a summary of this section).

Table 1.36 Main causes and major impacts of land scarcity and degradation

ISSUES	MAIN CAUSES	MAJOR IMPACTS
Scarcity	• Demography. • Loss of land because of unsustainable practices. • Loss to urban expansion, infrastructure development and extractive industry.	• Greater pressure on land, tensions and conflicts. • Deforestation and use of unsuitable marginal land for agriculture. • Intensification of agricultural production through irrigation and use of agrochemicals and improved seeds.
Degradation	• Pervasive and systemic.	• Species extinction, loss of production and productivity, and of ecosystems services.

Table 1.36 (cont.) Main causes and major impacts of land scarcity and degradation

ISSUES	MAIN CAUSES	MAJOR IMPACTS
– Erosion	• Topography and soil characteristics, climatic events. • Vegetation and agricultural practices. Absence of appropriate anti-erosion measures.	• Loss of soil. • Reduced yields and capacity to store carbon, nutrients and water.
– Soil organic carbon loss	• Land-use change. • Intensification of production. • Reactive nitrogen.	• Degradation of soil health and soil biodiversity. • Reduced ecosystems services (water retention). • GHG emissions.
– Soil salinization and sodification	• Poorly managed irrigation or fertilization. • Saline water intrusion from sea, rivers or groundwater.	• Decline of soil health and loss of capacity for biomass production, natural filtration, carbon sequestration and other necessary ecosystem functions.
– Soil acidification	• Over-application of fertilizers and atmospheric pollutants (reactive nitrogen).	• Decline of soil health and loss of capacity for biomass production.
– Diffuse pollution	• Industries, mining, waste treatment, agriculture (pesticides), fossil-fuel extraction and processing, transport emissions and human settlements.	• Decline of soil health and loss of capacity for biomass production.

Source: Authors' elaboration.

Freshwater

Similar to land, freshwater is a key natural resource for agriculture. This has become increasingly true with the growing importance of irrigation that has taken on a central role in agricultural development during the last decades. As is the case for land, both quantity and quality of water matter. Moreover, seasonal variation of water availability and demand may create additional stress.

The pressure on renewable freshwater resources is growing. Currently, irrigated agriculture accounts for more than 70 percent of global water withdrawals, the rest being used for industries (20 percent) and municipalities (10 percent). Around 41 percent of these withdrawals are not compatible with sustaining ecosystem services. Water scarcity, as expressed by the SDG indicator 6.4.2, is estimated to be around 17 percent globally, with huge regional variations of the ratio of water withdrawn for all economic activities to water availability, corrected for environmental flow requirements.[18] In many regions, the amount of water withdrawn is larger than the renewable water resources, indicating unsustainable water resources management or the use of fossil groundwater.

Important factors causing a greater demand for water are higher incomes and urbanization, leading to increased water demand from industry, energy and services, and dietary changes. As incomes, urbanization and nutrition standards rise, people are moving towards more land- and water-intensive diets, in particular through the consumption of more meat and dairy products, although such goods can have vastly different water footprints depending on how and where they are produced.[19]

Climate change may exacerbate challenges through temperature increase and changes in the distribution of rainfall that impact crop water demand, as well as spatial and temporal availability of water resources (see Section 1.16). Water storage is used to meet temporally varying water demand. Globally, around one-sixth of the annual flow can be stored in around 60 000 large reservoirs (dam height of more than 15 metres), with a cumulative capacity between 7 000 and 8 300 km^3[3,20] mostly used for irrigation purposes. Storage loss as a result of sedimentation,[21] increased seasonality of water supply and demand in relation to climate change may further increase the need for water storage, although many societal and environmental challenges are associated with this, and particularly with large reservoirs.

Table 1.37 further illustrates the contrasted conditions in various regions with respect to pressure placed by irrigation on renewable freshwater resources. As could be expected, it is in arid and semi-arid regions, such as NNA, and Central Asia that pressure on water resources is highest. In Northern Africa and Western Asia, per capita freshwater has considerably declined, to the extent that the average annual volume of water per person barely reaches 1 000 m^3, which is conventionally considered the threshold for severe water scarcity.

Table 1.37 Water requirement ratio and water resources for irrigation by region (2018–2020)

REGION/SUBREGION	TOTAL ACTUAL RENEWABLE WATER RESOURCES	IRRIGATION WATER REQUIREMENT	WATER REQUIREMENT RATIO	IRRIGATION WATER WITHDRAWAL	PRESSURE ON FRESHWATER RESOURCES DUE TO IRRIGATION
	(km^3/year)	(km^3/year)	(km^3/year)	(km^3/year)	(percent)
	(1)	(2)	(3)	(4)=(2)/(3)	(5)=(4)/(1)
Northern Africa	103.3	56.8	72	79.3	76.8
Sub-Saharan Africa	5 427.0	25.8	28	92.0	1.7
Northern America	6 428.2	137.1	57	241.0	3.7
Central America and the Caribbean	801.7	4.7	26	18.1	2.3
Southern America	17 131.9	53.5	39	138.2	0.8
Middle East	563.6	118.9	52	226.5	40.2
Central Asia	314.7	60.6	47	128.7	40.9
Southern and Eastern Asia	13 572.5	994.3	60	1 670.8	12.3
Western and Central Europe	2 627.3	33.5	61	54.6	2.1
Eastern Europe and Russian Federation	4 790.4	10.2	70	14.6	0.3
Oceania	819.0	5.4	59	9.1	1.1

Note: Regions in this table refer to the classification by region provided in Aquastat, not the one adopted in the rest of this report.

Source: FAO. 2021. *AQUASTAT - FAO's Global Information System on Water and Agriculture.* Rome. Cited 2 July 2022. www.fao.org/aquastat

Aggregate data that may appear satisfactory can hide specific water-stressed areas in regions of low water stress, such as the African Horn or the Central American Dry Corridor that runs through southern Mexico to Panama on the Pacific Coast.

Pressure on renewable water resources resulting from irrigation is expressed by the ratio of water withdrawal for irrigation to actual available resources. Water withdrawal is a function of water requirements (for irrigated crops) and of the water requirement ratio. This ratio depends not only on water availability, but also on availability of the financial resources required for establishing efficient water management infrastructure and governance mechanisms.

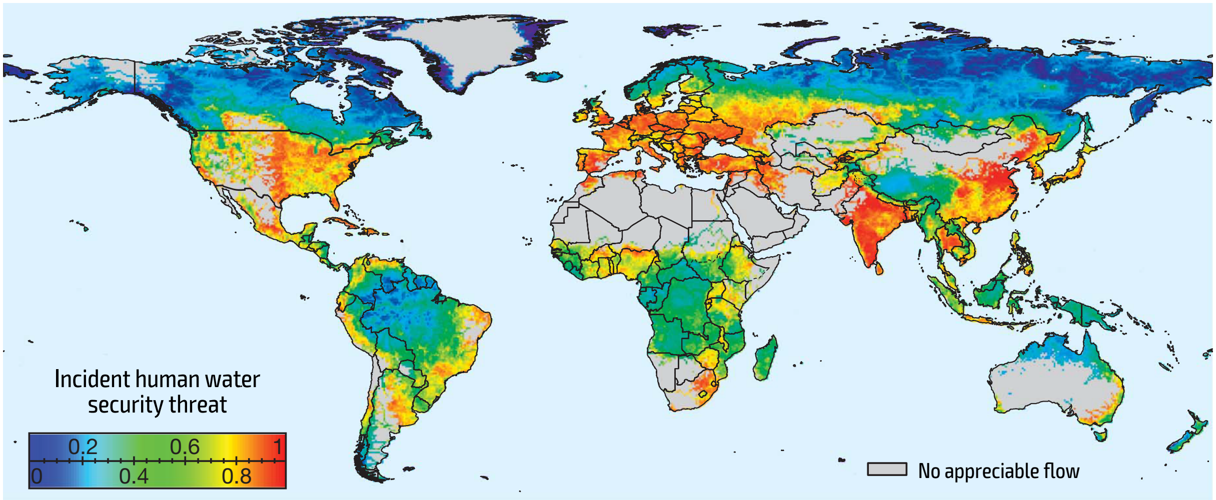
Worldwide, groundwater provides almost 35 percent of water for irrigated agriculture and 50 percent of all drinking water, while one-third of water is used by industry. Estimates suggest that 70 percent of groundwater abstraction is destined to food and feed production. More recent (though incomplete) figures indicate that increases in abstraction are slowing and even stabilizing. Nevertheless, as surface freshwater availability decreases, reliance on groundwater is growing and data show that groundwater is already facing a crisis situation in most regions, with water levels declining as aquifers are overexploited, polluted and poorly managed.

The priority given to irrigation rather than rainfed agriculture, particularly during the 1980s, when a large share of public expenditure by governments and loans provided by the World Bank were allocated to the development of irrigation infrastructure, has resulted in a huge expansion of irrigated area, the construction of reservoirs, and an intensification of agricultural production. It has simultaneously helped to establish a type of agriculture that was less dependent on meteorological conditions and more reliable. It contributed to boost the construction sector and made agriculture a major client of the chemical industry through a wide adoption of technologies using a variety of agrochemicals (fertilizers and pesticides). It, however, also led to a greater dependence on freshwater resources that are now increasingly under pressure, as can be seen from the above-mentioned data. Lack of recognition of the economic value of water, poor water governance and inadequate water conservation efforts are among the causes of the current situation.[19]

In addition to the lack of water (physical water stress), many regions experience economic water stress, as people cannot afford water to adequately meet their demand because of a lack of income, poor infrastructure owing to missing investment, or insufficient human or institutional capacities, despite the abundance of water resources. Furthermore, many countries experience increasing water scarcity (i.e. an excess of water demand over available water supply) driven by large numbers of governance and socio-cultural factors that determine user access to water of an acceptable quality (e.g. water tenure, social exclusion, poverty, or conflicts).

Freshwater quality is a source of concern. The intensification of anthropogenic activities is a major factor of water quality degradation. Simultaneously, the capacity of the receiving freshwater to dilute pollutants is reducing rapidly as some pollutants, which are highly persistent and resistant to breakdown, stay active for long periods of time. Figure 1.61 shows the global distribution of water pollution threat from human activities, including nitrogen loading, phosphorous loading, mercury deposition, pesticide loading, organic loading, salinization, acidification and sediment loading.[22]

Figure 1.61 Global geography of incident threat to human water security (2010)



Notes: Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties. Final boundary between the Sudan and South Sudan has not yet been determined. Final status of the Abyei area is not yet determined.

Source: Vörösmarty, C.J., McIntyre, P.B., Gessner, M.O., Dudgeon, D., Prusevich, A., Green, P., Glidden, S., Bunn, S.E., Sullivan, C.A., Reidy Liermann, C. & Davies, P.M. 2010. Global threats to human water security and river biodiversity. *Nature*, 467: 555–561. www.nature.com/articles/nature09440

Polluted water has social, economic and environmental impacts. The number of rural people being exposed to polluted surface waters has been estimated as approximately 8 to 25 million people in Latin America, around 32 to 164 million in Africa, and 31 to 134 million people in Asia.[23]

Although LMICs are major hotspots for water quality issues because of unregulated point-source pollution and diffuse pollution, high-income countries (HICs) also endure high levels of pollutants in water. The assumption that water pollution would decline with economic growth has been deconstructed mostly because of the expansion of the range of pollutants (known and new) brought about by prosperity,[24] despite a much larger share of wastewater being treated in wastewater treatment plants. Pollution of freshwater from anthropogenic sources originates from non-point (diffuse) and point pollution, and includes excessive nutrients (phosphorus, nitrogen), pathogens, heavy metals, plastic and emerging pollutants.

Phosphorus plays a series of functions in the plant metabolism and is one of the essential nutrients required for plant growth and development.[25] In freshwater systems, phosphorus is generally the limiting nutrient for plant growth and, in excess, it can often cause freshwater eutrophication.[26] It has been estimated that global inputs of phosphorus to water bodies from the sum of anthropogenic sources (diffuse and point source) is around 1.47 million tonnes/year with about 62 percent of this total load from point sources (domestic, industrial), while diffuse sources (agriculture) contributes the difference, mainly from fertilizer application, and livestock and poultry faeces.[27] Around 52 percent of the global anthropogenic phosphorus load occurs in Asia (30 percent for China alone). The second polluter is Europe, contributing approximately 19 percent, followed by Latin America and the Caribbean (LAC) (13 percent) and Northern America (7 percent).[28]

Reactive nitrogen. Reactive nitrogen includes all forms of nitrogen (e.g. nitrous oxide, nitrates, nitrites, ammonia and ammonium) that are biologically, photochemically, and radiatively active, in contrast to N_2, that is inert and constitutes 80 percent of the Earth's atmosphere. Although natural processes can create reactive nitrogen (i.e. cyanobacteria), human intervention has become the major contributor to this process, mainly through fertilizer and fossil-fuel combustion, but also via the manufacturing of ammunition.[29] Reactive nitrogen has been linked to air pollution, soil acidification, water eutrophication, biodiversity loss,[30] corrosion of human-made infrastructures and climate impacts.

Anthropogenic sources of reactive nitrogen have sharply increased from 15 percent in 1850 to 60 percent in 2005, with the expectation that it will be kept at the same level until 2050, mostly driven by a global demand for food where industrial fertilizer production and biological fixation of nitrogen in agriculture account for 80 percent of anthropogenic nitrogen fixation.[31] The last century has experienced a great increase of the annual atmospheric deposition of nitrogen from 1.9 million tonnes nitrogen in 1900 to 3.8 million tonnes nitrogen in 2000, of which 63 percent was deposited into agricultural land.[32]

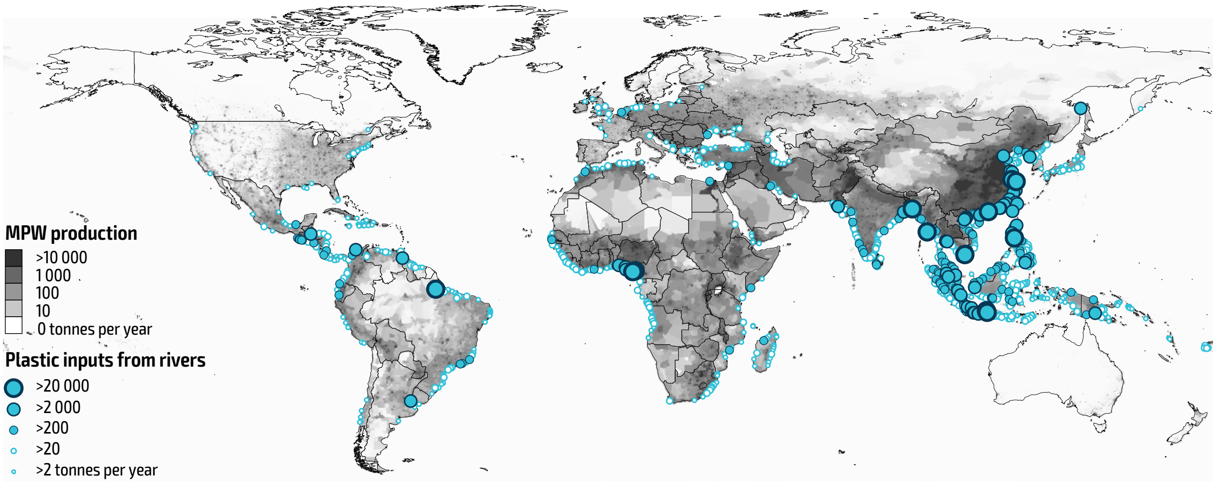
In agricultural systems, reactive nitrogen is a major threat to water quality (i.e. eutrophication of surface water), soil quality (soil acidification, changes in soil organic matter content and loss of soil biodiversity), plant biochemistry, insects (e.g. pollinators), functional composition of vegetation communities and mammal herbivores (i.e. grazing animals). It has been estimated that the total annual cost to the European Union of nitrogen pollution's environmental impacts is somewhere between EUR 70 billion and EUR 320 billion.[33]

Pathogens, heavy metals and other contaminants. Urbanization increases the impervious surfaces, the generation of pollutants by urban land surfaces and activities, and surface runoff (or stormwater runoff) rates and volumes. Stormwater runoff is usually polluted with pathogens (i.e. Escherichia coli), heavy metals (i.e. lead and arsenic), contaminants (i.e. mercury), nutrients (i.e. phosphorus and nitrogen), organic compounds (i.e. polycyclic aromatic hydrocarbons) and suspended solids.[34] Urban stormwater drainage can be either connected to sewer systems or discharged untreated directly into freshwater systems.

Plastic has been in evidence in the last years especially because of its "visual" pollution of waterways and oceans. The production of plastic has substantially increased since its commercial launch in the 1950s, reaching a world output of almost 350 million tonnes in 2017, 3.8 percent more than in 2016.[35] It has been estimated that between 1.15 and 2.41 million tonnes of plastic are transported annually by the global freshwater systems into the oceans, with Asia accounting for 67 percent of the global yearly inputs(see Figure 1.62).[36]

Microplastics (pieces smaller than 5 mm) are ubiquitous in the environment as either a subproduct of plastic degradation, or intentionally manufactured to be used in other products, and have been detected in a broad range of concentrations in marine water, wastewater, freshwater, food, air and drinking water, both in bottled and tap water.[37] The direct health effects on humans is still not well understood but the exposure to microplastics may cause particle toxicity, with oxidative stress, inflammatory lesions and increased uptake or translocation.[38]

Figure 1.62 Mass of river plastic flowing into oceans (2017)



Notes: Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties. Final boundary between the Sudan and South Sudan has not yet been determined. Final status of the Abyei area is not yet determined.

Source: Lebreton, L.C.M., van der Zwet, J., Damsteeg, J.-M., Slat, B., Andrady, A. & Reisser, J. 2017. River plastic emissions to the world's oceans. *Nature Communications*, 8(15611). www.nature.com/articles/ncomms15611

Emerging pollutants, or contaminants of emerging concern, are the new substances for which no regulations are currently in place, but that are being used and discharged into the freshwater systems via human activities. Organic compounds make up the major part of these, which are present as pharmaceuticals (i.e. antimicrobials) and personal care products, hormones, food additives, pesticides, plasticizers, wood preservatives, laundry detergents, disinfectants, surfactants, flame retardants and other organic compounds.[17]

Since they are not usually regulated, emerging pollutants are also not generally monitored by regulatory agencies. It has been reported that no fewer than 700 substances, categorized into 20 different classes, have been identified in aquatic ecosystems in Europe.[39] Every year, the United States of America receives notices for the discharge of more than 1 000 new chemicals into the environment.[24]

As can be deducted from the contaminants reviewed above, intensive agriculture is a major source of water degradation. It has resulted in widespread eutrophication of rivers, lakes, dams and wetland systems–with oxygen-deficient areas in waterways and at the mouths of large catchments having profound impacts on coastal fisheries resources. This is primarily driven by the overuse of fertilizers and is also a consequence of industrial livestock production systems.5

It is crucial to realize that land, water and soil are deeply interlinked and that degradation of one resource induces the degradation of the others. For instance, lower rainwater infiltration on degraded soils can lead to the depletion of groundwater resources and possibly increase the risk of floods. FAO's *The State of the World's Land and Water Resources for Food and Agriculture 2021*[40] data show that in almost 75 percent of the identified affected regions, lack of freshwater availability was strongly correlated to human-induced land degradation. Hence, the preservation and restoration of land, water and soil resources need to be addressed as a whole through Integrated Landscape Management approaches (e.g. sustainable land management; integrated watershed management; source to sea; coastal area management; agrosilvopastoral management; forest and landscape restoration; and climate-smart agriculture) (see Table 1.38 for a summary of this section).

Table 1.38 Main causes and major impacts of freshwater scarcity and degradation

ISSUES	MAIN CAUSES	MAJOR IMPACTS
Scarcity	• Water availability and capacity for establishing efficient water management infrastructure and governance mechanisms. • Demography. • Priority given to irrigation development for securing reliable food production. • Development of industries, services and energy. • Increased domestic water use with rising income and urbanization. • Dietary changes (meat, dairy products). • Climate change (in some regions). • Lack of recognition of the economic value of water, poor water governance and inadequate water conservation efforts.	• Tensions and conflicts. • Tensions on food production. • A growing share of world population living in a situation of water stress. • Unsustainable groundwater abstraction, overexploited aquifers.
Degradation	• Intensification of human activities. • Reduced capacity of freshwater to receive and dilute pollutants (scarcity). • Pollutants stay active in water for long periods. • Expansion of the range of pollutants linked to economic growth and increase of flows.	• Growing number of people exposed to polluted surface water (health implications). • Pollution of aquifers.
Phosphorus	• Application of phosphorus fertilizer. • Livestock and poultry faeces.	• Eutrophication of freshwater bodies and pollution of groundwater. • Air pollution, water eutrophication, biodiversity loss (e.g. pollinators), corrosion of human-made infrastructures.
Reactive nitrogen	• Fertilizer. • Fossil-fuel combustion. • Ammunition manufacturing and other industries.	• Soil acidification, changes in soil organic matter content and loss of soil biodiversity. • Disruption of plant biochemistry. • Functional composition of vegetation communities and mammal herbivores (i.e. grazing animals). • Change of vegetation communities in grazing areas. • Impact on climate.
Pathogens, heavy metals, and other contaminants	• Contaminated runoff from impervious surfaces in urban areas.	• Health of humans and animals.
Plastic	• Increased use since the 1950s.	• Health effect on humans through water and food. • Health effects on animals in freshwater and marine waters.
Emerging pollutants	• Proliferation of pharmaceuticals (i.e. antimicrobials), personal care products, hormones, food additives, pesticides, plasticizers, wood preservatives, laundry detergents, disinfectants, surfactants, flame retardants and other organic compounds.	• Health impact on humans and animals.

Source: Authors' elaboration.

Biodiversity

General biodiversity. Biodiversity is the sum of all terrestrial, marine and other aquatic ecosystems, species and genetic diversity. It includes the variability within and among living organisms and the ecological complexes of which they are part. Biodiversity is understood at three levels: (i) the variety of species; (ii) the variety of genes contained in plants, animals, fungi and microorganisms; and (iii) different habitats or ecosystems characterized by complex relationships between living components, such as plants and animals and non-living components such as soil, air and water.[41]

Biodiversity is essential for sustainable agrifood systems. Species and genetic diversity of crops and animals directly involved in production is indispensable for maintaining resilient agrifood systems capable of facing emerging diseases, consequences of climate change, and the degradation of land and water resources that have just been analysed. It is also essential among the myriad of living organisms providing vital ecosystems services to agriculture.[41]

There is well-established evidence indicating an irrevocable and continuing decline of genetic and species diversity, and degradation of ecosystems at local and global scales. This decline has mostly taken place since 1900 and may be accelerating. The global rate of species extinction is already at least tens to hundreds of times higher than it has averaged over the past 10 million years.

The growing concern is that, if pressures put by humans on biodiversity persist unabated, there is a risk of precipitating a sixth mass extinction event in Earth history, with profound consequences on human health and equity, as the loss of biodiversity reduces ecosystem resilience and increases vulnerability to threats, including negative impacts of climate change.

Biodiversity is being eroded by land-use change (agricultural and urban expansion and infrastructure construction), direct exploitation (hunting and gathering), sometimes overexploitation, climate change (temperature, fire, extreme meteorological events), pollution and invasive alien species. Freshwater species have the highest rates of population decline.

Climate change, beyond impacting on the level of biodiversity, is also modifying its spatial distribution, creating disruption in ecosystems services.[42, 43] Cumulative records of alien species have leapt by 40 percent between 1980 and 2019, associated with increased trade and human population dynamics and trends. Nearly one-fifth of the Earth's surface is at risk of plant and animal invasions.[43] In 2005, for the United States of America alone, the environmental and economic costs associated with some 50 000 alien-invasive species were estimated at almost USD 120 billion.[44]

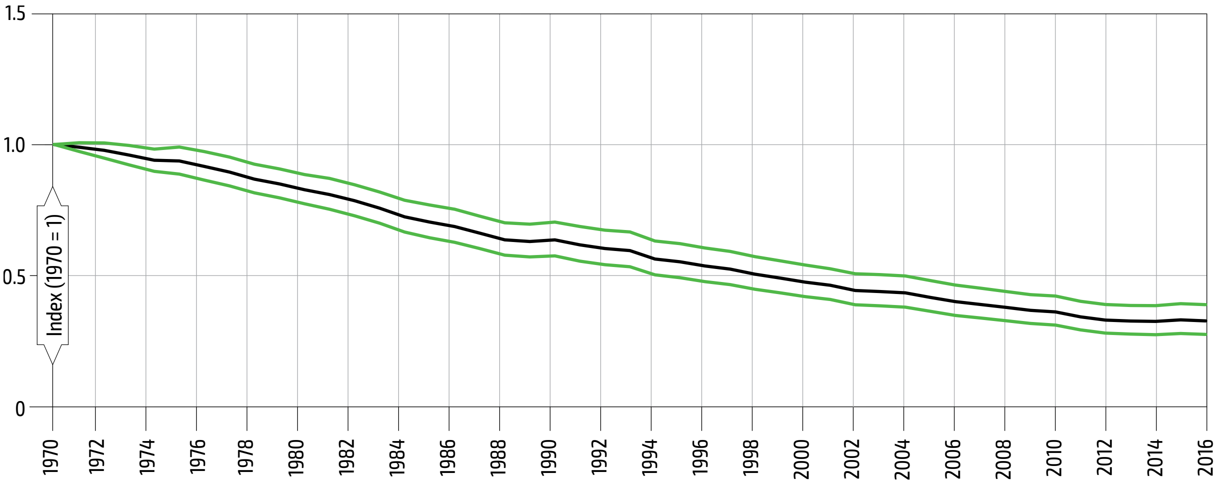
The global deterioration of biodiversity, as illustrated by trends in species, remains striking.[45] The status of vertebrates has been relatively well studied, but fewer than 1 percent of described invertebrates and only about 5 percent of vascular plants have been assessed for extinction risk.[42] World trends in insect populations are not known although rapid declines have been well documented in some places.[43]

Figure 1.63 illustrates this downward trend, indicating a near to 60 percent fall between 1970 and 2014.

The International Union for the Conservation of Nature's (IUCN) Red List of Threatened Species[46] provides the most comprehensive inventory of the global conservation status of plant, animal and fungi species. More than 37 400 species are threatened with extinction. This represents 28 percent of all assessed species, but the list remains incomplete

Losses of biodiversity occur not only at the species level, but also in the genetic diversity of individual species – a particular concern for the resources available for future breeding of crop species. The distribution of declines is not geographically uniform, and losses are heavier in some land-cover and land-use types than in others: mines, industrial areas, urban areas, croplands and improved pastures have the greatest decreases compared with primary ecosystems and secondary growth. The main causes of erosion of biodiversity are destruction and fragmentation of habitat, and the overexploitation of species by humans, pollution, climate change, and disease and invasive species (especially on rangelands).[43]

Figure 1.63 **Global living planet index (1970–2016)**

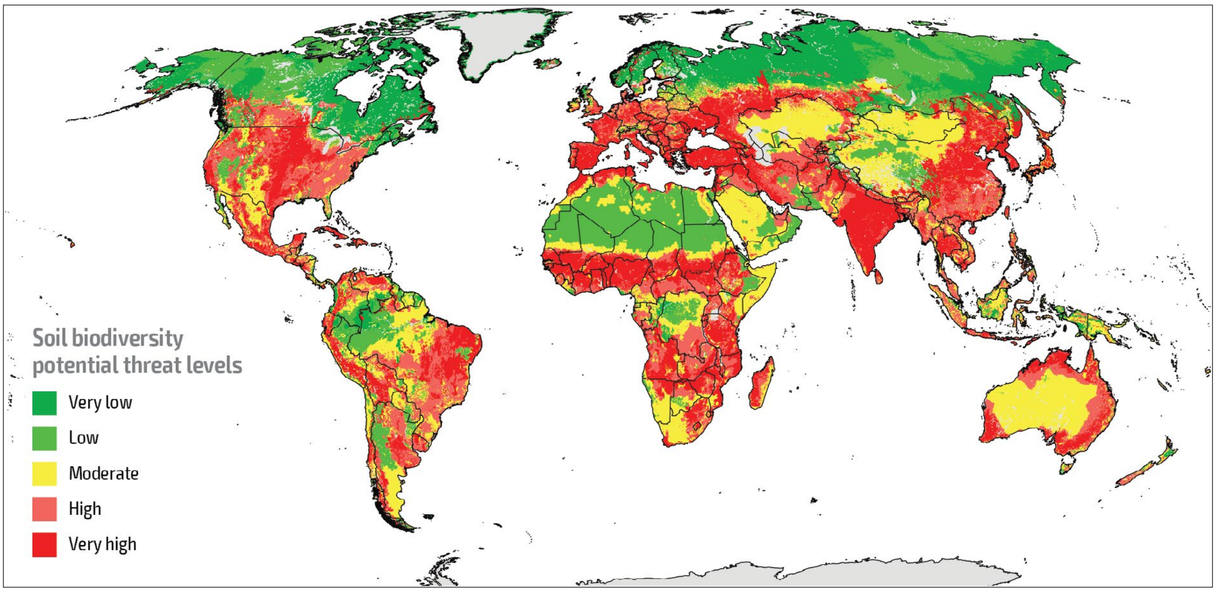


Notes: The centre line shows the index values indicating a 60 percent decline between 1970 and 2016 and the upper and lower lines represent the 95 percent confidence interval boundaries. This is the average change in population size of around 4 000 vertebrate species, based on data from 16704 time series from terrestrial, freshwater and marine habitats.

Source: WWF. 2020. *The living planet report 2020*. Gland, Switzerland. https://f.hubspotusercontent20.net/hubfs/4783129/LPR/PDFs/ENGLISH-FULL.pdf

For example, in the case of soil biodiversity, essential for crop growth, these causes are global and hit all regions in the world and countries regardless of their level of income. Threats considered include pollution and nutrient overloading, agricultural use, overgrazing, fire risk, soil erosion, vulnerability to desertification, aridity and loss of aboveground diversity (Figure 1.64). Agricultural practices, such as tillage, crop rotations and associations, and application of fertilizers and pesticides impact on soil biodiversity.[47]

Figure 1.64 **Global map of potential threat levels to soil biodiversity**



Notes: Global potential threats to soil biodiversity. The map shows the potential rather than the actual level of threat to soil organisms. To derive this map, several sets of data were used. "soil biodiversity threats map" associated to the Global Soil Biodiversity Atlas, developed by the European Soil Data Centre (ESDAC), Joint Research Centre of the European Commission, June 2016. Permission to reprint this map was obtained from the ESDAC. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties. Final boundary between the Sudan and South Sudan has not yet been determined. Final status of the Abyei area is not yet determined.

Source: Orgiazzi, A., Bardgett, R.D., Barrios, E., Behan-Pelletier, V., Briones, M.J.I., Chotte, J-L., De Deyn, G.B., Eggleton, P., Fierer, N., Fraser, T., *et al.* eds. 2016. *Global Soil Biodiversity Atlas*. Luxembourg, European Commission, Publications Office of the European Union. https://esdac.jrc.ec.europa.eu/content/global-soil-biodiversity-atlas

Loss of biodiversity for food and agriculture. Biodiversity for food and agriculture (BFA) is the part of the biodiversity that contributes directly or indirectly to agriculture and food production. It includes domesticated plants and animals raised in crop, livestock, forest and aquaculture systems, harvested forest and aquatic species, the wild relatives of domesticated species, other wild species harvested for food and other products, and what is known as "associated biodiversity", the vast range of organisms that live in and around food and agricultural production systems, sustaining them and contributing to their output.[48, 49]

Examples of these latter categories include pollinators that are responsible for around 35 percent of the world's crop production, increasing outputs for about 75 percent of the leading food crops worldwide.[41]

Biodiversity loss is occurring among plants and animals used for production, as farmers are encouraged to raise the most productive and abandon others. Fewer and fewer varieties and breeds of plants and animals are being cultivated, bred, traded and maintained around the world. From the 8 800 livestock breeds known, 7 percent are extinct, 24 percent are at risk of extinction and 59 percent are classified as being of unknown risk status because of lack of data.[41]

With time, humanity has progressively relied on a small group of eight crop species (barley, beans, groundnut, maize, potatoes, rice, sorghum and wheat) for supplying the greatest share of average daily calories consumed (53 percent), and on five animal species (cattle, sheep, goats, pigs and chickens) for providing 31 percent of average daily protein eaten. In fact, three crop species (wheat, rice and maize) represent alone 48 percent of average daily calories consumed.[41]

Within these few plant species that supply the bulk of food, only a small group of the most productive varieties are used extensively as they are best adapted to dominant technologies. This genetic erosion limits the possibilities for adapting agrifood systems to challenges such as population growth, emerging pests and pathogens and changing ecological conditions (soil, water and climate). To combat the possible consequences of this genetic impoverishment, gene banks have been established that gather about 3.6 million crop accessions (collections of plant material from a particular location), with approximately half the total holdings belonging to nine major food crops. Around 13 percent of the world's gene bank holdings are composed of wild crop relatives. Moreover, 524 million hectares of forests have been primarily designated for biodiversity conservation to protect the diversity of the almost 8 000 species of forest trees and other woody plants (scrubs, palms and bamboo) that are used for various purposes throughout the world.[41]

However, genetic erosion is likely to continue and weaken the resilience of agrifood systems, as dominant policy environments frequently disadvantage traditional production systems that harbour adapted local livestock species and breeds, in favour of more standardized, unified and productive systems.41 More broadly, policies have generally provided incentives for expansion of economic activities over conservation or restoration, and have all but ignored the value of ecosystem functions, relying almost exclusively on signals given by the market (see Section 1.8)[43] (see Table 1.39 for a summary of this section).

Table 1.39 Main causes and major impacts of decline of biodiversity

ISSUES	MAIN CAUSES	MAJOR IMPACTS
Decline of general biodiversity	• Human pressure. • Land-use change (agricultural and urban expansion, and infrastructure construction), destruction and fragmentation of habitat. • Overexploitation (e.g. overgrazing, hunting and gathering) and pollution. • Agricultural practices, such as tillage, crop rotations and associations, and application of fertilizers and pesticides. • Invasive species. • Climate change.	• Risk of precipitating a sixth mass extinction, with profound consequences on human health and equity. • Reduced ecosystem resilience and increased vulnerability to threats because of disruption. • Reduced ecosystems services.

Table 1.39 (cont.) Main causes and major impacts of decline of biodiversity

ISSUES	MAIN CAUSES	MAJOR IMPACTS
Loss of biodiversity for food and agriculture	• Priority given to most productive plants and animals, abandoning others. • Priority given to the breeds and varieties best adapted to dominant technologies. • Policy environments frequently disadvantage traditional production systems that harbour adapted local livestock species and breeds, in favour of more standardized, unified and productive systems. • Policies have generally provided incentives for expansion of economic activities over conservation or restoration. • Policies have all but ignored the value of ecosystem functions, relying almost exclusively on signals given by the market.	• Limits the possibilities for adapting agrifood systems to challenges such as population growth, emerging pests and pathogens, and changing ecological conditions.

Source: Authors' elaboration.

Forests

According to the latest data from the *Global Forest Resources Assessment 2020*,[50] the proportion of forest area of the world's land area has gradually decreased from 31.9 percent in 2000 (4.2 billion ha) to 31.2 percent (4.1 billion ha) in 2020. Forest area losses amounted to almost 100 million hectares in the past two decades. However, the rate of reduction has slightly slowed down within the last ten years. Forests mostly disappeared in SSA, Southeast Asia and Latin America, mainly because of the expansion of agricultural activities[51] (Table 1.40).

Table 1.40 Annual rate of forest change

PERIOD	NET CHANGE (million ha/year)	NET CHANGE RATE (percent/year)
1990–2000	-7.84	-0.19
2000–2010	-5.17	-0.13
2010–2020	-4.74	-0.12

Source: FAO. 2020. *Global Forest Resources Assessment 2020: Main report*. Rome. https://doi.org/10.4060/ca9825en

Africa had the highest annual rate of net forest loss between 2010 and 2020, at 3.9 million hectares, followed by South America at 2.6 million hectares. This rhythm has increased in Africa since 1990, while it declined substantially in South America. In contrast, there was a gain of forest areas between 2010 and 2020 in Asia, Oceania and Europe.[50]

The world has at least 1.11 billion hectares of primary forest (mostly in Brazil, Canada and Russian Federation) composed of native species, rich in biodiversity, in which there are no clearly visible indications of human activity and the ecological processes have not been significantly disturbed.[50]

Large-scale commercial agriculture (primarily cattle ranching and cultivation of soya bean and oil palm) accounted for 40 percent of tropical deforestation between 2000 and 2010, and local subsistence agriculture for another 33 percent.[52] The loss of biodiversity incurred is a threat to the resilience of agrifood systems to future shocks, as mentioned earlier.

The continued decrease of forests puts a wide range of goods and services in danger that are important for human well-being, while creating an additional risk for floods and droughts and more difficult access to clean water. It is also a threat to the diversity of forest ecosystems, as most of the loss takes place in tropical forests which host at least two-thirds of the terrestrial species, while temperate and boreal forests have slightly expanded. Furthermore, stopping deforestation contributes to reducing the impacts of climate change, as forests absorb carbon dioxide from the atmosphere and store it as biomass.[43, 51]

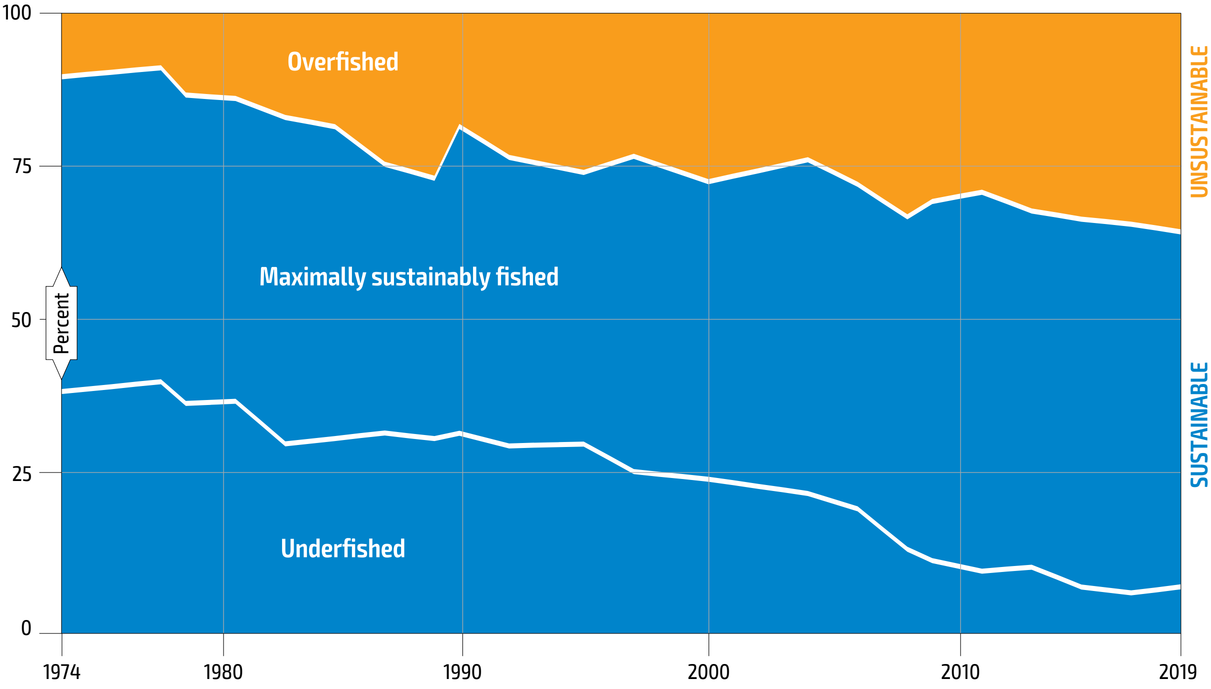
Deforestation occurs because of the extension of agricultural land, the exploitation of mining resources, infrastructure works such as hydroelectric dams or roads, urbanization and also of excessive logging in response for demand for biomass. There is evidence that forest degradation is a predecessor of deforestation. This is the case with tropical moist forests of which 17 percent of the area has disappeared between 1990 and 2019, and of which 10 percent are degraded.[53] Forest degradation can also be a consequence of the introduction of invasive species and changes in the insect pests population and pathogens resulting from climate change (see Section 1.15).

Another recent study found that while many HICs, China and India have obtained net forest gains domestically, these gains were made at the expense of increased deforestation embodied in their imports (e.g. coffee and cocoa), of which part comes from endangered tropical forests. Consumption patterns of G7 countries drive an average loss of 3.9 trees per person per year. Some of the hotspots of deforestation embodied in international trade are also biodiversity hotspots, such as in Central America, EAP, Madagascar, Liberia and the Amazonian rainforest.[54]

Marine resources

Based on FAO's assessment, the proportion of world marine fish stocks that are within biologically sustainable levels has declined from 90 percent in 1974 to around 65 percent in 2019 (Figure 1.65).[55]

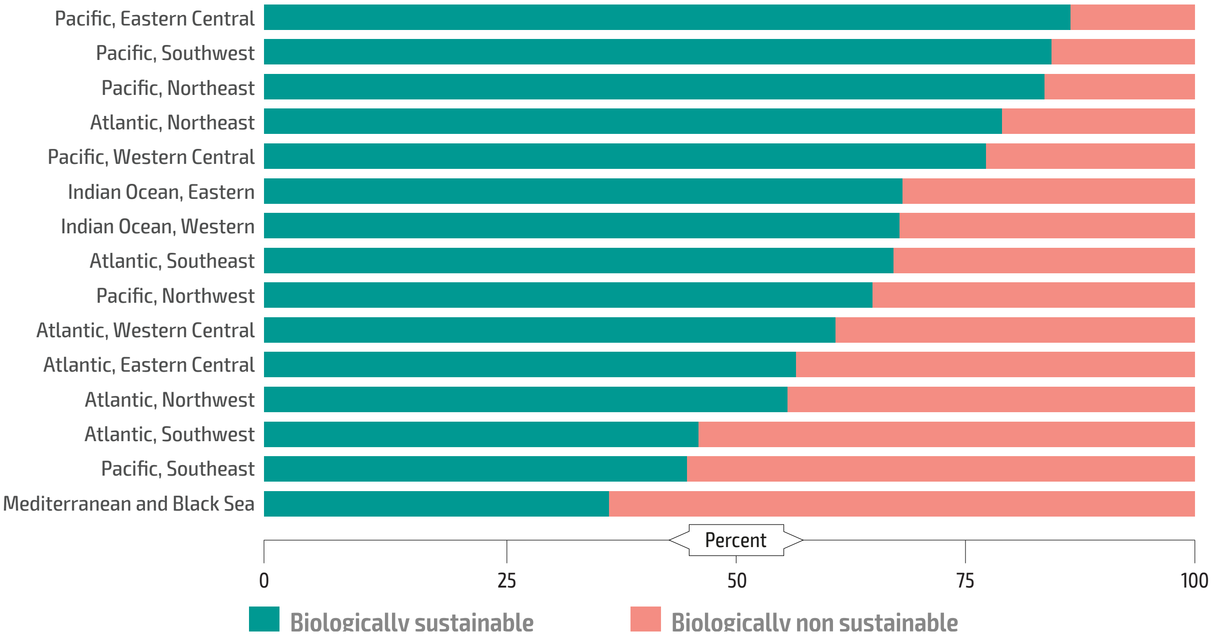
Figure 1.65 Global trends in the state of the world's marine fish stocks (1974–2019)



Source: FAO. 2022. *The State of World Fisheries and Aquaculture 2022. Towards Blue Transformation.* Rome, FAO. https://doi.org/10.4060/cc0461en

Geographically, there are great variations in the proportion of sustainable fish stocks. In 2017, the Mediterranean and Black Sea continued to have the highest percentage of stocks fished at unsustainable levels (62.5 percent), followed by the Southeast Pacific (54.5 percent) and Southwest Atlantic (53.3 percent). By contrast, the Eastern Central Pacific, Southwest Pacific, Northeast Pacific and Western Central Pacific had the lowest proportion (13 to 22 percent) of stocks fished at biologically unsustainable levels (Figure 1.66).[55]

Figure 1.66 Percentages of stocks fished at biologically sustainable and unsustainable levels by FAO statistical area (2017)



Source: Authors' elaboration based on FAO. 2020. *The State of World Fisheries and Aquaculture 2020. Sustainability in action.* Rome. https://doi.org/10.4060/ca9229en

There are clear signals that marine resources are degrading: around half the live coral cover on coral reefs has been lost since the 1870s, with an accelerating trend in recent decades because of climate change exacerbating other factors,43 including the pollution of waters discussed earlier (see Table 1.41 for a summary of this section).

Table 1.41 Main causes and major impacts of decline of forest and marine resources

ISSUES	MAIN CAUSES	MAJOR IMPACTS
Deforestation and forest degradation	• Expansion of agricultural activities, including both commercial and subsistence farming. • Mining, infrastructure (dams and roads), urbanization and logging. • Trade in commodities produced in areas resulting from deforestation (e.g. meat, coffee, cocoa and palm oil). • Pests and diseases.	• Loss of biodiversity. • Production of meat and tropical commodities. • Loss of ecosystems services, creating additional risks of floods and drought. • Reduced amount of carbon fixed by forests.
Degradation of marine resources	• Overfishing. • Pollution of oceans.	• Reduced stock and loss of biodiversity.

Source: Authors' elaboration.

1.14.2 Natural resources and agrifood systems

Just as agrifood systems have an impact on the evolution of natural resources, the quantity and quality of natural resources available have an impact on agrifood systems.

Agrifood systems play a major role in processes that threaten natural resources essential for human survival. There are also synergies, such as sustainable agricultural practices, that enhance natural resources, thus improving productivity and other ecosystem functions.

Conversely, the degradation of indispensable natural resources, such as land, water and biodiversity, also induced by urbanization and industrialization, is dramatically affecting agrifood systems. Tables 1.42 to 1.45 provide a comparative view of the mutual relationship between natural resources and agrifood systems.

Table 1.42 Mutual relationships between land and agrifood systems

IMPACTS OF AGRIFOOD SYSTEMS ON LAND	IMPACTS OF LAND ON AGRIFOOD SYSTEMS
Agricultural expansion. Expansion of crop and grazing lands through deforestation, and unsustainable agricultural and forestry practices are among the main direct drivers of land degradation.[5]	**Land scarcity.** For smallholders who produce most of the food worldwide, natural resources are the foundation of their livelihoods. Land, water and soil resources are embedded in social systems which, in turn, determine their access and use. When the effects of scarcity of the resources caused by depletion and climate change increase, the social consensus on the access to resources is challenged and violent conflicts often arise (see Section 1.5).[56]
Irrigation. Poorly managed irrigation (use of salty water, treated grey water, water produced in oil fields, or effluents from mining) or application of certain fertilizers cause salinization. In 2014, it was estimated that the global annual cost of salt-induced land degradation in irrigated areas was USD 27.3 billion because of lost crop production.[57]	**Salt-affected soils** have serious impacts on soil functions, including lower agricultural productivity, water quality, soil biodiversity, and greater vulnerability to erosion. Salt-affected soils also have a decreased ability to act as a buffer and filter against pollutants: hydrological, nutrient and biogeochemical cycles and ecosystem services that soils usually provide – critical for supporting human life and biodiversity – are disturbed and reduced.[26]
Soil organic carbon depletion. Despite knowing that soil carbon constitutes the largest terrestrial carbon pool,[10] considerable amounts of CO_2 have been released into the atmosphere because of land-use change and unsustainable management practices. It has been estimated that this process involved 115 to 154 gigatonnes of carbon.[58] This is all the more worrying as the IPCC (Intergovernmental Panel on Climate Change) *Special Report on Climate Change and Land* reaffirms that raising soil organic carbon content is one of the most cost-effective options for mitigating climate change, combatting desertification, stopping land degradation and improving food insecurity.[59]	**Consequences of loss of soil organic carbon.** According to the *Status of the World's Soil Resources Report*,[6] loss of soil organic carbon is the second greatest global threat to soil functions. Less soil organic carbon in the soil means more difficulty to cope with environmental problems such as food insecurity, soil degradation, drought and erosion as well as climate change adaptation and mitigation, as it contributes to better water retention, resistance to erosion and a higher level of biological activity.
Use of alternative nutrient sources. The use of alternative nutrient sources, such as biosolids, sewage sludge and animal manure may also present pollution risks.[60] Organic fertilizers benefit soil health, but they may be purveyors of contaminants, such as trace elements, pharmaceuticals and personal care products, micro- and nano-plastics, organic contaminants and other toxic substances. Some of these contaminants are not easily removed during waste treatment and pass from livestock to their faeces and manure.[61] **Sustainable soil management practices**, such as regenerative agriculture, improve soil health and raise biological activity, creating favourable conditions for plant growth by increasing soil organic matter and reducing pests. They also result in profitable production of nutrient-dense farm products.[62]	**Soil degradation, loss of biodiversity and ecosystems services.** Healthy quality soils are one of the main global reservoirs of biodiversity, as more than 40 percent of living organisms in terrestrial ecosystems are associated directly with soils during their life-cycle.[63] Soil degradation reduces the ecosystems services indispensable for agriculture and impacts negatively on productivity. **Food contamination.** When soils are polluted, contaminants can enter the food chain when crops and pastures absorb them and accumulate them in edible parts. Pollution of soils affects crop yields and induces severe poverty in the most vulnerable communities unable to migrate to uncontaminated areas. In China, some 10 million tonnes of crops are lost annually because of contamination, through reduced yields or unmarketable crops and food products.[64]
Population density and soil nutrients deficit. Low-income countries (LICs) with large and growing populations are found to be more likely to present negative soil nutrients balances compared to HICs with stable populations. The denser the population, the greater the nitrogen and phosphorus deficit, as for instance in SSA.[65] One reason for this being that more demand for land makes the practice of leaving land fallow no longer an option, therefore leading to soil nutrient loss.[66]	**Impact on productivity and production.** Over 1.5 billion people worldwide are directly affected by land degradation, which has already reduced the productivity of the Earth's surface by about 25 percent between 1981 and 2003.[67] According to the United States Department of Agriculture (USDA), approximately 10 million hectares of arable land annually drop out of agricultural use around the world, with causes including salinization, sodification and desertification. An estimated 2 billion hectares, or 17 percent of all biologically productive land, could benefit from restoration.[68]

Source: Authors' elaboration.

Table 1.43 Mutual relationships between freshwater and agrifood systems

IMPACTS OF AGRIFOOD SYSTEMS ON FRESHWATER	IMPACTS OF FRESHWATER ON AGRIFOOD SYSTEMS
Food habits and demand for water. With irrigated agriculture accounting for more than 70 percent of global water withdrawals and new food habits implying a shift of diets towards more water-intensive foods (e.g. meat and dairy products), the diet-related water footprint is exerting a greater pressure on water resources. **Intensive and concentrated industrial farming** units that have sprung up to meet with the changing food demand, require large volumes of freshwater,[69] while extensive animal production globally relies mainly on rainfed systems.[70] A study in Brazil, China and India has shown a transition in diets towards more livestock products and cereals and, consequently, a significant increase in the diet-associated water footprint.[71] **The challenge of changing diets.** Even moving towards healthier diets – varied with water-intensive nutritious foods, such as fruits and vegetables, legumes, nuts, and moderate amounts of dairy, eggs and poultry – needs more water than a cereal-based diet, making the sustainable use of water resources more difficult to achieve in some regions.[19]	**Risk of losing irrigated land.** Climate change impacts on heavily irrigated regions, and could cause reversion of between 20 million to 60 million hectares of cropland from irrigated to rainfed management in some regions,[72] while other regions could see improved availability of freshwater.
Water pollution. Globally, agriculture remains the major source of water pollution (mainly through diffuse pollution), followed by human settlements and industries.[73] Polluted soils, in turn, affect aquatic ecosystems. Contaminants leach into groundwater and pollute surface water and marine environments. Rainfall, flooding, the melting of snow and irrigation increase the soil water content and encourage runoff and flooding, resulting in the transport of contaminants to nearby wetlands, rivers, lakes, causing eutrophication and, eventually, the pollution of oceans.[74] Pollution reduces water quality, and washes out soil particles that add turbidity to water and diminish the depth of watercourses.[75]	**Poor quality water** (salt, contaminants) affects agricultural output in terms both of quantity and quality. When water is contaminated by plastic and industrial waste, nano- and microplastics and heavy metals eventually enter in food chains and in human food, particularly of marine origin.[76, 77] Contaminated water also impacts the effectiveness of aquatic ecosystems, and the availability of ecological services indispensable for agriculture.
Agriculture is the main source of **phosphorus** in freshwater, after the domestic sector. It weighs 38 percent of the total, of which 12 percent is from cereals, 6.3 percent from vegetable production and 5.5 percent from oil crops. As mentioned earlier, the presence of reactive nitrogen in water is mostly driven by the use of industrial nitrogen fertilizer.[31]	**Reactive nitrogen** and **phosphorus** are associated to soil acidification, water eutrophication and biodiversity loss that impact on agricultural production.

Source: Authors' elaboration.

Table 1.44 Mutual relationships between biodiversity and agrifood systems

IMPACTS OF AGRIFOOD SYSTEMS ON BIODIVERSITY	IMPACTS OF BIODIVERSITY ON AGRIFOOD SYSTEMS
Most threats to soil biodiversity and its functions are directly related to human activities and associated with **land-use cover** management and change, mostly caused by agriculture and agricultural intensification.[6] Recent decades are notable for marked **land-use change** in tropical regions associated with increasing oilseed production, in particular soya and oil palm, much of which has come at the expense of very biodiverse biomes.[78] However, agricultural systems could **enhance soil biodiversity** and improve soil health, if sustainable practices were adopted, such as those that promote accumulation and retention of soil organic carbon.[79]	The degradation of soil biodiversity can have highly negative consequences for multiple ecosystem functions and services. For example, it can affect **GHG emissions from agriculture** that result from the process of nitrogen and carbon transformation by soil microorganisms. Minimizing emissions requires more sustainable soil management by agriculture.[6] Biodiversity loss reduces **ecosystem resilience** and increases **vulnerability** to threats, and it affects negatively soil health and ecosystems services indispensable for effective and resilient agricultural production.[79]

Source: Authors' elaboration.

Table 1.45 Mutual impacts between forests and agrifood systems

IMPACTS OF AGRIFOOD SYSTEMS ON FORESTS	IMPACTS OF FORESTS ON AGRIFOOD SYSTEMS
Agriculture is estimated to be the main direct driver for around 80 percent of deforestation worldwide. Commercial agriculture is the most important driver of deforestation in Latin America, accounting for approximately two-thirds of total deforested area. In Africa and tropical and subtropical Asia, subsistence agriculture is responsible for a larger share of deforestation than commercial agriculture.[80] The global expansion of agricultural land has stabilized over the last 20 years at around 4.9 billion hectares, while forest losses have amounted to less than 100 million hectares. Globally, net forest conversion has been decreasing over the last 15 years, and annual losses have been reduced by 50 percent since 1990.[81]	Deforestation and forest degradation result in a loss of biodiversity that is a **threat to the resilience of agrifood systems to future shocks**. Forests play a key role in combatting erosion, regulating the supply of water, mitigating climate change and in providing habitat for many pollinators essential for food production.[52]
Worldwide, around 1 billion people depend to some extent on **wild foods** such as wild meat, edible insects, edible plant products, mushrooms and fish, which often contain high levels of key micronutrients. More than 2 000 animal species are thus used as wild meat.[82] In terms of dietary protein, in remoter communities, wild meat can account for 60–80 percent of dietary protein, and up to 100 percent of meat protein,[83, 84] and can act as an important "safety net" during times of hardship, in both rural and urban areas, when livelihoods and food systems are disrupted.[85] The value of forest foods as a nutritional resource is not limited to LMICs; more than 100 million people in the European Union regularly consume wild food. Some 2.4 billion people – in both urban and rural settings – use wood-based energy for cooking.[52]	Forests provide more than 86 million jobs and support the livelihoods of many more people. They are the source of a multitude of timber and non-timber products. An estimated 880 million people worldwide spend part of their time collecting fuelwood or producing charcoal, many of them women. Human population in LICs tends to be less in areas of with high forest cover and high forest biodiversity, but poverty rates in these areas are high.[52]

Source: Authors' elaboration.

In the effort to develop more sustainable and resilient agrifood systems, understanding the key values of Indigenous Peoples' food and knowledge systems – such as the respect for all forms of life (biocentrism); the circularity of biological processes, including food generation, consumption and disposal; and the management of natural resources at community level – may shed further light on the complex mutual relationships between agrifood systems and natural resources (see Box 1.42).

Box 1.42 Indigenous Peoples' knowledge systems for sustainable natural resources management

Access to land, territories, waters and natural resources is the first driver of food security and resilience for Indigenous Peoples across the world.[89, 90] In addition, Indigenous Peoples are also custodians of traditional governance systems that ensure the sustainable management of natural resources, which Indigenous Peoples carry out collectively. Through their traditional knowledge, Indigenous Peoples manage the resources in a way that it enables food generation, while it ensures the replenishment of the natural resource base, the enhancement of biodiversity and climate resilience in times of scarcity.

Indigenous Peoples' food and knowledge systems cannot be understood without reference to territorial management practices. Territorial management often includes nomadic, semi-nomadic and shifting practices, such as shifting cultivation, mobile fishing and hunting, transhumance, and other practices that include mobility as an essential territorial management practice.

Box 1.42 (cont.) Indigenous Peoples' knowledge systems for sustainable natural resources management

The territory is where the spiritual and material worlds manifest and where harmony is sought through the maintenance of balance and peace between the different elements. Territorial management is not a management of resources dedicated only to production, but a management that maintains reciprocal relationships, storytelling, cosmogony (beliefs regarding the universe) and natural resources, as well as generating food and preserving biodiversity.[89]

However, the mobility and adaptability of Indigenous Peoples are increasingly constrained by forced resettlement, land dispossession, landscape fragmentation[91, 92] and environmental degradation. For many indigenous pastoralists, traditional institutions for managing risk through mobility and the joint ownership of assets and resources have been replaced by the privatization of land and the enforcement of administrative boundaries, increasing their vulnerability to environmental stress.[93] Restrictions on the movement and ability of Indigenous Peoples to draw upon local environments and wildlife for food have a detrimental effect on their food sovereignty, dietary quality[94] and physical health.[95]

Inadequate technical analysis and limited understanding of the relevance of ancestral Indigenous Peoples' mobile practices and livelihoods, such as shifting cultivation, have resulted in ill-conceived policies and programmes. These policies have limited the mobility of Indigenous Peoples, impacting their food security and negatively impacting the environment. New evidence and comparative analysis are showing the difference in biodiversity count between settled cultivated areas and those under shifting cultivation, questioning the validity of the movement restriction programmes. More research is needed, along with new programmes and policies co-designed with Indigenous Peoples. For instance, the food system of Inari Sámi reindeer herders in Finland has traditionally relied on fishing, hunting and gathering wild edibles. The Inari Sámi normally follow nature's cycles, practicing seasonal transhumance to grazing lands.96 However, continuous encroachment on their traditional land, in particular because of the implantation of logging activities, as well as changes in temperature and rain patterns due to climate change have reduced the sustainability of reindeer herding, forcing reduced mobility and grazing intensification.

Reconsidering Indigenous Peoples' traditional knowledge with the same level of respect and consideration as the dominant scientific knowledge systems may contribute to expanding the knowledge-base for more sustainable and resilient agrifood systems.[97] The Coalition on Indigenous Peoples' Food systems, emanating from the 2021 UN Food Systems Summit and supported by FAO, the UNPFII, seven countries (Canada, Dominican Republic, Finland, Mexico, New Zealand, Norway, Spain) and indigenous leaders from the seven sociocultural regions of the world, is expected to be a space of collective work to shed light, provide evidence on and draw lessons from Indigenous Peoples' food and knowledge systems. Findings from this exercise may be game changers in support of the transformation of different agrifood systems towards sustainability and resilience.

1.14.3 Future trends

FAO's report *The future of food and agriculture – Alternative pathways to 2050*

In 2018, FAO explored alternative pathways to 2050 through three scenarios that envisioned different future patterns in natural resource use.[86] Table 1.46 summarizes the main scenario characteristics regarding land and water resources use.

First, an estimate of future available arable land, based on the analysis of biophysical constraints such as soil suitability, land degradation and taking into consideration the influence of climate change, socioeconomic changes such as urban expansion and land conservation measures, as well as protection of valuable ecosystems is provided. Then the needs of total potential additional arable land suitable for irrigated and rainfed crop production are projected for the three alternative scenarios. In the BAU scenario, compared to the base year, the land expansion to 2050 is projected to be +11 percent. In the SSS scenario, characterized by exacerbated land degradation and a more resource-intensive consumption pattern, land is projected to expand by +21 percent. In the TSS scenario, characterized by a more sustainable use of natural resources, the expansion is projected to be +8 percent. with more than three-quarters. In all the three scenarios, the bulk of the land expansion is projected to occur in LMICs and including China. Projected figures of arable land by scenario and production system are given in Table 1.47.

Table 1.46 Land and water use characteristics of the three scenarios in FAO's report *The future of food and agriculture – Alternative pathways to 2050*

SCENARIO	LAND AND WATER USE TRENDS
Business as usual (BAU)	In this scenario, arable land (the physical area under temporary and permanent agricultural crops) expands at faster annual rates than in the last decades and land degradation is only partially addressed. Land intensity, which is to say the quantity of land per unit of output, decreases as crop and animal yields increase, but these achievements require the progressive use of chemicals. Deforestation and unsustainable raw material extraction both continue, while water efficiency improves and the lack of major changes in technology leads to the emergence of more water-stressed countries.
Towards sustainability (TSS)	In this scenario, low-input processes lead water intensity to substantially decrease and energy intensity to significantly improve against the levels seen under the "business as usual" scenario. Regarding land-use intensity, the quantity of land per unit of output drops with respect to current amounts, thanks to sustainable agricultural intensification and/or other practices aimed at enhancing resource efficiency. This helps to preserve soil quality and restore degraded and/or eroded land. Agricultural land is no longer substantially expanded, and land degradation is tackled. Water abstraction is limited to a smaller fraction of available water resources.
Stratified societies (SSS)	In this scenario, the world witnesses further deforestation. New agricultural land is used to compensate for increased degradation and to satisfy additional agricultural demand, which is left unmanaged. The quantity of land per unit of output decreases for commercial agriculture, but remains stable or rises for family farmers as they increasingly suffer from crop losses that are also fuelled by extreme climate events. Water is not sustainably managed in many regions and little investment is made towards water use efficiency. Both water and land constraints are exacerbated by climate change.

Source: Based on FAO. 2018. *The future of food and agriculture – Alternative pathways to 2050.* Rome. www.fao.org/3/i8429en/i8429en.pdf

Table 1.47 Projected harvested area by production system according to FAO's report *The future of food and agriculture – Alternative pathways to 2050*

PRODUCTION SYSTEMS	BASE YEAR	BUSINESS AS USUAL	TOWARDS SUSTAINABILITY	STRATIFIED SOCIETIES	BUSINESS AS USUAL	TOWARDS SUSTAINABILITY	STRATIFIED SOCIETIES
	(million ha)						
	2012	2030			2050		
Irrigated	302	337	288	336	342	286	338
Rainfed	1 264	1 353	1 306	1 475	1 389	1 367	1 554
Total	1 567	1 690	1 594	1 812	1 732	1 653	1 892
	(index base year = 100)						
Irrigated	100	112	95	111	113	95	112
Rainfed	100	107	103	117	110	108	123
Total	100	108	102	116	111	105	121

Source: Authors' elaboration based on FAO. 2018. *The future of food and agriculture – Alternative pathways to 2050.* Rome. www.fao.org/3/i8429en/i8429en.pdf

Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) *The Assessment Report on Land Degradation and Restoration*

In 2018, the IPBES, after analysing past trends in land and water resources, considered different scenarios projecting them in the future.[5]

IPBES (2018)[5] found that "in the coming decades, the occurrence of incidental and structural deficits in food, water and energy are likely to grow with local variations in type and extent", thus creating a "serious risk that these may lead to unmanageable societal and environmental problems in regions that combine features such as low productivity soils that are vulnerable to degradation". IPBES highlights climate change, low land reserves of productive land, high population growth and density, weak institutions and political systems and the absence of economic coping mechanisms as the main factors at work.[5]

On **soil organic carbon**, future losses by 2050 were estimated at around 65 gigatonnes of carbon, of which about 15 gigatonnes result from conversion of natural land, 10 gigatonnes from the decline of land cover and detrimental land management, 10 gigatonnes from degradation of peatlands and 30 gigatonnes from global warming.[5]

Regarding **biodiversity**, future reduction of biodiversity would reach 38 to 46 percent compared to the natural state by 2050, from around 34 percent in 2010. Drops are expected to continue in all world regions, but the greatest losses will most likely be in Central and South America, SSA and Asia.[5]

For **water**, the IPBES report flags the key role of agriculture, particularly irrigation and agricultural intensification, and it projects that "nearly half of the global population will live in water scarce areas in 2050, with the highest proportion in Asia".[5]

IPCC report *Climate Change and Land*

The IPCC shows high confidence in the fact that climate change will increase rates of land degradation, thus affecting livelihoods, habitats and infrastructure.[87]

Based on the review of a great number of studies modelling the future, the IPCC report states with high confidence that land degradation is primarily determined by land management.[87]

The IPCC also envisions that measures to mitigate climate change could increase considerably afforestation as a means of carbon sequestration.[88]

1.14.4 Concluding remarks

This brief review of the causes and impacts of natural resource scarcity and degradation, and of the relations between natural resources and agrifood systems, illustrates the systemic interlinkages between agrifood systems and natural resources. Agrifood systems are highly dependent on natural resources and natural resources are strongly affected by activities conducted within agrifood systems.

If past trends continue at the current rate in the future, scarcity and degradation of natural resources will create an untenable situation as agrifood systems greatly depend on them. This would drive the world along a path incompatible with achieving the SDGs and securing the emergence of agrifood systems that are sustainable from economic, social and environmental perspectives. At the same time, agrifood systems are one of the major reasons of degradation of natural resources.

Achieving the SDGs would require serious changes in the way food is being produced and processed, in the diets adopted by consumers, and in the incentives and guidance provided by policies to all actors operating within agrifood systems.

Land area per person and land quality have been decreasing throughout the world, resulting in loss in ecosystems services, biodiversity and production. Erosion, loss of soil organic carbon, salinization and sodification, acidification and diffuse pollution are among the main processes through which land degrades. They are driven by expansion of crop and grazing lands, unsustainable agricultural and forestry practices, climate change, urban growth, and the development of infrastructure and extractive industry.

Increased pressure on water is a consequence of greater demand from agriculture, households and industries, and of climate change. A growing number of people are living in agricultural territories with severe water stress affecting irrigation, or with very high drought frequency parching rainfed cropland and pastureland. Water quality is threatened by pollutants (phosphorus, reactive nitrogen, pathogens, heavy metals, plastic and other contaminants) resulting from human activities.

Biodiversity is following an irrevocable and continuing decline of genetic and species diversity, and this trend may be accelerating, with the risk of precipitating a sixth mass extinction. Causes include land-use change, agricultural practices, overexploitation of resources, climate change, pollution and invasive species. Consequences include disruption in ecosystems services, affecting vital processes such as those provided to plants by soil biodiversity or pollinators.

Deforestation, resulting from expansion of agriculture, endangers forests along with the goods and services they offer, while depletion of marine resources by unsustainable fishing threatens future production.

NOTES – SECTION 1.14

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1.15 Epidemics and degradation of ecosystems (Driver 16)

Beyond the ongoing COVID-19 pandemic, epidemics and degradation of ecosystems may increase in the future because of rising trends in transboundary animal and plant diseases and pests; as agriculture encroaches on wild areas and forests, antimicrobial resistance develops and production and consumption of animal products increase. According to a report from the United Nations Environment Programme (UNEP) and the International Livestock Research Institute (ILRI):

> "the pathogens originate in animals, and the emergence or spillover of the diseases they cause in humans is usually the result of human actions, such as intensifying livestock production or degrading and fragmenting ecosystems, or exploiting wildlife unsustainably" (UNEP and ILRI, 2020, p. 39).[1]

All this adds to the increasing occurrences of events that threaten food safety, aggravated by climate change, and calls for the One Health approach (see Box 1.48).

In the same way as agrifood systems are affecting the state of natural resources (land, water and biodiversity), they are deeply transforming the planet's ecosystems and their internal processes. There are the two sides to this impact: one is intensification and "artificialization" of production processes; the other is the expansion of human activities.

In turn, these changes are triggering imbalances, some of which provide feedback to agriculture and human health. Among the consequences on agriculture, the multiplication of crop and animal pests and diseases increasingly threatens world food production and its sustainability. Effects on human health include emerging zoonotic infectious diseases, antimicrobial resistance, foodborne diseases and pesticide poisoning, with their cohort of victims and their imprint on the global economy.

The above considerations raise some important questions:

- To what extent is food safety jeopardized by the possible emergence of epidemics? What measures/actions can increase the resilience of food safety to shocks?
- Does antimicrobial resistance require transforming intensive animal systems? If so, why and how?
- How are the encroachment of human activities into forests, the loss of biodiversity and the emergence of epidemics related? What transformative changes may be needed to address these issues?

This section addresses some of these issues. Others are addressed in the other sections of the report.

1.15.1 Recent trends

Intensification of agriculture and climate change pose a threat to world food production and its sustainability.

Plant pests and diseases

Plant pests and diseases are responsible for the loss of 20 to 40 percent of crop output.

Locusts and grasshoppers have, since time immemorial, been among the most devastating threats to agriculture. Currently, they affect the livelihoods of one in every ten people worldwide.[2] They are profoundly and qualitatively different from other pests. Their populations can quickly grow to catastrophic levels, and some species form very dense bands and swarms that can cause a great deal of damage in a very short time. Their swarms can migrate hundreds of kilometres per day and invade areas covering millions of square kilometres, resulting in major economic, social and environmental impacts on an international scale. Weather remains the main driver of outbreaks.

Fall armyworm is a fast-spreading transboundary pest that feeds on more than 80 species of crops, including maize, sorghum and wheat. Originating in the Americas, it has been propagating beyond its native boundaries since 2016 and is now found in Africa (2016), the Near East and India (2018) and East Asia and the Pacific (EAP) (2019).[3] It could soon be present in Europe. As temperature rises with climate change, it could further spread to currently cooler areas. In the

Americas, control of the fall armyworm has depended exclusively on insecticide for many years. As a result, the pest has developed resistance to major classes of insecticides.[4,5,6] Its expansion is stimulated by monoculture and can be combatted by intercropping (with leguminous crops or cassava),[7,8] push-pull,[9] and biocontrol.[10,11]

Other important pests and diseases include **cassava viruses** (cassava mosaic and cassava brown streak virus diseases) that are causing annually a 15 to 24 percent loss in Africa,[12] **wheat rust**, *Xylella fastidiosa*, affecting olive trees in the Mediterranean region, and a new **fungus** striking bananas (see Table 1.48).

Table 1.48 Examples of plant pest and disease outbreaks

PEST/PATHOGEN	CROP	OUTBREAK LOCATION	OUTBREAK PERIOD	EXTEND OF OUTBREAKS, COST OF TREATMENT OR DAMAGE
Cassava viruses (*Cassava mosaic viruses* [CMDs] and *Cassava brown streak disease* [CBSD])	Cassava	Eastern and Central Africa. CMDs are also widely present in tropical parts of Asia	1990s–2020 for CMDs; 2004–2020 for CBSD	Spread widely in Africa, causing loss of around USD 1 billion annually
Banana Fusarium wilt (*Fusarium oxysporum Tropical Race* [TR4])	Banana	Widespread in Southeast and South Asia, the Near East and present in Mozambique, Colombia and Peru	1990–2021	In Asia alone, 100 000 ha are estimated to be affected
Migratory locust (*Locusta migratoria*)	General	Madagascar	1997–2000	4.2 million ha treated; cost: USD 50 million
Italian locust (*Calliptamus italicus*)	Grain crops (mostly wheat)	Kazakhstan	1999–2000	8.1 million ha treated in 2000; cost: USD 23 million
Desert locust (*Schistocerca gregaria*)	General	Africa and Southwest Asia	2003–2005	13 million ha damaged: cost: USD 500 million
Wheat rust diseases (e.g. yellow rust, stem rust and leaf rust)	Wheat	Central and West Asia, North and East Africa, China and India	Continuous, recent most significant ones occurred in 2009–2012	An estimated global annual loss of 5.4 million tonnes worth more than USD 979 million
Migratory locust (*Locusta migratoria*)	General	Madagascar	2013–2016	2.3 million ha treated; cost: USD 37 million
Olive Quick Decline Syndrome (*Xylella fastidiosa*)	Olives (but can also affect vines, almonds, coffee, citrus, peach, plums and oleander)	Italy	2013–2021	The disease spread to more than 715 000 ha. Estimated cost of loss: more than EUR 1.2 billion
Fall armyworm (*Spodoptera frugiperda*)	Maize	Africa (first introduction outside endemic areas in the Americas)	2016–present	Estimated cost of damage: USD 9.4 billion annually

Source: Authors' elaboration.

All in all, plant pests and diseases trigger yearly losses estimated at 20 to 40 percent of the global world crop production: plant diseases cost up to USD 220 billion and invasive insects approximately USD 70 billion per annum.[13] Detailed recent estimates document losses in wheat, rice, maize, potato and soybean worldwide related to 137 pathogens and pests. Yield loss (range) estimates made at a global level and per hotspot were: for wheat, 21.5 percent (10.1 to 28.1 percent); for rice, 30.0 percent (24.6 to 40.9 percent); for maize, 22.5 percent (19.5 to 41.1 percent); for potato, 17.2 percent (8.1 to 21.0 percent); and for soybean, 21.4 percent (11.0 to 32.4 percent). Findings suggested that the highest losses are associated with food-deficit regions with fast-growing populations, and frequently with emerging or re-emerging pests and diseases.[14]

The scale and intensification of agriculture, along with the expansion of monoculture and reliance on a reduced number of species – and within species, of varieties – have all contributed to making agrifood systems more vulnerable. Climate change supplements this vulnerability by facilitating the extension of pest and disease geographic distribution.[15] It is also expected to cause higher losses in temperate zones and a higher metabolic rate of pests,[16] and multiply the number of generations per season,[17] resulting in greater risks of new pest and disease introduction across regions and higher annual production loss worldwide. For example, the outbreak of the South American Locust, *Schistocerca cancellata*, that occurred in 2015, after almost 60 years, is explained by the hypothesis that several mild winters in a row allowed the locust to break the embryonic diapause and produce an extra annual generation in the permanent breeding area in north-western Argentina and the Plurinational State of Bolivia, causing an exponential growth.[18]

Experience shows that the impact of these pests and diseases could be considerably reduced through prompter interventions and the application of crop protection measures according to rule. Locusts invasions, in particular, which occur mostly in low-income countries (LICs), could largely be controlled at an early stage, provided adequate resources are mobilized in time (see Table 1.49 for a summary of this section).

Table 1.49 Main causes and major impacts of pests and diseases on crops

ISSUES	MAIN CAUSES	MAJOR IMPACTS
Plant pests and diseases on crops	• The scale and intensification of agriculture. • The expansion of monoculture and reliance on a reduced number of species, and within species, of varieties. • Climate change facilitates the extension of pest and disease geographic distribution and multiplies the number of generations per season. • Lack of prompt interventions and application of crop protection measures.	• Plant pests and diseases trigger yearly losses estimated at 20 to 40 percent of the global world crop production. • Plant diseases cost up to USD 220 billion, and invasive insects approximately USD 70 billion, per annum. • Water and soil pollution. • Damage to living organisms (contamination of the environment, causing loss of biodiversity and destroying beneficial insect populations that act as pollinators or natural enemies of pests). • Pest resistance. • Loss of human lives because of pesticide poisoning. • Chronic consequences such as loss of quality of life, of well-being, and of ability to work and food contamination.

Source: Authors' elaboration.

Pests and diseases impact on forests

Invasive species (non-native insect pests, pathogens, vertebrates and plants) and outbreaks of native forest insect pests and diseases have significant impacts on the world's forests and forest sector. Damage caused reduces vegetation and wildlife habitat, thereby reducing local biodiversity and species richness. Increasing international trade, longer range and faster travel and human mobility, exacerbated by the consequences of climate change, have contributed to the spread of transboundary invasive insect pests and pathogens into new regions, causing extensive direct economic impacts and losses of ecosystem services. Important examples include chestnut blight in Northern America, and ash dieback and Dutch elm disease in Europe.

Climate change modifies the populations of forest insect pests as a result of longer warm seasons, variations in precipitation patterns, modifications in food availability, and changes in predator and parasite populations. Higher temperatures and an increase in the frequency of droughts affect insects that are sensitive to heat and cause a northward or upward shift in their geographical ranges (prominent examples are the pine processionary and the oak processionary moths).

As a result, there have been large-scale forest diebacks and declines caused by a combination of both biotic and abiotic factors, with consequences for the maintenance of biodiversity, ecosystem function, and resilience of native forests and woodlands.[19,20] See Table 1.50 for a summary of this section.

Table 1.50 Main causes and major impacts of pests and diseases on forests

ISSUES	MAIN CAUSES	MAJOR IMPACTS
Plant pests and diseases in forests	• Climate change modifying insect pests and pathogens population and spreading them into new regions. • Increasingly invasive species (insect pests, pathogens, vertebrates, plants) because of increased international trade, longer range and faster travel and human mobility.	• Large-scale forest diebacks • Impacts on vegetation and wildlife • Damage on biodiversity

Source: Authors' elaboration.

Loss of animal production and diseases

Twenty-five percent of animal production is lost because of disease. High-impact animal diseases, including Peste des Petits Ruminants (PPR), African Swine Fever (ASF) (see Box 1.43), Foot-and-Mouth Disease (FMD), Contagious Bovine Pleuro-Pneumonia (CBPP), Lumpy Skin Disease (LSD) and Newcastle disease (NCD), directly affect the livelihoods, food security and nutrition of farming households through increased mortality and reduced livestock productivity, as well as indirect losses associated with cost of control, loss of trade, loss of international market access and decreased market values.[21]

With the exception of ASF, the above-listed diseases could be stopped through vaccination, but the poor-quality vaccines and lack of accessibility seriously constrain risk prevention and management.[22]

Box 1.43 Two major transboundary animal diseases

Peste des Petits Ruminants (PPR) an extremely contagious and devastating disease, affects sheep and goats in around 70 countries across Africa, Asia, the Near East and Eastern Europe since its first appearance in 1942. More than 80 percent of the global 2.5 billion small ruminant population are vulnerable to PPR in infected and at-risk countries. The disease also strikes wildlife, with an elevated effect on biodiversity.

African Swine Fever (ASF) is spreading at an alarming pace in Asia, Europe and Africa, and has recently been reported in the Americas, with severe consequences for swine production. The inflection of 3 percent in world pig meat production, in 2019, is probably related to the impact of this disease on that sector.[23]

The emergence of animal diseases is largely driven by the exposure of livestock to wildlife,[24] which acts as a reservoir for many pathogens (see Box 1.46). The propagation of pathogens is influenced by production systems, income and level of biosecurity. Intensified farming practices and methods can be linked to disease emergence and amplification.

Intensive livestock systems generally have high-density populations of low genetic diversity, which may favour increased disease transmission and adaptation,[29] especially in pigs and poultry. Ineffective management and biosecurity measures contribute to the between-herd spread of zoonotic diseases, while those that are used to protect animals generally involve their permanent confinement in an artificial environment.

Climate change can exacerbate disease in livestock, and some diseases are especially sensitive to climate change. Among 65 animal diseases identified as most important to poor livestock keepers, 58 percent are climate sensitive. Climate change may also have indirect effects on animal disease (see Box 1.44), and these may be even greater than the direct effects.[25]

Box 1.44 Impact of climate change on animal health

The wildlife-livestock-human interface is not only being enhanced by humans encroaching on wild habitats, but also by wildlife living in human-dominated environments or being forced to move towards urban areas because of habitat loss, climate change, extreme weather events or fires.

Climate change is leading to changes in the geographic ranges of wild species – contracting, expanding or shifting to new areas where cross-species pathogen transmission may occur.

The direct effects are more likely to influence diseases that are associated with vector transmission, water or flood, soil, rodents, or air temperature and humidity. Indirect impacts of climate change are more complex and include those deriving from changes in land use and biodiversity, and the attempt of animals to adapt to these climatic and environmental changes, or from the influence of climate on microbial populations, distribution of vector-borne diseases and host resistance to infectious agents, feed and water scarcity, or foodborne diseases. Prolonged droughts determine water and pasture shortages, which decrease livestock immunity against infectious diseases and trigger livestock movements to areas at higher risk of animal diseases (e.g. water points, grazing areas in proximity to wildlife reserves).

Vector-borne diseases that are strongly associated with vector amplification because of climate variability include Rift Valley fever (RVF), West Nile virus (WNV), Bluetongue virus (BTV) and African trypanosomosis. Soil-borne diseases, such as anthrax, are also affected by precipitation variability.

Climate change has already been shown to determine a mismatch between migratory bird nesting and peak food abundance, leading to changes in migration routes and timing.[26] Climate change may reduce available habitats, determining higher congregations of birds of several species in smaller areas of remaining resources, thus increasing the chance of within-species and cross-species disease transmission. Changes in migration routes and timing may also favour the emergence and introduction of a pathogen carried by birds in novel areas. This scenario is a likely explanation for the recent spread of highly pathogenic H5N8 avian influenza in Africa.

Source: Authors' elaboration based on FAO. 2017. *Climate-Smart Agriculture Sourcebook Summary - Second edition*. Rome.

Animal, aquaculture and forest biological threats, including zoonotic infections of pandemic potential and antimicrobial resistance, jeopardize food security and have broad economic, social and environmental impacts, representing a serious danger for global food security in all of its dimensions. The global impact of these threats has been estimated at 25 percent of animal production. They may indirectly determine loss of consumer confidence, as in the case, for example, of highly pathogenic avian influenza. This affects the income and well-being of people depending on both livestock and crop production, particularly in LICs. The transboundary nature and speed at which these high-impact animal diseases can move across borders have resulted in devastating consequences on global agrifood systems, affecting trade at all levels,[22] requiring prevention and control measures, and eradication programmes.

Globally, livestock provides support to the food security and livelihoods of at least 1.3 billion people and contributes to nearly 40 percent of total agriculture output in high-income countries (HICs) and 20 percent in low- and medium-income countries (LMICs).[27] Drawn forward by a rapidly increasing consumer demand, it is one of the fastest growing subsectors of the agricultural economy and represents a key source of livelihood for poor people in marginal areas.[23]

Small- and medium-sized farms are responsible for 48 percent of world production of livestock,[28] and they have a particularly important role in LMICs. By contrast, large farms contribute between 75 percent and 100 percent of livestock output in HICs, especially in Northern America, South America, Australia and New Zealand (see Table 1.51 for a summary of this section).

Table 1.51 Main causes and major impacts of animal livestock diseases

ISSUES	MAIN CAUSES	MAJOR IMPACTS
Animal diseases	• Exposure of livestock to wildlife. • Intensive livestock systems with high-density populations of low genetic diversity, which may favour increased disease transmission and pathogen adaptation. • Ineffective biosecurity and risk management measures. • Lack of vaccination and poor access to quality vaccines. • Rapid transboundary spread of diseases. • Climate change, as it affects spatial distribution of disease vectors and modifies exposure of livestock to wildlife.	• Increased mortality. • Reduced production (by 25 percent). • Loss of trade and of international market access. • Decreased market value of production. • Affects livelihoods and food security of farming households.

Source: Authors' elaboration.

1.15.2 Recent trends - Human health impact

Emerging infectious diseases (EIDs) are on the increase

Global public health is severely affected by the way agriculture is being managed. In the last century, improved nutrition and hygiene, and the use of vaccines and antimicrobials, contributed to reducing the infectious disease burden.

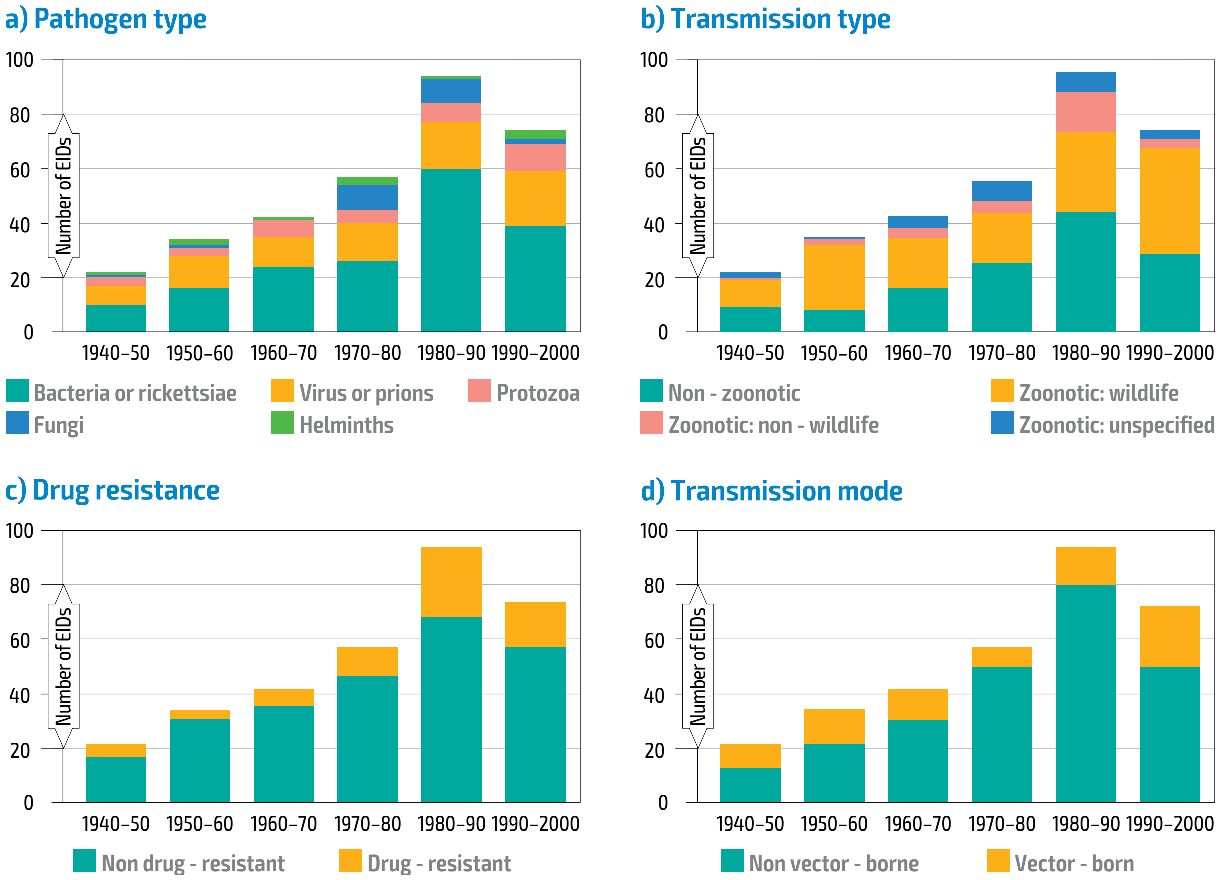
However, in recent decades, there has been a rise in disease emergence risk and in the potential for pandemics.[29] The threat of pandemics is growing rapidly, with more than five new diseases emerging in people every year, any one of which has the capacity to spread and become pandemic.[30] Infectious diseases of animal origin take a central place in this trend.

Vector-borne diseases are also significantly increasing with time,[31] corresponding to climate anomalies occurring over the past two decades. This supports the hypothesis that climate change may drive the emergence of diseases that have vectors sensitive to alterations in environmental conditions such as rainfall, temperature and severe weather events.[32]

In addition, endemic zoonotic and neglected diseases (e.g. anthrax, rabies and brucellosis) and vector-borne diseases such as Rift Valley fever, continue to inflict an enormous burden, particularly in LICs.[22] The emerging infectious disease events of viral epidemic disasters in the 1990s are shown by decades in Figure 1.67 while Figure 1.68 reports them on an annual basis until 2022.

Spatial analysis of emerging infectious diseases events have shown reporting bias towards latitudes between 30 and 60 degrees north and between 30 and 40 degrees south, as a matter of greater surveillance and infectious disease research effort in HICs.[31, 33] However, those events caused by zoonotic pathogens from wildlife appear to significantly correlate with lower latitude and wildlife biodiversity, particularly in tropical forest regions with high mammal biodiversity,[33] while those caused by drug-resistant pathogens appear to be more correlated with higher latitude and socioeconomic conditions, driven also by human population density, growth and rainfall.[31]

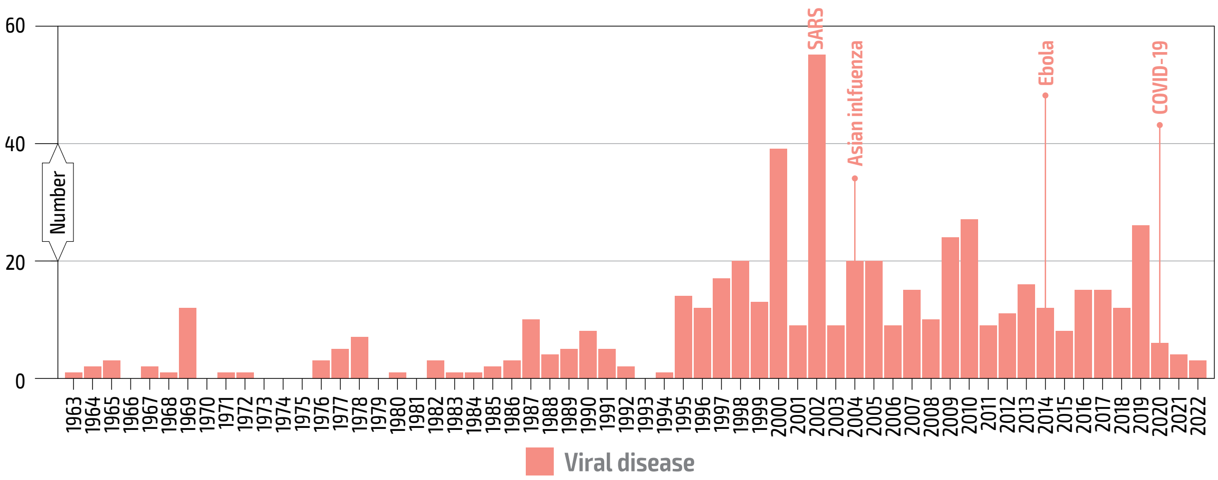
Figure 1.67 Global trends in emerging infectious diseases events



Notes: Emerging infectious disease (EID) events (defined as the temporal origin of an EID, represented by the original case or cluster of cases that represents a disease emerging in the human population, see methods) are plotted with respect to panel a) pathogen type; panel b) transmission type; panel c) drug resistance; and panel d) transmission mode.

Source: Jones, K.E., Patel, N.G., Levy, M.A., Storeygard, A., Balk, D., Gittleman, J.L. & Daszak, P. 2008. Global trends in emerging infectious diseases. *Nature*, 451: 990–993. www.nature.com/articles/nature06536

Figure 1.68 Evolution of annual viral epidemic disasters (1963–2022)



Notes: These data do not provide a comprehensive representation of all disasters but rely on reporting and alignment with the selection criteria of the Emergency Events Database (EM-DAT). A disaster event is defined as including at least one of the following criteria: 10 or more human deaths, 100 or more people affected, injured, or made homeless, or a declaration by the country of a state of emergency and/or appeal for international assistance. The natural disaster indicators include meteorological (extreme temperature), hydrological (flood), climatological (wildfire and drought), and biological (viral epidemic) events. These indicators have been selected to illustrate the variability of climate and disease events and are not intended to represent a causal relationship between climate and epidemic events.

Source: EM-DAT. 2022. *The international disasters database. Centre for Research on the Epidemiology of Disasters – CRED.* Brussels, Université catholique de Louvain. Cited 22 May 2022. https://public.emdat.be

With deforestation and globalization, emerging infectious diseases of animal origin are becoming more frequent and more devastating. The upsurge in emerging, re-emerging and the spread of infectious diseases of animal origin is following an alarming trend. These diseases can significantly impact the global economy and public health.[24, 31, 33]

Most of the emerging or re-emerging epidemic and pandemic diseases of humans have their origins in wild or domestic animals (see Box 1.45). At least 60 percent, or two-thirds, of EIDs are caused by pathogens shared between humans and other vertebrates, i.e. are zoonotic.[31, 34] The majority of these zoonotic EIDs (71.8 percent) originate in wildlife.[31]

Box 1.45 Host species, reservoir and risk of exposure

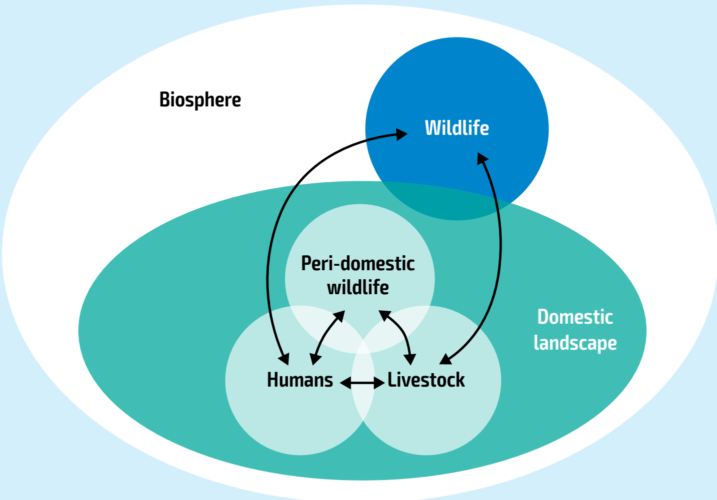
Wild animal species are an important reservoir of potential zoonotic pathogens.[35]

New pathogens typically emerge from a pool of previously undescribed, potentially zoonotic, microbes that have co-evolved over millions of years with their wildlife hosts without causing any health issues.[36] They may, however, become problematic if they spillover to humans.[37]

According to the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), **an estimated 1.7 million currently undiscovered viruses** are thought to exist in mammals (in particular, bats, primates and rodents) and avian hosts; **of which 37–48 percent (between 631 000 and 827 000) could have the ability to infect humans**.[30]

The interaction of humans or livestock with wildlife exposes them to sylvatic disease cycles and to the risk of a spillover of potential pathogens (Figure A).

Figure A. Pathogen transmission across the wildlife-livestock-human-environment system



Source: Jones, B.A., Grace, D., Kock, R., Alonso, S., Rushton, J., Said, M.Y., McKeever, D., Mutua, F., Young, J., McDermott, J. & Udo Pfeiffer, D. 2013. Zoonosis emergence linked to agricultural intensification and environmental change. *Proceedings of the National Academy of Sciences of the United States of America*, 110(21): 8399-8404. https://doi.org/10.1073/pnas.1208059110

Host species abundance, diversity and adaptability to rapid changing environments caused by human activities are also playing a significant role in disease emergence.

The highest proportion of zoonotic viruses are reported among species in the orders Rodentia (61 percent), Chiroptera (30 percent), Primates (23 percent), Artiodactyla (21 percent) and Carnivora (18 percent). Rodents, bats and primates host together about 76 percent of zoonotic viruses and represent around 73 percent of all terrestrial animal species. Among domesticated species, pigs, chicken and cattle share the highest number of viruses with humans and are responsible for animal and public health issues.[38]

During the current decade, primary forests are expected to continue to decrease, suggesting a greater wildlife-livestock-human interface.

These diseases comprise highly pathogenic avian influenza (HPAI), Ebola, swine influenza, Nipah virus, the Middle East Respiratory Syndrome (MERS) and the Severe Acute Respiratory Syndrome group of coronaviruses that includes SARS-CoV-2, involved in the current COVID-19 pandemic. Zoonotic emerging infectious diseases represent a growing and very significant threat to global health. They are highly infectious in nature and can spread across large distances very rapidly, causing sickness and death in humans, putting global food security at risk and generating major disruption in the world economy.[22, 39]

The current Coronavirus Disease 2019 (COVID-19), caused by SARS-CoV-2, is an emerging infectious disease of animal origin that spreads with alarming speed and is responsible for millions of deaths – almost 6 million human fatalities as of 24 February 2022.[40]

Agricultural encroachment into wild areas and forests, global travel and trade, expanding human and livestock populations – particularly poultry and pigs[23] – changing behaviour as well as wildlife trafficking, unsustainable hunting and use of natural resources have determined a rise in the risk of the emergence of diseases of animal origin and the potential for pandemics(see Box 1.46).[29]

Box 1.46 Drivers of disease emergence

According to the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), the main drivers of disease emergence are of anthropogenic origin and include the following:

- **Land-use change and deforestation** – often driven by agricultural expansion – are leading drivers of emerging zoonoses. Land-use change (including agricultural expansion and urbanization) caused the emergence of more than 30 percent of new diseases reported since 1960.[30] Examples are Ebola[41] and malaria.[42]
- **Agricultural intensification** and its measures, such as dams, irrigation projects, factory farms, etc., were associated with more than 25 percent of all – and more than 50 percent of zoonotic – infectious diseases that emerged in humans.[43] In Malaysia, for example, agricultural intensification led to the emergence of the Nipah virus, and in West Africa, links were found between the 2013–2014 Ebola outbreak and change in government policy related to granting land leases.[44]
- **Unsustainable livestock intensification**, especially of pigs and poultry, facilitates disease transmission by increasing the size and density of populations with low genetic diversity. For instance, the majority of conversions of low pathogenic avian influenza (LPAI) to high pathogenic avian influenza (HPAI) occurred in intensified systems.[45]
- **Wildlife farming** has taken off mostly to supply luxury markets. For the last few decades, an increasing number of tropical animal species have been bred under intensive production systems. These include antelopes, ostriches and large rodents in Africa, and pangolins in Asia. However, the limited knowledge of animal needs, inadequate biosecurity measures and insufficient veterinary support, may facilitate the emergence of infections.[46, 47]
- **Overhunting** decreases the density of wildlife and changes the wildlife species composition: large-bodied wildlife species, first depleted, are replaced with smaller-bodied species that are more resilient because of their higher reproductive rates and lowered predation pressure,[48] with the consequence of increasing direct contact with species of higher zoonotic risk, such as rodents, primates and bats.[47]
- **Globalized food value chains of livestock and wildlife** have increased the frequency and volume of trade of livestock and wildlife, increasing the risk of infection in importing countries.[49, 50]
- **Global connectivity** dramatically increased over the last decades with the development of global trade, international transport and changing human migration patterns (for example, as a result of conflicts or political and environmental instability). Rapid long-distance transport of animals, animal products and humans increases the risk of global spread of high-impact animal and plant pests and diseases.[47]

Risk of zoonotic emerging infectious diseases was found higher in tropical forest regions rich in mammalian species and experiencing anthropogenic land-use changes related to agricultural expansion and intensification. Tropical forest, rich in high mammalian biodiversity, increases the "depth" of the pathogen pool from which novel pathogens may emerge, creating a greater potential for such emergence.[33] However, there is also evidence that biodiversity loss, particularly when caused by exploitation and loss of habitat, may increase transmission of microbes from animals to people under certain circumstances.[30,38]

Expansion of agricultural fields promotes encroachment into wildlife habitats, leading to ecosystem changes, and bringing humans and livestock into closer proximity to wildlife and vectors, exposing them to the sylvatic cycles of potential zoonotic pathogens.[29] Deforestation and encroachment on natural ecosystems increase and expand ecotones, which are defined as areas of steep transition between ecological communities, ecosystems or ecological regions. In those areas, species assemblages from different habitats mix,[51] providing new opportunities for pathogen spillover, genetic diversification and adaptation (Table 1.52).[52]

Table 1.52 **Conceptual framework of types of wildlife – livestock – human interface and their characteristics**

TYPE OF WILDLIFE-LIVESTOCK-HUMAN INTERFACE	LEVEL OF BIODIVERSITY	CHARACTERISTICS OF LIVESTOCK POPULATION	CONNECTEDNESS BETWEEN POPULATION	EXAMPLES OF ZOONOTIC DISEASE WITH ALTERED DYNAMICS
"Pristine" ecosystem with human incursion to harvest wildlife and other resources	High	No livestock	Very low, small populations and limited contact	Ebola, HIV, SARS, Nipah virus in Bangladesh and India
Ecotones and fragmentation of natural ecosystems: farming edges, human incursion to harvest natural resources	High but decreasing	Few livestock, multiple species, mostly extensive systems	Increasing contact between people, livestock, and wild animals	Kyasanur forest disease, Bat rabies, E. co/interspecies transmission in Uganda, Nipah virus in Malaysia
Evolving landscape: rapid intensification of agriculture and livestock, alongside extensive and backyard farming	Low, but increasing peridomestic wildlife	Many livestock, both intensive and genetically homogenous, as well as extensive and genetically diverse	High contacts between intensive and extensive livestock, people, and peridomestic wildlife. Less with endangered wildlife	Avian influenza, Japanese encephalitis virus in Asia
Managed landscape: islands of intensive farming, highly regulated. Farm land converted to recreational and conservancy	Low, but increased number of certain peridomestic wildlife species	Many livestock, mainly intensive, genetically homogeneous, biosecure	Fewer contacts between livestock, and people; increasing contacts with wildlife	Bat-associated viruses in Australia, West Nile virus and Lyme disease in the United States of America

Source: Jones, B.A., Grace, D., Kock, R., Alonso, S., Rushton, J., Said, M.Y., McKeever, D., Mutua, F., Young, J., McDermott, J. & Udo Pfeiffer, D. 2013. Zoonosis emergence linked to agricultural intensification and environmental change. *Proceedings of the National Academy of Sciences of the United States of America*, 110(21): 8399-8404. https://doi.org/10.1073/pnas.1208059110

Associations between disease emergence and ecotones have been suggested for several diseases, including yellow fever, Lyme disease, hantavirus pulmonary syndrome, Nipah virus encephalitis, influenza, rabies, cholera, leptospirosis, malaria and human African trypanosomiasis. Most of these are zoonoses, and several involve both wildlife and livestock in their epidemiology.[29]

Pandemics and other emerging zoonoses are apt to cause more than a trillion dollars in economic damages annually.[30] The heaviest burden of zoonotic diseases is borne by poor people, but new infectious diseases impact everyone, with monetary losses resulting from novel infectious diseases being much greater in HICs in part because of their population age structure.[1,53] See Table 1.53 for a summary of this section.

Table 1.53 Main causes and major impacts of emerging zoonotic infectious diseases

ISSUES	MAIN CAUSES	MAJOR IMPACTS
Emerging infectious diseases of animal origin (zoonoses)	• Expanding human and livestock populations. • Agriculture encroachment into wild areas and forests create more contact between people, livestock and wildlife, and opportunities for pathogen spillover. • Unsustainable hunting that leads to depletion of large mammals and increased contact with higher zoonotic risk animals. • Unsustainable management of natural resources. • Agricultural intensification (e.g. dams, irrigation, factory farms, etc.). • Unsustainable livestock production and intensification, especially pigs and poultry, that facilitates disease transmission by increasing size and density of populations of low genetic diversity. • Global rapid travel and trade, and wildlife trafficking. • Consumption and trade in wild meat. • Wildlife farming. • Poorly regulated and low biosecurity value chains.	• Impact on health (sickness and death). • Impact on the economy (particularly in the case of pandemics) – damages of more than a trillion dollars. • The heaviest burden of zoonotic disease is borne by poor people, but new infectious diseases impact everyone, with monetary losses of novel infectious diseases much greater in HICs.

Source: Authors' elaboration.

Food safety, antimicrobial resistance and foodborne diseases

Food safety shocks are multiplying because of the development of antimicrobial resistance and foodborne diseases. Inappropriate use of drugs in animal production is aggravating antimicrobial resistance. Emerging infectious disease events caused by drug-resistant pathogens have significantly increased with time. This is probably related to a rise in the use of antimicrobials in animals for growth performance enhancement, disease prevention, treatment and control, particularly in high latitude HICs.

With expansion of intensive livestock farming driven by growing demand for animal protein,[54] overuse and abuse of these drugs are observed as a replacement for good biosecurity practices in animal production. This contributes to the increased emergence and spread of antimicrobial resistance in pathogens, causing drug-resistant infections in animals and humans across the globe.[55]

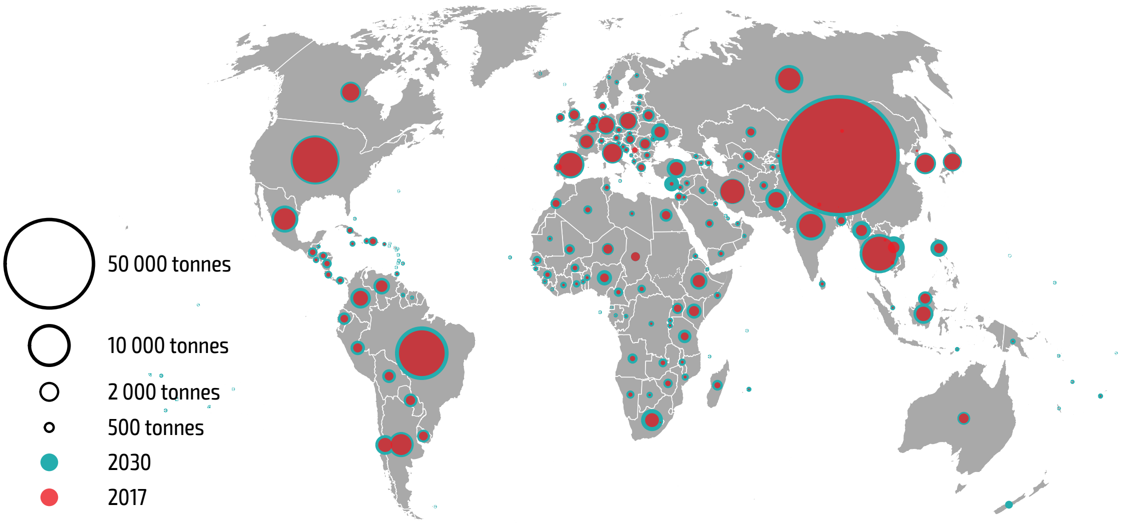
About 73 percent of all antimicrobials sold globally are used in animals raised for food. Antimicrobial resistance can affect food-producing animals, food items, the environment and humans who work closely with animals, live in the vicinity of farms or consume food contaminated with drug-resistant germs.

Inappropriate use, overuse and abuse of antimicrobials in animal production contribute to the increase in antimicrobial resistant pathogens causing human infections across the globe.[55] Fungus has equally developed resistance.[56] An estimated 4.95 million people who died in 2019 suffered from at least one drug-resistant infection and antimicrobial resistance directly caused 1.27 million of those deaths.[57] It has also been estimated that, if no action is taken now, by 2050, ten million lives a year and USD 100 trillion in economic output will be at risk from drug-resistant infections through disruption of food supply chains, forcing tens of millions more people into extreme poverty.[58] Low- and middle-income countries (LMICs) face the greatest burden from the growth in drug-resistant infections.[59]

Studies of antimicrobial use trends and projections showed that in 2017, 93 309 tonnes of active ingredients were utilized for chicken, cattle and pigs (which account for more than 90 percent of all food animals) and this amount is expected to increase 11.5 percent by 2030.54 Pigs had the fastest projected growth in antimicrobial consumption (45 percent), while cattle had the smallest (22 percent of the global increase). Chickens contributed 33 percent to the total increase in antimicrobial use.

Asia consumed the largest volume of antimicrobials with an expected growth by 10.3 percent by 2030. While Africa used lower quantities of antimicrobials in 2017 compared to other regions, it has the highest projected increase by 2030 (37 percent), but this amounts to just 6.1 percent of the world total in 2030 (Figure 1.69).

Figure 1.69 **Antimicrobial consumption per country in 2017 and projected to 2030**



Notes: Contrarily to the other maps and tables in this report, China refers to mainland only. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties. Final boundary between the Sudan and South Sudan has not yet been determined. Final status of the Abyei area is not yet determined.

Source: Tiseo, K., Huber, L., Gilbert, M., Robinson, T.P. & Van Boeckel, T.P. 2020. Global Trends in Antimicrobial Use in Food Animals from 2017 to 2030. *Antibiotics*, 9(12): 918. https://doi.org/10.3390/antibiotics9120918

Aquaculture contributes 8 percent of animal protein intake to the human diet, and per capita consumption is increasing faster than for meat and dairy. It is estimated that it will use 5.7 percent of total antimicrobials by 2030, the highest use intensity per kilogram of biomass. The Asia-Pacific region represents the largest share (93.8 percent) of world consumption, with China alone contributing 57.9 percent of the total in 2017.[60]

A recent study shows an increasing trend for antimicrobial resistance in common indicator pathogens (Escherichia coli, Campylobacter spp., Non-typhoidal Salmonella spp. and Staphylococcus aureus) found in livestock. There are hotspots in several parts of the world.[61]

New scientific evidence indicates that a simple reduction in antibiotic consumption will not be enough to contain antimicrobial resistance. The spread of resistant pathogens and genes seems to be enhanced by additional determinants, such as increasing local temperatures, population density and other anthropological and socioeconomic factors.[62, 63]

Each year, foodborne diseases cause several hundred million of cases. Every year, unsafe food and water are responsible for hundreds of millions cases of illness, hundreds of thousands of deaths and tens of millions disability-adjusted life years (DALYs).[64] It was estimated, in 2012, that foodborne diseases cost USD 77.7 billion in the United States of America, in terms of loss of productivity, medical expenses and illness-related mortality.[65] Among some of the most common causes of foodborne illness are diarrhoeal diseases resulting from the norovirus and to Non-typhoidal

Salmonella. Annually, norovirus, a human pathogen not shared with animals but contaminating the food supply, is involved in over 685 million cases of illness, of which 200 million among children aged under five, leading to an estimated 50 000 child deaths every year, and costing an estimate of USD 60 billion worldwide every year.[66] Non-typhoidal Salmonella, a zoonotic agent, contributed to 25 percent of all deaths and 4.0 million DALYs associated with foodborne diarrhoeal diseases.[67]

Foodborne diseases disproportionally affect LMICs where food safety practices and regulations are often lacking, and disease surveillance and health care systems are weak. The problem is exacerbated by the threat of bacteria becoming more and more resistant to antimicrobials, leaving a shrinking number of medicines, and sometimes none at all, available to treat infections.

The causes of emergence and the impacts of epidemics and pandemics of food and waterborne disease are complex and diverse. Climate change, novel and alternative foods and feeds, processing technologies, agriculture intensification and encroachment on wildlife habitat are some of the influencing factors.[47] These factors may drive outbreaks of foodborne disease not previously recognized, such as Bovine Spongiform Encephalopathy (BSE) from the use of meat and bone meal as a dietary supplement for cattle prepared from rendering of slaughterhouse offal.[68]

Trade and animal movement may also contribute to global dissemination of foodborne pathogens, as shown by a comprehensive analysis of the genomes of Shiga toxin-producing *Escherichia coli* serotype O157,[69] or the outbreak of salmonellosis on one continent after a change in insect pest management practice in mango protection in another part of the world.[70] See Table 1.54 for a summary of this section.

Table 1.54 Main causes and major impacts of antimicrobial resistance and foodborne diseases

ISSUES	MAIN CAUSES	MAJOR IMPACTS
Antimicrobial resistance	• Expansion of intensive livestock farming because of rapidly growing demand for animal products. • Poor sanitation and limited access to clean water. • Limited biosecurity and production practices, leading to an overuse of antimicrobials. • Misuse of antibiotics because of absent or inadequate oversight in agriculture with limited access to well-trained and supported expert advice. • Unregulated sales of antimicrobials and increased availability of counterfeit and low-quality antimicrobials, including products with harmful combinations and subtherapeutic concentrations.	• On food-producing animals, food items, the environment, and on humans who work closely with animals, live in the vicinity of farms or consume food contaminated with drug-resistant germs. • Antimicrobial resistance was related with almost 5 million deaths and was the direct cause of more than 1 million of these deaths in 2019. LMICs face the greatest burden from the growth in drug-resistant infections.
Foodborne diseases	• Unsafe food and water. • Lack of food safety practices and regulations. • Weak disease surveillance and health care systems. • Climate change. • Novel and alternative foods and feeds. • Processing technologies. • Agriculture intensification and encroachment on wildlife habitat. • Trade and animal movements. • Poorly regulated and low biosecurity value chains.	• Every year: – 600 million cases of illness; – 420 000 deaths; and – 33 million disability-adjusted life years (2015). • Foodborne diseases disproportionally affect LMICs.

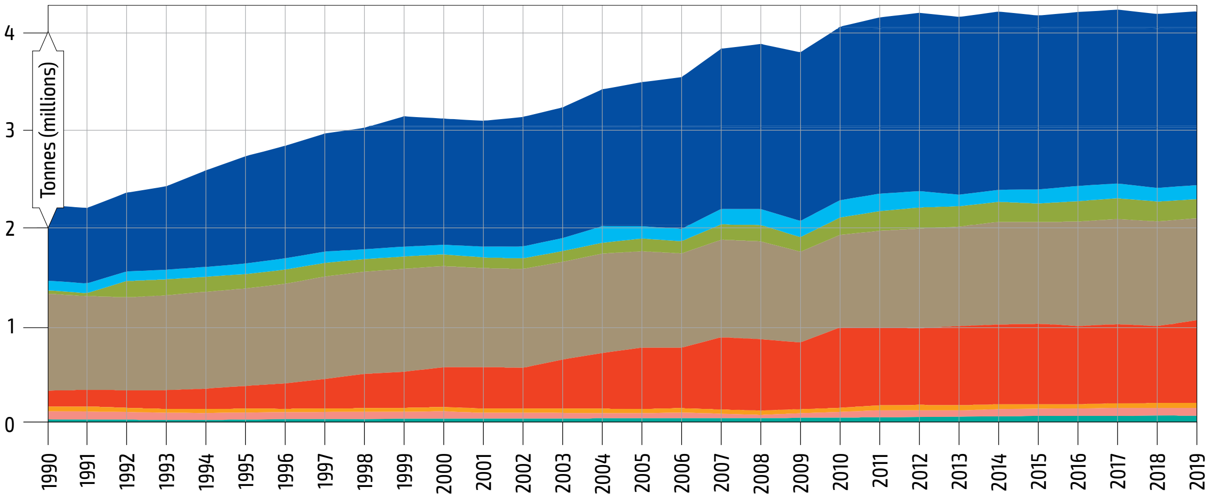
Source: Authors' elaboration.

Pesticides, producers, consumers and biodiversity

Pesticides impact on health of producers as well as consumers, and cause loss of biodiversity. Pesticide is one of the main tools used for pest management worldwide. The global application of pesticides has almost doubled between 1990 and 2010, and has now stabilized at slightly more than 4 million tonnes annually. The largest increase occurred in Asia, followed by the Americas, while other regions showed a relative stability of volumes used (Figure 1.70). Over this period, pesticides use per area of cropland increased from 1.80 kg/ha to 2.66 kg/ha. The increase was mainly owing to a greater application of herbicides.

Overuse of pesticides pollutes water and soil, damages living organisms and contributes to the spreading of pest resistance. It poses a risk for food safety and it harms the health of consumers and agricultural workers.[71] Approximately 200 000 people die every year from pesticide poisoning.[72] Moreover, it is estimated that there are annually 385 million cases of unintended, acute pesticide poisoning involving 44 percent of the global farmer population, causing 11 000 fatalities and countless chronic consequences, such as loss of quality of life, loss of well-being and loss of ability to work for those poisoned.[73] Pesticide contamination was ranked as one of the major food safety concerns of consumers in fresh food chains, together with bacterial pathogens, foodborne viruses and mycotoxins.[74]

Figure 1.70 Pesticide use by region (1990–2019)



Source: Authors' elaboration based on FAO. 2022. Pesticides Use. In: *FAOSTAT*. Rome. Cited 14 June 2022. www.fao.org/faostat/en/#data/RP

Pesticides can also persist for decades and pose a threat to the entire ecological system upon which food production depends. Excessive use and misuse of pesticides result in contamination of the environment, causing loss of biodiversity and destroying beneficial insect populations that act as pollinators or natural enemies of pests. Indiscriminate and ill-informed application of pesticides has been linked to degradation of biodiversity and ecosystems.[75] Some organochlorine pesticides were found to have a direct negative impact on production, as they suppress symbiotic nitrogen fixation, resulting in lower crop yields.[76] See Table 1.55 for a summary of this section.

Table 1.55 Main causes and major impacts of the use of pesticides

ISSUES	MAIN CAUSES	MAJOR IMPACTS
Use of pesticides	• Increase of frequency and magnitude of crop pest and disease outbreaks. • Use of herbicides to combat weeds.	• Hundreds of millions of cases of acute poisoning, annually. • Hundreds of thousands of deaths every year. • Loss of quality of life, loss of well-being and loss of ability to work for poisoned people. • Persistence for decades of pesticide in the environment. • Loss of biodiversity, including loss of pollinators and, in some cases, reduced symbiotic nitrogen fixation, with impacts on production.

Source: Authors' elaboration.

1.15.3 Future trends

To date, there are only a limited number of formalized prospective studies on epidemics and ecosystems degradation. However, there is a general consensus in the scientific community that, with climate change affecting ecosystems, risks of epidemics, pests and diseases will increase in the future. Below are some examples of findings and projections.

Zoonoses. A review of the current literature on the future trends of zoonoses in the context of climate change reveals the potential future geographical expansion and increased severity of vector-borne, waterborne, foodborne, rodent-borne, and airborne zoonoses.[77] A summary is provided in Box 1.47.

In addition, there could be an expansion of Rift Valley Fever to currently unaffected areas in Africa and to Europe, because of increased habitat suitability for the vectors of this disease.[78, 79] Monkey pox is expected to shift into the Central African region, as suitability increases in eastern Democratic Republic of the Congo,[80] and Crimean-Congo Haemorrhagic Fever will potentially expand to Europe and particularly to the Mediterranean region as a result of the predicted increase in habitat suitability for ticks.[81]

Box 1.47 Future trends in zoonoses

Mosquito-borne diseases:

- **West Nile virus:** higher probability and expansion (southeastern Europe and northwestern Türkiye.
- **Aedes-transmitted zoonoses** (chikungunya, West Nile virus [WNV], Zika, yellow fever) northward expansion in the United States of America and southern Canada; increasing in favourable niches in Western and Central Europe; decreased climatic suitability in Southern Europe.
  - **Dengue: global increase of population at risk (5 to 6 billion people by 2085 against 3 to 5 billion if climate change does not ensue).**
  - **Malaria:** net global increase in climate suitability and of population at risk. Increased risk in Europe (Portugal, southern part of the United Kingdom of Great Britain and Northern Ireland), in tropical highlands (East Africa) and in southern part of the Sahel. Decreased risk in semiarid parts of the Sahel, lower regions of East African highlands.
- **Leishmaniasis**: northward expansion in Central and Northern Europe (after 2060) and in the United States of America; increase in southern Brazil.
- **Lyme disease**: expansion in Northern America into Canada. Shift from southern to central parts of the United States of America. Disease season to start earlier in the United States of America.
- **Tick-borne encephalitis**: shift to higher latitudes (Northern and Central Europe). Reduced risk in Southern Europe.
- **Onchocerciasis**: decrease in Liberia and Ghana.
- **African trypanosomiasis**: decrease in Tanzanian Masai Steppe. Shift in suitable areas in southern and eastern Africa.
- **Scrub typhus**: increase in the Republic of Korea.
- **Waterborne diseases**: increase in Vancouver, Canada; New Zealand; parts of East Africa and China (Schistosomiasis).
- **Foodborne diseases**: increase Northern Europe (Campylobacteriosis, Salmonellosis).
- **Rodent-borne diseases**: plague increase in Central Asia and the United States of America. Increased risk of Hantavirus infection (Europe).
- **Airborne diseases**: Highly pathogenic avian influenza (Europe, northern Africa, southern and western Asia and, more generally, in northern regions).

Pest and diseases. One way to combat pests and diseases has been, and could increasingly be, the use of genetically engineered crops with herbicide tolerance or insect resistance. While, in the past, transgenic crops were designed to carry beneficial foreign genes, in the future – because of concerns regarding toxicity, environmental risks, such as possible adaptation and resistance in weeds and insects – the use of technologies such as cisgenesis, intragenesis and genome editing could become more frequent.[82]

Another direction taken has been the search for natural products that could be used as herbicides, fungicides, insecticides and virucides, on the grounds that natural remedies could be safer than synthetic chemicals. Plant extracts (e.g. amaranths, castor beans), bacteria, fungi and viruses are known to produce substances toxic for plants or that can be used as fungicide or insecticide (e.g. papaya, thyme and lemongrass).[83]

In food preservation, current methods of preservation have several disadvantages, such as a reduction in nutritional quality, loss of flavour, colour or aroma, and diseases such as cancer, in extreme cases. Here too, plant extracts and even microbes have been found to have antimicrobial or antioxidant preservation abilities. So have certain nanoparticles produced by "green synthesis" involving plant extracts, fractions and isolates.[83]

Antimicrobial resistance. During the ongoing pandemic, bacterial and fungal infections occurred in patients with COVID-19. Some cases showed resistance to antimicrobials, resulting in worsened outcomes and deaths. Evidence suggests that the proliferation of adulterated antimicrobials in some LMICs, frequent international travel, insufficient or inadequate health care financing, and their use and misuse by humans and in agricultural production, as well as climate change, are determinants of antimicrobial resistance. These interrelated determinants could amplify the potential of a future antimicrobial resistance pandemic,[84] all the more so as LMICs are likely see livestock production intensify significantly in the near future, as demand for animal products increase (see Sections 1.1 and 1.13), and if lessons learned elsewhere are not being transferred rapidly to develop risk mitigation capacity in these settings.[85] For example, simulations suggested that third-generation cephalosporins and carbapenems could be ineffective against a substantial proportion of infections by E. coli and K. pneumoniae in most parts of the world by 2030, if stewardship efforts are not enhanced and if no new antibiotics for resistant Enterobacteriaceae are developed.[86]

1.15.4 Summary remarks

The remarkable growth of agriculture, mostly through intensification, land-use change, deforestation and climate change are deeply transforming the planet's ecosystems and their internal processes, and contributing to an alarming degradation of natural resources (see Section 1.14). In turn, these changes trigger imbalances, some of which have a feedback on agriculture and human health. Consequences on agriculture involve the multiplication of crop and animal pests and diseases that threaten world food production and its sustainability. Effects on human health comprise emerging zoonotic infectious diseases, antimicrobial resistance, foodborne diseases and pesticide poisoning, with their cohort of victims and their imprint on the global economy.

These consequences are the result of a great number of factors, including the way agrifood systems and the technologies that underpin them have evolved. The time has come to reflect and reverse this trend.

The scale and intensification of agriculture, monoculture and reliance on a reduced number of species, and within species, of varieties, as well as the lack of prompt intervention in cases of outbreaks, are major causes of plant pests and diseases. Intensive livestock systems with high-density populations of low genetic diversity, exposure of livestock to wildlife, ineffective management and biosecurity measures, as well as insufficient vaccination, are responsible for the spreading of animal diseases.

Pest and pathogens are constantly and dynamically evolving. Occasionally, novel characteristics allow some of them to emerge and dominate because of enhanced fitness or, in the case of pathogens, because of changes in their host range or their ability to evade the immune system or treatments.

Agriculture encroachment into wild areas and forests, unsustainable management of natural resources, agricultural intensification and massive global rapid travel and trade are the main factors providing an explanation for the increasingly frequent emergence of zoonotic infectious diseases.

The inappropriate use of drugs in animal production is aggravating antimicrobial resistance, while unsafe food and water are responsible for hundreds of millions of foodborne disease cases. At the same time, massive application of pesticides impacts on human health and biodiversity.

Regarding animal diseases, the complexity of the processes involved point to the need for a One Health approach that addresses the multiple causes stemming from different sectors that lead to disease (see Box 1.46 and Box 1.48).

Box 1.48 One Health

One Health is an integrated, unifying approach that aims to sustainably balance and optimize the health of people, animals and ecosystems. It recognizes that the health of humans, domestic and wild animals, plants and the wider environment (including ecosystems) are closely linked and interdependent. The approach mobilizes multiple sectors, disciplines and communities at varying levels of society to work together to foster well-being and tackle threats to health and ecosystems, while addressing the collective need for clean water, energy and air as well as safe and nutritious food, taking action on climate change and contributing to sustainable development.[87]

Collaboration across sectors and disciplines will contribute to protecting health and addressing health challenges, such as the emergence of infectious diseases and antimicrobial resistance, and promoting the health and integrity of our ecosystems. Moreover, One Health, linking humans, animals and the environment, can help to address the full spectrum of disease control – from disease prevention to detection, preparedness, response and management – and to improve and promote health and sustainability.

Ensuring a One Health approach is essential for progress towards anticipating, preventing, detecting and controlling diseases that spread between animals and humans, tackling antimicrobial resistance, ensuring food safety, preventing environment-related human and animal health threats, and combatting many other challenges.

The approach can be applied at the community, subnational, national, regional and global levels, and relies on shared and effective governance, communication, collaboration and coordination. With the One Health approach in place, it will be easier for people to better understand the co-benefits, risks, trade-offs and opportunities to advance equitable and holistic solutions.

Existing regulations and food safety management practices are often unable to effectively prevent and respond to the pest and disease shocks and risks to human health. Many LMICs lack the infrastructure, resources and conducive environment to fully implement Codex Alimentarius principles.

For example, in sub-Saharan Africa (SSA), as much as 80 percent of all food types are traded in informal markets.[88] Poorly regulated and organized markets usually gather the conditions allowing the spillover and quick spread of epidemics/pandemics, whether of domestic or wild animal origin. Informal markets frequently lack facilities such as clean water, and traders are not encouraged to perform basic sanitary handling and processing. Although these markets are the primary source of food in rural settings, they are becoming increasingly common in urban centres where live animals, including wildlife and animal-derived food products are mixed before being sold.[89, 90, 91] Spillover events may occur as a result of poor biosecurity and hygiene practices along value chains.

In the case of crop pests and diseases, improved international collaboration, information exchange and prevention strategies are needed, including sustainable pest management to reduce pesticide use. There is a need to develop and adopt technologies that address the root causes of proliferation of pests and diseases, and preserve the ecosystems services that are indispensable for a sustainable agriculture.

Unless the determinants that are deeply transforming the planet's ecosystems and their internal processes are tackled, it is most probable that the consequences of this transformation on plant, animal, human and environmental health will worsen.

Addressing these causes will imply modifying significantly the way agrifood systems operate (e.g. production technologies, spatial expansion of agriculture, speed of movements of goods and people and consumption) as well as implement preventive and mitigation strategies, including ecological interventions, using a One Health approach, and integrating One Health Intelligence across sectors, and including early warning and risk assessments.

NOTES – SECTION 1.15

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1.16 Climate change (Driver 17)

Climate change is already affecting food systems, and it is expected to accelerate hunger and poverty. In Latin America, for instance, food systems will be impacted, both currently and in the medium and long term, by climate change. It is estimated that production from rainfed agriculture in selected areas (e.g. in the Southern Cone of Latin America) will be reduced because of seasonal water stress. In addition, fishery and aquaculture production will be affected. The Small Island Developing States (SIDS) and coastal areas will face sea-level rise, hurricane frequency and intensity, saline intrusion, ocean acidification and warming that is threatening shell-forming organisms (clams, oysters and corals), increasing incidence of coral bleaching.

At the same time, an estimated 23 percent of total anthropogenic greenhouse gas (GHG) emissions (2007–2016) derive from agriculture, forestry and other land use (AFOLU).[1] Not only do agrifood systems contribute a large share of total global CO_2-equivalent emissions, including through deforestation and other land-use changes, but also almost all prevailing economy-wide development paradigms are based on fossil fuels and huge GHG emissions.[br] Overall, there are no risk-informed measures to tackle a warming planet beyond achieving a 1.5 °C limit, and there is limited understanding of the implications of deep decarbonization. Vision and knowledge about these issues are particularly important for the post-COVID-19 recovery process that is assumed to "build back better".

Climate change is one of the greatest challenges of this century. Public awareness of this problem is relatively recent, and it is only during the last four decades that it has progressively become a shared concern worldwide.[bs]

The interaction between food systems and the climate is a major driver of change. Food systems play a key role in the dynamic of anthropogenic GHG emissions causing climate change, as they may emit or absorb variable volumes of GHG, depending on the way they are managed. On the other hand, climate change impacts food systems, forcing adaptation in the manner food is produced, processed and consumed, and affecting both producers and consumers.

As recognized by the Paris Agreement,[2] the need to address this threat is the fundamental priority in safeguarding food security and ending hunger, as well as the particular vulnerabilities of food production systems against the adverse consequences of climate change.

Therefore, designing sustainable and resilient agrifood systems is central for achieving simultaneously the Sustainable Development Goals (SDGs) and the Paris Agreement.

The above considerations raise some important questions:

- Are there effects of climate change for agrifood systems that go beyond reduction of yields? How can they be measured?
- What plausible alternative scenarios for climate change mitigation can be designed and what are the implications for agrifood systems?
- How can agrifood systems contribute to deep decarbonization?
- Will trade-offs emerge between decarbonization, food security and nutrition?

This section addresses some of these issues. Others are addressed in the other sections of the report.

1.16.1 Recent trends

Agrifood systems produced one-third of all anthropogenic GHG emissions in 2015. Agrifood systems are a major source of GHG emissions, including carbon dioxide (CO_2), methane (CH_4) (with a global warming power of 28 to 36 times higher than CO_2 over a period of 100 years) and nitrous oxide (N_2O) (global warming power nearly 300 times that of CO_2). They also emit some fluorinated gases (F-gas) with a global warming power several thousands. or tens of thousands, times that of carbon dioxide.[3]

[br] This also applies to some activities that are increasingly portrayed as complementary to agricultural activities in rural areas, such as tourism, the GHG footprint of which has largely to be investigated.

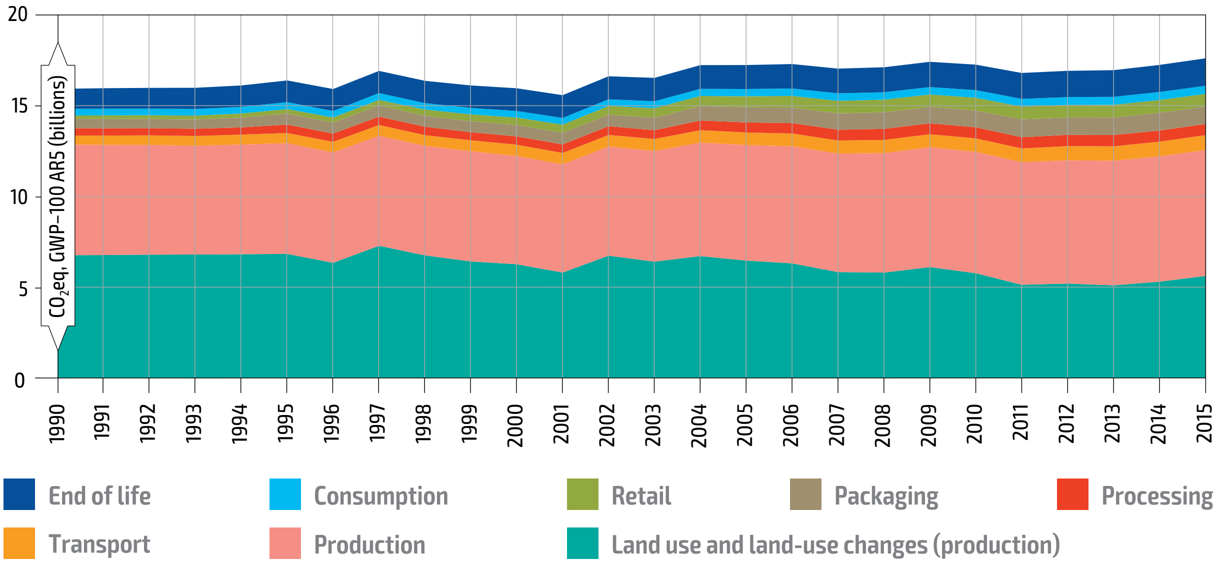
[bs] According to Ngram Viewer, the frequency of the expression "climate change" in books published in English language in any country has been multiplied by more than 60 since 1980.

Emissions from agrifood systems

Growing emissions from agriculture and post-harvest activities are only partly compensated by reduced land-use-related emissions. Anthropogenic GHG emissions from agrifood systems originate from land use and land-use changes (LULUC) activities, primary production (agriculture, forestry and fisheries), transport, processing, packaging, consuming and end-of-life disposal. Figure 1.71 shows how GHG emissions from food systems evolved between 1990 and 2015.

Over the period considered, total emissions from food systems increased from 16.3 billion tonnes of CO_2 equivalent per year in 1990 to 18.2 billion tonnes in 2015 (+11 percent)[4] (Figure 1.71). This relatively slow growth meant that while food systems represented 44 percent of total anthropogenic GHG emissions in 1990, they only weighed 34 percent in 2015, emissions resulting from non-food activities growing faster than those generated by food systems.[bt] It is noteworthy that at the same time, global food production, taking cereals as proxy, increased by more than 40 percent, indicating an overall decrease in the emission intensity of food.[4]

Figure 1.71 **Global greenhouse gas emissions from agrifood systems by source (1990–2015)**



Source: Authors' elaboration based on Crippa, M., Guizzardi, D., Solazzo, E., Ferrario-Monforti, F., Tubiello, F.N. & Leip, A. 2021. *EDGAR-FOOD emission data. figshare. Dataset.* Cited 22 May 2022. https://doi.org/10.6084/m9.figshare.13476666.v1

The analysis of the origin of these emissions sheds some light on the evolution of food systems between 1990 and 2015:

- Emissions resulting from land use and land-use changes activities (around 31 percent of the total from agrifood systems in 2015) dropped by 17 percent over the period. These emissions are mainly caused by deforestation linked to agricultural expansion, a consequence of a growing population and increased exports to high-income countries (HICs),[5,6] as well as by soil degradation caused by loss of organic matter (see Section 1.14). These GHG emissions were overwhelmingly carbon dioxide emissions.
- Annual emissions resulting from agricultural production (39 percent of the total in 2015) grew by almost 0.9 billion tonnes of CO_2 equivalent over the period (+13 percent). This can largely be explained by the development of livestock production, a major source of methane, and, to a more limited extent, by more mechanization requiring fuel and electricity. This latter cause has been particularly strong in China, East Asia and the Pacific (EAP), Latin America and the Caribbean (LAC) and sub-Saharan Africa (SSA), where energy use increased by up to 50 percent. In HICs, on the contrary, the development of more efficient agricultural technologies explains diminished emissions (see Section 1.4 on precision agriculture). These emissions are made

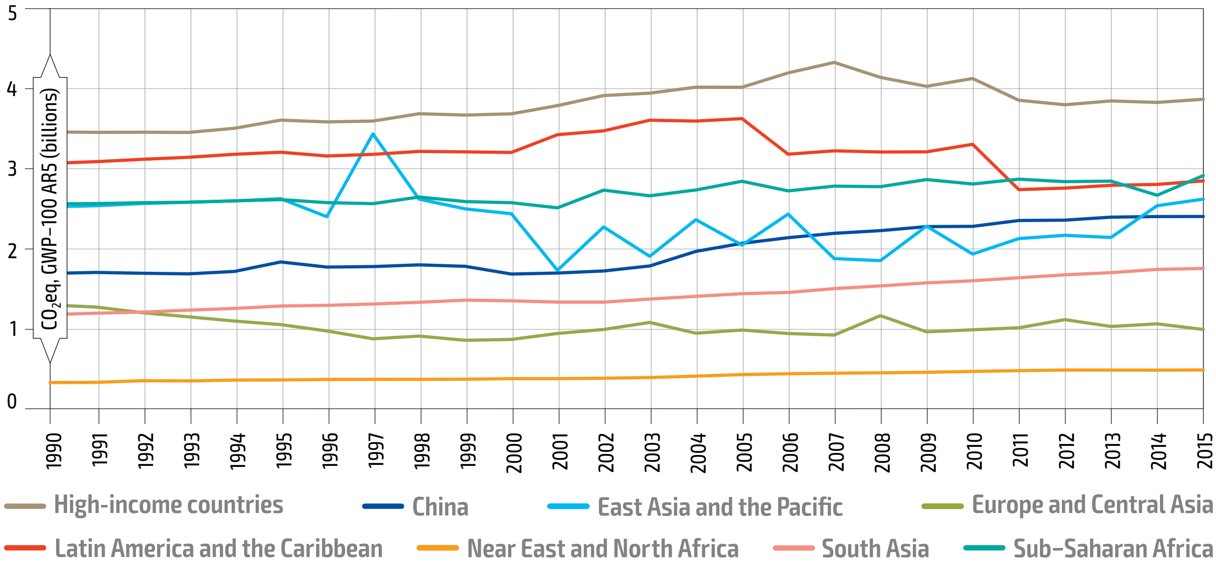
[bt] The estimate provided by Crippa *et al.* (2021)[4] is actually within in a range of 25 percent to 42 percent.

predominantly of CH_4 (63 percent), N_2O (23 percent) and CO_2 (14 percent). Emissions occurring in the post-farm part of agrifood systems (transport, processing, packaging, retail, consumption and end-of-life disposal) add up to 30 percent of the total in 2015. They have increased by around 2.2 billion tonnes of CO_2 equivalent since 1990 (+66 percent growth) mostly because of the development of commercialization, processing and storage of food, and the energy these activities require. The fastest increase of emissions took place in retail (they were four times greater), and in packaging (+88 percent). The amount fluorinated gases (F-gases) emitted has exploded over the period mainly because of the development of refrigeration. Cold chains account for 5 percent of global GHG emissions of agrifood systems and they are likely to grow as refrigeration spreads in low- and middle-income countries (LMICs). Packaging is also an important source of emissions, representing 5.4 percent of total food systems emissions in 2015, more than transport (4.8 percent) or retail (4 percent).[7] Urbanization (see Section 1.1) certainly played a major role in this evolution by accelerating the development of food processing activities. Emissions at post-farm stages are made of carbon dioxide (51 percent), methane (39 percent) and F-gas (7 percent).

This depicts food systems that use more and more energy and in which almost one-third of GHG emissions come from energy-related activities.[7]

A more detailed analysis shows that there are differences in the changes observed in various regions (see Figures 1.72 and 1.73).

Figure 1.72 Share of greenhouse gas emissions from agrifood systems by region (1990–2015)



Note: t CO_2eq GWP-100 (AR5) refers to tonnes (t) of Carbon Dioxide (CO_2) equivalent gases with Global Warming Potential calculated at 100 years (GWP-100) according to the values set in the fifth assessment report of the Intergovernmental Panel on Climate Change (AR5).

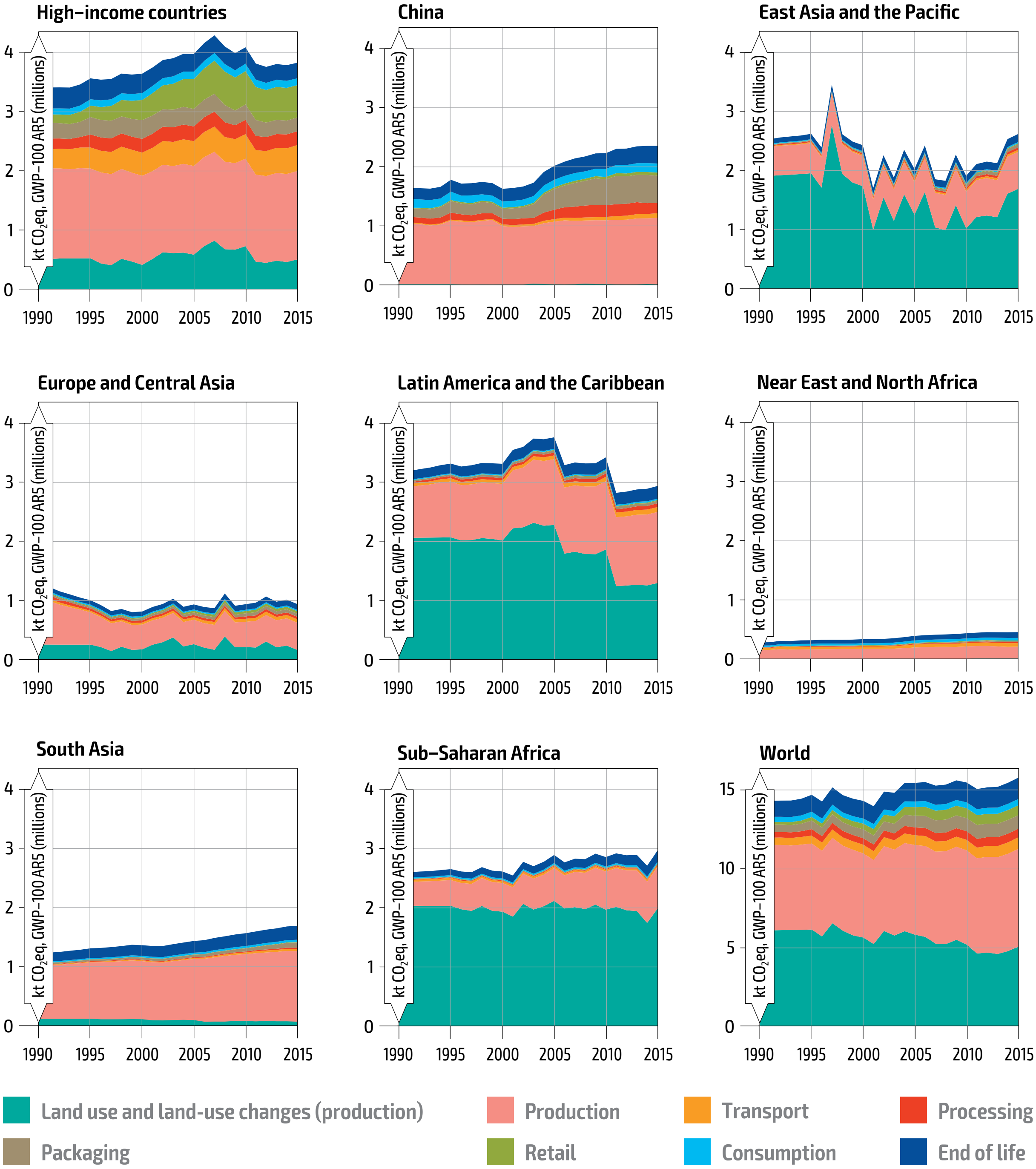
Source: Authors' elaboration based on Crippa, M., Guizzardi, D., Solazzo, E., Ferrario-Monforti, F., Tubiello, F.N. & Leip, A. 2021. *EDGAR-FOOD emission data. figshare. Dataset.* Cited 22 May 2022. https://doi.org/10.6084/m9.figshare.13476666.v1

HICs rank first, with almost 4 giga tonnes of CO_2 equivalent GHG emissions (around 22 percent of the total of agrifood systems). They seem to have achieved a maximum in 2007. Post-farm is the major source of GHGs, while land use and land-use change are minor.

LAC ranks second in terms of GHG emissions for most years of the period considered, with more than 3 gigatonnes of CO_2 equivalent GHG emissions, but since 2005 it follows a downward trend that bring its emissions below the 3 gigatonnes by 2015 (around 16 percent of the total). In this region, land use and land-use change are the main sources.

SSA follows an upward trend that by 2015 brings its emissions close to 3 gigatonnes (17 percent of the total). There, the main source of emissions is by far land use and land-use change, followed by agricultural production.

Figure 1.73 Greenhouse gas emissions of agrifood systems by source and region (1990–2015)



Note: t CO_2eq GWP-100 (AR5) refers to Tonnes (t) of Carbon Dioxide (CO_2) equivalent gases with Global Warming Potential calculated at 100 years (GWP-100) according to the values set in the fifth assessment report of the Intergovernmental Panel on Climate Change (AR5).

Source: Authors' elaboration based on Crippa, M., Guizzardi, D., Solazzo, E., Ferrario-Monforti, F., Tubiello, F.N. & Leip, A. 2021. *EDGAR-FOOD emission data. figshare. Dataset.* Cited 22 May 2022. https://doi.org/10.6084/m9.figshare.13476666.v1

China has experienced a steep increase in GHG emissions since the beginning of the century, from around 1.7 gigatonnes in the 1990s to around 2.4 in 2015 (14 percent of the total) mainly because of post-farm activities, and particularly from packaging.

EAP follows a more erratic pattern mostly between 1.8 and 2.8 gigatonnes, the value of 2015, thus reaching around 15 percent of the total. Variations in the emissions of this region are mainly owing to change in land use and land-use change, South Asia (SAS) follows a growing trend since the beginning of the period reaching around 1.8 gigatonnes in 2015 (9 percent of the total). In this region, production and end-of-life of food products are the major, and increasing, sources of emissions.

Europe and Central Asia (ECA) oscillates in the whole period around 1.0 gigatonne, contributing to around 5 percent of total emissions of agrifood systems in 2015, while Near East and North Africa (NNA) contributes only minimally to total emissions with less than 0.4 gigatonnes in 2015 (2 percent), albeit following an upward trend.

Emissions from agriculture

Within agriculture, the major sources of GHG emissions are livestock, and to a lesser extent fires and cultivation of soils rich in organic matter such as peatland.

In 2019, enteric fermentation and forest conversion contributed to around one-third of the total emissions each, followed by fires and cultivation on drained organic soils (Table 1.56). Livestock altogether (including consequences of manure management) was the source of exactly half of GHG emitted by agriculture.

Table 1.56 Global greenhouse gas emissions from agriculture by source (2019)

SOURCE	MEGATONNES CO_2EQ (AR5)	PERCENTAGE OF TOTAL
Enteric fermentation	2 823	34.2
Manure management	390	4.7
Rice cultivation	674	8.2
Synthetic fertilizers	601	7.3
Manure applied to soils	161	2.0
Manure left on pasture	764	9.3
Crop residues	189	2.3
Burning – crop residues	37	0.4
On-farm energy use	533	6.5
Drained organic soils	833	10.1
Net forest conversion	2 945	35.7
Forestland	-2 637	-31.9
Savannah fires	209	2.5
Fires in humid tropical forests	112	1.4
Forest fires	178	2.2
Fires in organic soils	445	5.4
Total	8 258	100

Note: CO_2eq (AR5) refers to Carbon Dioxide equivalent (CO_2eq) according to the values set in the fifth assessment report (AR5) of the Intergovernmental Panel on Climate Change.

Source: Authors' elaboration based on FAO. 2022. Emissions Totals. In: *FAOSTAT*. Rome. Cited 18 June 2022. www.fao.org/faostat/en/#data/GT

Over the last three decades, the sources of GHG in agriculture that have most increased are fires on organic soils, followed by crop residues and the use of synthetic fertilizer, which grew respectively by 57 percent, 44 percent and 42 percent between 1990 and 2019. Meanwhile, emissions from on-farm energy use, forest conversion and savannah fires were those that decreased most.

Reducing GHG emissions from agrifood systems

How can GHG emissions from agrifood systems be reduced in the future? There appear to be three avenues for decarbonizing food systems:

- First, continue decreasing emissions from land use and land-use changes activities by combatting deforestation, and develop and take up agricultural technologies that preserve carbon stored in soils.

- Second, diminish emissions from livestock-related activities. For this, there are three main possibilities: (i) improve livestock management, and particularly the way livestock is fed, in order to cut enteric fermentation; (ii) improve management of animal dejection; and (iii) reduce livestock production and adopt less resource-intensive and healthier diets with less meat and meat products. This third way requires consumers to become actors in the transition of food systems (see Section 1.13) and supporting producers who will have to repurpose their activities.
- Third, reduce the carbon emission intensity of post-harvest operations and encourage consumption of local food to reduce needs for transport, processing and storage.

1.16.2 Climate change and agrifood systems

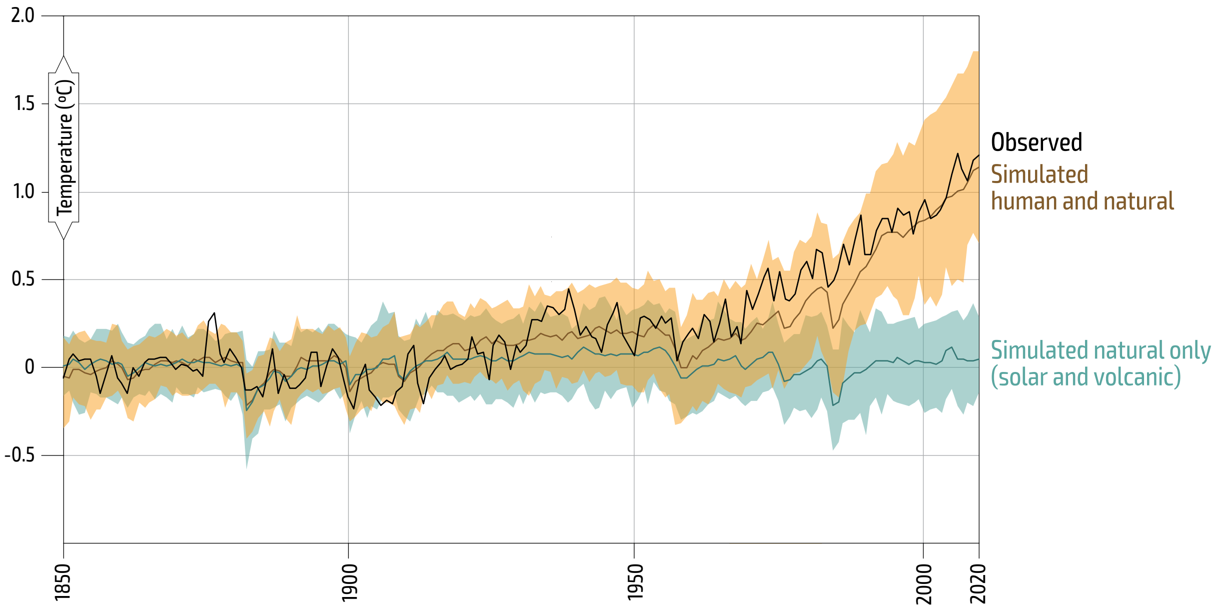
Climate change is accelerating, and its impacts are being felt on food systems, affecting quantity, quality and accessibility of food. Climate change is affecting human, ecological and agrifood systems, posing substantial challenges to the achievement of SDG targets. It has consequences on food security and nutrition worldwide, and weighs on food value chains. Climate change generates slow, onset events as well as extreme weather events, both resulting potentially in significant loss and damage for food and agriculture with dire implications for the livelihoods of a great number of people.

How climate change affects agrifood systems

Higher temperatures and extreme weather events are two main elements through which climate change affects agrifood systems. According to the Intergovernmental Panel on Climate Change (IPCC), global warming is occurring faster than expected. If the current rhythm of global warming and GHG emissions continue, the limits of 1.5 °C or even 2 °C temperature rise will be exceeded.[8]

Figure 1.74 depicts how the rate of increase of global surface temperatures accelerated abruptly since the 1960s. This is the consequence of atmospheric CO_2 concentrations that are greater now than at any time in at least two million years, and levels of CH_4 and N_2O higher than at any time in at least 800 000 years.[9]

Figure 1.74 Change in annual average global surface temperature as observed and simulated using human and natural and only natural factors (1850–2020)



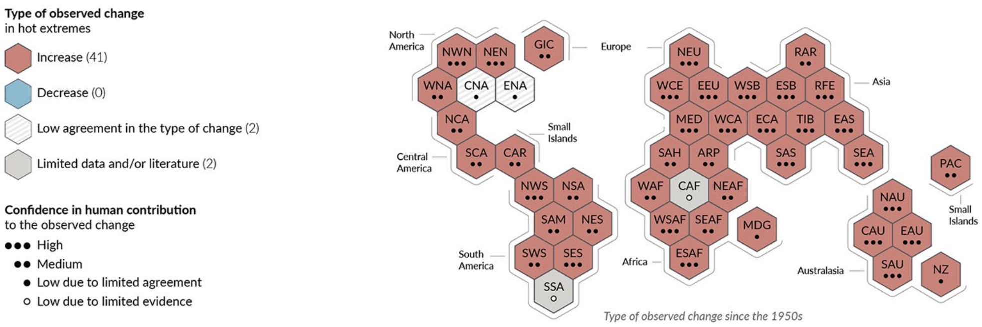
Notes: Changes in global surface temperature over the past 170 years (black line) relative to 1850–1900 and annually averaged, compared to Coupled Model Intercomparison Project Phase 6 (CMIP6) climate model simulations of the temperature response to both human and natural drivers (brown) and to only natural drivers (solar and volcanic activity, green). Solid coloured lines show the multi-model average, and coloured shades show the very likely range of simulations.

Source: IPCC. 2021. Summary for Policymakers. *In* IPCC. *Climate Change 2021: The Physical Science Basis.* Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK and New York, USA, Cambridge University Press. www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM_final.pdf

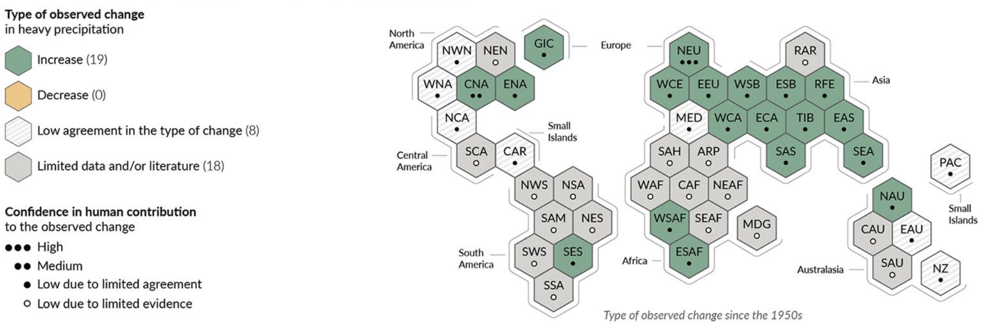
Simultaneously, hot temperature extremes and heatwaves have become more common and more intense, and the frequency and intensity of heavy precipitation events have also increased over most regions. Frequency of concurrent heatwaves and droughts on a global scale, fire weather in some regions and compound flooding in some locations have also been worsening (Figure 1.75). At the same time, the sea level continues to rise and cause flooding, and more frequent marine heatwaves, ocean acidification, and reduced oxygen presence affect ocean ecosystems.[9]

Figure 1.75 Changes in hot extremes, heavy precipitations and droughts observed since the 1950s

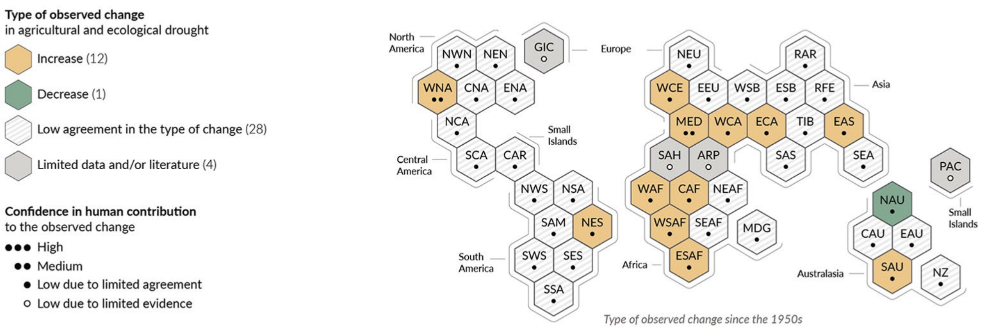
a) Synthesis of assessment of observed change in hot extremes and confidence in human contribution to the observed changes in the world's regions



b) Synthesis of assessment of observed change in heavy precipitation and confidence in human contribution to the observed changes in the world's regions



c) Synthesis of assessment of observed change in agricultural and ecological drought and confidence in human contribution to the observed changes in the world's regions



Notes: Each hexagon corresponds to one of the reference regions used in the sixth assessment report (AR6) of the Intergovernmental Panel on Climate Change (IPCC), Working Group I (WGI). IPCC AR6 WGI reference regions: Northern America: NWN (North-Western Northern America, NEN (North-Eastern Northern America), WNA (Western Northern America), CNA (Central Northern America), ENA (Eastern Northern America), Central America: NCA (Northern Central America), SCA (Southern Central America), CAR (Caribbean), South America: NWS (North-Western South America), NSA (Northern South America), NES (North-Eastern South America), SAM (South American Monsoon), SWS (South-Western South America), SES (South-Eastern South America), SSA (Southern South America), Europe: GIC (Greenland/Iceland), NEU (Northern Europe), WCE (Western and Central Europe), EEU (Eastern Europe), MED (Mediterranean), Africa: MED (Mediterranean), SAH (Sahara), WAF (Western Africa), CAF (Central Africa), NEAF (North Eastern Africa), SEAF (South Eastern Africa), WSAF (West Southern Africa), ESAF (East Southern Africa), MDG (Madagascar), Asia: RAR (Russian Arctic), WSB (West Siberia), ESB (East Siberia), RFE (Russian Far East), WCA (West Central Asia), ECA (East Central Asia), TIB (Tibetan Plateau), EAS (East Asia), ARP (Arabian Peninsula), SAS (South Asia), SEA (South-eastern Asia), Australasia: NAU (Northern Australia), CAU (Central Australia), EAU (Eastern Australia), SAU (Southern Australia), NZ (New Zealand), Small Islands: CAR (Caribbean), PAC (Pacific Small Islands).

Source: IPCC. 2021. Summary for Policymakers. *In* IPCC. *Climate Change 2021: The Physical Science Basis.* Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK and New York, USA, Cambridge University Press. www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM_final.pdf

Changing climate, agricultural productivity, hunger and malnutrition

Changing climate patterns impact food systems, threatening to erode and even reverse the gains made in the combat against hunger and malnutrition. Changes in temperature, precipitations, carbon dioxide and ozone concentration in the air, intensity of solar radiation, frequency and strength of winds as well as seasonal shifts and loss of biodiversity (e.g. pollinators and soil microbial communities) all weigh on the performance of agricultural systems, and create circumstances that modify processes and outcomes at various stages of food chains.[10,11]

In agricultural production, these changes can cause conditions in which plants and animals used in farming do not thrive so well anymore, by disrupting existing biological processes and synergies. As a result, climate change affects the amount of food produced by impacting directly yields, or indirectly, by modifying water availability and quality, presence of pests and diseases, and availability of pollination services. Exposure to extreme temperatures also affects the health of agricultural labour force, increases food required by people to cope with heat and it impairs productive activities. By raising the concentration of CO_2 in the atmosphere, it also affects biomass and the nutritional quality of food. At the stage of transport and storage of food supply chains, modified climatic conditions can exacerbate food safety risks.[10]

A major issue is that agricultural and industrial systems often cope with climate impacts through maladaptive practices, contributing to more pollution, greater land and water resource stress, and more rapid biodiversity degradation, when attempting to maintain safe levels of productivity, for example, by increasing the use of chemical pesticides, increasing waste, and aggravating social and economic inequalities.[12] This inappropriate reaction potentially creates a vicious circle.

Lower yields, changing crop suitability, higher presence of pests and diseases, and reduced nutritional quality of crop production are some of the consequences of climate change. Agricultural production is highly dependent on climate and weather conditions, and therefore highly vulnerable to climate change.

Yields. There is good evidence that crop yields have been adversely affected by temperature and rainfall variability and extreme weather events such as droughts, floods and hurricanes, during the second half of the twentieth century, particularly at lower latitudes.[13,14] The significance of such impacts depends on specific crops, geographical regions and environmental characteristics, but they are a source of increased instability in food availability and prove to be more commonly negative than positive.[15] Semi-arid zones, which make up 15.2 percent of global land surface, are marked by intense solar radiation and very high inter-annual rainfall variability. The observed climate trends for most of these regions indicate greater warming rates over land, and reduced and more erratic rainfall leading to increased exposure to drought.[16] In contrast, temperate areas benefit from higher temperatures.

Crop suitability. Research suggests that large shifts in land-use patterns and crop choice are likely to be necessary to sustain production and its growth in the future, and keep pace with current trajectories of demand.[17] However, it is expected that total land area climatically suitable for high attainable yield, including territories not dedicated for crops, will be similar in 2050 to today.[10]

Pests and diseases. Climate change affects the distribution, population size and impacts of pests and diseases on food production.[18] It can modify the level of susceptibility of plants to them and influence the biology of pests and diseases, or their vectors (e.g. higher metabolic rate, greater number of generations per season and changes in selection pressure driving evolution), create mismatches in timing between pests or vectors and their natural enemies, and impact the survival or persistence of pests or disease pathogens.[10,19,20] It can also amplify attacks by diseases and pests (e.g. locust) – as when herbivorous insects increase their metabolism, they consume larger amounts of plant tissues – and trigger their migration to new areas where there were as yet unknown (see Section 1.15). In some cases, pests or diseases may force relocation of crop species and varieties in others, conditions may become such that some diseases may disappear, for example, because of a reduced capacity of certain fungi to survive.[10]

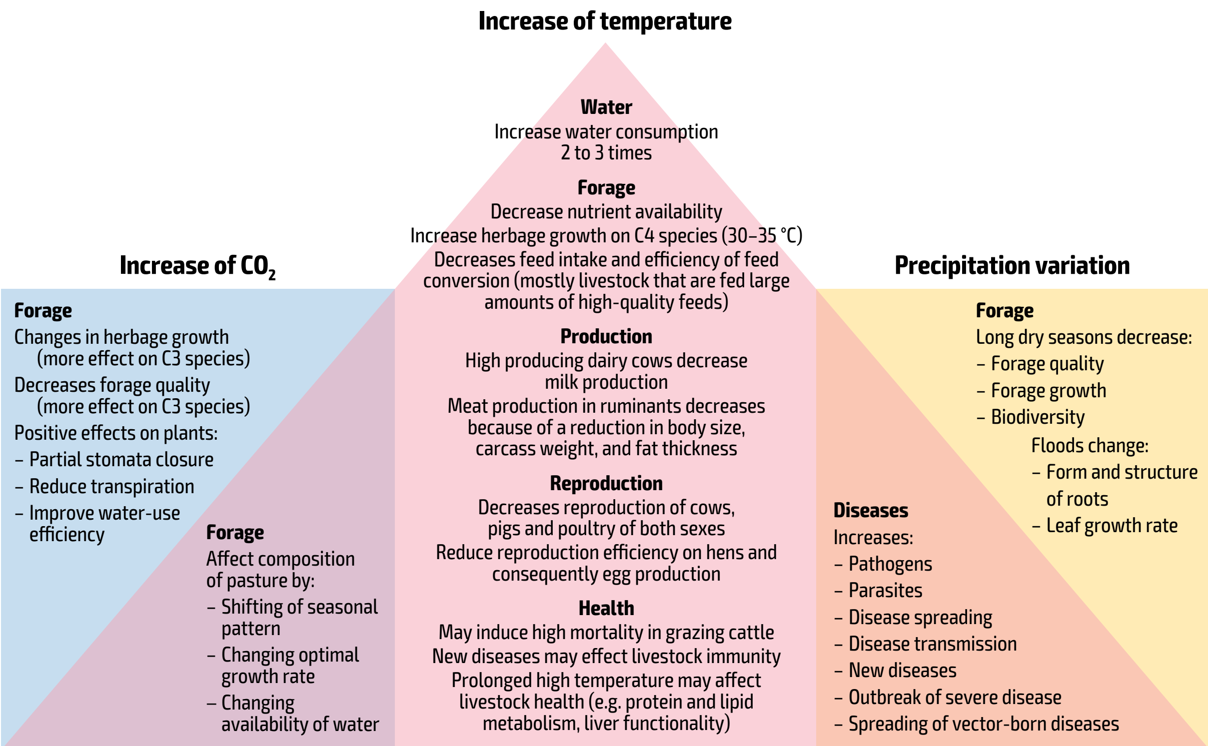
Pollinators. Pollination plays a key role in agricultural production. Pollinators are responsible for around 35 percent of the world's crop production, increasing outputs of about 75 percent of the leading food crops worldwide.[21] It is estimated that approximately 1 500 crops require pollination by insects, birds or bats.[22] The impact of climate change on pollinators is to a large degree context-dependent and it rests on complex processes, but there is already some evidence that it is occurring. Factors involved include, for example, a possible loss of simultaneity of flowering of crops and presence of pollinators, emergence of pests, or proliferation of parasites affecting pollinators (e.g. *Nosema* in the case of bees).[23]

Food quality. Climate change influences food quality because higher temperature, water stress and greater concentration of CO_2 modify biological processes. This can mean that nutrients assimilated by plants vary, with impact on the content of their output. For instance, higher temperatures and greater CO_2 presence in the air can reduce protein and nutrient concentration in food. In the case of fruit, there is evidence that warmer temperatures modify composition and taste, while higher CO_2 levels lower protein and minerals found in wheat and rice, thus potentially increasing prevalence of mineral deficiencies.[10]

Increased livestock health risks, lack of sufficient water and lower quality of biomass produced by rangeland and pastures are among the problems generated by climate change. Climate change impacts animal production because of hotter temperatures, variations of precipitations and greater CO_2 concentration in the air (Figure 1.76). Higher temperature affects animal production and reproduction, as well as health, particularly through heat stress and additional presence of parasites and pathogens. For instance, global warming is likely to increase sheep tick activity and the risk of tick-borne diseases, in the autumn and winter months in temperate areas;[15] and by complex interactions with hosts, vectors and environment, it has facilitated the spread of the bluetongue virus into Europe, of Rift Valley fever in Africa, and of very virulent influenza viruses in Asia. There is growing evidence to suggest that outbreaks or epidemic diseases may become more frequent as climate continues to evolve (see Section 1.15).[24]

Climate change can also reduce water availability and impact negatively the quantity and quality of biomass produced by rangeland and pastures, affecting several hundreds of millions of pastoralists and smallholders whose systems combine livestock and crops. Industrial livestock systems are impacted indirectly through the cost of animal feed and damage on facilities in cases of extreme meteorological events. Moreover, modified climatic conditions affect productivity, quality of output and animal immunity.[10]

Figure 1.76 Impact of climate change on livestock



Source: Adapted from Rojas-Downing, M.M., Nejadhashemi, A.P., Harrigan, T. & Woznicki, S.A. 2017. Climate change and livestock: Impacts, adaptation, and mitigation. *Climate Risk Management*, 16: 145–163. https://doi.org/10.1016/j.crm.2017.02.001

Aquatic ecosystems are among the most vulnerable to climate change and there is growing evidence that climatic drivers are impacting their capacity to provide goods and services.[25,26] Increasing sea surface temperature, expanding low oxygen zones, ocean acidification, enhanced intensity and frequency of extreme weather events, directly affect fisheries and aquaculture resources, contributing to an estimated loss of nearly 50 percent of coastal wetlands over the past 100 years. While some large predators might benefit from the expected changes, trophic efficiency of food webs and carbon transfer are expected to be negatively impacted.

As sea level rises, saltwater intrusion into a freshwater system may eliminate some aquatic species, thus removing predators or preys that are critical in the existing food chain. Some fish species are already migrating towards the poles, and it is anticipated that changes in environmental conditions, habitat types and phytoplankton primary production will trigger a large-scale redistribution of global marine fish catch potential, with an average 30 to 70 percent increase in high-latitude regions and a drop of up to 40 percent in the tropics.[27]

Land-based aquaculture is also affected by extreme meteorological events such as floods, by greater risk of diseases, proliferation of toxic algae and parasites, and by decreased productivity owing to suboptimal farming conditions.[26]

Climate change alters forests and ecosystems dynamics, creating a major challenge for adapting forests to new conditions. Climate change impacts forests with implications for water ecosystems so crucially important for maintaining the integrity and productivity of agricultural systems, exacerbating land and water degradation, water scarcity and driving biodiversity and ecosystem service losses.[12]

As temperature increase impacts terrestrial biogeochemical processes, such as soil respiration, litter decomposition, nitrogen mineralization and nitrification, denitrification, methane emission, fine root-soil interactions, plant productivity and nutrient uptake, it alters forests and ecosystem dynamics. Because of the permanent nature of forests, rapid changes in climatic conditions (frost, heat or precipitations) can become incompatible with tree species existing in a particular location or favour their expansion into other areas.[28] Moisture stress or excess, and drought also affect forest health by creating conditions for the proliferation or new introduction of insect pests and pathogens (e.g. defoliating and wood-boring insects and pathogens) and risks of forest fires. However, increased presence of CO_2 in the air stimulates growth rates of trees, provided other circumstances remain favourable. In general, long-lived trees are under greater threat from transformation of ecosystems induced by climate change because they cannot adapt to the altered local environment quickly enough. Extreme meteorological events, such as hurricanes and storms also constitute a threat for forests.[29] These impacts have to be considered when creating new tree plantations to ensure that the species selected fit future climatic conditions.

Climate change increases food safety risks during transportation and storage. Modification of population dynamics of contaminating organisms resulting from higher temperature and humidity creates food safety risks (e.g. mycotoxin-producing fungi, bacteria such as salmonella and dinoflagellates in the case of aquatic food chains) at the production, transport or storage stage.[18] For instance, there is good evidence that aflatoxin contamination of maize in southern Europe and deoxynivalenol contamination of wheat in north-western Europe will increase significantly.[10]

Climate change threatens gains made in combatting global food insecurity. Climate change impacts several dimensions of food security and threatens to erode and even reverse the gains made in the combat against hunger and malnutrition. It has been one of the main drivers behind the recent increase in global hunger. For example, in almost 36 percent of the countries that experienced a rise in undernourishment between 2005 and 2016, there had been severe drought.[30]

Food availability. Climate-related hazards increasingly affect crop growth and yields, water resource availability, livestock productivity, as well as every other step of the food value chain, such as storage, processing, transportation and distribution, impacting food availability.[31]

Food access. Weather events undermine food access by obstructing consumers' physical access to food, particularly in countries lacking proper infrastructures.[10] For agricultural producers, such events make it difficult to sell their output at a remunerative price, thus further reducing their income and ability to access food.[30] There is also solid evidence that rising temperatures affect negatively agricultural revenues, with consequences for food security of producers (Table 1.57).[32]

Table 1.57 Changes in agricultural revenues associated with rising temperatures, in selected areas of Latin America

GEOGRAPHICAL COVERAGE	REFERENCE	INCREASES IN TEMPERATURE (ºC)	REVENUE CHANGE (percent)
Argentina	Lozanoff and Cap (2006)	2.0 to 3.0	–20 to –50
Brazil	Sanghi and Mendelsohn (2008)	1.0 to 3.5	–1.3 to –38.5
Mexico	Mendelsohn, Arellano and Christensen (2010)	2.3 to 5.1	–42.6 to –54.1
South America	Seo and Mendelsohn (2007)	1.9, 3.3 and 5	–20, –38 and –64 (small farms)
			–8, –28 and –42 (large farms)
	Seo and Mendelsohn (2008)	1.9, 3.3 and 5 by 2020	2.3 to –14.8
		1.9, 3.3 and 5 by 2060	–8.6 to –23.5
		1.9, 3.3 and 5 by 2100	–8.4 to –53
	Seo (2011)	1.2, 2.0 and 2.6	17 to –36 (private irrigation)
			–12 to –25 (public irrigation)
			–17 to –29 (dry farming)

Source: FAO. 2016. *The State of Food and Agriculture 2016. Climate change, agriculture and food security.* Rome. www.fao.org/3/i6030e/i6030e.pdf

Prices. The risk is high, with reduced agricultural productivity resulting from climate change, of a substantial increase of the price of food (see Section 1.8). This puts low-income consumers – because of higher prices – as well as producers and actors along the value chain – because of lower volumes – in a situation of reduced income that undermines their capacity to meet their food requirements and afford healthy diets.[10] Moreover, for communities hit by floods, droughts or cyclones, there is strong evidence that the price of the food basket is higher than in control groups, and this effect can persist for up to nine months.[30] The impact on food security is then particularly high on the urban poor, who often spend as much as 75 percent of their income on food.[15]

Stability. A greater frequency of extreme weather events, including droughts and floods, contributes to instability of food availability and access, because of higher variability of both volumes and prices.33

Utilization. A reduced access to food of a lesser quality, in terms of protein and micronutrient content, affects people's diets and health, and increases malnutrition.[13] Moreover, more frequent floods prevent access to safe water and adequate sanitation, with consequences for the utilization of food, because of reduced quality and safety of food along with foodborne or waterborne disease outbreaks.[30]

Vulnerability. Smallholder farmers are considered to be disproportionately vulnerable to the impacts of climate change,[34] and Africa has been identified as a particularly exposed region,[35] because of the combined effect of frequent climate change-related weather events and of the importance of agriculture in the economy (see Section 1.1).

Smallholder farmers and coastal communities, who are highly dependent on natural resources and agriculture, are especially vulnerable to climate change as they lack appropriate technological and economic resources and knowledge as well as social support to tackle such challenges. Often they are neither able to invest in technology and apply less GHG-intensive practices, nor in a position to adapt to impacts of climate change. Thus their opportunities to increase productivity, incomes and well-being are reduced.[10]

Conflict and humanitarian crises. Climate change exacerbates food insecurity, conflicts and humanitarian crises, with the highest impacts being on most vulnerable groups, such as women and minorities, because of existing social and economic inequalities, limited access to resources and decision-making capacities.[10] In 2019, extreme weather events caused the displacement of 7 million people worldwide, and it is anticipated that these numbers will continue to rise[18] (see Section 1.5).

Natural resources governance. Climate change is also impacting governance and management of natural resources in the wider contexts of society and economy. Shifts in crop and animal productivity are exacerbating competition for land and freshwater resources, and modifications in marine species distribution are expected to lead to more transboundary stocks, putting national and international agreements and governance under pressure, including agreements to protect the rights of Indigenous Peoples.

1.16.3 Future trends

In its Sixth Assessment Report, the IPCC envisages five scenarios for possible climate futures named after the respective Shared Socioeconomic Pathway (SSP) and related additional radiative forcing by the end of the century with respect to the pre-industrial period:[9]

- two scenarios with very high and high GHG emissions:
  - **SSP5-8.5** – This is considered the direst situation, with complete inaction regarding mitigation of climate change. Burning coal, oil and natural gas, continues to be the approach to support economic growth, resulting in a warming of 4.4 °C, large-scale coastal inundation, extremely devastating weather and unliveable parts of the planet.
  - **SSP3-7.0** – In this scenario, economic nationalism is the driving force of governments and voters, precipitating a retreat from international cooperation. It is characterized by a persisting exploration of fossil fuels resources and a lowering of investments in education and technology. Population growth slows in industrialized countries, but remains high elsewhere. The world warms by roughly 3.6 °C and sea levels rise catastrophically.

- one scenario with intermediate GHG emissions:
  - **SSP2-4.5** – This is the "middle of the road" scenario. It is aligned with current pledges on climate change, which lead to about 2.7 °C of warming by 2100. The Arctic Ocean is ice in the summer; there is a considerable fall in global food production, a serious increase in extreme heat, more destructive flooding from extreme rainfall, and inequalities persist among and within countries.

- two scenarios with low and very low GHG emissions:
  - **SSP1-2.6** – In this scenario, climate action is eventually taking place, but slower than in the fifth and last scenario. The economy achieves net-zero emissions after 2050, and global warming is by up to 1.8 °C. Sea levels rise, inundating major coastal metropolises on a regular basis and there is risk of coastal flooding.
  - **SSP1-1.9** – This scenario is "taking the green road" and is the most ambitious. It sees global cooperation acting to adapt and mitigate climate change. The world shifts to clean energy from fossil fuel usage. Substantial advances in education and health help stabilize population growth.[9]

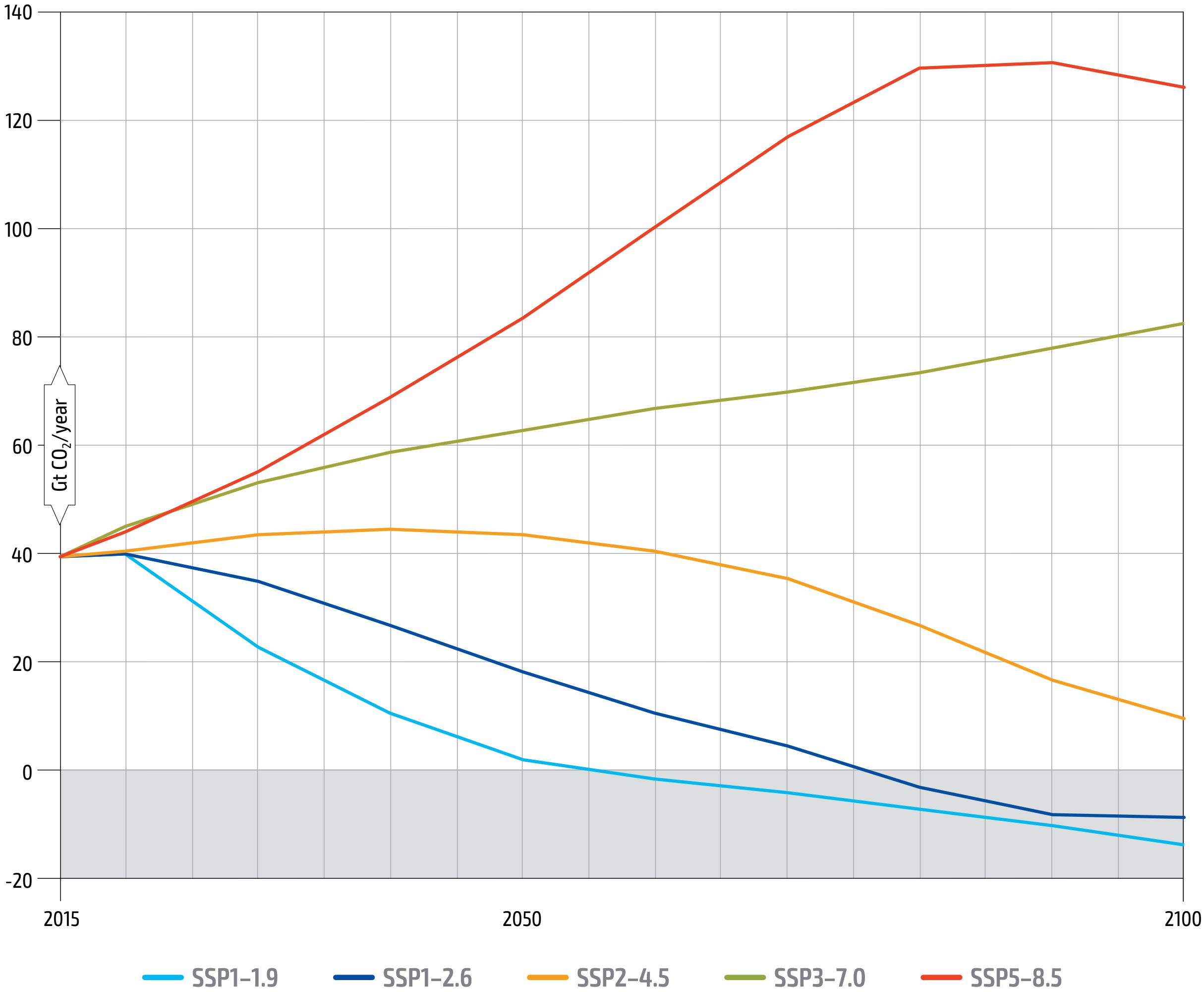
Figure 1.77 shows the projected evolution of CO_2 emissions in the above five scenarios.

The IPCC emphasizes the fact that many changes in the climate system become larger in direct relation to increasing global warming. They include increases in the frequency and intensity of hot temperature extremes, marine heatwaves, heavy precipitation and, in some regions, agricultural and ecological droughts.[9] It is also "virtually certain" that land surface will warm more than ocean surface.

As temperatures rise, the global water cycle is projected to intensify. It will become more variable, and there will be an increase of global monsoon precipitation and of the severity of wet and dry events. Many changes resulting from past and future GHG emissions are irreversible for centuries to millennia, especially those taking place in the ocean, ice sheets and sea level.

Several regions in Africa, South America and Europe are projected to experience more frequent and/or severe droughts.[9]

Figure 1.77 Projected annual emissions of carbon dioxide across the five IPCC scenarios (2015–2100)



Notes: Gt CO_2/year refers to gigatonnes of carbon dioxide per year. SSP1, SSP2, SSP3 and SSP5 refer to the Shared Socioeconomic Pathways one, two, three and five, respectively. The values 1.9, 2.6, 4.5, 7.0 and 8.5 refer to the additional radiative forcing, expressed in watts per square metre, with respect to the pre-industrial level, as reflected by different representative concentration pathways.

Source: IPCC. 2021. Summary for Policymakers. *In* IPCC. *Climate Change 2021: The Physical Science Basis.* Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK and New York, USA, Cambridge University Press. www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM_final.pdf

1.16.4 Summary remarks

The interaction between food systems and the climate is a major driver of change. Food systems play a key role in the dynamic of anthropogenic GHG emissions causing climate change, as they may emit or absorb variable volumes of GHG, depending on the way they are managed.

On the other hand, climate change affects food systems, forcing adaptation in the manner food is produced, processed and consumed, and impacting both producers and consumers.

Food systems generate around one-third of all anthropogenic GHG emissions. Over the last two decades, growing emissions in agriculture and in post-harvest activities are only partly compensated by reduced land-use-related emissions.

Within agriculture, livestock and, to a lesser extent, fires and cultivation of soils rich in organic matter such as peatland, are the major sources of GHG emissions.

Meanwhile, climate change is accelerating, and its impacts are being felt on food systems, affecting quantity, quality and accessibility of food. Higher temperatures and extreme weather events are two main elements through which food systems are impacted. The consequences of climate change (lower crop yields, lower quality of biomass produced by rangeland and pastures, alteration of forests and ecosystems dynamics, higher presence of crop and animal pests and diseases, reduced nutritional quality of food, loss of aquatic systems' production capacity and large-scale redistribution of marine fish resources) threaten to erode, and even reverse, the gains made in the combat against hunger and malnutrition. Moreover, food quality under higher temperatures could turn into a major nutritional issue in the future.

Future development of post-harvest activities and increased livestock production would add to the GHG emissions already emitted by food systems, while limitation in agricultural expansion and related deforestation would help reduce them.

Adaptation of food systems to higher temperatures and extreme weather events will likely become an important domain for research, as future trends indicate that climate change will continue its course in the coming decades.

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1.17 Sustainable ocean economies (Driver 18)

The concept of "sustainable ocean economies" also referred to as "Blue Economy", grew out of the Rio+20 United Nations Conference on Sustainable Development, held June 2012, and refers to the application of "Green Economy" principles to aquatic environments (primarily oceans and seas, but sometimes including inland waters).[1, bu] It aims at reorganizing the aquatic sectors to achieve environmental, economic and social stability, providing decent jobs, and securing sustainable livelihoods and rights to all people through traditional sectors such as fisheries, irrigation, tourism and maritime transport, but also through new and emerging activities like renewable energy, water desalinization, marine aquaculture, seabed extraction, marine biotechnology and bioprospecting.[2]

The annual global economic value of the Blue Economy is estimated at USD 2.5 trillion, equivalent to the world's seventh largest economy, and is organized from a USD 24 trillion oceanic asset base.[3] This represents vast opportunities for prosperity, as well as benefits to human culture and well-being, if used sustainably.

Aquatic food production systems are a core sector within the Blue Economy. However, the opacity of the "Blue Economy" concept often results in policies that favour big projects such as oil/gas and shipping/ports or even tourism, which bring economic benefits but also environmental degradation, particularly on biodiversity.[4] Resolving trade-offs require further investigation for risk-informed, sound policymaking and investments for resilient and sustainable development.

The considerations put forward above raise some important questions:

- To what extent can Blue Economy activities address major issues, such as human nutrition and health, ocean pollution, loss of aquatic biodiversity and the gradual deterioration of fish stocks, while contributing to mitigating climate change?
- What are the main weaknesses and challenges facing Blue Economy development?
- What international and national level governance mechanisms could help address trade-offs between aquatic food production and other uses of ocean spaces?

This section identifies elements of how the Blue Economy may drive trends in aquatic food systems and the challenges and potential changes this may bring, and addresses some of the questions at stake.

1.17.1 Blue Economy

Interpretations on what a Blue Economy entails vary according to perspectives as well as policy priorities. In fact, there are at least four ways of understanding the concept of Blue Economy.[6] These varying views cause conflict in the construction and implementation of Blue Economy policies, management and action plans, leading to confusion among stakeholders.

Some countries, institutions and stakeholders have expressed concern over the use of the term "Blue Economy" in international and regional fora, and FAO does not use it in its normative or programmatic processes, preferring instead the terms "blue transformation" (when referring to aquatic food systems) and "sustainable ocean economies" (when referring to processes beyond aquatic food). This notwithstanding, the idea is by now significantly widespread and is driving dialogue, policy and investments in (mainly) oceanic sectors, and is commonly viewed as a critical component to achieve the 2030 Agenda for Sustainable Development.

The Blue Economy serves as the central theme of dozens of global conferences and dialogues. It underpins the ocean strategies of international organizations and non-government organizations (NGOs) and is the driving force behind significant changes to ocean policy and planning in countries and regions. Blue Economy strategies, or even Blue Economy ministries, are now increasingly common. Many more countries are engaged in dialogue and policy, or action plan developing processes, to incorporate the Blue Economy into their governance arrangements. All these initiatives are occurring without standardized or common basic principles for a Blue Economy – but with a common concern for the long-term opportunities arising from ocean resources.

[bu] Unless otherwise specified, this document uses the World Bank definition of "Blue Economy" as "the sustainable use of ocean resources for economic growth, improved livelihoods, and jobs while preserving the health of ocean ecosystem" (World Bank, 2017, p.6).[5]

Transitioning towards a Blue Economy requires transformation of current structures, improved governance and partnerships. A review of the past decade offers various pathways, suggestions, and lessons learned on building a Blue Economy.[7,8,9,10,11,12,13] Recommendations include establishing social and environmental baselines on Blue Economy sectors and calculating monetary and non-monetary values from ocean capital. The process also requires integrating ocean policies and creating ocean-oriented ministries or inter-ministerial working groups that design and execute ocean-related strategies. To transform policy into actions, such bodies must receive decision-making powers, adequate financial and human resources, and the competence to integrate and manage diverse ocean sectors.

Partnerships with the private sector remain essential to ensure sustainable use. Both the private sector and philanthropic actors have emerged as key knowledge producers and potential contributors and funders of sustainable investments in ocean industries and in the stewardship of global ocean commons.

This move towards a Blue Economy and its associated practices will determine the evolution of aquatic food systems over the next decades.

1.17.2 Recent trends

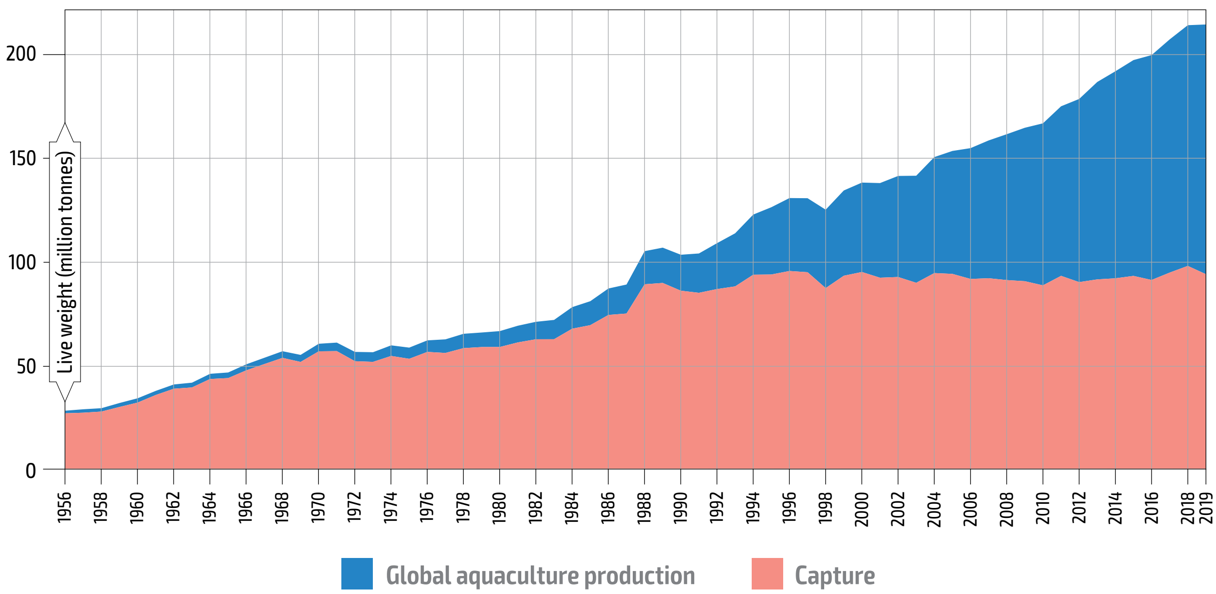
Aquatic food systems, both oceanic and inland, continue to grow in size and value. Recent trends demonstrate the increasing contribution of fisheries and aquaculture to food security and livelihoods.

Production[bv]

Global fisheries production has multiplied almost 12 times over the last seven decades to reach 213 million tonnes in 2019.

By 1995, when the Code of Conduct for Responsible Fisheries was endorsed,[16] capture production entered a phase of stabilization with slow long-term growth, illustrating improvements in management and data collection as well as expansion towards new or under-exploited stocks (Figure 1.78). Conversely, from 1995 to 2019, aquaculture production increased by 250 percent. While this growth rate has slowed in the past few years, aquaculture continues to be the fastest-growing, food-producing sector.

Figure 1.78 Global fish production (1956–2019)



Note: Total fish production includes capture fisheries and aquaculture.

Source: FAO. 2022. FishStatJ - Software for Fishery and Aquaculture Statistical Time Series. In: *FAO – Fisheries and Aquaculture*. Rome. Cited 15 June 2022. www.fao.org/fishery/en/statistics/software/fishstatj/en

[bv] For a more complete overview current status and trends in fisheries and aquaculture please consult the FAO report *The State of Fisheries and Aquaculture 2022*[14] and FAO *Statistical annuaire for fisheries and aquaculture 2022*.[15]

The boom in aquaculture took place mostly in Asia, with around 80 percent of output stemming from Asia, and with China being, by far, the largest producer in the world, with more than 68 million tonnes (57 percent of global aquaculture outturn). Table 1.58 shows that 83 percent of China's fisheries production was coming from this activity. On the contrary, in sub-Saharan Africa (SSA), aquaculture is supplies less than 10 percent of total fish products.

Table 1.58 Share of capture and aquaculture production by region (2019)

REGION	AQUACULTURE	CAPTURE
	(percent)	
High-income countries	27	73
China	83	17
East Asia and the Pacific	57	43
Europe and Central Asia	12	88
Latin America and the Caribbean	18	82
Near East and North Africa	42	58
South Asia	55	45
Sub-Saharan Africa	7	93
World	**56**	**44**

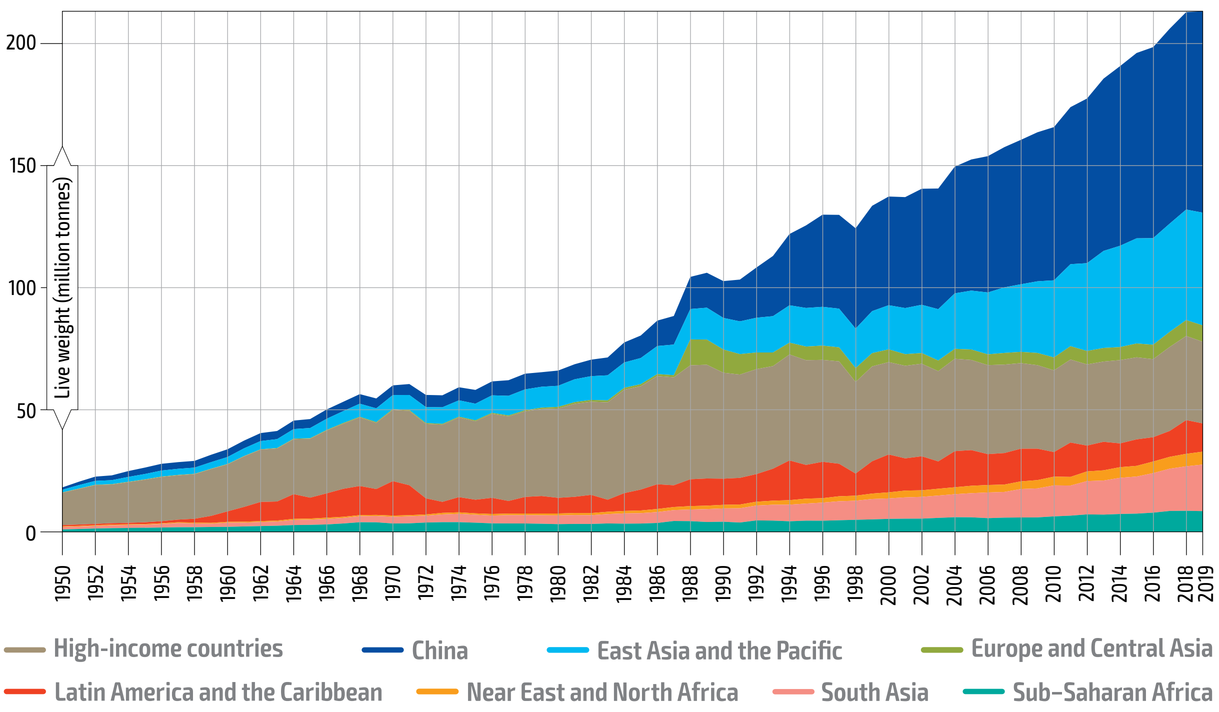
Note: Total fish production includes capture fisheries and aquaculture.

Source: FAO. 2022. FishStatJ - Software for Fishery and Aquaculture Statistical Time Series. In: *FAO – Fisheries and Aquaculture*. Rome. Cited 15 June 2022. www.fao.org/fishery/en/statistics/software/fishstatj/en

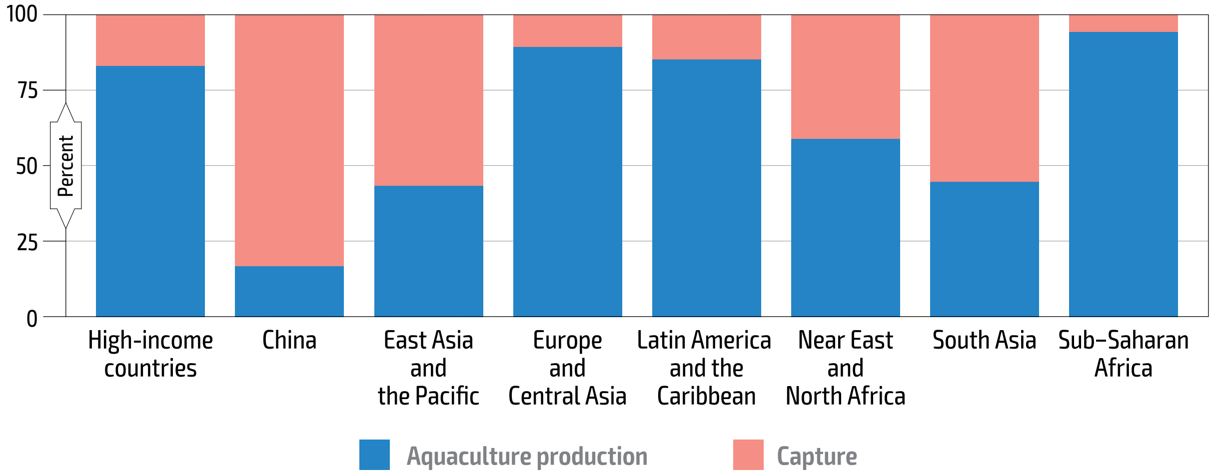
Overall, China and East Asia and the Pacific (EAP) dominate the production of aquatic foods, particularly from aquaculture (see Figure 1.79).

Figure 1.79 Global fish production by region (1950–2019) and production system (2019)

a) Total fish production by region



b) Share of aquaculture production and capture fisheries in total fish production by region



Note: Total fish production includes capture fisheries and aquaculture.

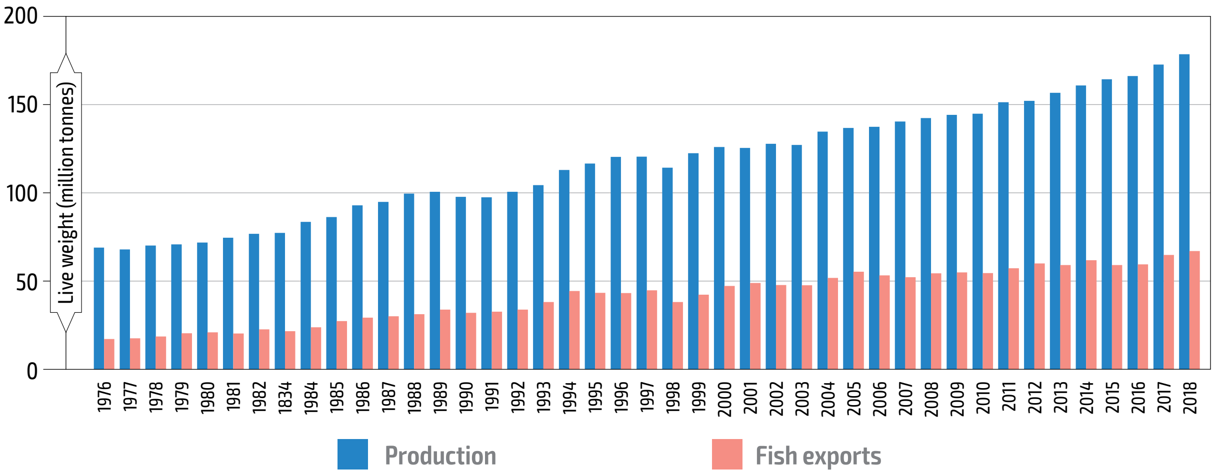
Source: FAO. 2022. FishStatJ - Software for Fishery and Aquaculture Statistical Time Series. In: *FAO – Fisheries and Aquaculture.* Rome. Cited 15 June 2022. www.fao.org/fishery/en/statistics/software/fishstatj/en

Trade of fish products

Trade in fish has expanded rapidly,[bw] **as has the emergence of global value chains** (see Section 1.12). Today, a given fish may be harvested in one country, processed in another and consumed in yet another. Consumers can eat fish caught or farmed in regions far from their point of purchase and they are being introduced to products that were previously available only on faraway local or regional markets.

In 2018, almost 38 percent of all fish caught or farmed were traded internationally. The 67 million tonnes of fish (live weight equivalent) had a value of USD 164 billion, and represented near to 11 percent of the export value of agricultural products (excluding forest products). From 1976 to 2018, global exports of fish and fishery products grew by 3 percent annually in quantity, and 4 percent in value (Figure 1.80). This reflects higher fish prices and of a larger share of processed products in volume traded.[17]

Figure 1.80 World fish production and exports (1976–2018)



Notes: In accordance with the internationally-recommended practice, imports and exports statistics have been adjusted to include as imports fish caught by foreign fishing vessels and landed in domestic ports and as exports fish caught by domestic fishing vessels and landed directly in foreign ports. Exports include re-exports. World totals of major groups of species may be understated due to statistics being reported as unspecified fish in some national trade statistics. This results also in imbalances between figures for world imports and exports of given major groups.

Source: FAO. 2020. *The State of World Fisheries and Aquaculture 2020. Sustainability in action.* Rome. https://doi.org/10.4060/ca9229en

[bw] The term "fish", here, indicates fish, crustaceans, molluscs and other aquatic animals, but excludes aquatic mammals, reptiles, seaweeds and other aquatic plants.

Employment and livelihoods

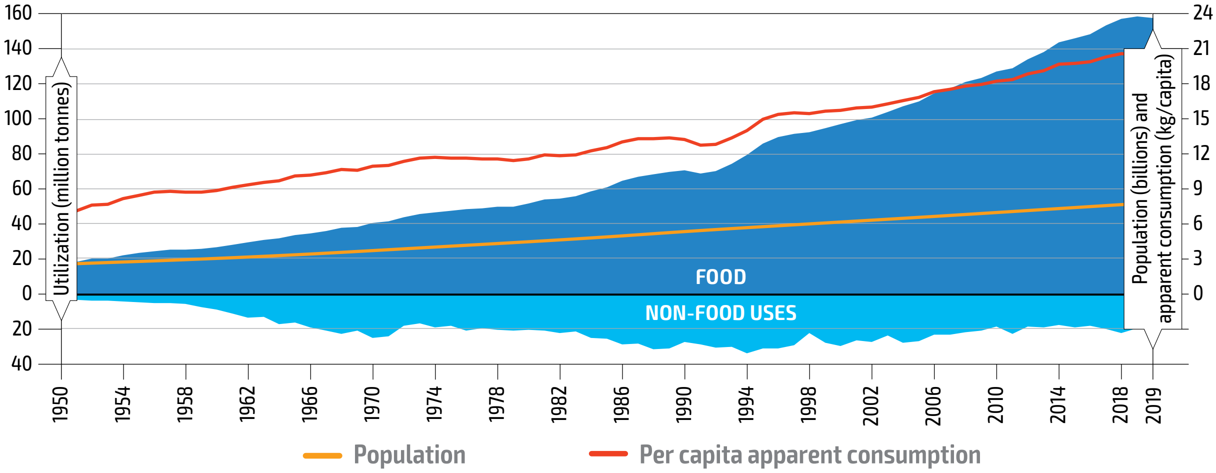
In 2019, an estimated 61 million people were engaged in the primary sector of fisheries and aquaculture. About 22.3 million people were employed in aquaculture and 38.6 million in fisheries. Of these totals, almost 80 percent and more than 95 percent were, respectively, for capture and aquaculture, in Asia.[17] The multiplier effect of these jobs is believed to have created approximately three additional jobs along the value chain, providing an income to about three dependants per active, thus procuring a livelihood for up to 600 million people worldwide. An upcoming global exercise led by FAO and Duke University,[18] should estimate employment in small-scale fisheries, giving a more accurate assessment of the true impact of this sector on livelihoods.

Human consumption

Eighty-nine percent of fishery and aquaculture products are now consumed as food. As total fish and aquaculture products increased considerably over this period, the share of non-food use of these products fell by more than half, globally, from 28 percent between 1988 and 1997, to only 11 percent between in 2019.

The growth rate of apparent consumption of fish has been higher than population increase. Total global apparent per capita consumption of fish grew by an average rate of close to 3 percent between 1961 and 2019,[bx] faster than all other animal proteins, other than poultry, and significantly faster than population, as consumption per capita more than doubled from 9.0 kg in 1961 to close to 21 kg in 2019 (Figure 1.81). Despite this growth, only 1 percent of caloric intake and 17 percent of animal protein intake (or 7 percent of all proteins consumed globally) come from blue food systems.[17]

Figure 1.81 World fish utilization and apparent consumption (1950–2019)



Notes: Excluding aquatic mammals, crocodiles, alligators, caimans and algae. Data expressed in live weight equivalent. For more details see the Glossary in the source below.

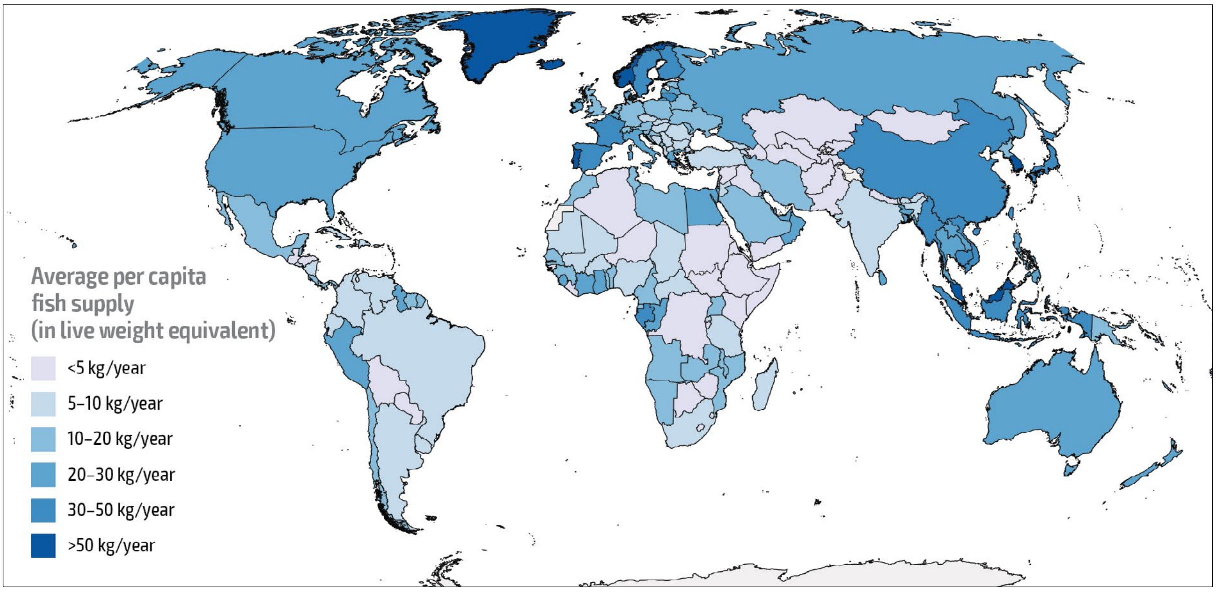
Source: FAO. 2022. *The State of World Fisheries and Aquaculture 2022. Towards blue transformation.* Rome. https://doi.org/10.4060/cc0461en

Factors explaining this growth include higher aquaculture production and technological developments in processing, cold chain, shipping and distribution, which allowed more effective and efficient supply along with reduced waste. Other factors are rising incomes and increased awareness among consumers of the health benefits of fish.

There are considerable variations in the level of fish consumption at the national level, as can be seen from the map in Figure 1.82. Not surprisingly, highest levels are found in Asia and in high-income countries (HICs), and in some coastal countries in Africa and Latin America. Since 1995, the fastest cumulated growth in per capita consumption has been in Near East and North Africa (NNA), as well as EAP.

[bx] Apparent consumption is the food available for consumption, which, for a number of reasons (for example, waste at the household level), is not equal to food intake.

Figure 1.82 Apparent fish consumption per capita by country (average 2017–2019)



Notes: Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties. Final boundary between the Sudan and South Sudan has not yet been determined. Final status of the Abyei area is not yet determined.

Source: FAO. 2022. FishStatJ - Software for Fishery and Aquaculture Statistical Time Series. In: *FAO – Fisheries and Aquaculture.* Rome. Cited 15 June 2022. www.fao.org/fishery/en/statistics/software/fishstatj/en

1.17.3 Consequences and challenges

Consequences

NUTRITION

Fish is a major source of high-quality animal protein, polyunsaturated fatty acids as well as a wide array of micronutrients essential for nutrition.[19,20] For approximately 3.3 billion people, fish is the source of almost 20 percent of their average per capita intake of animal protein. In some countries, particularly in Small Island Developing States (SIDS), fish weighs 50 percent or more in total animal protein uptake.

Fish offers healthy, long-chain omega-3 fatty acids, essential amino acids, vitamins (especially A, B and D) and minerals such as iron, calcium, zinc, selenium and iodine, making it a valuable source for healthy dietary diversification, even when consumed in relatively small quantities. It is not only important for young children during early-life physical and cognitive development, but also throughout adolescence and adulthood.[21]

The nutritional profile of fish varies from species to species and depending on their intake.[22,23] These differences must be understood given the envisioned production increases in certain aquaculture species, which are not a direct substitute to wild, highly nutritious species consumed in vulnerable riparian communities.[24] This implies that the variety of species and the feed provided to fish in fast-growing aquaculture is a main issue for preserving the benefits from the consumption of fish products, as the quality of proteins and nutrients they supply are vital for healthy diets. Moreover, for these benefits to be shared widely, access is essential because billions of people either cannot afford fish or do not have physical access to it.

HEALTH AND POLLUTION

Fisheries resources are affected by pollution, including pollution originating from fisheries-related activities. In particular, there is evidence that the development of the fisheries sector, particularly aquaculture, is accompanied by intensified environmental pollution of coastal areas[25] and that abandoned, lost or otherwise discarded fishing gears are an important source of pollution and environmental damage.[26]

Regarding inland fisheries, the seven major river basins produce about 50 percent of the 12 million tonnes,[by] live weight, of inland fish catch, or around 5 percent of total fish production. People living in these basins have some of the highest levels of per capita fish consumption in the world. Some of the Earth's largest inland fisheries come from river basins or systems that are facing severe threats from anthropogenic and natural environmental pressures that are a consequence of human activities, and in particular, from agriculture (deforestation, land degradation, fertilizer runoff, aquaculture effluents), and more specifically, from irrigated agriculture (loss of connectivity and water use), damming, industries (pollution) and urbanization (sewage).[17]

Pollution jeopardizes the sustainability of marine aquatic ecosystems and can contaminate aquatic foods. The amounts of marine litter and plastic pollution have been growing rapidly, reaching an estimated total of 75 to 199 million tonnes that currently can be found in aquatic ecosystems. Sources include land-based and sea-based industries, and municipal-based sources.[27]

At least 85 percent of this litter is made of plastics, its most persistent component, that causes lethal and sublethal effects in whales, seals, turtles, birds and fish as well as invertebrates, such as bivalves, plankton, worms and coral. It degrades and breaks into nano- and microplastics and releases heavy metals that enter eventually marine food chains and into human food.[28, 29] When ingested, these act as vectors for harmful organisms and can spark changes in gene and protein expression, inflammation and alterations in brain development. They can accumulate in human organs and are associated with serious health impacts, particularly in women.[30, 31, 32, 33] (see also Section 1.14)

Fish are also prone to be contaminated by mycotoxins synthesized by pathogenic fungi, some of which have been classified as human carcinogens. The risk is especially high in aquaculture where contamination may originate from the feed used to raise fish.[34]

Moreover, seas and oceans are also polluted by pharmaceuticals and various chemical compounds, some of which are accumulated by living organisms as well as by the fisheries sector itself.[25]

Antimicrobial resistance resulting from overuse of antibiotics in aquaculture may threaten the expected growth in aquaculture. It creates a potential danger to human health,[35] and could tarnish the reputation of aquatic food.

Unless action is taken, contamination of seafood will pose an increasing danger to human health and cause financial losses for the fisheries sector,[27, 36] significantly jeopardizing the transition towards a Blue Economy.

FISH STOCKS

Section 1.14 on scarcity and degradation of natural resources highlights the gradual decrease of sustainable state marine fish stocks, as well as the diminishing underfished fish stocks. In terms of landed production, this means that 21.3 percent of fish outputs come from biologically unsustainable resources.

For the ten species that had the largest landings between 1950 and 2017, three had greater than average proportions of overfished stocks. Tunas are of particular importance, given their high catches and economic value, and their extensive international trade. They pose additional challenges owing to their highly migratory and often straddling distributions.[17]

Overfishing occurs when stock abundance is fished to below the level that can produce maximum sustainable yield. This negatively impacts biodiversity and ecosystem functioning, reduces fish production and generates unsatisfactory social and economic consequences.[17] The continued existence of widespread illegal, unreported and unregulated (IUU) fishing threatens the economic, social and environmental viability of the sector.

Effective fisheries management is a non-negotiable requirement for the long-term sustainability of aquatic resources. Mismanagement may cost countries up to USD 83 million a year,[5] and long-term overfishing causes significant strife in the world's coastal and riparian communities.

FISHERIES AND CLIMATE CHANGE

Despite having a low carbon footprint, fisheries and aquaculture are among the sectors most impacted by climate change. For instance, greenhouse gas (GHG) emissions from aquaculture are

[by] Mekong, Nile, Ayeryarwady, Yangtze, Brahamaputra, Amazon and Ganges.

significantly less than those for terrestrial animals,[35] but fisheries, particularly marine fisheries, are energy-intensive activities.

As fish stocks degrade, the energy intensity of marine fisheries increases, with fuel consumption rising faster than production. This is what occurred between 1990 and 2011, a period during which emissions from the global fishing industry grew by 28 percent, with little simultaneous increase in output. Meanwhile, the average emissions per tonne landed jumped by 21 percent.[37]

In 2017, aquaculture (aquatic plants excluded) accounted for around 0.5 percent of total anthropogenic GHG emissions or 1.5 percent of food emissions (downstream releases along the value chain excluded), comparable to that of sheep production. The GHG intensity (the amount of GHG per unit of output) is significantly lower than for terrestrial animals (especially ruminants) and marine fish products, and depends a great deal on the feed used. Aquaculture also has some negative environmental impacts,[35] and affects water quality and marine biodiversity.[38]

Climate change creates more risks for fisheries. Climate change is causing increasing sea surface/ocean temperatures, generating heat stress, altering timing and reducing productivity across marine water systems. It leads to ocean acidification that impacts production of calciferous marine resources and brings about declines in yields. It expands low oxygen zones, and heightens intensity and frequency of extreme weather events, making fishing at sea more dangerous,[39] and leading to significant changes in the accessibility, availability and trade of aquatic food products, with potentially important nutritional, geopolitical and economic consequences, especially for those countries and communities most dependent on the fisheries and aquaculture sector.

Exposure to these risks varies according to geographical location and the nature of fisheries-related activities. Equatorial small islands and islands in northern latitudes are the most at risk. Warming and acidification of oceans have greater impact on fish catch at higher latitudes, while flooding, cyclones and high waves are affecting more equatorial countries.[39] Thus, strategies to cope with these risks will need to be different depending on local conditions.

Ocean warming has already driven a 4.1 percent decline in the maximum sustainable yield of 235 of the largest industrial fisheries over the past 80 years.[40] Fish stocks are moving with changing water temperatures, with the ocean food web shifting their range at an average of 72 kilometres per decade.[41]

Climate change also impacts productivity and distribution of fish stocks, population movements to and away from coastal areas, potentially creating challenges to prevailing maritime boundaries and becoming a source of conflict.[42]

Freshwater ecosystems too are sensitive to climate-related shocks and variability. There is a wide range of physiological and ecological impacts on both fish and the freshwater ecosystems supporting inland fisheries, related to water temperature, water availability and flow, and other ecological perturbations.

Aquaculture is unevenly affected in different regions and countries across the planet. Direct and indirect climate change drivers may result in favourable (potential complex interactions between drivers such as mutual cancellation or amplification), unfavourable (e.g. loss of production or infrastructure because of damage caused by extreme events, diseases, toxic algae, parasites and diminished productivity owing to suboptimal farming conditions), or neutral changes, with the unfavourable predominating in low-income countries (LICs).[43]

Challenges

WEAK NATIONAL CAPACITIES AND PRIORITIES

Fisheries and aquaculture often receive lower political and institutional prioritization than other economic sectors. They suffered significantly from the COVID-19 health and economic crisis which severely affected small-scale fisheries,[44] and disrupted value chains causing major negative impacts on volumes of fish production and trade, access to output markets, sales, prices and on competition as well as the welfare of fish value chain actors.[45] Budgetary restrictions that impede proper management and enforcement and higher poverty levels threaten to increase the pressure on depleted stocks and to bankrupt fishers, farms and firms. This reduces technical and financial investment required to develop viable and resilient aquaculture.

Governance of oceans and inland waters also tends to be fragmented in various sectors and at multiple scales, with different regulations and governing bodies managing specific activities, habitats or species.[46] This exacerbates challenges posed by weak governance.

Other constraints include institutional inefficiencies, lack of planning and integration among sectors, lack of awareness of the concerns of local communities, shortages in financing and challenging market dynamics. Additionally, initiatives and investments often fail, because of short-term thinking, loss of support in communities and government, external shocks and failure to address unsustainable industry growth.[11]

UNSUSTAINABLE PRACTICES TOUTED AS BLUE ECONOMY TO GAIN FAVOUR

Given the lack of a globally agreed upon definition of Blue Economy, or set of principles to characterize it, blue interventions often fail to satisfy sustainability criteria. This prevents the uptake of blue economic ideals, as practitioners, countries and stakeholders are confused and unsure about the steps or theory of change for a Blue Economy transition. Misapplication of the Blue Economy may catalyse risk of unbridled development that threatens environmental and social outcomes.[47]

Traditional investments with significant deleterious impacts on the environment and local communities are frequently touted as Blue Economy in order to gain political or financial favour, but often do not consider social and economic sustainability. Blue Economy interventions in Africa showed that large-scale projects such as port construction or expansion, canal building or mining development that prioritized economic gains, regularly had harmful effects on social and economic indicators and threatened the viability of economic activities that compete spatially, such as fishing.[48]

Misapplied Blue Economy interventions can endanger livelihoods by commodifying aquatic resources, or reducing access for traditional users and coastal communities;[49] they can also incentivize overexploitation by subsidizing unsustainable practices or investing in fleet expansion without promoting proper management measures.

On the opposite side of the spectrum, well-intentioned plans for conservation, such as Marine Protected Areas, may potentially also cut off access to traditional users, particularly fisherfolk, causing significant rejection of Blue Economy initiatives by local populations and threatening the viability of these approaches.

The need for more sustainable finance is increasingly recognized. Initiatives such as the United Nations Environment Programme (UNEP) Sustainable Blue Economy Finance Initiative, provides a guiding framework that includes 14 principles for financing a sustainable ocean economy.[50] Enhanced recognition of these principles by banks, insurers and investors can play a key role in promoting better investments. Further refinement and tailoring of the principles and what these mean for aquatic food production specifically, can improve the overall sustainability of aquatic foods. This may entail cooperation with voluntary industry certifications or commitments to certain practices to verify that such schemes meet the necessary sustainability standards.

INEQUALITIES IN THE BLUE ECONOMY

Inequalities in the Blue Economy damage the aquatic food sector's relevance. At its core, Blue Economy seeks a systemic reorientation of the aquatic economy, using multi-sectoral approaches to plan current and future riparian and coastal development. However, traditional valuation measures and national accounting tend to undervalue the environmental, social and economic contributions of aquatic food systems vis-à-vis other sectors such as tourism, maritime transport and energy. Without proper accounting and valuation of aquatic food systems – including their ecosystem services, multiplicative impacts for food and nutrition security, and cultural and social role – Blue Economy planning may underestimate the contribution of these sectors when evaluating trade-offs for "blue" investment and policies.

While actors in large-scale industrial fisheries are effectively involved in decision-making processes, small-scale fishers and fish farmers are mostly absent, despite providing about 50 percent of world production and more than 70 percent of direct employment in the sector. Their absence may be owing to lack of organization or capacity, and represents a risk of being neglected in Blue Economy strategy development and resources allocations.

COST OF TRANSFORMING COASTAL AND RIPARIAN ECONOMIES

Transforming coastal and riparian economies requires substantial investments. Estimates indicate that shifting towards a Blue Economy requires between USD 2 trillion and USD 3.7 trillion,[51] not including inland aquatic food systems. While the overall cost of a transition towards a Blue Economy appears prohibitive, given current global trends, the investments needed to transform aquatic food systems are only a relatively small fraction of that amount. It was calculated that over the next 50 years, stakeholders and government should invest USD 130 billion to USD 230 billion (in 2012 USD) to rebuild marine fisheries.[52] No similar estimates exist for inland fisheries.

Countries spent USD 8 billion on fisheries management in 2018, but appropriate management would require at least USD 134.5 billion per year. Nevertheless, long-term returns justify the upfront investment in management,[51, 52] especially since about USD 83 billion a year are lost in fisheries because of poor management.[1] Erroneous beliefs that the sector cannot drive development often lead to underfunded institutions, inadequate enforcement, and unsatisfactory social and environmental outcomes.

TRADE-OFF CHALLENGES

Frameworks for decision-making on trade-offs must be strengthened. Transforming aquatic food systems entails trade-offs. Aquaculture, for example, needs wild fish or agriculture-raised crops for feed inputs. It utilizes water resources and physical spaces in land, sea or freshwater ecosystems. Sustainable fisheries require trade-offs between conservation, and economic and social viability. Governments and stakeholders must prioritize investment in certain sectors or projects, and emphasize some outcomes over others.

The construction of formal decision-making and stakeholder consultation frameworks, anchored in Blue Economy principles and ideas, is in its infancy. It is perhaps one of the main theoretical and practical obstacles in the transition towards a Blue Economy.

Marine/Maritime Spatial Planning, Integrated Coastal Zone Management and the Ecosystem Approach to Fisheries/Aquaculture, among other decision-making frameworks, provide conceptual and useful processes for multi-stakeholder decision-making in aquatic and coastal environments. Practitioners and institutions must adopt these approaches judiciously and understand that they still require efforts to ensure that all sectors can effectively represent themselves and their needs. This is particularly true of interventions, plans or management actions that affect small-scale fishers or farmers, Indigenous Peoples and vulnerable groups.

1.17.4 Future trends

Given the production and consumption trends described above, as well as their contribution to trade, livelihoods, cultural value and food security and nutrition, aquatic foods must form a core focus of Blue Economy investments and practices.

Future projections reflect this importance. According to the Organisation for Economic Co-operation and Development (OECD) and FAO, fish production is projected to reach 200 million tonnes by 2029, a 25 million tonnes increase from the 2017–2019 average baseline.[53] Annual growth rate is, however, expected to be lower than during the previous decade (1.3 percent compared to 2.3 percent), and aquaculture should be increasing faster than capture fisheries. This reduced growth is linked to the assumption that China, by far the world's largest fisheries and aquaculture producer, will be prioritizing the promotion of sustainability (Figure 1.83).

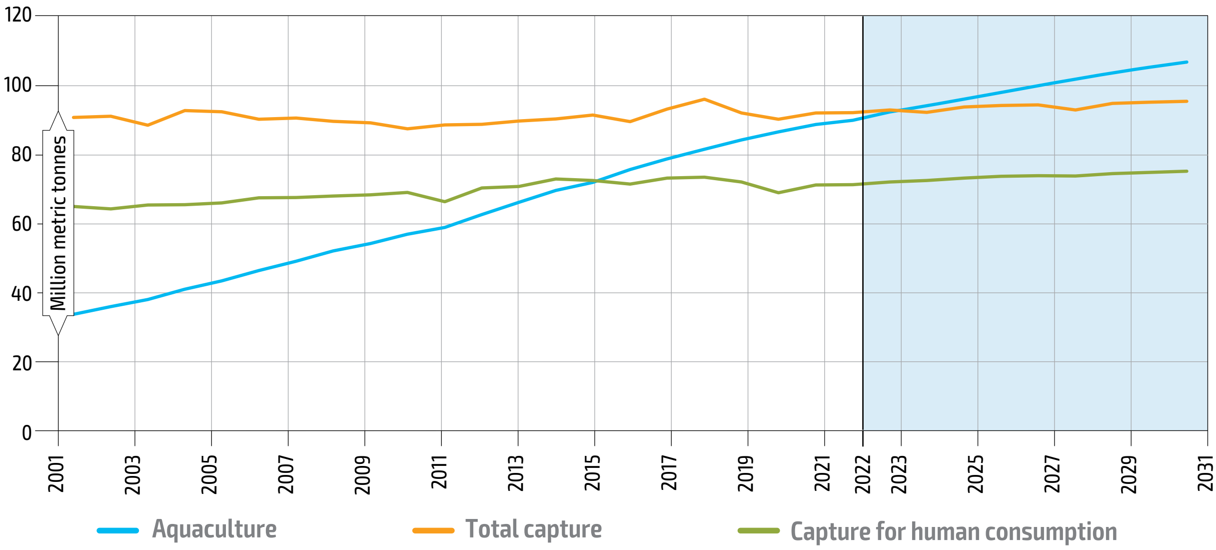
More recent projections of fisheries production by 2050 envisage three scenarios:[21]

- **Business as usual scenario**, in which marine capture fisheries grow by a modest annual 0.05 percent from 2030 to 2050, while inland capture fisheries increase by a yearly 0.3 percent over the same period. The percentage of marine capture fisheries not used for direct human consumption is 21.3 percent of the total marine capture, decreasing by 0.05 percent per annum after 2031, as technological improvements get underway.
- **High-road scenario** that projects positive outcomes that allow aquaculture development and intensification along sustainable lines, and ensure that marine capture fisheries move steadily towards the estimated maximum sustainable yield for oceans and seas. Marine and inland capture fisheries grow by 0.7 percent and 0.55 percent per year to 2030, respectively, however, yields

of both are subject to a 4.05 percent decrease in 2050, consistent with a "strong mitigation" scenario for climate change impacts in capture fisheries. With improved technologies and reduced loss and waste, the proportion of marine capture fisheries not used for direct human consumption falls from 21.3 percent in 2020 to 19.35 percent by 2050.

- **Low-road scenario** that projects failures in aquaculture and unsustainable practices, leading to deterioration in many new ventures and resulting in limited growth. Capture fisheries, both marine and inland, see continued degradation of the resource base, estimated at a 0.25 percent production loss per year to 2040, rising to 0.5 percent in 2050. It also foresees a 9.6 percent fall in the 2050 yield, consistent with the "business as usual" scenario of climate change impacts. The proportion of marine capture fisheries not used for direct human consumption remains at 21.3 percent, with no benefit from further technological innovation.

Figure 1.83 Global aquaculture and capture fish production by production system and use: historical (2001–2021) and projected (2022–2031)



Source: OECD & FAO. 2022. *OECD-FAO Agricultural Outlook 2022-2031.* Chapter 8: Fish. Paris and Rome. https://doi.org/10.1787/f1b0b29c-en

The outcomes of these scenarios are given in Table 1.59.

Table 1.59 Projections of fish production and per capita apparent consumption in 2050 under three scenarios

REGION	BUSINESS AS USUAL (million tonnes)	LOW ROAD (million tonnes)	HIGH ROAD (million tonnes)
Marine capture	85.4	65.8	95.5
Inland capture	13.0	10.1	13.5
Total capture	98.3	75.8	109.0
Inland aquaculture	89.9	75.6	98.4
Marine aquaculture	50.1	45.3	62.0
Total aquaculture	140.0	120.8	160.3
Total production	238.3	196.7	269.3
Fish for direct food	217.4	180.5	248.2
Per capita apparent consumption (kg/year)	22.3	18.5	25.5

Source: UN Nutrition. 2021. *The role of aquatic foods in sustainable healthy diets.* Discussion Paper. New York, USA, United Nations. www.unnutrition.org/wp-content/uploads/FINAL-UN-Nutrition-Aquatic-foods-Paper_EN_.pdf

Another prospective analysis found that without strong concerted efforts to cut emissions, the total maximum catch potential in the world's exclusive economic zones could decrease by 12.1 percent by 2050. Tropical regions are projected to suffer generally negative impacts from climate change, driven by ocean warming, acidification, deoxygenation and sea-level rise. This could lead to a drop of up to 40 percent in maximum catch potential, while areas in high latitudes are projected to have an increase of up to 70 percent in catch potential, including from new fisheries.[54] Climate-driven reductions in fisheries production and alterations in fish species composition will subsequently increase the vulnerability of those tropical countries with limited adaptive capacity.[55]

For freshwater, climate change will lead to transformation of habitats and the fish assemblages that they support: only a few of these effects are expected to be beneficial to inland fisheries, especially those based on native fish populations.[56]

Technological advances in aquaculture, for example, through investments in land-based Recirculating Aquaculture Systems (RAS) are less dependent on local climatic conditions and represent a growth opportunity independent of climatic conditions.

The fisheries and aquaculture sector is at the forefront of climate change impacts, and the extent of these impacts will depend on the specific geopolitical and ecosystem conditions, and will largely be determined by the sector's ability to develop and implement adaptation and mitigation strategies. There is an urgent need for the sector to take adaptation and mitigation measures to address these effects, as well as increase efforts to further reduce its contribution to GHG emissions as much as possible. This can be accomplished by, for example, reducing energy consumption, better feed and feed management, and low-impact fishing methods and gears.

1.17.5 Summary remarks

Fisheries, and particularly aquaculture, have been growing at a very fast rate over the last three decades and have become a major source of high-quality animal protein, polyunsaturated fatty acids and micronutrients.

Aquaculture is now the main provider of fish products and it supplies animal proteins, while emitting low amounts of GHG per kilogramme of output, compared to terrestrial animals, especially ruminants.

However, the increasing level of marine litter, particularly plastic, negatively impacts fisheries production and quality of its outputs that run a greater risk of being contaminated. This, along with the extensive use of antimicrobials in aquaculture, creates potential hazards for human health.

If past trends persist, fisheries – and more specifically aquaculture – will continue to grow. Growth of aquaculture has a potentially beneficial impact on climate, as it is more GHG-efficient (less GHG emitted per kg of output) than other animal protein production processes. However, it generates effluents that pollute water and negatively affect biodiversity.

Aquaculture could also contribute to better nutrition, provided the choices of species and feed are made with the view to preserving quality of the fish produced, rather than just maximizing profits.

Unless more sustainable practices are adopted in capture fisheries, marine fish stocks will probably decrease and their exploitation will require more fuel and generate more GHG emissions.

The concept of "Blue Economy" refers to the implementation of "Green Economy" principles to aquatic environments in order to achieve greater sustainability in both traditional and emerging water-related activities. The practical application of the "Blue Economy" approach is constrained by weak national capacities, dubious "Blue Economy" interventions with deleterious consequences, and insufficient involvement of fishers and fish workers in decision-making. This includes a lack of information to make accurate trade-off decisions when prioritizing one aquatic-based sector over another. If there is no general agreement on, and application of, the principles defining "Blue Economy" – and if governance of aquatic activities is not more inclusive of fishers, fish farmers and fish workers – the implementation of the "Blue Economy" concept could favour aquatic activities other than fisheries (e.g. tourism, maritime transport, water desalinization, bio-prospecting) and benefit large economic operators rather than fisher and fish farmer communities.

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2 | Alternative scenarios for the future of agrifood systems

2.1 Introduction

Concurring factors combine to generate multiple future risks and challenges for agrifood systems and their expected performances. The interplay of the drivers presented in Chapter 1, possible changes in individual and collective behaviour, materialization of natural events, risks and uncertainties, and the influence of public strategies and policies, may lead to radically divergent futures, where the fundamental questions on sustainability of agrifood systems find diverse answers. In these different future scenarios, various transformative opportunities may arise and be seized, depending on the current and future capacities to identify and exploit them. This applies to individual citizens, local communities, entrepreneurs, academia, the media, national and transnational corporations as well as civil society bodies, such as consumer associations, trade unions, political parties and others. The path that agrifood systems will follow is also contingent, of course, on the extent to which governments, parliaments and other political organizations are able and willing to steer their decisions towards specific outcomes.

It is apparent that the current and future power structures – political, economic, social, cultural and military – will significantly influence the scale and direction of change. Indeed, the centres of power will determine whether and to what degree triggers of transformation will be activated by different stakeholders, depending on who controls them and what their values are.

Without any pretention to "defogging" the medium- and long-term future per se – which is not predictable as such, given the uncertainty affecting all the drivers of agrifood systems – but just to clarify how the current and immediate future behaviour of public and private decision-makers could influence the medium- and long-term future, this part of the report explores four alternative scenarios and their possible implications for the future of agrifood systems. The number of futures chosen is arbitrary, as it all takes place in scenario-based foresight exercises. However, in selecting these scenarios, two guiding criteria were applied: (a) scenarios are diversified enough to highlight how trade-offs emerging along development patterns could be differently addressed and balanced (see Table 2.2); and (b) the number of scenarios is easily manageable, and thus useful to inform multi-stakeholder decision-making processes.

The four scenarios proposed are summarized in Table 2.1.

Table 2.1 Alternative medium- and long-term scenarios for agrifood systems

More of the same (MOS). Muddling through reactions to events and crises, while doing just enough to avoid systemic collapses, led to degradation of agrifood systems sustainability and to poor living conditions for a large number of people, thus increasing the long-run likelihood of systemic failures.
Adjusted future (AFU). Some moves towards sustainable agrifood systems were triggered in an attempt to achieve Agenda 2030 goals and some improvements in terms of well-being were obtained, but the lack of overall sustainability and systemic resilience hampered their maintenance in the long run.
Race to the bottom (RAB). Gravely ill-incentivized decisions led the world to the worst version of itself after the collapse of substantial parts of socioeconomic, environmental and agrifood systems with costly and almost irreversible consequences for a very large number of people and ecosystems.
Trading off for sustainability (TOS). Awareness, education, social commitment, sense of responsibility and participation triggered new power relationships, and shifted the development paradigm in most countries. Gross domestic product (GDP) growth was traded off for inclusiveness, resilience and sustainability of agrifood, socioeconomic and environmental systems.

Source: Authors' elaboration.

The time frame of these scenarios extends from the near future (the current decade) to a more remote one, towards the end of the century. In a comprehensive foresight exercise on agrifood systems it is undoubtedly important to span such a period because, on the one hand, most policymakers and part of their constituencies are interested in short-term achievements with respect to immediate effects on well-being. On the other hand, civil society and selected political movements across many countries are increasingly looking ahead with expectations regarding long-term implications of development patterns. Given that structural long-term inertias exist both in socioeconomic systems, such as demographic dynamics, capital accumulation processes or the structuring of geostrategic influences, as well as in environmental ones, such as climate change or ecosystems degradation, focusing on a shorter time period would not allow for a consideration of the implications of imminent strategic choices in the close future on the long-term destiny of agrifood systems.

2.2 Alternative futures: key elements for scenario building

Forward-looking exercises based on scenarios for alternative futures examine some key elements that contribute to shaping up and qualifying the respective narratives. The narratives of this report, which are set as retrospective storylines, are built by considering, *inter alia*: the internal consistency of narratives and the causal linkages that tie together the various drivers of agrifood systems and their outcomes; "weak signals" of possible futures already detected in the current reality; "end-states" of different futures, related pathways; "priority triggers" of development for policymaking that can shift the future from one scenario to the other; and selected trade-offs among developmental objectives.

- **Internal consistency of scenarios and causal linkages.** Mapping causal linkages that tie together the drivers of agrifood systems, agrifood activities and related outcomes is a precondition to building internally consistent scenarios, whether they are qualitative or quantitative.[bz] The diagram provided in Figure 1.1 outlines the existing linkages and related feedback effects, but more detailed mapping is needed to ensure internal consistency among the various elements of complex agrifood systems. In addition, considering that agrifood systems fit within broader socioeconomic and environmental systems, the analysis of causal interlinkages has to take into account the mutual relationships among these three systems and their expected outcomes.

[bz] Quantitative socioeconomic, agronomic or environmental models help build consistency, as they are based on a set of assumptions that can formalize causal linkages that show drivers, activities and outcomes are explicitly interlinked.

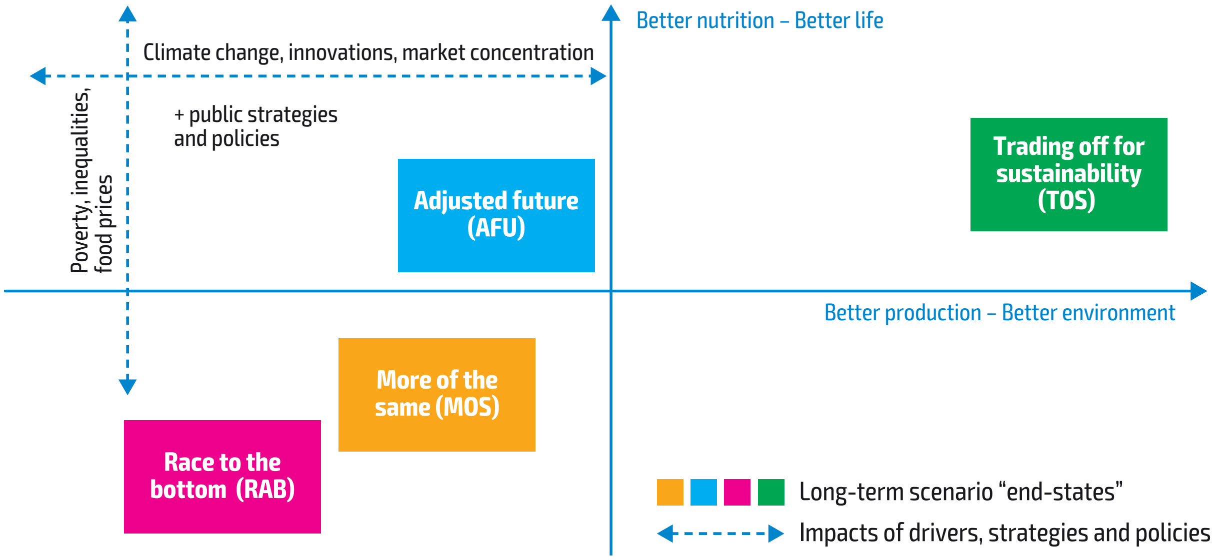
For instance, the set-up and performances of economy-wide systems are of particular relevance for food security and nutrition outcomes (see Box 2.1). Analogously, societal well-being outcomes, also through the performances of agrifood systems, depend on the linkages between land and water availability and management, economy-wide development patterns and climate change (see Box 2.2). The narratives of the possible futures provided in this chapter are built by considering many causal interlinkages existing among agrifood, socioeconomic and environmental systems.

- **"Weak signals" of possible futures.** "Weak signals" of possible futures are events or existing phenomena actually observed that may reveal important features of possible medium- to long-term futures.[ca] For instance, increasing land degradation can be seen as a weak signal of a plausible future characterized by very strong land degradation. It should be noted that signals are considered weak with respect to a possible future, not per se. Each scenario narrative emphasizes or deemphasizes different sets of current trends and events, resulting in diversified futures. Weak signals which ground the four proposed narratives are drawn from analyses of drivers of agrifood systems and their related trends, as provided in Chapter 1 and referred to in the narratives themselves. For instance, the future might bring increasing or decreasing shared economic growth; improving or worsening inequalities; multilateral cooperation or fragmentation and geopolitical disorder; accelerated or decelerated degradation of natural resources; and improving or deteriorating environmental sustainability.
- **Future "end-states" and the "four betters".** In defining the four scenarios, a "backcasting" approach is typically followed.[1] This process begins with the identification of a particular "end-states", that is to say, a snapshot of agrifood systems in the socioeconomic and environmental context, at a given point in time in the future. The socioeconomic, climatic, biophysical, institutional, cultural, and policy pathways that lead from the current situation to the aforementioned "end-states" are then described. "Backcasting" is useful when aspirational objectives are preliminarily set to frame the foresight exercise. Although all the proposed narratives depict quite broad outcomes and development pathways, the aspirational FAO's "four betters": better production, better nutrition, better environment and better life, are adopted to set the space of possible future outcomes, as represented on a two-dimensional plan in Figure 2.1.[cb]
  Casting the alternative future "end-states" of each scenario in the outcome space of the "four betters" is in some way subjective, and therefore Figure 2.1 only aims to portray the relative position of each scenario with respect to the others. The "more of the same" (MOS) scenario depicts a situation where the few attempts to improve production and the environment did not succeed, and nutrition and the quality of life degraded. The "adjusted future" (AFU) scenario envisions a future where some gains in nutrition and quality of life and, to a much lesser extent, in production processes and the environment were achieved. The "race to the bottom" (RAB) scenario entails unsettling overall agrifood systems outcomes. The "trading off for sustainability" (TOS) scenario leads to significant advances in production, environment, nutrition and life, despite modest global gross domestic product (GDP) growth which was traded off for inclusiveness, resilience and sustainability.

[ca] The term "weak signals" in future studies is borrowed from Strategic Early Warning Systems (SEWS) (available at https://en.wikipedia.org/wiki/Strategic_early_warning_system) and refer to signs detected in the reality which could lead to strategic surprises, namely, events which have the potential to jeopardize an organization's strategy.

[cb] The "four betters" are defined in FAO *Strategic Framework 2022–31*:[2] (i) better production: ensure sustainable consumption and production patterns, through efficient and inclusive food and agriculture supply chains at local, regional and global level, ensuring resilient and sustainable agrifood systems in a changing climate and environment; (ii) better nutrition: end hunger, achieve food security and improved nutrition in all its forms, including promoting nutritious food and increasing access to healthy diets; (iii) better environment: protect, restore and promote sustainable use of terrestrial and marine ecosystems and combat climate change (reduce, reuse, recycle and residual management) through more efficient, inclusive, resilient and sustainable agrifood systems; and (iv) better life: promote inclusive economic growth by reducing inequalities (urban/rural areas, rich/poor countries and men/women).

Figure 2.1 Future "end-states" of alternative scenarios in the space of the outcomes



Notes: The "four betters" are paired to allow for visualization under some assumptions. Better nutrition is assumed to be a dimension of better life and to be positively correlated with it if the other dimensions are kept constant. Better production is assumed to be an important contributor to better environment and to be positively correlated with it if other factors affecting the environmental quality are kept constant. Note that the "end-states" of the scenarios in the space of the "four betters" are placed for illustrative purposes, just to portray the relative position of each scenario with respect to the others.

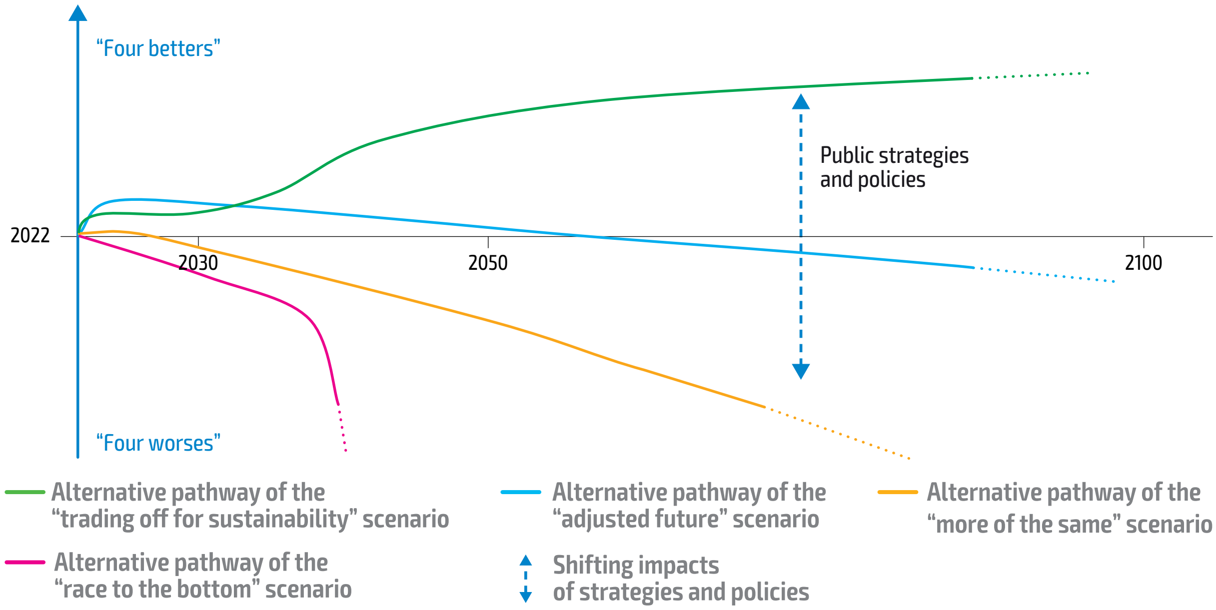
Source: Authors' elaboration.

- **Alternative pathways.** Not only do future end-states matter, but the dynamics that agrifood, socioeconomic and environmental systems exhibit in reaching them matter as well (see Figure 2.2). MOS is characterized by a slowly, but progressively, degrading situation in all of the "four betters" dimensions, just after possible very modest short-term improvements. This may eventually lead to a substantial collapse of the systems, because reactive strategies and short-termism fail to address root causes of overall unsustainability.[cc]
  Under AFU, some issues related to income and food distribution are tackled, thus bringing about some achievements in terms of better nutrition and better life, particularly in the medium run. In contrast, a piecemeal approach to sustainable production processes and natural resource preservation reduces resilience to shocks and hampers long-term sustainability of outcomes. Under RAB, a systematic neglect of sustainability by governments and transnational corporations, masked behind a façade of social-washing and green-washing initiatives, leads to the collapse of substantial parts of agrifood, socioeconomic and environmental systems and to off scale "four worses". TOS is characterized by early actions that aim to improve the nutrition and life of poor population segments despite a modest Gross World Product (GWP) growth, and associated with long-term investments in better production and environmental sustainability that increase resilience and stabilize long-term achievements.
  As the four pathways represented in Figure 2.2 cover a quite large spectrum of possible dynamics of outcomes, they are necessarily intended as iconic representations of a multitude of different sets of possibilities. In fact, they are not rigid, predetermined rail tracks along which agrifood systems would move, because strategic decisions and policies would almost always have the potential to shift actual pathways towards the "four betters" or away from them, unless irreversible events or processes were triggered, such as: substantial collapses of ecosystems resulting from, for instance, loss of biodiversity or exacerbated climate change; large-scale conflicts leading to substantial losses of material and immaterial capital, and natural

[cc] Most forward-looking exercises in areas relevant to sustainable development have been recently carried out by the climate-change community in support to the work of the Intergovernmental Panel on Climate Change, notably to its Sixth Assessment Report (AR6).[3,4] These exercises are based on selected combinations of alternative narratives of socioeconomic systems, as in the Shared Socio-economic Pathways (SSPs)[3] and alternative climate change scenarios, the Representative Concentration Pathways (RCPs).[4]

resources; pandemics generating substantial shrinking of animal or human population; or other unknown irreversible events. Clearly, earlier actions to steer future pathways towards desirable outcomes entail larger probabilities of success, while belated actions may prove to be comparatively extremely costly and of limited impact.

Figure 2.2 Alternative future pathways



Source: Authors' elaboration.

- **Shifting the future across scenarios: the "priority triggers" for transformation.** All the drivers of agrifood systems are going to be influenced by the choices of stakeholders involved in development processes. In actual fact, notwithstanding inertias, and known and unknown irreversible phenomena, the directions along which the future will move depends most plausibly, and to a large extent, on strategies and policies that will be designed and implemented (or ignored) by sovereign entities and by the behaviour of all the other relevant agents. This report portrays and analyses four "priority triggers" for transformation, identified by FAO's Corporate Strategic Foresight Exercise (CSFE), and incorporated in FAO *Strategic Framework 2022–31*,[2] that comprise: 1) institutions and governance; 2) consumer awareness; 3) income and wealth distribution; and 4) innovative technologies and approaches (see Chapter 3). These are effective starting points or accelerators of transformative processes, to be activated by means of suitable strategies and policies, which are expected to mutually interact and influence important drivers of agrifood systems and thus spread impacts throughout all agrifood, socioeconomic and environmental systems to achieve desired outcomes. Each narrative of alternative futures assumes that these triggers will be activated (or disabled) to different extents by the various stakeholders intervening in development processes (see also Table 3.1).
- **Trade-offs in policymaking.** The position of each end-state, and the pattern followed to reach there, will both depend on the sets of strategies and policies presumed to be implemented under each of the scenarios. More specifically, the narratives are characterized by different ways in which strategies and policies will address emerging trade-offs along development patterns (see Table 2.2). If, for instance, other things being equal in resolving these trade-offs, short-termism prevailed on longer-term visions (long-termism), more emphasis would be given to immediate better nutrition and better life, with relatively less attention paid to investing on resilient and sustainable production processes and the environment. This would imply, for instance, prioritization of high crop yields to the expense of soil fertility or artificially lowering food prices, while also deliberately maintaining low-productivity jobs instead of favouring a transition towards widespread access to capital assets and related profit-sharing. Should this be

the case, the medium-term milestones (see dashed boxes in Figure 2.3) would be located above the respective end-states, and would most likely be characterized by more uncertainties and less resilience. Indeed, the limited investment on physical capital, maintenance and restoration of natural assets would eventually hamper not only long-term development perspectives, but also short- and medium-term achievements regarding well-being. This is, in effect, the case of AFU, where better nutrition and better life achievements are only temporary. In contrast, TOS is characterized by comparatively lower medium-term progress in these achievements, being social protection measures only focused on selected high-priority social groups. However, this would give room to increased investment in long-term better production and environment and would, in turn, ensure significant resilient progress towards better nutrition/life in the long run.

Analogously, different futures may emerge if some objectives were prioritized with respect to others, thus inducing outcomes to become dependent upon the sequence of objectives, e.g. as when income distribution and social justice (equity) are prioritized with respect to economic growth (efficiency) per se.

Overall, trade-offs emerging along development patterns may not reflect contrasting objectives in absolute terms. Given the multiple cross-linkages among the various elements in agrifood systems, policy solutions may exist which reconcile apparently contrasting objectives. In the TOS scenario, for example, adopting sustainable agricultural practices that may imply lower yields in comparison to conventional agriculture, can concurrently lead to limited expansion of arable land if full-cost accounting for food prices is adopted. This would imply higher food prices which would be likely to lead to a comparatively lower expansion of food demand and reduced pressure on land requirements.[cd] At the same time, food security in a context of higher food prices could be achieved if income and food distribution were improved by means of appropriate governance at all levels, fiscal policies and other policies aimed at increasing wages and income earning opportunities.[ce]

Table 2.2 **Potential trade-offs arising along development patterns**

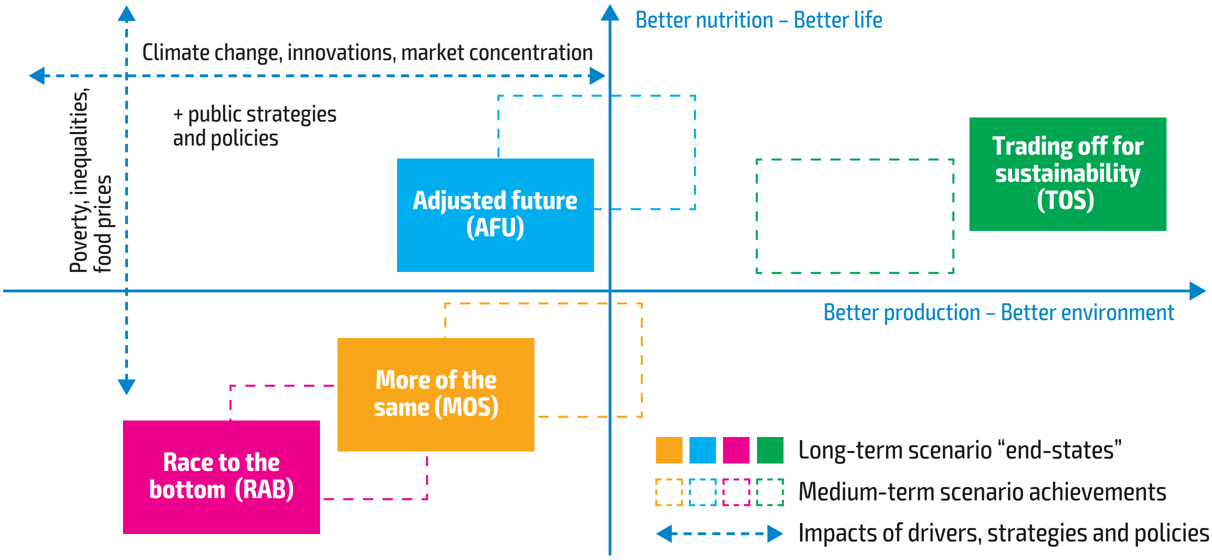
SELECTED (POTENTIALLY) CONFLICTING OBJECTIVES	
Internalizing social and environmental costs in agrifood production processes (full-cost accounting)	Achieving affordable healthy diets and food security
Increasing agrifood output	Reducing agrifood greenhouse gas (GHG) emissions
Adopting sustainable practices with comparatively lower yields	Minimizing land-use expansion
Increasing employment	Increasing wages
Innovating through automation technologies	Increasing employment
Increasing economic diversification	Ensuring foreign currency inflows from commodity exports
Increasing food availability	Using biomass for renewable energy
Funding social protection schemes	Funding public infrastructure and research and development
Achieving food security	Pursuing food safety
Minimizing production costs	Minimizing food waste and losses

Source: Based on FAO. 2018. *The future of food and agriculture – Alternative pathways to 2050*. Rome and FAO. 2020. *Report on the Findings of the Corporate Strategic Foresight Exercise*. Internal Expert Consultation (Unpublished).

cd For a quantitative simulation of a scenario where similar assumptions are explored, see FAO (2018)[5] scenario entitled "towards sustainability" (TSS).

ce For strategy and policy options for transforming agrifood systems and moving them towards sustainability see Chapter 3.

Figure 2.3 Medium-term achievements and future "end-states" of alternative scenarios in the space of the outcomes



Notes: The "four betters" are paired to allow for visualization under some assumptions. Better nutrition is assumed to be a dimension of better life and to be positively correlated with it if the other dimensions are kept constant. Better production is assumed to be an important contributor to better environment and to be positively correlated with it if other factors affecting the environmental quality are kept constant. Note that the "end-states" of the scenarios in the space of the "four betters" are placed for illustrative purposes, just to portray the relative position of each scenario with respect to the others.

Source: Authors' elaboration.

Box 2.1 Linkages between the economy-wide system and food security and nutrition outcomes

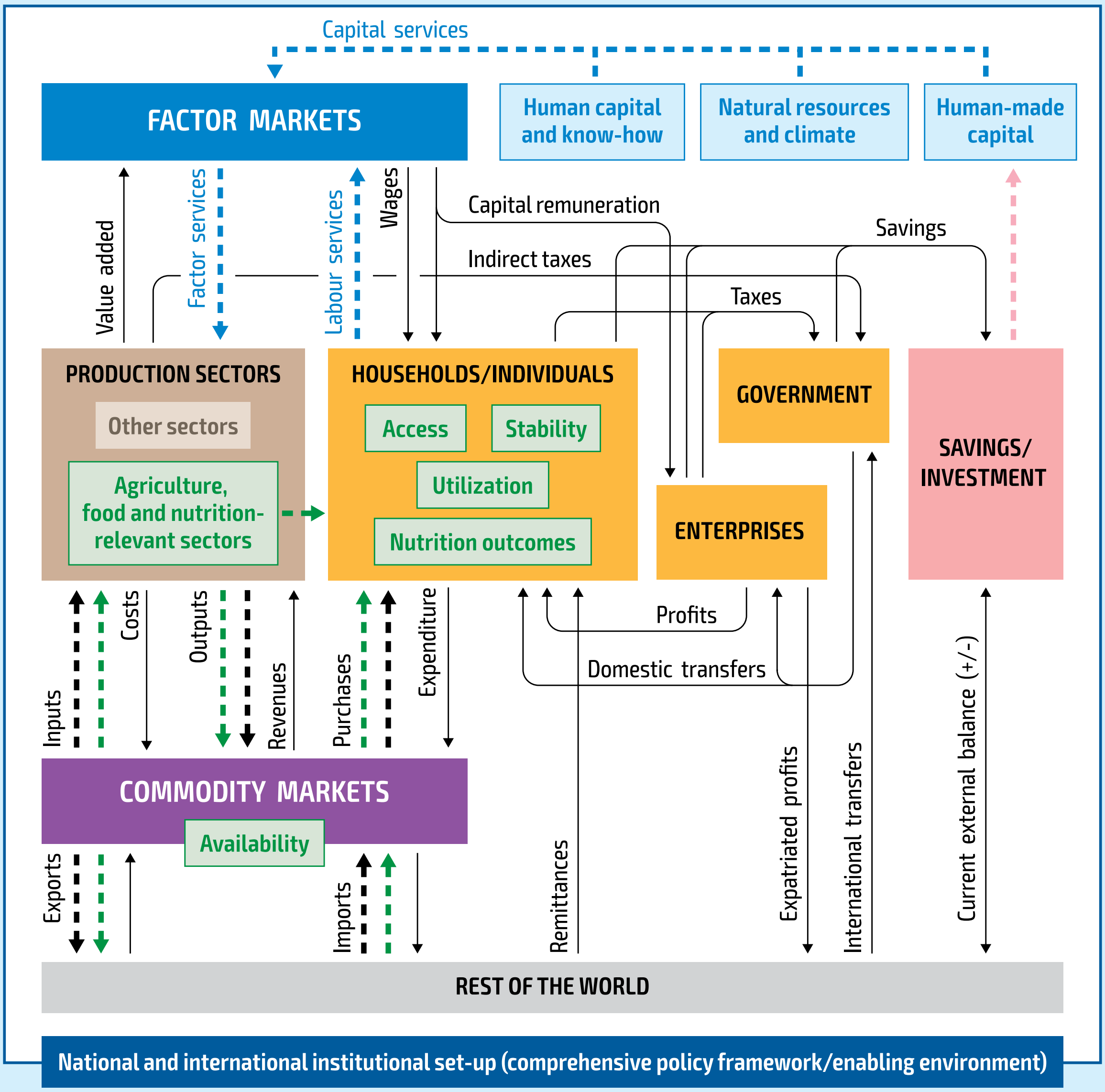
In economies where goods and services are exchanged on markets, food availability, access, stability, utilization and resulting nutritional outcomes all depend on complex interactions among diverse agents and institutions, comprising households, governments, enterprises, production sectors, foreign investors and other agents. To analyse the food security and nutrition outcomes of agrifood systems in an economy-wide context, the scenario narratives portrayed in this report take into consideration most of these interactions.

In this framework, food availability and stability at national level is ensured by domestic production and/or the ability of the country to pay for imports. Both domestic production and imports (net of exports) flow into domestic markets. The same applies for nutrition-relevant goods (cookers, energy, cleaning products, storing facilities, medicines, products for personal hygiene, etc.) and services (health care, education, know-how for food utilization, etc.).* Income ensures food access and stability at household level, as it provides the purchasing power required to buy food and nutrition-relevant goods and services, at prevailing market prices.** Income (value added) is distributed by the production sectors to households as remuneration of labour (wages) and capital services (profits, net of expatriated profits that remunerate foreign investors). Transfers from the government, such as pensions or social protection payments, and/or from citizens abroad (remittances from the rest of the world) complement household income.*** The government collects taxes from the production sectors (indirect taxes and net of subsidies), households (income and consumption taxes) and enterprises (corporate taxes), as well as taxes on transactions with the rest of the world (e.g. import tariffs and taxes on exports). The government can influence food prices through sector-specific and international trade policies, while through social and fiscal policies (income taxes, transfers, provision of public services, and social protection policies), it shifts the purchasing power of households up or down. The possibilities for a government to implement selected food security and nutrition-relevant policies depend on macroeconomic and institutional conditions, such as the

Box 2.1 (cont.) Linkages between the economy-wide system and food security and nutrition outcomes

state of its budget and/or efficiency of the fiscal system. The specific socioeconomic status of a household and its location (rural, urban or intermediate areas) contribute to determining its potential to achieve more or less positive nutrition outcomes, the earning opportunities for its members, as well as their food requirements, tastes and dietary patterns.

Figure A. Food security and nutrition in the economy-wide context



Notes: Physical flows of goods and services are represented by dashed lines, while income flows in monetary terms occurring in the opposite direction are represented by solid lines. Food security and nutrition-relevant flows and items are reported in green. Not all the flows of goods and services and countervailing payments are represented.

Source: FAO. 2018. The future of food and agriculture – Alternative pathways to 2050. Rome. www.fao.org/3/i8429en/i8429en.pdf

The capital assets required to run production activities, including food-related ones, are funded by the savings of households, enterprises, government and foreign investors. Human-made capital is complemented by the natural resource base, including land, water, biodiversity, climate and non-material capital such as know-how. The possibility for a country to domestically produce food and nutrition-relevant goods and services, or to produce other goods and services in exchange, is largely determined by its capital assets.

Box 2.1 (cont.) Linkages between the economy-wide system and food security and nutrition outcomes

Macroeconomic policies and the institutional set-up of a country contribute to determining the savings and investment potential of households and enterprises. Through savings and investments, households accumulate capital and smooth their consumption patterns, ensuring stability of food access and availability at household level, thus reinforcing their long-term food stability. The national and international institutional set-up and the quality of governance contribute to determining the overall food security and nutrition performance of a socioeconomic system.

Source: FAO. 2018. *The future of food and agriculture – Alternative pathways to 2050*. Rome. www.fao.org/3/i8429en/i8429en.pdf

* In the case of self-production, food flows directly from the agriculture sector to households without transiting through markets. The possibility for a country to import food and nutrition-relevant goods and services is constrained by its external balance which, in turn, is determined by the capacities to export, the capacity to borrow from abroad and/or benefit from other foreign flows, such as international transfers, grants and remittances.

** In the case of food self-consumption, access is ensured by the possibility to buy food and tradable inputs, and by access to land and water and the availability of agricultural labour.

*** This framework is broadly consistent with the United Nations System of National Accounts.[6]

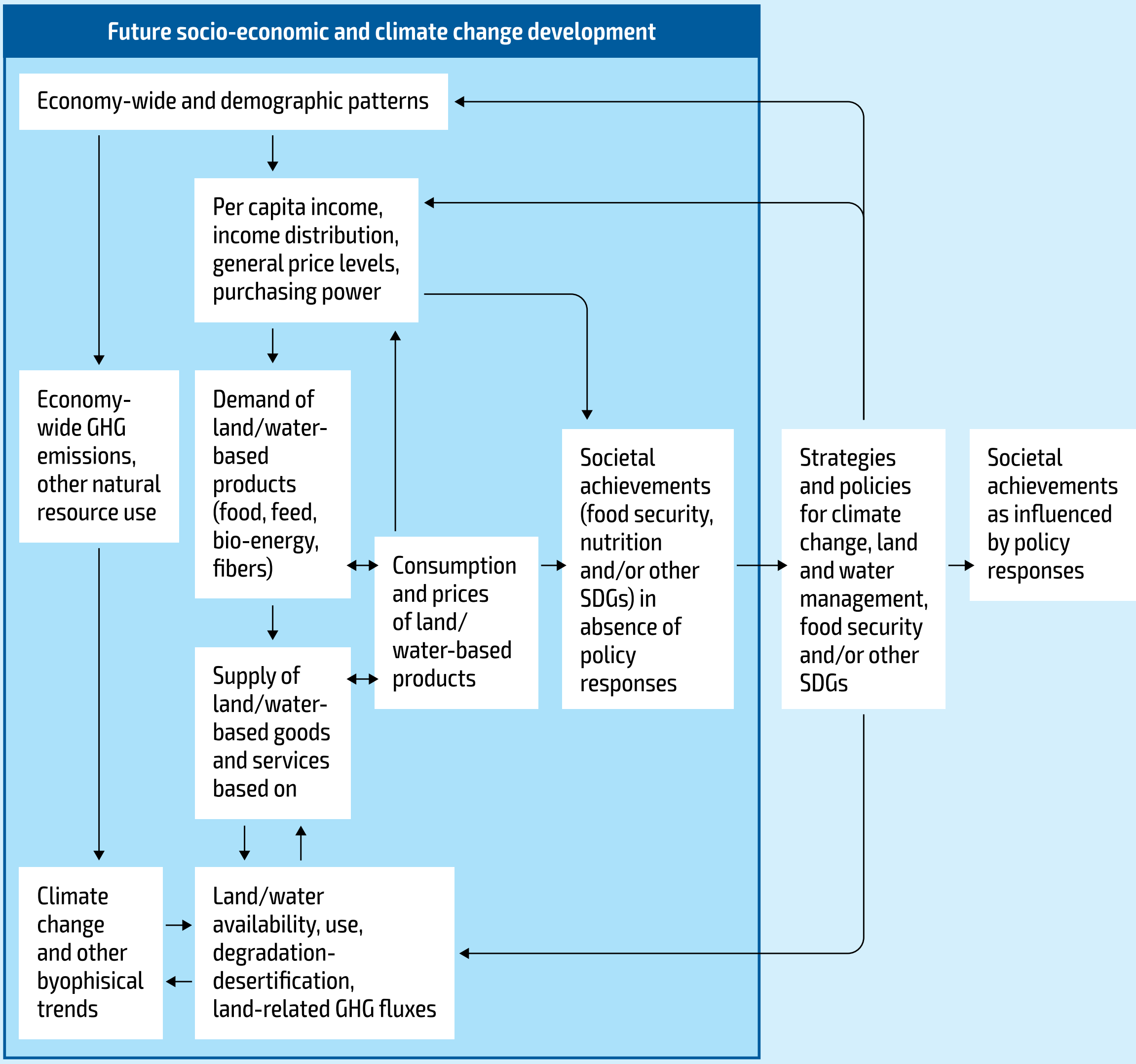
Box 2.2 Linkages between land and water, economy-wide development patterns, climate change and societal well-being outcomes

Land and water availability, and management practices are strongly influenced by socioeconomic developments and climate change which, in turn, have an impact upon the demand and supply of products that require land and water as resources. The achievement of societal goals such as food security and nutrition, as well as the creation of opportunities for income generation, equitable income distribution and several other Sustainable Development Goal (SDG) targets, are determined largely by production processes and related outputs based on land and water resources, including food, raw materials, energy and a range of environmental services. As such, the future achievement of land- and water-dependent goals will be highly influenced by how land and water quality and availability will be affected by climate change; by how technical processes to produce land- and water-dependent products will be managed; and by the extent to which development strategies and policies will move land- and water-based production systems towards social, economic and environmental sustainability. The design and implementation of effective strategies for the sustainable management of land and water resources, and the achievement of well-being goals, including food security and better nutrition, require an understanding of the cause-effect and impact interrelationships between these factors (see Figure A).

Future economic and demographic trends will determine changes in income-earning opportunities and income distribution and thus people’s purchasing power; this purchasing power will in turn condition the consumer demand for goods and services dependent on land and water resources. Economic and demographic patterns will also determine the dynamics of GHG emissions, which will affect land and water availability. The demand for goods and services based on land and water resources induces the supply of such goods and services. The land and water requirements – and thus the pressure upon land and water resources and the amount of GHG emissions produced – are influenced by technologies and management practices that impact on the productivity of land and water resources.

Box 2.2 (cont.) Linkages between land and water, economy-wide development patterns, climate change and societal well-being outcomes

Figure A. Climate change, land, water and well-being outcomes in the economy-wide context



Source: FAO. 2018. *The future of food and agriculture – Alternative pathways to 2050*. Rome. www.fao.org/3/i8429en/i8429en.pdf

The interplay between the supply and demand of land- and water-based products and services determines their actual production and consumption, as well as their prices. The achievement of land- and water-based well-being goals is thus affected by both the consumption of such products and the income generated throughout their production processes. Strategies and policies to mitigate climate change, improve land and water management, achieve food security, improve nutrition and achieve other SDG targets will influence the production processes of land- and water-based goods and services. Thus, such strategies and policies are expected to feed into economy-wide processes and influence income generation and distribution. The response of the socioeconomic agents involved in land- and water-based production and consumption processes influences the achievement of land- and water-related objectives and societal well-being targets.

Source: FAO. 2018. *The future of food and agriculture – Alternative pathways to 2050*. Rome. www.fao.org/3/i8429en/i8429en.pdf

2.3 Future scenario narratives

The four scenarios proposed are inspired by, and have been woven together from, various contributions, including: (a) data of past and recent trends of 18 drivers for agrifood systems identified and analysed in Chapter 1; (b) existing futures narratives and data projections for agrifood systems in the FAO report entitled *The future of food and agriculture – Alternative pathways to 2050*;[5] (c) prospects for agrifood systems discussed in the report entitled *The future of food and agriculture – Trends and challenges*;[7] (d) other narratives and projections, including the scenarios recently considered by the *Sixth Assessment Report I - Physical Science Basis (AR6-I)*[8] and *Report II–Climate Change 2022: Impacts, adaptation and vulnerability*[9] –of the Intergovernmental Panel on Climate Change (IPCC); (e) the findings of the External Expert Consultation on scenarios' narratives, held at FAO in November 2021, involving more than forty experts from academia, civil society, media and United Nations bodies;[10] (f) the findings of the workshop on Emerging technologies and social innovations held at FAO in April 2022;[11] (g) the FAO report *Thinking about the future of food safety*[12] and (h) FAO's aspirations catalysed in the "four betters" featured in the FAO *Strategic Framework 2022–31*:[2] better production, better nutrition, better environment and better life.[cf] The four future scenario narratives are summarized in Table 2.3.

Table 2.3 Summary of alternative long-term retrospective narratives for agrifood systems

SCENARIOS	NARRATIVES
More of the same (MOS) Muddling through in reaction to events and crises while doing just enough to avoid systemic collapses, led to degradation of agrifood systems sustainability and to poor living conditions for a large number of people, thus increasing the long-run likelihood of systemic failures.	Ineffective development strategies and policies, economic imbalances across and within countries and skewed international trade, including persisting commodity dependency of many low-income countries (LICs), resulted in national and geopolitical grievances, deteriorating social and humanitarian outcomes, and a continuous environmental neglect throughout the 2020s and beyond. Agrifood systems kept struggling to satisfy an increased food demand as a result of the persistence of conventional agricultural practices that eroded the natural resources base. Dramatic crop yield improvements that materialized during the second half of the twentieth century turned out to be unsustainable in the long run. On the demand side, diets had been only marginally rebalanced to limit reliance on resource-intensive food, rich in animal products. Short-termism and the belief that it was possible to solve issues without questioning the prevailing development paradigm based on fossil energy and power concentration, drove most decisions in the majority of countries and at the global level. Key social and environmental trade-offs were left unaddressed, with no progress made on poverty and hunger eradication. Global corporations continued to prioritize shareholder profit as their primary bottom-line indicator and their fiscal elusion kept jeopardizing public budgets and actions. Public-private partnerships (PPPs), quite fashionable in the 2020s, could have had some potential for transformation, but were mostly ill-conceived and not monitored, so they mostly ended up becoming "green-washing or social-washing" devices. As a consequence, the 2030 Agenda and the "four betters" were substantially not achieved by 2030, and the few temporary successes were disproportionately distributed. During the subsequent decades, issues related to climate change, including weather extremes, economic downturns, conflicts and mass migrations, did not allow for any further progress, but rather led to further degradation and high risks of systemic failures.

[cf] For an overview of the relationships between the scenario narratives presented here and other foresight exercises, see Section 2.5.

Table 2.3 (cont.) Summary of alternative long-term retrospective narratives for agrifood systems

SCENARIOS	NARRATIVES
Adjusted future (AFU) Some moves towards sustainable agrifood systems were triggered in an attempt to achieve Agenda 2030 goals and some improvements in terms of well-being were obtained, but the lack of overall sustainability and systemic resilience hampered their maintenance in the long run.	Efforts towards adjusting some drawbacks of the development paradigm prevailing in the 2020s ensured some successes in terms of access to basic services, food security and nutrition. Some civil society movements temporarily succeeded in pushing governments to engage in multilateral agreements aimed at addressing issues that required global governance, such as mass migrations and blatant inequalities across and within countries. Some governments, in a quite timid last-minute attempt to meet selected SDG targets, tried to tackle the most urgent economic, social and environmental trade-offs and adopted fiscal policies to fund social protection measures, as well as modest GHG emissions measures and trade regulations. Agrifood and socioeconomic and environmental systems at large could have benefited from such interventions. However, piecemeal approaches, conflicts of interest among public decision-makers subject to the pressure of private lobbies, did not allow for the achievement of more resource-efficient food production or for a substantial internalization of environmental externalities, or the implementation of disincentives for consumption of resource-intensive food. PPPs contributed in some instances to progress towards SDGs, but in several others, they revealed themselves to be only "green-washing or social-washing" devices, as was spotted by a few civil society movements, while systemic governance weaknesses persisted at all levels. Therefore, although some well-being-related SDG targets and "betters" had been achieved in the aftermath of 2030, agrifood and socioeconomic and environmental systems at large failed to transform and ensure maintenance of these achievements in the subsequent decades.
Race to the bottom (RAB) Gravely ill-incentivized decisions led the world to the worst version of itself after the collapse of substantial parts of socioeconomic, environmental and agrifood systems with costly and almost irreversible consequences for a very large number of people and ecosystems.	Societies had been progressively structured in separate layers where self-protected elite classes, i.e. groups of wealthy individuals with transnational interests, held a strong decisional power and largely influenced sovereign governments. To preserve their interests, various means, differently blended depending on the institutional set-up of the different geostrategic blocks, had to be increasingly used in order to manipulate and control people, including ideological propaganda, the myth of good versus evil, the creation of external enemies, more traditional "command-control-punishment" instruments associated with pervasive social media restrictions and remote surveillance. Both agrifood technologies and consumer preferences had been increasingly shaped to satisfy the needs of business oligarchs. They not only disregarded natural resource conservation and climate change, but also maximized their surplus extraction from domestic and international agrifood value chains by ignoring diversification and resilience. In this context, PPPs became an element of deceptive narratives about development and played a mere "green-washing or social-washing" temporary function. In addition, the lack of social cohesion, citizens' limited awareness, the increasing dependency of most sovereign countries on oligarchies had left ungoverned global issues, such as climate change, pandemics, energy transition, big data generation and control, international capital flows and migrations. A series of consecutive economic crises, exacerbated inequalities and widespread poverty worldwide, and fuelled instability, civil wars and international conflicts. Ineffective or lacking multilateral cooperation at all levels along with diverging interests of leaders of geostrategic blocks engendered conflicts at a global scale, leading to the collapse of substantial parts of socioeconomic, environmental and agrifood systems. Famine, forced mass displacements, degradation of natural resources, loss of biodiversity and ecosystems' functions, and emergence of new pandemics, as well as nuclear and bacteriological contamination, were just signs of a world in complete disarray. By 2030, most SDG targets and the "four betters" were far from being achieved and by 2050, they had become a remote dream.

Table 2.3 (cont.) Summary of alternative long-term retrospective narratives for agrifood systems

SCENARIOS	NARRATIVES
Trading off for sustainability (TOS) Awareness, education, social commitment, responsibility and participation triggered new power relationships and shifted the development paradigm in most countries. GDP growth was traded off for inclusiveness, resilience and sustainability of agrifood, socioeconomic and environmental systems.	New power relations, systems and actors emerged during the second half of the 2020s, thanks to civil society movements that progressively increased individual awareness and social commitment towards sustainable development at large. Distributed and participatory power and governance models gradually took over and complemented, or partially replaced, other power relationships based either on "command-control-punishment" mechanisms – typical of autocratic governments – or on the enormous influence of big transnational companies able to steer formally democratic sovereign governments. At world level, this brought about the reshaping of the institutional structures created in the aftermath of the Second World War and of the global development paradigm that ensued and prevailed in the last part of the twentieth century and during the first decades of the current century, based on narrowly defined GDP growth. As a result, multi-stakeholder national and global governance systems became much more effective in conducting global transformative processes. Thanks to these forces, before 2030, governments implemented strictly targeted social protection policies that significantly improved the quality of life of most vulnerable layers of societies. The immediate well-being of all the other citizens was traded off for longer term investments in sustainable production processes, energy transition, GHG reduction, and natural resource conservation and restoration, which paid back before 2050, also thanks to some well-designed and closely monitored PPPs. Agrifood systems largely contributed to the overall socioeconomic and environmental transformation. Small and commercial farms and multinational corporations progressively adopted more sustainable technologies for food production, integrated multi-output energy and agrifood processing and the generation of remunerated environmental services. Concurrently, consumers, starting from those in high-income countries (HICs), shifted away from excessive consumption of energy- and natural resource-intensive animal products also because of increased food prices that fully reflected production costs, including social and environmental ones. Paradoxes, disparities, uncertainties and challenges had not disappeared, but they played out differently because well-educated citizens had developed critical thinking, had become much less prone to manipulation, more aware of trade-offs that emerged in development processes, and readier to engage in addressing and solving them. Although, by 2030, the "four betters" had not yet materialized fully, solid bases had been built that led to full achievement and maintenance in the subsequent decades.

Source: Authors' elaboration.

In the following subsections, each narrative of an alternative future is explored by investigating how key domains relevant to agrifood systems would develop under that scenario. Some domains considered pertain to the context within which agrifood systems develop, comprising geopolitics and power, economic growth and employment, demography, and resources and climate. Others pertain more specifically to agrifood dynamics, technologies and investment. A further domain considers how agrifood systems would contribute to determining socioeconomic outcomes, such as poverty reduction, inequalities, food security and nutrition.

2.3.1 More of the same

Geopolitics and power. The world shifted from a unipolar to a multipolar system and a more uncertain international set-up, while the order established after the Second World War and adjusted after the fall of the Soviet Union, gradually weakened. While power transitioned among states, substantial power also shifted from sovereign governments to transnational corporations or, in some hotspots, to criminal gangs benefiting from international trafficking. Development strategies and policies based on fossil energy and power concentration that had been ineffective in dealing with global issues of the twentieth century continued to drive most decisions in a majority of countries, feeding national and geopolitical grievances, deteriorating social and humanitarian outcomes and perpetuating environmental neglect. Given the permanent geo-economic tensions, coordinated responses to some of the most serious global environmental, social and humanitarian crises showed very limited effectiveness. Violent conflicts, including international ones, peaked. As a causal anticipation, military expenditures progressively increased, diverting budgets from the provision of public goods. Major powers formed mutually competing blocs and spheres of influence characterized by centre-periphery asymmetries, which undermined multilateralism and macroeconomic coordination. Localized conflicts and violence rose because of power transitions and adjustments, in combination with increased competition for resources, water and energy in particular. While states focused on controlling territories, transnational corporations and oligarchs appropriated global resources and income. A hardening of border defenses occurred to deal with mass migrations, while incentives for authoritarian or less democratic regimes, in collusion with multinationals and oligarchs, grew.

Economic growth and employment. Fossil fuel-led GDP growth continued despite an alleged "green" transformation. The same development strategies elaborated under short-termism pressures, continued to produce the same economic imbalances across and within low- and middle-income countries (LMICs) and HICs; a skewed international trade and persisting commodity dependency of many LMICs induced by foreign investors, interested in maximizing their own profits instead of the resilience of agrifood and socioeconomic systems. In any event, social well-being and environmental sustainability were traded off for economic growth. It progressively featured as "immiserizing, jobless growth". A rampant gig economy characterized by underpaid precarious jobs, the continuous drainage of wealth by illicit financial flows, decreased revenues from remittances, along with increasing budget deficits resulting from military expenditure and ad-hoc social protection measures attempting to offset such structural trends, fuelled compounding social crises throughout decades. At the same time, economic growth in the poorest regions was disproportionately affected by climate change and related environmental degradation. Millions of people lost or did not find jobs and were displaced by climate- and weather-related events. Biodiversity loss, pollution and conflicts, all gave rise to new unforeseen or neglected challenges.

Demography. By 2050, the global population reached slightly less than ten billion, following a pattern that would lead to close to eleven billion by the end of the century.* In HICs, the population became older because of both improvements in health as well as economic and environmental difficulties that affected birth rates. Thus, the world's demographic centre of gravity progressively shifted towards LICs, notably in urban areas. In HICs, private health care companies thrived while pension systems struggled, thereby forcing governments to extend the retirement age, increase spending on pronatalist programmes, downsizing welfare programmes and managing immigration to fill jobs that had not been automatized yet. Despite this policy mix, HICs had to face a long baby bust period.

Providing employment to youth, particularly in sub-Saharan Africa (SSA), was challenging because the development of industries and services did not occur fast enough to offer decently remunerated jobs to new urban dwellers and cohorts of new youth. Globally, rural populations still made up the majority of the poor, however, urban poverty dramatically increased, particularly in SSA.

Resources and climate. Concerted multilateral attempts to restore natural resources, protect biodiversity and address climate change proved to be of limited effectiveness. Competition for natural resources intensified as a result of demographic growth and the shift towards more resource-intensive diets with consequential natural resource degradation, yet further affecting the climate.

Global arable land requirements increased despite improvements in crop and animal yields, while a non-marginal share of very suitable arable land was lost because of urbanization and degradation. This resulted in losses of ecosystems services, and biodiversity further shrank because pollution from chemicals and disruption of natural habitats had been neglected.

More intense competition for natural resources increased particularly in some export-oriented, commodity-dependent LICs, while in others weak governance prevented the adoption of resource-saving technologies.

Deforestation, resulting from the expansion of agricultural land, hampered the provision of forests' environmental services, while depletion of marine resources by unsustainable fishing affected capture in the long run. Increased competition for water came from greater demand from agriculture, manufacturing and households. GHG emissions from agrifood production and other activities rose because of unenforceable, non-binding multilateral agreements, despite efforts made by some countries to hold to the latter.

Unsurprisingly, climate change accelerated. It became mostly unbearable in the second half of the century, with global warming reaching slightly less than 4 °C by 2100 and when sea levels rose catastrophically with losses of huge, fertile coastal areas. Higher temperatures and extreme weather events brought comparatively lower crop yields; lower quality of biomass produced by rangeland and pastures; alteration of forests and ecosystems' dynamics; higher incidence of crop and animal pests and diseases; reduced nutritional quality of food produced; and loss of aquatic systems' production capacity and subsequent large-scale redistribution of marine fish resources. Being a major driver of food insecurity, climate change has continued to be one of the three main factors in hunger and malnutrition trends. By way of consequence, scarcity and degradation of natural resources and climate change had seriously started to jeopardize agrifood supplies well before mid-century, as climate extremes and related natural disasters kept contributing to significant displacements, including forced ones, as populations moved in search of new land, water and food, fuelling social unrest and conflict.

Agriculture. Monoculture and reliance on a reduced number of species, and within species, varieties, prevailed despite some pioneer attempts in the first decades of the century to adopt integrated agroecological and agroforestry approaches that exploited synergies between various crops and livestock, used organic fertilizers and adopted integrated pest management (IPM).

The different standards in the various countries regarding pesticides and herbicides were enforced at production level only, thus setting in motion unfair competition and the dumping of low-quality food in more strictly regulated countries.

Intensive livestock systems with low genetic diversity, exposure of livestock to wildlife, ineffective management and biosecurity measures together with delayed interventions in cases of outbreaks, exacerbated antimicrobial resistance, zoonotic infectious diseases, and epidemics and pandemics, thus aggravating the distress of health care systems, already weakened by frenzied privatizations.

Fisheries production and consumption grew faster than it had in the past. Increasing demand for fish and the deterioration of management standards sustained this growth, increasing the threat to biodiversity. Marine capture in fact decreased from around 85 million tonnes in the 2020s to 65 million by mid-century, owing to deteriorating stocks. In the same period, with no technological improvements and no loss and waste reduction, marine capture not used for direct human consumption remained well above 21 percent, as it was in 2020s. These interrelated trends fostered intense competition between countries, which have made national resources and food supply issues of top priority with regard to national security.

The use of plastic intensive packaging and antimicrobial additives expanded in an attempt to ensure food safety. Over time, consumption patterns favouring animal-based and ultra-processed foods outweighed the more sustainable consumption trends supported by activists, consumer movements and associations.

Therefore, agrifood systems struggled to satisfy an increased food demand with conventional agricultural practices that had already eroded the natural resources base. The expansion of production did not offset the pressure from demand, also because of unadjusted preferences towards animal-based products in HICs resulted in significant increases in food prices.

Technology and investment in agrifood systems. Science progressed and supported innovation, however, with investment in research and development being concentrated in a few HICs. Other investment was mainly in physical capital and IT equipment, induced by growing capital and information intensity. The financialization of agrifood systems continued. Much less domestic investment occurred in LMICs, because of lower savings and higher risks, while foreign direct investment (FDI) mainly focused on land grabbing and few export-oriented value chains. The official development assistance (ODA), on the other hand, decreased as a result of the lack of political backing for such measures in HICs.

A fragmented and ever more competitive multipolar system facilitated the acceptance of doubtful biotechnologies, owing to neglected precautionary principles and weak global regulations. Agroecological and other environment-friendly approaches were developed only to a limited extent, mostly as a result of efforts made by local authorities, consumers and citizen initiatives. Technological solutions had the potential for addressing some trade-offs between increasing output and safeguarding natural resources, such as precision agriculture that limited the use of inputs and reduced yield losses resulting from the early detection of pests and diseases.

Artificial intelligence (AI) and machine learning facilitated agricultural robotics, soil and crop monitoring, while blockchain applications and predictive analytics improved data-driven decision-making. However, the few investors controlling these technologies had no incentives to transfer or adapt them to multi-cropping or small-scale systems. Data harvesting, storing and processing were controlled by few monopolistic, global big data platforms. Owing to robotization, decreased labour requirements and in spite of the creation of new job categories, there was a net job loss. Employment and income distribution were traded off for automation, thus forcing people to look for jobs in other sectors which, incidentally, were undergoing the same capital intensification processes.

Digitalization, e-commerce, connectivity and social media also involved consumers, who traded off personal data for apparent convenience, thus increasing the monopolistic power of global big data platforms, able to manipulate individual preferences. Agrifood data became a national security matter, but most governments could not implement effective legal, ethical and technical big data governance frameworks. This was partly because international organizations, increasingly influenced by private interests, did not support them. Additionally, cyberattacks on critical national infrastructure, widespread remote surveillance and the subversion of democratic institutions all became significant challenges.

In this context, public investment in agrifood systems and the provision of broader public goods, which could have offset the above-mentioned drawbacks, kept progressively shrinking, as already observed in the first decades of the century, because of public short-termism, privatization of public utilities, and budget constraints following difficulties in raising taxes resulting from systematic corporate fiscal elusion.

Overall, the lack of sound diagnoses on the issues at stake, replaced increasingly by a focus on technological means rather than on goals, led to missing out on innovations in governance, institutions and social spheres, thereby hampering the transformation of agrifood systems.

Poverty, inequality, food security and nutrition outcomes. The decreasing poverty trend observed in the first decades of the century proved to be fragile and temporary. In LMICs, poverty in agrifood systems was fuelled by lack of land distribution and access, low wages resulting from persistent excess labour supply and the asymmetric contractual power of small producers vis-à-vis domestic and foreign investors. In HICs, the shrinking wages due to the declining power of trade unions reinforced the cohorts of the so-called “working poor”.

As a result of ineffective regulations, both in LMICs and HICs dysfunctional financial institutions drained small savings of poor that could have triggered capital accumulation processes and profit generation to replace shrinking wages due to capital intensification. As a consequence, capital ownership increasingly concentrated everywhere.

The global income inequality reduction observed up until the 2020s, led by some big lower-middle-income countries, was hampered by the unsustainability of their development. The increasing within-country income and wealth inequality grew even further in some countries as a result of the many economic shocks that hit the low and middle classes the hardest, while the income share of the top 1 percent continued to increase. This fuelled social unrest and anti-immigration protests by poorer classes, particularly in HICs. Corporate tax allowances prevailed for fear of losing investments and job creation. Women, children and Indigenous Peoples continued to be among the poorest people living in both LMICs and HICs. Pandemics, such as COVID-19 in the 2020s, highlighted that successes in reducing hunger obtained in the previous years were not resilient to shocks. Thus, the number of people who experienced food insecurity steadily rose both in absolute and relative terms in LMICs and, later on, also in HICs. The lack of purchasing power for healthy diets was very closely associated with inadequate nutrition as were obesity rates resulting from the consumption of cheap "junk food". Whereas nutrition improved in the first decades in some big middle-income countries, the increased consumption of meat and dairy products, processed food and beverages rich in salt, fat and sugar, also contributed to keeping rates of adult obesity and incidence of non-communicable diseases on the rise.

* This scenario broadly refers to the UN-medium variant projection estimates[13] correspond to the median of several thousand distinct trajectories of each demographic component derived using a probabilistic model of the variability in changes over time. Lower population estimates (closer to the UN-low variant), which reach a tipping point close to nine billion at mid-century and then slightly decline in the second half of the century, are associated to SSP2 and SSP4 scenarios in *The human core of the shared socioeconomic pathways: Population scenarios by age, sex and level of education for all countries to 2100*.[14]

2.3.2 Adjusted future

Geopolitics and power. The world went through a shift from a unipolar to a multipolar setting. Multilateralism, intended as internationally agreed ways of addressing common issues, improved to some degree but not enough to be able prevent, rather than react to, humanitarian crises. Some tensions and confrontations among superpowers, resulting in potential conflicts in peripheral countries in their spheres of influence, were kept under control. As a result, the number of conflicts and forced displacements did not increase although some localized violent conflicts persisted where national and regional pressures, e.g. population growth, weak states and resource scarcity, encountered global challenges such as climate change.

Particularly in the second half of the 2020s, when the probable failure of Agenda 2030 became apparent, multilateral institutions managed to agree and act on limited but immediate social targets. Military expenditure did not drop, but some governments, sensitive to pressures from civil society, relocated parts of its planned increases to sustainable development, including public research and development for sustainable agrifood systems, to increase resilience against pandemics and, to a limited extent, to addressing climate change issues.

The excessive power of big transnational companies, able to steer governments, and of a few oligarchs who managed to appropriate enormous wealth through unregulated financial mechanisms or other illicit systems, becomes apparent as some civil society movements everywhere, supported in some instances by academic research and few independent media investigations, spotted some of the most blatant abuses. The so-called "public-private partnerships" (PPPs), very fashionable in the 2020s, in some instances actually contributed to progress towards SDGs but in many others, as highlighted by civil society movements, were revealed to be no more than "green-washing and social-washing" devices. In a few countries, the political economy challenges of passing transformative agrifood policies through lobbies, parliaments and citizens were addressed. In many others, however, conflicts of interest between public decision-makers and private lobbies prevented substantial changes. Overall, despite some attempts to rebalance corporate power to the advantage of sovereign governments and civil society, fundamental asymmetries persisted, together with systemic governance weaknesses at all levels.

Economic growth and employment. Despite structural power imbalances around the globe, quick fixes improved the well-being of most vulnerable people, both in LMICs and HICs, and proved that a transformation towards a fairer socioeconomic development was possible. This process was triggered in the second half of the 2020s by the mounting evidence that Agenda 2030 would not be achieved. A mix of redistributive policies previously experimented in a few countries served as "canaries in a coalmine" for other countries to follow, addressing the most striking inequalities, such as hunger, extreme poverty and basic health care services, particularly in LICs.

With labour-saving AI innovations based on digitalization, the problem of excess labour supply emerged. Universal basic income programmes in selected countries smoothed the social impacts of job losses resulting from automation and a few new "green jobs" emerged. However, capital and information intensification of production processes further concentrated capital ownership.

Redistributive policies supporting incomes, both in HICs and LMICs, continued as a few timid attempts to tax transnational corporations and "robot-taxes" allowed for an increase in the fiscal space to a certain degree. Illicit financial flows to fiscal havens decreased, but weak global governance prevented them from being fully fixed. Most countries were indeed too small to influence these global dynamics. Short-term economic well-being improvements were not supported by structural fixes.

Civil society movements, both in HICs and LMICs, kept pressuring governments to engage in multilateral agreements to address global issues such as fiscal, environmental and social dumping ensuing from the unduly competitiveness of unregulated countries, capital and information-intensive economic growth, migrations and inequalities across and within countries. Widespread access to capital, which could have compensated the loss of jobs resulting from automation did not materialize at all. Despite the push for decarbonization after repeated global energy crises negatively affecting the GWP, under the influence of "big oil" most governments did not trade off short-term growth for long-term resilience. Much was left to be done on labour regulations, contractual frameworks and minimum wages to make short-term efforts to improve income distribution sustainable in the long term.

Demography. Growing population trends were somehow mitigated by policies and improved well-being, although population growth remained a major factor contributing to an increased demand for food, which remained a challenge for agrifood systems. On a positive note, some jobs in rural areas were created through diversification of activities within and outside the agrifood systems. In addition, some efforts were made to regulate access to natural resources and reduce unfair competition resulting from the asymmetric power of major foreign corporations vis-à-vis medium- and small-scale domestic investors and local populations. However, particularly in regions where population was growing at a faster pace, challenges of access to resources persisted. Some mindful governments both in LMICs and HICs attempted to reinforce the network of secondary cities and medium and small towns to mitigate the negative impacts of unregulated urbanization that occurred in the first decades of the century as well as improve rural–urban linkages for agrifood systems. As a consequence, megacity expansions were somewhat dampened.

Resources and climate. The challenge of food production pushed civil society movements, both in LMICs and HICs, to demand more resource-efficient, resilient and climate-friendly agrifood systems where food sovereignty and local food agency could be accommodated. In that vein, some global partnerships, supported by international organizations, were led to identify selected resource-saving technological innovations that were adopted in some countries, including some LICs. As a result, the trend of degradation of natural resources, biodiversity, soils, water, air and ecosystems services at different levels slowed down in some localized spots, thus creating examples of good practices to follow. Unfortunately, a failure to adapt and scale up such approaches across countries and continents drastically reduced their impacts at global level.

Despite a higher awareness of civil society in many countries, governments, influenced by private corporations, failed to agree on a global strategy for cutting GHG emissions from agrifood systems. In some countries, youth movements managed to set an example and consumers reduced fossil fuel consumption. Overall, global warming would reach slightly less than 3 °C by the end of the century, with negative long-run impacts on food production.

Agriculture. The most striking drawbacks of conventional agricultural practices became apparent, and it was no longer possible to continue moving along a "business as usual" pattern. Monoculture still prevailed, particularly in commodity-dependent, export-oriented LICs. However, in other LMICs, where the pressure from foreign investors and immediate forex needs were lower, and in selected HICs, multi-cropping and integrated crop-livestock systems based on agroecology, organic and "circular economy" approaches were attempted. Animal pest and disease management was more coordinated across countries, a change from the trend that had led to pandemics in the past. Although these efforts led to some improvements, they failed to introduce structural changes in agriculture at global level. Intensive livestock systems, with low genetic diversity, and which in many instances encroached into wilderness areas and were exposed to wildlife, prevailed. Antimicrobial resistance still remained an unresolved challenge as antibiotics were still widely used on livestock and in aquaculture. Foodborne diseases and pesticide poisoning were barely under control.

Some attempts occurred to negotiate common rules in multilateral fora to trade off economic and social viability of agrifood systems with the conservation of natural resources. However, most governments, being aware that even a partial implementation of such agreements would have brought further increases in food prices, withdrew because of concerns about immediate food security objectives and environmental dumping from unregulated countries.

Governments negotiated multilateral rules and prioritized sustainable fisheries. By mid-century, marine capture only slightly grew compared to the 2020s, owing to very timid conservative policies. With little technological improvements and only slightly reduced loss and waste, marine capture not used for direct human consumption very modestly shrank in the same period. However, selected powerful transnationals convinced LICs to sign unfair fishing agreements by promising "easy money". Some countries moved towards sustainable aquaculture but environmental dumping by others led them to fail.

In some HICs, and to a lesser extent in some LMICs, consumer movements pushed for transitioning towards the consumption of more sustainably produced, less resource-intensive food. Some food companies, including a few transnationals, gradually adjusted their supply to these consumer preferences but many other companies, including some big transnational companies, managed to steer mass consumption towards highly processed resource-intensive food items, by organizing targeted media campaigns using big data gathered through social networks.

Technology and investment in agrifood systems. Science, innovation and technology contributed to divert agrifood systems from what was "business as usual" and eliminate the risk of an otherwise quite likely collapse. Indeed, although the emphasis put in the 2020s on selected innovations such as digitalization proved to be in some way excessive, some applications proved to be very useful. For instance, soil, crop and animal monitoring through remote sensing and other Internet of Things (IoT) applications supported agricultural automation, robotization and machine learning. Predictive analytics favoured data-driven decision-making, while some blockchain applications permitted an improvement in the transparency of commercial and financial transactions, and precision agriculture improved input and resource efficiency. However, because of persisting asymmetries across countries and agrifood system agents concerning knowledge, capital, information and data ownership, as well as delayed technology transfers aimed at maintaining dominant positions, digital technologies based on big data, AI, IoT, etc. favoured different people to very different extents, thus fuelling inequalities.

To quickly ensure affordable healthy diets under the pressure of achieving at least some Agenda 2030 targets, LMICs became the target of attempts to increase land and water productivity through strong genetic manipulations. However, because of insufficient testing and lacking knowledge on systemic implications, most of them proved to be unsustainable or brought undesired side effects, and thus had to give way to other more controllable biotechnologies.

Although AI and robotization created new job categories in the agrifood sector and in rural areas, this was by far not enough to achieve the widespread integration of the rural population in agrifood systems, and many people had to move to urban areas to look for jobs in other sectors.

Unfortunately, also other sectors underwent the same capital and information intensification. Therefore, despite a reduction in daily working hours and the creation of new jobs, unemployment grew.

It was only in some LMICs that capital and information-intensive digital innovations brought actual widespread benefits, owing to public investment on productivity-enhancing research and development that created public goods and stimulated private investment; controlled PPPs set within strong institutional frameworks that ensured symmetric information, granted balanced bargaining power and avoided privatizing benefits and socializing losses.

In many other countries, including most HICs, regulations to ensure widespread technology-induced benefits, digital data protection and ownership were still limited. Concurrently, global agreements on legal, ethical and technical governance frameworks for big data, AI and digital technology uses and ownership were still lacking.

On the one hand, the capital and information intensification of agrifood production and distribution processes reinforced the concentration of market power, thus generating asymmetries and inequalities that in the medium and long run, negatively affected the inclusion of large layers of societies. On the other hand, the lacking general adoption of systemic agrifood approaches, such as multi-cropping, organic agriculture, agroforestry and agroecology, as well as unequal investment across countries and neglecting to remunerate environmental services all combined to prevent a full transformation.

Poverty, inequality, food security and nutrition outcomes. During the 2020s, when it became clear that the bulk of 2030 Agenda would be out of reach, both HICs and LMICs governments, in an attempt to achieve at least those targets concerning the most striking social injustices and inequalities, concentrated their efforts on SDG 1 and SDG 2 targets related to well-being. In LMICs, investments in well-targeted social protection policies, made possible by concessional loans, targeted grants, and modest ODA increases, were able to counteract the social impacts of increasing inequalities and the consequences of conflicts and extreme weather events, thus reducing hunger and extreme poverty. In HICs, some fiscal space gained through the timid profit taxation of information and communication technology (ICT) transnationals and "big oil" allowed for some ODA funding, and for some redistributive policies that counteracted, at least to some extent, the impact of the COVID-19 pandemic, the mounting inequalities resulting from a growth in joblessness and the rampant gig economy, thus reducing somehow social vulnerabilities. The poverty "miracle" required to meet the 2030 Agenda did not occur but, overall, poverty, hunger and food insecurity decreased. Therefore, some SDG targets and "betters" were closer to being met in the aftermath of 2030, although healthy diets remained a dream for billions of people. Production processes and societies did not undergo substantial transformations. Capital and information remained concentrated, power asymmetries across HICs, LMICs and layers of societies were not tackled, and climate change mitigation measures were not substantially implemented. Hence, these achievements proved to be not resilient in the long term. Overall, many opportunities had been identified and some of them were converted into actions, demonstrating that a truly transformative future for agrifood systems was possible, but many others were simply neglected and squandered.

2.3.3 Race to the bottom

Geopolitics and power. Societies had been progressively structured within separate layers where self-protected elite classes, i.e. groups of wealthy individuals with transnational interests, held a strong decisional power and largely influenced sovereign governments. While elites mutually interacted through integrated financial systems, the geopolitical blocks existing at the beginning of the century, characterized by typical centre-periphery relationships, became consolidated. In order to reinforce their power, elites used various and differently blended means depending on the institutional set-up of each geostrategic blocks, to manipulate and control people, including ideological propaganda, the myth of good versus evil, the creation of external enemies, and more traditional "command-control-punishment" instruments associated with pervasive marketing, social media restrictions and remote surveillance. International organizations, the only institutions with the potential to question this situation, were progressively influenced and diverted from their original goals through underfunding of regular programmes, thus forcing them to embrace private foundations providing conditional funds, fictitious public-private global partnerships and the creation of a *façade* of global alliances of various sorts, firstly paralleling and then progressively replacing them. Eventually they became fully ineffective, thereby complying with the self-fulfilling prophecy of their ineffectiveness. A vicious circle of fragmentation, authoritarianism, erosion of democratic values and shrinking public goods increased insecurity worldwide. Terrorism, regional and national conflicts, coupled with the threat of growing criminalization and corruption, in a world where the trafficking of drugs, weapons and people, proliferated across paradoxically rigorously policed, yet porous, borders. In this context, defence spending steadily increased as public opinions were deceived by the narrative that "hard power" was vital to survive in a world "in disorder". The number of nuclear-armed states rose as also did investment in chemical, biological, tactical nuclear and electromagnetic pulse weapons. In fact, this further diverted public funds, reinforced the dependency of sovereign countries on oligarchies piloting the military sector and increased the risks of generalized conflicts. Public opinions, more than governments and elites themselves, were pushed into the "Thucydides Trap" of believing that a conflict among superpowers would have eventually been unavoidable. Elites in the various blocks saw this as an opportunity to rearrange global power relationships. Several regional clashes over control of resources (energy, minerals, land, water, etc.) generated massive, forced displacements and mass migrations, owing also to the use of biological and tactical nuclear weapons. Hence the risk of escalation into a nuclear third world war dramatically increased.

Economic growth and employment. While the colossal aspirations for a better quality of life grew stronger because of the added expectations of citizens in LMICs, the hugely skewed economic growth in the first decades of the century, followed by decades of recurrent deep global economic crises, would have largely disappointed them. In fact, financial competition and fear of losing investment capital and associated jobs continued to discourage governments from billing the richer classes. In this context, rent-seeking from transnationals, including in agrifood systems, was exacerbated. Very weak institutions at all levels allowed their power accumulation and extraction of huge rents from agrifood value chains, while wages and job security were sacrificed. Recurrent economic crises, driving severe recessions, pandemics and high unemployment led to massive migrations from LICs that fuelled nationalist and anti-immigration political movements.

In HICs, redistributive economic policies and the direct provision of fundamental public goods such as education, health care, safety and justice, which had made it possible to generate widespread well-being in the past century, progressively shrank whereas in most LMICs, they did not occur at all. People, whether backed or induced by the media, shifted their focus from sustainability to survival. Critical civil society almost disappeared under the urgency of addressing internal or external security problems, and governments and businesses allied to impose on citizens what was 'good' for them. The control of few big superpowers over LICs increased to secure agrifood, mineral and energy supplies. LICs shaped their economies accordingly, thus preventing effective diversification and resilience. Exacerbated geostrategic tensions and conflicts over resources control led to dramatic increases in military expenditures, thus not only diverting resources from social protection programmes and the provision of public goods, but also causing public budget collapses in many countries. Fossil fuel subsidies remained massive across the world, which deterred transition to renewables. The blame game on which countries were more historically responsible for the exponential rise in GHG emissions continued, fuelling the “race to the bottom”.

Demography. The geopolitical, social and economic relative order has been spiralling downwards. Populations and governments lost the grip that had previously helped maintain a business as usual environment. In the first decades of the century increased, widespread poverty pushed birth rates down, particularly in LICs. This downward spiral created abundant circumstances for humans to perceive the worst possibilities and to act pessimistically, thereby contributing to a self-fulfilled prophecy. Chaotic urbanization and mass migrations ensued. In the second half of the century, booming child mortality and reduced life expectancy in several parts of the world started to significantly limit population growth.

Resources and climate. A world in progressive disarray incentivized governments and corporations to disregard long-term environmental and climatic consequences. As elites succeeded in maximizing short-term rent extraction from agrifood systems, biodiversity dropped while export-oriented mono-crop agriculture expanded in many LICs. Extensive agricultural encroachment into wilderness areas further degraded forests and contributed to the increasingly frequent emergence of zoonotic infectious diseases and ensuing pandemics. Careless use of drugs in intensive livestock production systems aggravated antimicrobial resistance, and unsafe food and water were responsible for hundreds of millions of foodborne diseases cases. Furthermore, massive use of pesticides impacted on human health and biodiversity. Globally, crop and grazing lands significantly expanded to compensate for soil degradation due to unsustainable agricultural practices, while significant portions of most suitable land were lost because of disordered urban expansion, infrastructure development and extractive industry activities. Air pollution became a major cause of diseases in urban areas. Severe water stresses affected irrigation and water quality while oceans degraded considerably as a result of uncontrollable and neglected global pollution and waste. Entire land areas in both LMICs and HICs were lost owing to chemical, bacteriological and nuclear contamination, resulting from accidents and conflicts. Tipping points were surpassed in many domains, so that several environmental damages became irreversible.

Inaction regarding mitigation by larger per capita GHG-emitting countries lasted for decades to safeguard elites’ interests. Fossil fuel use persisted in an attempt to maintain economic growth in what was an increasingly unstable context.

Cumulative damages from climate change and linked environmental degradation reached trillions of US Dollars before the mid-century, with disproportionate effects borne by the world’s poorest regions, which became marginalized and unable to tackle these issues and protect their citizens. GHG emissions would have led to a global warming exceeding 4° C by 2100, if the collapse of significant parts of socioeconomic and agrifood systems due to large-scale coastal inundations and extremely devastating weather and climate that made vast parts of the planet unliveable, had not brought about to generalized conflicts, mass forced displacements and ensuing demographic crises.

Agriculture. In early decades of the century, monoculture and reliance on a reduced number of species and varieties prevailed. Agrifood systems were increasingly controlled by a few transnationals acting in domestic and international agrifood value chains. National and international regulations were shaped to allow maximizing rent extraction to the advantage of elites. They disregarded natural resource conservation and climate change by ignoring diversification and the need for preserving resilience. In the early decades, systematic social, fiscal and environmental dumping discouraged the few countries and communities that timidly attempted to implement more stringent regulations. LICs fully lost national control over their agrifood systems and left them in the hands of private corporations that dominated inputs to farmers and downstream trade channels.

Food prices went through several hikes because of massive agrifood systems disruptions, degradation of natural resources, negative impacts of climate change on yields, conflicts, pests and diseases and pandemics, which affected food production and supply, while demand increased as a result of demographic trends in the first half of the century. Policies to orient consumer preferences towards less resource-intensive foods were completely disregarded. In some countries, agrifood production became a strategic matter piloted by governments that increasingly relied on unsafe technologies and ignored precautionary measures. Their intense use of resources and agrochemical inputs led to severe consequences for sustainability. In other countries, attempts to contain food price increases resulted in continued subsidies that contributed to jeopardize the stability of government budgets and incentivized unsustainable agrifood practices.

Overfishing, lack of compliance with multilateral rules for fish stock management, overexploited stocks, deepening impacts from climate change and dramatic ocean and river pollution, all led to a drastic deterioration of fish stocks worldwide. Small Island Developing States (SIDS) and coastal populations have been hit the hardest.

A fragmentation of responses, or no responses at all, to global integrated challenges contributed to repeated crises of agrifood systems and even, in the last decades, to significant collapses. In some instances, subsequent attempts to restore local agrifood systems had to rely on a degraded resource base, including genetic material, limited knowledge of resilient practices and very unstable social setting.

Technology and investment in agrifood systems. Instead of facilitating the adoption of sustainable techniques, agrifood technology and digitalization became tools used to constrain farmers and control value chains at all levels. Digital equipment was increasingly provided almost for free by a few transnationals controlling big data and AI systems to smallholders, to obtain strategic digital information used to steer agrifood systems and buy geopolitical allegiances.

In the absence of regulations at all levels, these innovations caused serious problems in agrifood chains. The huge data sets used for analysis allowed for information asymmetries and, in some instances, deceiving information. Centralization, concentration and uniformity of information and technology control were established, and abuse of power went unpunished. Agrifood transnationals gained an even stronger and powerful control over input and equipment supply to farmers (pesticides, tractors, drones, etc.), downstream activities, and, owing to social media and predictive analytics, over consumer preferences.

Private investment in agrifood systems was mainly used by export-oriented transnationals in global value chains to take over smaller national businesses and make mass land acquisitions. Thus, in many instances, large numbers of farmers became landless and jobless, forced to urbanize or migrate abroad.

In LMICs, public investment focused on infrastructure to ease commodity exports while smallholders' lack of income and savings further pushes them aside.

The pioneer attempts carried out in the early decades of the century to adopt integrated agroecological and agroforestry approaches that exploited synergies between various crops and livestock, which used organic fertilizers and adopted IPM, became no more than a remote dream.

In some instances, however, after the collapse of significant parts of agrifood systems, in the last decades of the century, such technologies had to be retrieved to ensure the survival of the remaining population.

Poverty, inequality, food security and nutrition outcomes. Owing to progressively degrading natural resources, increasing demand associated with demographic trends, climate change and logistical impediments linked to conflicts, forced displacements, pandemics and other factors, food prices progressively increased. In the meantime, incomes of large sections of societies shrank, because of job losses within and outside agrifood systems. These losses resulted from capital and information intensification of production processes, a shrinking supply of basic public goods and services, and reduced wages stemming from an asymmetric contractual power that was not mitigated by a solid institutional framework.

Consequently, food insecure people fell into hunger, as highlighted by the prevalence of undernourishment that started increasing in the early decades of the century and never stopped. At the same time, large segments of poor classes started experiencing extreme poverty and food insecurity and middle- and lower-income classes also fell into poverty.

In the absence of any effective regulations from institutions at all levels, financial gains increasingly benefited transnational elites. Inequalities dramatically increased and were further exacerbated by huge power imbalances created by large investors in agrifood global value chains that boosted rents and illicit financial flows.

Corruption and lack of public services induced mass migrations. Recurrent pandemics, owing to unsustainable agricultural practices, ineffective and inaccessible health care systems and precarious working and living conditions, further skewed income and asset distribution, entailing a vicious cycle of growing inequalities, famine events and seemingly perpetual food insecurity.

In HICs, during the early decades, diets ever more based on meat and highly processed foods rich in fat and sugars, combined with urban sedentary lifestyles, boosted obesity and non-communicable diseases (NCDs). Moreover, LMICs, pushed to emulate HICs through extreme advertising and pervasive social media, suffered even more devastating food security and nutrition impacts because extreme poverty and a lack of health services.

Consumer rights were not acknowledged nor protected, and commercial and political interests reigned supreme. Consumers progressively came to passively accept being surveilled as they traded off their independence and privacy for the promise of protection against food insecurity, economic shocks and potential conflicts. This, of course, did not pay off.

Major and consecutive economic crises and instability, civil war-inducing income and wealth inequalities occurred while nationalist rhetoric pointed to “foreigners” as the culprits for all of the above. The ensuing large-scale conflicts fuelled further instability, poverty, food insecurity and hunger.

2.3.4 Trading off for sustainability

Geopolitics and power. After the prolonged COVID-19 pandemic, almost overlapping with some severe international conflicts that nurtured global instability, governing classes attempted to install a “new normal”, that, allegedly, should have allowed for increasing resilience, achieving Agenda 2030 and preparing a more stable future. However, in many countries, civil society movements realized that there was really nothing new or normal in such perspectives. In fact, while during the pandemic normal people suffered from the collapse of public health systems and economic turmoil, wealth became further concentrated in the hands of those who were offering solutions to the world’s problems, including “big pharma”, “big oil” and few “big data” global digital platforms.

The tangible material and technological benefits of profit-driven economic activities were undeniable. But, in light of the impressive dimensions achieved by transnationals and the pervasive power that they had gained, people realized the shortcomings of the "limited liability corporation" model based on uncontrolled profit accumulation and ungoverned financial capital movements across the globe. Individual and collective awareness progressively increased and civil society movements pushed for new power relations and towards sustainable development at large.

Distributed and participatory power models and "transformative governance" gradually took over and complemented or partially replaced other power relationships based either on "command-control-punishment" mechanisms – typical of autocratic governments – or on the enormous influence of big transnational companies able to steer formally democratic sovereign governments.*

To address global challenges, the world reversed the piecemeal governance of the early decades of the century to adopt a more integrated approach. This brought about the reshaping of the institutional structures created in the aftermath of the Second World War, and thus global governance transformed into an effective, polycentric, integrated network of balanced powers. The new institutional setting was also accompanied by concrete actions to reduce tensions. For instance, civil society movements realized that the dependency on fossil energy and raw materials nurtured geopolitical instability, and therefore drove governments to shift to circular economies and renewables. Concurrently, consumers in HICs increasingly avoided unsustainable food consumption that contributed to deforestation, while citizens in LMICs pushed governments to support economic diversification, limit social and environmental dumping and engage in fairer trade. All this contributed to reducing grounds for the creation of international tensions.

Economic growth and employment. Aware of the unsuitability of GDP in capturing resource degradation, social costs, resilience and other many well-being items, citizens, supported by independent academia, began to question GDP as a measure of progress and the need for its growth as a priority. The new ecological worldview engendered new metrics, such as a Genuine Progress Indicator (GPI) and Gross National Happiness Index (GNHI), which factored in components such as volunteer and household work, pollution and crime. Academia, United Nations and national statistical offices also developed additional indicators to evaluate the symbiosis between human societies and ecosystems, and the regenerating power of human actions. A new development paradigm emerged that proposed to trade off conventional economic growth with more sustainable and resilient agrifood, socioeconomic and environmental systems.

All this contributed to refocus objectives on more modest, but widespread, resilient, sustainable and inclusive growth, and hence the trade-off between short-term traditional GDP growth and sustainability at large bent towards the latter. Hazardous events continued to occur, yet risks were well-understood, monitored and analysed thus reducing the sphere of "unknown unknowns".

National regulations and international agreements ensured that markets were truly competitive, while natural monopolies were duly regulated, because most of the "voluntary guidelines" issued by the various international organizations in the early decades of the century inspired national legislations and international rules, so that they became mandatory and enforceable.

Illicit financial flows significantly shrank as transnationals were forbidden to use illicit or elusive profit transfers mechanisms (e.g. mis-invoicing) and were effectively chartered on social and environmental grounds. Interoperability of digital platforms was globally imposed.

Universal basic income programmes became the norm in many countries, given the increasing labour-saving automation, of most production processes supported by digitalization, significantly reduced the role of wages in the primary distribution of income. To fund such programmes, progressive fiscal systems were implemented, de facto limiting disproportionate wealth accumulation. Pilot communities proved that such programmes reduced crime, child mortality, malnutrition, truancy, teenage pregnancy and alcohol consumption. Nevertheless, incentives to engage in income-generating activities were provided to avoid parasitism, although a culture of cooperation gradually complemented the wisdom of competitiveness as the only engine of progress, as it had been previously inculcated through educational programmes in many countries. Concurrently, governments ensured the provision of public goods such as health, education, justice, security, freedom, regulated digital monopolies and protected savings, favouring capital sharing and thus widely spreading the benefits of innovations.

Overall, however, this transition did not present a "rosy" pattern. In fact, HICs, from the 2020s and for some decades that followed had to compress final consumption to invest in overhauling physical capital, research and development and support to LICs.

Demography. The global proportion of people with higher education dramatically increased before mid-century, and the global mean years of schooling of the total adult population by 2050 reached those observed in HICs at the beginning of the century. With higher education, the greater awareness of people about the limited carrying capacity of the planet, together with improved well-being, contributed to limit demographic growth, particularly after 2030.** The global population reached a tipping point lower than nine billion towards mid-century and then substantially declined in the second half of the century to reach levels close to those at the beginning of the century (around seven billion). At the same time, urbanization pressure on megalopolises reduced because diversified medium-sized rural centres emerged.

Resources and climate. Industrial agriculture based on mono-cropping and intensive livestock systems was replaced by a more resources- and climate-friendly agriculture relying on greater crop diversity, integrated livestock, improved water and carbon efficiency and the virtual elimination of synthetic agrochemicals. Food systems became part of a circular economy, in an attempt to counteract a possible "sixth mass extinction".***

A drastic reduction of meat consumption in HICs allowed for the abandonment of intensive livestock systems. The risk of zoonotic pandemics dropped remarkably. In most countries, antibiotics and pesticides use fell as a result of the adoption of more resilient crop and livestock systems. Furthermore, IPM and organic fertilizers improved food safety and helped towards the preservation of land and water resources.

Civil societies struggled during the first decades of the century to be heard, but a growing majority of citizens realized that a climatic meltdown was not an option. Eventually, the world economy shifted away from fossil fuels. Net-zero emissions were achieved by mid-century, limiting global warming by 2100 to slightly less than 2 °C. Nevertheless, sea levels rose, with recurrent inundations of major coastal metropolises, but the entire collapse of the socioeconomic and agrifood systems was avoided, also thanks to the reduced pressure on the demand side.

Agriculture. The twentieth century's conventional model of global agrifood systems was premised on commodity-based uniformity of mass-produced and processed foods, and was enabled by trade agreements and financial arrangements, While proving profitable in the past, this model could no longer be sustained. Diminished biodiversity, constrained food options and neglected nutritional needs, were just some of the outcomes of this model. However, despite increasing knowledge of negative externalities, in the early decades, defenders of such a model tenaciously resisted because of "path dependencies" and vested interests. The dominant narrative depicting conventional agriculture as the only way to deliver cheap food to feed an increasingly populated world and eliminate hunger kept encouraging extreme specialization, increased production of commodity crops, the overuse of natural resources, export orientation and increased agricultural trade flows. This narrative, stemming from eager-to-please think tanks and academia funded under blatant conflicts of interest, was echoed by mainstream mass media, in an attempt to counteract independent academia and civil society movements.

Despite all this, increasingly educated and aware civil societies adopting innovative decision-making, consensus building and knowledge exchange approaches, traded off part of output increases for sustainable yields and natural resource conservation. This was possible because on the one hand, consumers, specifically in HICs, stopped overconsuming animal-rich energy-intensive foods, owing to their greater education and awareness. On the other hand, demographic dynamics slowed down. In this context, the use of highly productive land for animal feed had been discouraged, and resilience had been enhanced by support of local food systems and integrated landscape approaches. Concurrently, science, technology and innovation were increasingly directed towards establishing sustainable agrifood systems because governments supported and rewarded technological innovation, with priority given to investment on local innovation. Thus, sustainable agriculture became part of a broader circular economy, leading to greater crop biodiversity, improved water and carbon efficiency and the virtual elimination of synthetic fertilizers. Food processing was also transformed by prioritizing circular flows with efficient reuse of waste products built into processes from their design phase. By mid-century, marine capture grew since the 2020s from around 85 to 95 million tonnes per annum as it moved steadily towards the maximum sustainable yields for oceans and seas thanks to some effective conservative capture policies. With technological improvements and reduced loss and waste, also marine capture not used for direct human consumption shrank from around 21 percent to less than 20 percent in the same period.

Since the 2020s, awareness emerged that prices did not reflect the full cost of food. Governments, pressured by civil society, started internalizing externalities. Strong multilateral coordination avoided social, fiscal and environmental dumping. Besides a reduced damage on natural resources, food waste shrank and consumption drifted towards less resource-intensive products. After an initial increase during the 2020s, prices almost stabilized.

Compliance with global fisheries regulations and fair international fisheries agreements steadily moved marine capture fisheries towards the maximum sustainable yields, consistent with a strong mitigation climate change scenario. The transition was eased by the creation of income-generating options for those who could no longer engage in fishing. Meanwhile, sustainable aquaculture developed.

Technology and investment in agrifood systems. After a period of uncertainty, as it had been hoped in early 2020s by the United Nations High-Level Committee on Programmes (HLCP), a subcommittee of the United Nations System Chief Executives Board for Coordination (CEB), data were established as a global public good, as were seen to have economic, social and environmental values. A new global governance of big data generation, use and ownership, progressively emerged and ensured that digitalization, IoT and AI worked for people and sustainable development. This process, pushed by civil society, independent academia and some governments, was fully supported and facilitated by the relevant United Nations bodies.

Once better regulated, the gains from technological innovation were not only prioritized towards previously neglected populations in LMICs, but also towards sustainable, resilient and integrated agrifood systems. Thus blockchain applications, AI, predictive analytics and machine learning positively contributed to data-driven decision-making, agricultural automation, and soil and crop monitoring. Over the years, advanced technologies improved agricultural production by cutting costs and making the use of inputs and resources more efficient, including water, and improved the efficiency of food supply chains.

A fully complemented agroecology could only benefit from and be integrated with digital innovations. It represented a major paradigm shift and triggered a variety of different initiatives and innovative social arrangements, with varying degrees of success. With its roots in the twentieth century and contributing to define sustainable agriculture, after challenging the conventional farming practices in the first decades, agroecology concepts progressively took momentum. To foster food system resilience, agroecology strategies included the integration of gender equity and social justice and fair trade in agrifood development programmes, the substitution of external inputs with ecological processes, the promotion of agrifood systems anchored to cultures and territories, and stronger links between nutrition and agriculture, just to mention some of the related aspects.

In the 2020s and beyond, the fiscal space created by progressive taxation reduced illicit financial flows and careful borrowing, allowed both to protect the well-being of poorest layers as well as incentivize scientific innovation. In HICs and LMICs, basic and applied research in public universities and research centres led to sustainable innovations in agrifood systems. Strong public institutions, monitored by an alert civil society, handled PPPs so that they yielded shared benefits.

Poverty, inequality, food security and nutrition outcomes. In the long run, improved governance, equitable taxation at all levels and widespread access to income-earning opportunities, especially in LMICs, reduced inequalities and boosted well-being.

In LICs, in the second half of the 2020s, in an attempt to catch up with the most sensitive SDG targets regarding hunger, food security and extreme poverty, social protection policies and basic public services such as education, health care and food safety, were enhanced, also thanks to significant international support.

In HICs, citizens who were well aware and educated began prioritizing not only healthier diets, but also more sustainably produced food, thus meat consumption shrank significantly. Voluptuary consumption items were traded off for more expensive high-quality foods so that final consumption shrank to give room to investing in sustainable innovations.

In both HICs and LMICs, investment aimed at transitioning towards sustainable production processes paid off in subsequent decades in terms of increased resilience to poverty because of widespread access to resources, innovated physical and human capital as well as mitigated climate change.

In LMICs, improved income distribution allowed most vulnerable people to access healthier diets and rely less on processed food, although in the aftermath of 2030, only the poorest strata of societies were targeted, as many resources were devoted to transformative investments for overhauling physical capital and increasing knowledge.

These transformations occurred too late to achieve Agenda 2030 as such, but they paved the way to progressively achieving sustainable development targets in subsequent decades.

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* Transformative governance is referred to as "an approach to environmental governance that has the capacity to respond to, manage, and trigger regime shifts in social-ecological systems (SES) at multiple scales".[15] Such transformations involve the development of new knowledge, the creation of social networks to build coalitions for change, the emergence of leaders shaping visions and guiding change, the seizing of windows of opportunity and the creation of enabling legislation.[16]

** This population scenario broadly fits SSP1 and SSP5 scenarios portrayed in Population scenarios by age, sex and level of education for all countries to 2100.[14] These scenarios also broadly mimic, at least in terms of global population, the UN low variant estimates.[13]

*** Based on findings that billions of populations of mammals, birds, reptiles and amphibians have been lost all over the planet in the last century, some scientists highlight that a "sixth mass extinction" has already progressed further than was thought: Ceballos *et al.* (2020)[17] state that "The resulting biological annihilation obviously will have serious ecological, economic and social consequences. Humanity will eventually pay a very high price for the decimation of the only assemblage of life that we know of in the universe."

2.4 A synopsis of scenarios by driver

Considering that each possible future may occur depending on how the dynamics of the drivers analysed in Chapter 1 materialize and cross each other, each alternative future is further analysed by sketching the pattern that each driver would follow to materialize the specific scenario.

Table 2.4 Drivers and related trends under alternative scenarios

Scenarios / Drivers	MORE OF THE SAME (MOS)	ADJUSTED FUTURE (AFU)	RACE TO THE BOTTOM (RAB)	TRADING OFF FOR SUSTAINABILITY (TOS)
1. Population dynamics and urbanization	Demographic growth was concentrated in LICs, with huge youth employment issues. Ageing in HICs threatened viability of pension funds. Due to the rise of unemployment in rural areas, megacities boomed.	Growing population trends were somehow mitigated by policies and improved well-being. Some jobs in rural areas were created through diversification. Megacity increases were somewhat dampened.	Widespread poverty pushed birth rates, chaotic urbanization and mass migrations. However, in the last decades, booming child mortality and reduced adult life expectancy significantly limited population growth.	Greater awareness of people and improved well-being contributed to limit demographic growth, particularly after 2030. Diversified medium-sized rural centres emerged.
2. Economic growth, structural transformation and macroeconomic stability	Fossil fuel-led GDP growth continued despite alleged green transformation. GDP measures not reflecting resource degradation deceived people and decision makers. Public deficit expanded everywhere with bankruptcies occurring in more fragile states.	"Decarbonization" was attempted after repeated global energy crises affecting GWP, but governments, steered by Big oil, did not trade off short-term expansion with long-term resilience. Some fiscal space allowed better funding of social policies.	Rent-seeking from transnationals, including in agrifood systems, exacerbated geostrategic tensions and conflicts over resources control, leading to deep global economic crises. Public budget collapsed in many countries because of huge military spending.	Awareness of the unsuitability of GDP for capturing resource degradation social costs, resilience and other many well-being items, contributed to refocusing objectives on more modest yet widespread, resilient and inclusive growth.
3. Cross-country interdependencies	While agrifood, energy and mineral commodity dependency of HICs from LICs continued as in the past century, also upper-middle-income countries absorbed commodities and surplus from LICs, thus increasing LICs' dependency. Global challenges became more and more intertwined, and responses more and more fragmented.	Fighting illicit financial flows (SDG 16.4) linked to trade and eased by international banks, reduced leakages from LMICs to fiscal heavens but weak global governance did not allow to stop them fully. Most countries were too small to influence these global dynamics. Civil society advocated for increasing resilience through diversification, but its influence was limited.	The control of few big superpowers over LICs increased to secure agrifood, mineral and energy supplies. LICs shaped their economies accordingly, thus preventing effective diversification and resilience. Fragmentation of responses to global intertwined challenges prepared the way for the collapse of significant parts of agrifood systems.	Consumers in HICs increasingly avoided unsustainable consumption. Civil society in LMICs supported economic diversification, limited social and environmental dumping, and engaged in fairer trade. To address global challenges, the world reversed the piecemeal governance of the early decades of the century to adopt a more integrated approach and achieve Agenda 2030.
4. Big data generation, control, use and ownership	Digitalization of agrifood and other production processes, social media and trade created a big data boom. However, institutions at all levels lost control to the benefit of large private digital companies.	Economies and societies, including agrifood systems, benefited from big data. Governments attempted to combat abuses and asymmetries to protect fundamental freedoms (SDG 16.10), although with limited success.	Big data shifted control over agrifood systems to a few transnationals. Autocratic countries exploited big data for surveillance and propaganda, while democratic governments became fully steered by big data companies.	A new global governance of big data generation, use and ownership supported by the United Nations, ensured that it worked for people and sustainable development. Fair taxation and data protection measures were globally enforced.

Table 2.4 (cont.) Drivers and related trends under alternative scenarios

Scenarios / Drivers	MORE OF THE SAME (MOS)	ADJUSTED FUTURE (AFU)	RACE TO THE BOTTOM (RAB)	TRADING OFF FOR SUSTAINABILITY (TOS)
5. Geopolitical instability and increasing impacts of conflicts	Multilateral institutions, directed by few powerful countries during the previous century, further weakened. The shift to a few big multipolar systems exacerbated centre-periphery asymmetries and fuelled geo-economic and armed conflicts with a view to controlling resources.	After recognizing their limited effectiveness, multilateral institutions tried to change rules to master global and local instabilities, but Superpowers did not give up their privileges acquired in the aftermath of the Second World War. Conflicts and forced displacement continued to some extent.	International organizations were increasingly manipulated by few governments and powerful transnational corporations. Military spending surged to fuel conflicts between superpowers and peripheral countries. Eventually the former directly confronted each other.	Global governance transformed into an effective polycentric integrated network of balanced powers. Citizens realized that the dependency on fossil-energy and raw materials nurtured geopolitical instability. Shifting to circular economies and renewables drastically reduced its causes.
6. Risks and uncertainties	Interconnected risks and crises escalated from the beginning of the century, presenting new challenges for agrifood systems as risk management strategies (e.g. early warning, prevention, and insurance) were either not available or inaccessible. Short-termism prevailed.	Risk management strategies were reinforced, at all levels, particularly after the COVID-19 pandemic, to increase systemic resilience, including in food and agriculture. However, because of trade-offs between immediate well-being and resilience, investments in this area were limited.	The neglect of social disparities, climate change, overuse of natural resources and the continuous pressure of MHICs on LICs expanded multi-layered risks and uncertainties. Eventually, economic crises, conflicts and global confrontations led substantial parts of systems to collapse.	A new development paradigm traded off economic growth with more sustainable and resilient agrifood, socioeconomic and environmental systems. Hazard events continued, yet risks were well understood, monitored and analysed thus reducing the sphere of "unknown unknowns".
7. Rural and urban poverty	The downward poverty trend since the 1990s turned out to be temporary. Successive pandemics, capital-intensive jobless growth and unmitigated climate change proved rosy projections by international organizations to be entirely wrong. Limited farmers' access to resources, and new technologies and huge capital concentration reduced incomes of vast sections of the population in most countries and fuelled social instability.	During the 2020s, in an attempt to achieve SDG 1 targets, investments in social protection policies made in many countries contributed to counteract the impact of the pandemic, conflicts and extreme weather events. However, as production processes did not substantially transform, capital and information concentration, power asymmetries and climate change made gains not lasting long.	Since the 2020s extreme poverty dramatically increased both in rural and urban areas of many countries, including HICs. The huge power gained by large investors in global agrifood value chains created imbalances, completely excluded poor farmers and boosted rents and illicit financial flows. Corruption, lack of public services and exacerbated climate change triggered soaring mass migrations. Large-scale conflicts further fuelled poverty.	In the 2020s, social protection policies and basic public services such as education, health care, food safety, were enhanced, particularly in LICs, with international support. Huge concurrent investment for developing inclusive production processes paid off in subsequent decades with increased resilience to poverty resulting from to widespread access to resources, innovative physical and human capital as well as mitigated climate change.
8. Inequalities	After two decades of decreasing across-country inequality following per capita income increases in India and China, both in-country and across-country inequalities increased because of weak fiscal systems and financial governance. Thus, well-being-related SDGs were never achieved.	To realize SDG 10, some governments attempted to tax transnational companies and stop illicit financial flows, in order to mobilize resources for funding domestic social protection policies. However, the failure to fix fundamental "centre-periphery" asymmetries made these successes temporary.	Successive pandemics further skewed income and asset distribution, generating a vicious cycle of growing inequalities. Financial gains increasingly benefited transnational elites while nationalist rhetoric, used to hide ill-gotten gains and global impoverishment, fuelled large-scale conflicts.	The trade-off between short-term GDP growth and sustainability bent towards the latter. Improved governance and equitable taxation at all levels along with widespread access to income-earning opportunities, especially in LMICs, reduced inequalities and boosted global well-being.

Table 2.4 (cont.) Drivers and related trends under alternative scenarios

Scenarios / Drivers	MORE OF THE SAME (MOS)	ADJUSTED FUTURE (AFU)	RACE TO THE BOTTOM (RAB)	TRADING OFF FOR SUSTAINABILITY (TOS)
9. Food prices	While population growth maintained pressure on demand, awareness emerged of the limits of green revolution recipes. Still, to keep prices artificially low, subsidies on chemicals and fossil fuels prevailed. Sustainability was traded off for short-term results. Natural resources degradation observed since the 1990s negatively reflected on yields and prices which continued to increase.	To ensure affordable healthy diets (SDG 2), attempts were made to increase land productivity through technological improvements. However, many technologies were not sufficiently tested and proved to be unsustainable or bringing undesired side effects. On the demand side, civil society advocacy for diets less rich in animal-based foods, particularly in HICs, had limited impact. Prices therefore kept increasing, most notably after 2030.	Since the 2020s, the resilience of agrifood systems was traded off for the "comparative advantage" of specializing in a few commodities. Reliance of countries on a small number of export products created conditions for an exacerbation of rent extraction by businesses controlling global agrifood value chains. Together with recurrent pandemics and large-scale conflicts, this sent prices skyrocketing.	In the 2020s awareness emerged that prices did not reflect the full cost of food. Governments, urged by civil society, started internalizing externalities. Strong multilateral coordination avoided social, fiscal and environmental dumping. Besides a reduced damage on natural resources, food waste shrank and consumption drifted towards less resource-intensive products. After an initial increase during the 2020s, prices almost stabilized.
10. Innovation and science	In the 2020s, agricultural robotics, innovative soil, crop and animal management, blockchain for agrifood transactions, AI, machine learning and predictive analytics were expected to support data-driven transformation of agrifood systems. However, the focus on means rather than goals and the absence of a diagnosis of real transformative needs including innovations in institutional and social spheres, hampered change.	Guided by SDG target 2.3, governments promoted the introduction of novel technologies to improve productivity. Some cuts in unit costs and resource use, including for water, were obtained. Still, the failure to adopt generally systemic approaches such as multi-cropping, organic agriculture, agroforestry and agroecology, along with unequal investment across countries and neglecting to remunerate properly environmental services, prevented a complete transformation.	Scientific innovation and technology transfer were used either to perpetuate the control of transnationals on global value chains or to buy geopolitical allegiance by superpowers. This reinforced centre-periphery inequalities, market concentration, information asymmetry and exclusion of small-scale actors, and accelerated the exhaustion of natural resources and causing agrifood systems to collapse in fragile countries.	Science, technology and innovation were directed towards establishing sustainable agrifood systems. Innovating efforts, advocated by increasingly educated and aware civil societies adopting innovative decision-making, consensus building and knowledge exchange approaches, not only allowed to trade off output with sustainability because of a greater awareness of consumers, but also contributed to creating diverse and resilient agrifood systems across communities.
11. Public investment in agrifood systems	Shrinking of public investment, observed in the 2010s, lasted for decades, because of government short termism, undue delegation of the provision of public goods to corporate investors, difficulties in raising taxes and consequent budget constraints. Private investment strongly expanded in HICs and much less in LMICs, associated to growing capital-information intensity, while financialization of agrifood systems intensified.	Public investment focused on productivity-enhancing technologies and stimulation of private investment. PPPs and blended finance, very fashionable in the 2020s, led to mixed outcomes and often resulted in privatization of benefits and socialization of losses. Only few countries and communities drew lessons from experience, raised their contractual power and benefited from such agreements.	The bulk of private investment in agrifood systems was generated by export-oriented transnationals in global value chains with the view to take control over smaller national businesses. Limited greenfield investment occurred. In LMICs, public investment focused on infrastructure to ease commodity exports. Smallholders were marginalized and almost stopped investing because of lack of income and savings. In HICs, public investment virtually disappeared.	In the 2020s and beyond, fiscal space created by progressive taxation, reduced illicit financial flows and careful borrowing, allowed both to protect the well-being of poorest strata of societies and incentivize scientific innovation. In HICs and LMICs, basic and applied research in public universities and research centres led to sustainable innovations in agrifood systems. Strong public institutions, monitored by a vigilant civil society, handled PPPs designed to yield shared benefits.

Table 2.4 (cont.) Drivers and related trends under alternative scenarios

Scenarios / Drivers	MORE OF THE SAME (MOS)	ADJUSTED FUTURE (AFU)	RACE TO THE BOTTOM (RAB)	TRADING OFF FOR SUSTAINABILITY (TOS)
12. Capital and information intensity of production	Energy- and data-intensive automation in agrifood systems entailed capital and information/labour ratios growth. Value added increasingly shifted towards profits and rents. Low bargaining power of workers resulting from to shrinking labour demand depressed wages, increased the "gig economy" and reduced access to capital for very many people.	Economy-wide labour-saving AI innovations based on digitalization dominated part of the twenty-first century. Despite a reduction of daily working hours and creation of new jobs, unemployment grew. Redistributive policies supported incomes, but capital concentration exacerbated inequalities, while "gig" job policies (labour regulations, contractual frameworks, and minimum wages) ultimately failed.	Digital capital (Internet of Things [IoT] devices) was provided by a few big data companies almost for free to smallholders for collecting strategic data required for steering agrifood systems. Very weak institutions at all levels allowed these companies to accumulate power and extract huge rents from value chains. "Gig economies" boomed while dual agrifood systems emerged.	Economy-wide labour-saving AI-based innovations dominated part of the twenty-first century. Concurrently, through the provision of public goods (e.g. health, education, security, and freedom), an aware and critical civil society emerged both in HICs and LMICs, prompting governments to regulate digital monopolies, protect savings and favour capital sharing, thus widely spreading benefits derived from innovations.
13. Market concentration	Major corporations managed to gain and maintain dominant positions in key segments of agrifood systems, thanks to horizontal and vertical integration through takeovers and mergers both in LICs and LMICs. Colluded governments remained inactive, allowing the emergence of dual agrifood systems where fragmented smallholders had to compete with mega-farms.	In search of low food prices and easy money to quickly fix out-of-track SDG 1 and 2, governments and international organizations relied on dubious PPPs that produced for some temporary successes in food security but reinforced concentration of market power, thus generating asymmetries and inequalities in the medium and long run.	The concentration of market power, traditionally resulting from mergers and acquisitions often funded by foreign investment, also took new avenues, with digital platforms locking in consumers and small producers in anti-competitive mechanisms. LMICs further lost control over their agrifood systems, while consumer preferences were shaped through big data applications.	National regulations and international agreements ensured that markets were competitive, while natural monopolies were duly regulated. Transnationals were forbidden to use illicit or elusive profit transfers mechanisms (e.g. mis-invoicing) and were effectively chartered on social and environmental grounds. Interoperability of digital platforms was globally imposed.
14. Consumption and nutrition patterns	Civil society in many countries favoured healthier and more sustainable dietary patterns but agrifood transformation did not materialize globally as businesses manipulated short-termist governments and steered global organizations via conditional and other easy-money funds. Resilience further dropped with negative impacts on food security and nutrition.	Governments, anxious to achieve SDGs, supported by international organizations kept food prices artificially low by pushing non-resilient and unsustainable agrifood systems. Hunger plummeted and nutrition improved despite worsening income inequalities. All this led to further degradation of natural resources, the bill for which had to be paid in subsequent decades.	In HICs, diets increasingly based on meat and highly processed food rich in fat and sugars, combined with urban sedentary lifestyles, boosted obesity and non-communicable diseases. LMICs, encouraged to emulate HICs through unruly advertising and pervasive social media, suffered even more from devastating food insecurity and nutrition ills, because of to lack of health services and higher prevalence of extreme poverty.	In HICs, well aware and educated citizens began prioritizing not only healthier diets, but also more sustainably produced food: meat consumption shrank significantly. Voluptuary consumption items were traded off for expensive high-quality food. Improved income distribution allowed many people in LMICs to access healthier diets relying on less processed food.

Table 2.4 (cont.) Drivers and related trends under alternative scenarios

Scenarios / Drivers	MORE OF THE SAME (MOS)	ADJUSTED FUTURE (AFU)	RACE TO THE BOTTOM (RAB)	TRADING OFF FOR SUSTAINABILITY (TOS)
15. Scarcity and degradation of natural resources	There was more intense competition for natural resources, particularly in export-oriented commodity-dependent LICs. In some of them, the relative abundance of resources and weak governance prevented the adoption of resource-saving technologies. Rivalry over water resources from other sectors increased.	Some innovative technologies, including biotechnologies, were implemented that allowed raising food production through higher productivity of natural resources. SDG 2 targets were partially achieved by 2030 but actual transformation never occurred as resource preservation was traded off for short-term output growth at low prices.	Elites succeeded in maximizing rent extraction from agrifood systems. Biodiversity dropped while export-oriented mono-crop agriculture expanded in many LICs. Extensive agricultural encroachment into wilderness areas further degraded forests. Uncontrollable global pollution and waste permanently damaged oceans.	Industrial agriculture based on mono-cropping and intensive livestock systems was replaced by a more resources- and climate-friendly agriculture relying on greater crop diversity, integrated livestock, improved water and carbon efficiency, and the virtual elimination of synthetic agrochemicals. Food systems became part of a circular economy.
16. Epidemics and plant diseases	Threats presented by zoonotic diseases and antimicrobial resistance proved real and increasing. Misuse and abuse of drugs and pesticides in intensive systems was regulated in some countries only. Eventually safety and resilience were traded off for immediate profits with global medium- and long-term well-being losses, more accentuated for LMICs.	Several occurrences of zoonotic diseases, mounting antimicrobial resistance and pesticide poisoning drove less productive but more resilient mixed crop-livestock systems, mostly in HICs. Environmental dumping, however, challenged them. In many LMICs, pressure from domestic demand and export to satisfy unmitigated overconsumption in HICs, discouraged the transition towards sustainable agrifood systems.	Encroachment into wilderness areas increased the frequency of zoonotic infectious diseases and their death toll. Unregulated abuse of drugs in intensive systems aggravated antimicrobial resistance, and massive use of pesticides impacted on human health and biodiversity with disastrous consequences on food production, safety and security in all countries. As a result, world population shrank.	A drastic reduction of meat consumption in HICs allowed for the abandonment of intensive livestock systems. The risk of zoonotic pandemics dropped remarkably. In most countries antibiotics and pesticide use fell because of the adoption of more resilient crop and livestock systems. Integrated pest management (IPM) and organic fertilizers improved food safety and helped to preserve land and water resources.
17. Climate change	Governments and international organizations, manipulated by "big oil", covered up climate green-washing by dispatching fake GHG reduction strategies and data. Unsurprisingly, impacts on agrifood systems were already severe in the first half of the century in terms of extreme weather events, new pests and diseases, droughts and forced displacements. They became mostly unbearable in the second half of the century with global warming reaching slightly less than 4° C by 2100 when sea levels rose catastrophically with losses of huge fertile coastal areas.	Despite higher awareness within civil society in many countries, governments, influenced by private corporations, failed to agree on a global strategy for cutting GHG emissions by agrifood systems. In some countries, youth movements managed to set an example and consumers reduced fossil fuel consumption. Overall, global warming would reach slightly less than 3 °C by the end of the century, with negative long-run impacts on food production.	GHG emissions by larger per capita emitting countries lasted for decades to safeguard elites' interests. Fossil fuel use persisted in an attempt to maintain economic growth in an increasingly unstable context. GHG emissions would have led to a global warming exceeding 4° C by 2100, if large-scale coastal inundations and extremely devastating weather and climate that made vast parts of the planet unliveable, had not brought about generalized conflicts leading to an earlier overall collapse of socioeconomic and agrifood systems.	Civil societies struggled during the first decades of the century to be heard but a growing majority of citizens realized that a climatic meltdown was not an option. Eventually, the world economy shifted away from fossil fuels. Net-zero emissions were achieved by mid-century, limiting global warming by 2100 to slightly less than 2°C. Nevertheless, sea levels rose, with recurrent inundations of major coastal metropolises, but the collapse of the whole socioeconomic and agrifood systems was avoided.

Table 2.4 (cont.) Drivers and related trends under alternative scenarios

Scenarios / Drivers	MORE OF THE SAME (MOS)	ADJUSTED FUTURE (AFU)	RACE TO THE BOTTOM (RAB)	TRADING OFF FOR SUSTAINABILITY (TOS)
18. The "sustainable ocean economies"	In the first decades of the century, fish consumption grew faster than it ever had previously. Increasing demand and the deterioration of management standards accelerated the over-exploitation of stocks and of environmental damage caused by aquaculture, including water pollution and antimicrobial resistance that threatened biodiversity and health. This eventually hampered sustainability and well-being in the long run.	Governments negotiated multilateral rules and prioritized sustainable fisheries. However, selected powerful transnationals convinced LICs to sign unfair fishing agreements by promising easy money. Marine capture not used for direct human consumption decreased to some extent. Some countries moved towards sustainable aquaculture but environmental dumping by others jeopardized their achievements.	Overfishing, lack of compliance to multilateral rules for fish stock management, overexploited stocks, and dramatic ocean and river pollution, led to the deterioration of fish stocks. This affected coastal populations, with SIDS being hit the hardest, and sparked new conflicts. The proportion of marine capture fisheries not used for direct human consumption increased because of no technological innovation.	Compliance with Global fisheries regulations and fair international fisheries agreements steadily moved marine capture fisheries towards the maximum sustainable yields, consistent with a strong climate change mitigation scenario. The transition was eased by the creation of income-generating options for those who could not fish any more. Concurrently sustainable aquaculture developed.

Source: Authors' elaboration.

2.5 Comparison with other scenario-based exercises

The above scenario narratives are based on multiple contributions gathered during FAO's Corporate Strategic Foresight Exercise (CSFE) and benefit from previous FAO foresight reports on the future of food and agriculture as well as from other recent strategic foresight exercises carried out at FAO, such as the workshop on "Emerging technologies and social innovations". This section compares the four narratives for MOS, ADF, RAB and TOS with the narratives proposed in selected foresight exercises previously implemented by FAO or by other organizations.

Compared with ***The future of food and agriculture – Alternative pathways to 2050***,[5] MOS adopts many underlying assumptions on agrifood systems similar to those adopted for the "business as usual" (BAU) scenario. However, expected agrifood system outcomes such as food security, nutrition, income generation and environmental footprint look worse, because of the greater uncertainties and more limited resilience, e.g. to future "COVID-19-like" pandemic shocks, assumed in the narrative. AFU, on the other hand, borrows part of its assumptions on agrifood systems from the "towards sustainability" (TSS) scenario in *The future of food and agriculture – Alternative pathways to 2050*,[5] but expected outcomes may appear less rosy in the light of the clearly diverging patterns with respect to Agenda 2030 that have emerged in recent years. The RAB scenario is somehow inspired by the "stratified societies" (SSS) scenario. However RAB, contrarily to SSS, considers that critical tipping points and the collapse of substantial parts of agrifood, socioeconomic and environmental systems are almost certain, although not explicitly placed within a specific period. Lastly, under the TOS scenario, many actors in agrifood systems and societies become more aware of trade-offs between short-term and long-term welfare, and, within context-specific limits and opportunities, adopt a deeply transformative behaviour. These assumptions recall in part those of TSS, although TOS explicitly assigns a powerful transforming role to civil societies, which act directly and pressure governments and international organizations to move along the lines of a transformative pattern.

The State of Food Security and Nutrition in the World 2021[18] report offers two scenarios of what hunger and malnutrition could look like by 2030. Both scenarios, in line with MOS, confirm that hunger could not be eradicated by 2030 unless bold actions are taken, especially to address inequality in access to food. With all other factors constant, around 660 million people may still face undernourishment by 2030, partly because of lasting effects of the pandemic–30 million more people than in a scenario in which the pandemic would not have occurred. The evolution between 2020 and 2030 is quite different across regions. While a substantial reduction is projected for Asia (from 418 million to 300 million people), a significant increase is forecast for Africa (from more than 280 million to 300 million people), placing it on a par with Asia by 2030, as the region with the highest number of undernourished people.

A 2017 study[3] portrays the five Shared Socioeconomic Pathways (SSPs) that have been adopted in different combinations with Representative Concentration Pathways (RCPs) in the myriad of studies that fed the Fifth and Sixth Assessment reports of the Intergovernmental Panel on Climate Change (IPCC). SSPs provide alternative qualitative descriptions of future changes in demographics, human development, economy and lifestyle, policies and institutions, technology, and environment and natural resources. In SSP1, "Sustainability–Taking the green road", in line with TOS, the priority given economic growth shifts towards a broader emphasis on human well-being, even at the expense of somewhat slower economic expansion over the longer-term inequality is reduced both across and within countries, consumption is oriented towards limited material growth and lower resource and energy intensity, although TOS may implicitly assume a globally weaker GDP expansion than SSP1. In addition, TOS envisages institutional transformative processes that would achieve a yet stronger tripartite power-sharing among educated and aware civil societies which develop visions and outline solutions, and also bring sovereign governments to reconcile private and public interests, designating intergovernmental organizations to trade off national and global interests. The SSP2 "Middle of the road" inspired to some extent the MOS scenario, where the world follows a path in which social, economic and technological trends do not shift markedly from historical patterns. However, MOS considers that the collapse of substantial parts of agrifood, socioeconomic and environmental systems could occur (although it would appear to be less likely than under RAB).

Some aspects of RAB were influenced by SSP3, "Regional rivalry–A rocky road". Still, what in SSP3 is referred to as "resurgent nationalism", in RAB takes the shape of a world characterized by a few alleged superpowers imposing centre-periphery relationships and stimulating peripheral nationalisms to maintain their spheres of influence. In addition, SSP3 emphasizes a reversal of globalization because of countries' concerns about competitiveness, security and regional conflicts that prompt them to increasingly focus on domestic or, at best, regional issues. Whereas in RAB, nationalisms and conflicts are functional to an even stronger globalization where, using various mechanisms, global elites appropriate public assets, benefit from large income shares and manage transnational corporations. In RAB, the persistence of conflicts and discrepancies is reinforced by progressively weakening global institutions unable to impose cooperation in addressing environmental and other questions, because they are increasingly influenced by large corporations. In fact, RAB borrows some features of the global power structure from SSP4, "Inequality–A road divided", where highly unequal investments in human capital, combined with growing disparities in economic opportunity and political power, lead to increasing inequalities and stratification both across and within countries. Power becomes more concentrated in a relatively small, political and business elite even in democratic societies, while vulnerable groups have little representation in national and global institutions. Some features of AFU were inspired by SSP5, "Fossil-fuelled development–Taking the highway", driven by the huge but unsustainable economic success of HICs, the so-called "developed" countries assumed to offer a paradigm for the so-called "developing" countries or for emerging economies. In this world, faith is still placed in presumably competitive markets where long-term resilience is traded off for short-term comparative advantage based on specialization.

While *The future of food and agriculture – Alternative pathways to 2050*[5] futures benefited from SSPs, they attempt to avoid some potentially contradicting parts of the SSP narratives. This is the case, for instance, of the SSP5 narrative where innovative, well-educated and participatory societies, able to produce rapid technological progress and build human capital, push for an economic and social development coupled with the exploitation of abundant fossil fuel resources and the adoption of resource- and energy-intensive lifestyles around the world. It is not really clear how such innovative, well-educated and participatory societies do not realize, even in the medium run, that fossil fuel-based development is a "no go" in terms of sustainable development.

The **European Commission's** ***2021 Strategic Foresight Report***[19] is in line with MOS and RAB, particularly with regard to agrifood systems: more than 200 million people could need humanitarian assistance every year partly because of climate-related disasters; over 40 percent of the European Union's agricultural imports could become extremely vulnerable to drought by 2050, inducing competition for water and fertile land; loss of biodiversity, pressure on animal habitats, the excessive use of antibiotics, risks pertaining to biological research of highly pathogenic microbes, unhealthy lifestyles – all these factors make future pandemics or diseases more likely; and, increased inequalities, lower environmental and labour standards remain key challenges for emerging economies.

The **United Nations Economist Network**[20] report focuses on the interlinkages of five megatrends: climate change; demographic shifts, particularly ageing; urbanization; the emergence of digital technologies in the fourth industrial revolution; and inequalities. These interlinkages produced qualitative assessments that show climate change, urbanization and inequalities as having negative impacts on other megatrends, with demographic shifts having mixed effects and technology having positive consequences. This is in line with MOS.

The **IPCC** ***Sixth Assessment Report***[21] brings out a set of five illustrative emissions scenarios based on combinations of SSPs and selected Representative Concentration Pathways (RCPs). In all of them, global surface temperature will continue to increase. The best-case scenario, "Taking the green road", provided inspiration for TOS. Both scenarios, specifically concerning climate change, drastically assume that more climate action than humans have ever carried out is required, and that the window for action is closing. Another scenario, in line with AFU, sees climate action eventually being achieved but more slowly than in the more optimistic scenario. The "Middle of the road" scenarios, where there is a considerable fall in global food production, serious increase in extreme heat, more destructive flooding from extreme rainfall, and inequalities persisting among and within countries has some similarities with MOS. The other two scenarios, the worst of the five, are in line with RAB.

A recent **United Nations Secretary-General report**,[22] entitled *Low Energy Demand (LED) better futures scenario*, describes an ambitious pathway for sustainable energy transition that would allow SDGs to be met. It is similar to the energy transition required for TOS, but perhaps even more ambitious and difficult to achieve. In the "LED better futures scenario", overall global energy, water and land use are reduced, despite increasing population, economic activity and rapidly increasing living standards. How can this take place? It is possible because of the large untapped potential for increasing end-use efficiencies through a combination of technological, behavioural and business innovations – a transition fuelled by information and communication technologies (ICTs). More specifically, it is achieved through strategies to: (i) electrify energy end-use worldwide; (ii) bring homes, appliances and transport modes to the technological efficiency frontier; (iii) support multi-functionality through convergence of multiple services onto single devices or business models; (iv) promote a generational shift from ownership of material goods to accessing services; (v) increase utilization rates of goods, infrastructure and vehicles (sharing and circular economy); (vi) promote user-oriented innovation; (vii) ensure decentralization by allowing new roles for end-users, not just as consumers but also as producers, innovators and traders; and (viii) achieve pervasive digitalization and rapid innovation in granular technologies. The report emphasizes recent technological and policy trends that might support the "how can this take place": growing fiscal support for a "green" recovery; total investment in the sustainable energy transition keeps increasing; and through recent energy technology and systems innovations, including in solar photovoltaic cells, electrified transport, hydrogen and digital consumer technologies.

The **United Nations Environment Programme**[23] released three flagship reports from which it built four future scenarios for 2100, differing by the extent of emissions and global warming.[cg] The best-case scenario, where the world sees low emissions and global warming is limited to 1.5 °C, is similar to MOS. The three other scenarios are comparable to RAB, with dire consequences for the world.

[cg] The COP 21 Paris Agreement on climate change, adopted in 2015, aims to limit global warming to well below 2 °C, preferably to 1.5 °C, compared to pre-industrial levels. To achieve this long-term temperature goal, countries aim at reaching a global peak of GHGs as soon as possible and achieving a climate neutral world by mid-century.

The ***Global Risks 2035***[24] report of the Atlantic Council outlined three scenarios: the "New bipolarity" scenario fits in with that of MOS, with two economic spheres – China at the core of one and the United States of America and Europe in the other – pushing for greater economic competition and militarization, resulting in a bipolar world that limits the potential for peripheral countries to develop. The "World restored" scenario envisions the middle classes playing a key role in shaping the future. Global challenges such as climate change and failing states spur cooperation that leads major powers to engage in more concerted and coordinated peace-building efforts. Some features of this scenario are in line with AFU. In AFU, however, the adoption of "quick fixes" to showcase results for some SDG targets hampers long-term sustainability and resilience. The "Descent into chaos" scenario, similar to RAB, sees a deep economic reversal in China that starts with impacts on its trading and investment partners in the global South. With political instability spreading, authoritarianism, violence and conflicts further increase.

The United States National Intelligence Council's ***Global Trends 2040***[25] report five global future scenarios. The "Renaissance of democracies" scenario is interesting because, beyond being a possible scenario per se, it is based on a sort of storytelling that could prevail in the century's first decades under MOS, RAB and even AFU, as provided for instance by politicians or CEOs and echoed by mainstream media, along the lines of: rapid technological advancements fostered by PPPs in democratic societies will transform the global economy, raise incomes and improve the quality of life for millions of people. The rising tide of economic growth and technological achievement will enable responses to global challenges, ease societal divisions and renew public trust in democratic institutions.

However, while under MOS, and even more so under RAB, this storytelling is supposed to prevail in the early stages to divert people's attention, anesthetize critical thinking and weaken the role of civil societies. Under AFU, selected parts of this narrative could actually influence the future. This refers, for instance, to possible genuine attempts of democratic governments to address concerns of their constituencies regarding the most evident SDG targets, such as hunger, extreme poverty or health care. The "World adrift" scenario, similar to RAB, envisions a chaotic, volatile and directionless international system, with countries plagued by widening societal divisions and political paralysis. Many global challenges, such as living conditions in LICs, climate change or global instability are largely unaddressed. In the "Competitive coexistence" scenario, akin to AFU, the risk of major wars is low, and international cooperation and technological innovation render global problems manageable over the short term for advanced economies, but longer-term climate challenges remain. In the "Separate silos" scenario, in line with MOS and RAB, the world is fragmented into several economic and security blocs of varying size and strength, centred on China, the European Union, Russian Federation, the United States of America and a couple of regional powers, focused on self-sufficiency, resiliency and defence, while climate change is only spottily addressed, if at all. However, while in this scenario international trade is disrupted, this may not be the case both under MOS and RAB in the first decades of the century. Quite the opposite, in fact: under these scenarios international trade may flourish but, instead of acting as a global well-being- and resilience-generating device, it becomes a device for rent extraction from poor people by elites and/or from commodity-dependent LICs by HICs. Lastly, the "Tragedy and mobilization" scenario, presents some features similar to TOS, where a global coalition working with non-governmental organizations and revitalized multilateral institutions, implements far-reaching transformations designed to tackle climate change, resource depletion and poverty. Richer countries help poorer countries manage the crisis and transition to low carbon economies through broad aid programmes and transfers of advanced energy technologies, recognizing how rapidly these global challenges spread across borders. The main difference between this scenario and TOS, however, is that it foresees all this occurring after a general food catastrophe caused by climate-related events and environmental degradation. Although it is fully plausible that after the occurrence of a global catastrophe, for example, under RAB, a TOS-style recovery could occur; under TOS, catastrophic events are not envisaged because it is assumed that globally emerging well-educated, informed, critical, increasingly aware and non-manipulable civil societies would be able to prevent them.

The Economist Intelligence Unit's ***EIU at 75–clarity in an uncertain world***[26] report presents some forward-looking scenarios on events that could reshape the global geopolitical, economic and business landscape. The so-called "Industry 4.0" is emphasized here as a possible new "green revolution", where technological advances would completely reshape societies, in a much stronger way than in previous industrial revolutions. Regarding pandemics, the world will suffer from "long COVID-19", fuelling poverty and further delaying the economic convergence between poorer and richer countries. However, the report anticipates that when the next pandemic occurs, the world will be more experienced and resilient, having learned from the COVID-19 pandemic. Regarding climate change, the report envisions advanced economies taking more action, but also that dramatic climatic developments (including even more frequent and extreme heat waves, floods and droughts) will not be averted. It is not possible to retrieve comprehensive similarities between the scenarios portrayed in the two reports. Some elements provided in this EIU report are in fact peppered through all the scenarios discussed in this report, yet their emphasis and expected impacts may be very different.

The EIU's ***Risk Outlook 2022***[27] has a particular scenario, similar to RAB, which is the famine scenario, as a result of an increased frequency of droughts, resulting from climate change, and extreme weather events. Water shortages would have short- and long-term consequences for the global economy. Multiple crop failures would drive up global commodity prices, most likely of highly irrigated crops such as maize and rice. Such a situation would fuel global inflation and weigh on world growth and its mind-set.

The World Economic Forum's (WEF) foresight report, ***Shaping the Future of Global Food Systems: A Scenarios Analysis***,[28] presents four scenarios for the future of global food systems – a "four-quadrant" framework along two axes: resource-efficient vs resource-intensive consumption and high market connectivity vs low market connectivity. The "Survival of the richest" scenario, is similar to MOS in terms of outcomes as it sees a world of resource-intensive consumption leading to the "Survival of the richest" and a stark division between the "haves" and "have-nots". However, while in this WEF scenario the "Survival of the richest" is the result of disconnected markets and a sluggish global economy, under MOS, there is no need for markets to be disconnected or the economy to be sluggish to lead to the "Survival of the richest". In fact, under MOS, as already specified in commenting the "Separate silos" scenario of the United Nations National Intelligence Council, ungoverned, connected markets and flourishing economies, under MOS and even more so under RAB, would become generators of progressive asymmetries, engines for rent extraction, and sources of within and between country inequalities. The "Unchecked consumption" scenario, in fact, is more in line with the pathway of MOS, as it depicts strong market connectivity coupled with resource-intensive consumption and dynamic GDP growth coupled with high environmental cost. Whereas the "Open-source sustainability" scenario presents some features of AFU and, to some extent, of TOS. It envisions a future with highly connected markets and resource-efficient consumption associated with an increased international cooperation and innovation, but it may leave some behind. What is probably missing here is the identification of a clear trigger of transformation, which is instead clearly present in TOS. Lastly, the "Local is the New Global" scenario, envisions a future of fragmented local markets with resource-efficient consumption and resource-rich countries that focus on local foods, whereas food import-dependent regions become hunger hotspots. In depicting this scenario, the WEF apparently suggests a causal relationship between consumers in HICs focusing on local food and food import-dependent LICs suffering from hunger. Such opposition is not portrayed in either AFU or in TOS, because the causal relationships among local consumption, international trade, agrifood systems resilience and their poverty, food security and nutrition outcomes are much more complex, as was also highlighted by the recent pandemic.

A report produced by **Project SHAPE**[29] deliberately chose to explore sustainable development pathways (SDPs), and therefore does not examine unsustainable options. Scenarios are set in the perspective that SDGs will be achieved. The report explores alternative ways to reach that achievement and envisages how the world would look under different scenarios that achieve the SDGs (each goal being associated to an indicator or set of indicators). This implies adopting a somewhat optimistic point of view in all branches and scenarios, although trade-offs are eventually considered. The SHAPE report identifies 11 dimensions that provide leverage towards achievement of the SDGs, and which of these the SDPs should therefore cover. The 11 dimensions address economic, socio-political, technological and lifestyle aspects of a sustainable future, along with environmental elements affecting resource provision and nature: (i) future of work (digitalization, growth, inequality); (ii) architecture of global governance; (iii) society and governance; (iv) cities and urban-rural relations; (v) mobility; (vi) sustainable production and consumption; (vii) energy; (viii) land; (ix) water; (x) health; and (xi) nature (biodiversity, ecosystems). They represent key societal subsystems or sectors, and reflect domains of literature on transformations and their current (and sometimes divergent) understandings about pathways to reach sustainable futures. Although, as is the case with the above-mentioned EIU report, while it is not possible to retrieve comprehensive similarities between the scenarios portrayed in the two reports, most elements portrayed by SHAPE are in fact peppered throughout all the scenarios discussed in this report.

2.6 Anticipatory analysis for triggering transformation

Having explored the future and what it might bring, it is useful to take the pulse of where the world stands at the moment, and in particular, when we think about the Agenda 2030. In what pertains more to the FAO realm, the current picture is not reassuring. The UN High-Level Political Forum (UN HLPF) of 2019 noted that the world was "off track" on SDG achievement.[30] The second edition of the FAO's report *Tracking progress on food and agriculture-related SDGs indicators*,[31] launched in September of 2021 after more than one year and half of pandemic, echoes UN HLPF's findings: progress is insufficient in the food and agriculture domain, and following the COVID-19 pandemic and the outbreak of a conflict directly involving superpowers, eradicating hunger, achieving food security and preserving natural and genetic resources remain even more challenging.

This telling picture of the current reality and what it means for Agenda 2030 and FAO's goals, implies that agrifood systems need priority triggers of change in order to start or accelerate transformative processes, specifically: institutions and governance; consumer awareness; income and wealth distribution; and innovative technologies and approaches. Considered as effective starting points or boosters of transformative processes to move away from "business as usual", these triggers are expected to mutually interact and influence important drivers of agrifood systems. Through them, impacts will spread throughout the socioeconomic and environmental systems. Furthermore, there is an urgent need for governments to balance trade-offs among conflicting objectives, and design risk-informed, inclusive and sustainable strategies and policies and, most importantly, to implement them in a manner that makes them possible and effective. The priority triggers, strategic policy options, as well as current and emerging challenges and opportunities that arise from what is discussed in Chapters 1 and 2, are depicted and explored in Chapter 3 of the report.

NOTES – CHAPTER 2

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3 | Challenges, triggers and strategic policy options

Having explored the future and what it might bring, it is useful to take the pulse of the world where it stands at the moment. In the words of the United Nations Secretary-General, the world is "tremendously off track"' to achieve the Sustainable Development Goals (SDGs) by 2030.[1] This sentence summarizes fittingly the 2021 edition of the FAO report that tracks the progress on agrifood-related SDG indicators.[2] Progress remains insufficient, and as a result of the COVID-19 pandemic, eradicating hunger, achieving food security and preserving natural and genetic resources has become even more challenging. The Russia–Ukraine conflict is contributing to further degrade the situation.

After seven years since the adoption of Agenda 2030, and now close to being at mid-way, the challenges to achieve Agenda 2030 and move agrifood systems along a sustainability and resilience pattern are apparent. Some of them are not new but have been left almost unaddressed, or not effectively addressed. Others are emerging in the light of current events such as the COVID-19 pandemic and the recent Russia–Ukraine crisis. In any case, all of them are becoming more difficult to address because the window of time available is progressively shrinking. It also appears that, beyond the objective difficulties to address problems that stand at the heart of economies and societies, there are underlying structural difficulties, ranging from the vested interests of decision-makers and investors to asymmetries of power and other "political economy" issues. Four "triggers" of change to address these challenges have been identified by the Corporate Strategic Foresight Exercise (CSFE) and placed at the basis of the FAO *Strategic Framework 2022–31*.[3] They require to be exploited through strategies and policies aimed at moving agrifood systems towards sustainability and resilience.

The first section of this chapter presents and discusses the challenges ahead to achieve Agenda 2030 and move agrifood systems along patterns of sustainability and resilience. In the second section, the four triggers of change that emerged during CSFE are discussed. The third section illustrates selected strategic policy options to exploit the triggers and address the challenges ahead.

3.1 Challenges ahead to achieve sustainable agrifood systems

Almost all the core activities of agrifood systems – primary production, processing, distribution, consumption and disposal – and their interactions with socioeconomic and environmental systems – present critical aspects, weaknesses and pitfalls. Critical aspects emerge because of trends in major "drivers" of agrifood systems, as well as weaknesses of the institutional set-up and inadequate governance processes. It is recognized that, increasingly, concurring factors combine to generate multiple risks and uncertainties in agrifood systems. Managing and transforming agrifood systems under the influence of the drivers presented in Chapter 1, and influencing their trends, present a series of challenges that arise for different, often entangled, reasons. Reversing these trends poses serious difficulties because of the systemic nature of agrifood systems and the context within which they develop.[ch]

Some of these challenges are overarching in nature, as they directly pertain to the need to achieve the global corporate goals in a context where important drivers make such goals harder to achieve:

A. Addressing climate change and the intensification of natural hazards by drastically reducing greenhouse gas (GHG) emissions of global agrifood systems and economy-wide impacts.
B. Making agrifood systems more resilient to shocks (climate hazards, geopolitical instabilities, pandemics, contaminations from poisonous substances, etc.), also by exploiting the Humanitarian-Development-Peace Nexus, where applicable.
C. Ensuring a sustainable use of natural resources and the restoration of the natural resource base.
D. Ensuring that all development processes contribute to definitively eradicating extreme and persistent poverty.
E. Ensuring that all strategies and policies contribute to end hunger, eliminate all forms of malnutrition and maintain these results in the long run.

Other challenges refer to specific modalities for triggering or boosting transformative changes of agrifood systems in a dynamic environment under the influence of the above-mentioned drivers and related trends. They comprise:

F. Addressing the weaknesses of institutions, lack of cross-sectoral coordination, governance processes and legal frameworks at all levels, and tackling their enforceability issues and their implications for agrifood systems,[ci] cutting across all the drivers.
G. Supporting countries and the global development community to increase consumer awareness on transformative consumption choices (affecting all the drivers).
H. Addressing between- and within-country income and wealth distribution, and their implications for agrifood systems.
I. Mastering technological changes, including biotechnologies, digitalization, as well as “systemic” innovative approaches and their addressing potential drawbacks, to sustainably improving food and agricultural productivity (specifically addressing drivers).
J. Ensuring “intelligence” of development processes, including humanitarian-peace-development nexuses, where required, and the brakes to development dynamics affecting agrifood systems, including institutional, governance and legal weaknesses at all levels. There is increasing need to understand the dynamics at global and local levels and their multiple nexuses as a precondition to engage in strategy design and policymaking. This intelligence goes well beyond the mere knowledge of the internal dynamics of agrifood systems per se. As highlighted in Chapter 1, the majority of elements that signal possible critical issues regarding agrifood systems originate outside the agrifood systems themselves, such as in the socioeconomic, geopolitical, legal and environmental spaces surrounding them. In addition, quick fixes, mostly based on the current technical domains and ready-made solutions to be applied across the board in so-called “developing” countries (as opposed to so-called “developed” ones), are no longer advisable.
K. Ensuring iterative processes of learning and capacity development of different actors, and bargaining and coalition building, which are necessary to enhance the legitimacy, sustainability and efficacy of solutions adopted. Indeed, the desired transformation of agrifood systems can only be achieved if governance is strengthened by capitalizing on the knowledge, experience, skills and capabilities for collective action on the part of a broad range of public and private actors, each of whom convey different interests, needs and resources.

[ch] All these challenges have been identified during the CFSE and discussed with the participants. Selected challenges were already identified in the FAO report *The future of food and agriculture – Trends and challenges*.[4] For instance, the challenge posed by the increasing population, which raises concerns for the capacity of agrifood systems to nourish a progressively larger number of people.

[ci] Laws and regulations are vital to build strong and transparent institutions and promote accountable governance. FAO’s legal work is pivotal to improve institutions and governance mechanisms, while anchoring policies and strategies for the achievement of Agenda 2030.

L. Ensuring that strategies and policies at all levels, be grounded on solid impact models (theories of change), from diagnoses through triggers and causal links to desired transformations of agrifood systems, and that risk factors, including potential or actual conflicts and crises, are duly considered. In the quest for understanding and a mastering of the complexities underlying development processes, strategies and policies need to be grounded on comprehensive economic, social, legal, political and environmental analyses, supported by sound technical (disciplinary) knowledge and reliable statistics.

However, the overall transformation of agrifood systems is not only seen as raising challenges, but also as a source of opportunities for the global transformation of economies and societies. Large margins of improvement offered by some subsectors present opportunities worth exploiting. Furthermore, after the dreadful impacts of the COVID-19 pandemic, there are new opportunities to "build back better" and transform agrifood systems.

Ensuring that strategy and policy advice, and implementation support, where required, be grounded on comprehensive economic, social, legal, political, and environmental analyses, supported by sound technical (disciplinary) knowledge and reliable statistics. On the one hand, endowing FAO with enhanced multidisciplinary technical knowledge in economic, governance (including social sciences and gender analyses) and legal expertise (drafting, adopting, implementing and enforcing laws and regulations), agronomics and sustainable natural resource management (including climate change) requires a progressive overhauling of staff supported by good managerial capacities.

Some of the above challenges and opportunities directly impact on agrifood systems, while others lie outside the strict domains of food and agriculture. They require a broader understanding of development processes and, even more importantly, of factors that act as brakes on development dynamics, conflicts and risk factors that need to be understood to insert specific agrifood technical interventions in larger global, regional and national governance, development frameworks and humanitarian peace-development processes, where required. It also requires partnerships, normative work, emergency and resilience work that harness science, technologies and innovation for global sustainable development, and build more resilient agrifood systems – i.e. fit-for-purpose and future-proof institutions and organizations capable of fulfilling the aspirations outlined in the "four betters". Overall, stakeholders in decision-making processes and institutions supporting them need to be endowed with the required knowledge, technical skills, professional expertise and organizational capacity. This applies, of course to United Nations organizations which have to support member countries and the development community at large.

3.2 Triggers to move agrifood systems towards sustainability and resilience

As already clearly stated in the FAO report *The future of food and agriculture – Trends and challenges*,[4] business as usual is no longer an option. Transformative changes are needed to accelerate development, achieve Agenda 2030 and the FAO global corporate goals and, more importantly, beyond 2030, to move away from the current negative path to one leading towards sustainable and resilient systems.

Climate change and variability; conflicts, socio-political and economic crises; the outbreak of epidemics and pandemics such as COVID-19; and other food chain threats from transboundary animal and plant diseases and pests, natural resource degradation – just to mention some of the critical elements – jeopardize access to food, food security and nutrition and wreck agricultural livelihoods, especially those of vulnerable small- and medium-sized enterprises (SMEs). All of this also impacts on the overall sustainable development processes of economies and societies, and weakens achievements, including in terms of gender equality and empowerment of rural women.

To shift agrifood systems towards sustainability and resilience, several "triggers of change" are available that can be taken advantage of. These are areas of development that, because of their transformative potential, deserve particular attention, institutional boosts, and skills and organizational suitability in order to accelerate transformative processes. Key priority triggers identified by FAO's CSFE, and later incorporated in FAO *Strategic Framework 2022–31*,[3] comprise:

- institutions and governance
- consumer awareness
- income and wealth distribution
- innovative technologies and approaches.

Considered as effective starting points or accelerators of transformative processes, these triggers are expected to mutually interact and influence important drivers of agrifood systems and, through them, spread impacts throughout all agrifood, socioeconomic and environmental systems to achieve desired outcomes (see Figure 1.1).

Triggers for transformation are all expected to mutually interact and have systemic impacts on agrifood systems and on the context within which they develop. Whether they will be activated or disabled, the modalities of their utilization and the extent of their effectiveness will definitely influence the future that could develop according to a "more of the same" type of scenario, or move away towards alternative futures.[cj] Table 3.1 portrays how the various triggers could be activated or deactivated to determine the four scenarios presented in this report.

Table 3.1 Triggers and scenarios

Scenarios / Triggers	MORE OF THE SAME (MOS)	ADJUSTED FUTURE (AFU)	RACE TO THE BOTTOM (RAB)	TRADING OFF FOR SUSTAINABILITY (TOS)
Institutions and governance	Public institutions will progressively lose the power to orient and regulate economies and societies because of the emergence of private entities allegedly supplying public goods. Some civil society movements will question this drift with no success, given the limited space left to independent media and other communication channels. In fact, media and data platforms will progressively become concentrated in the hands of a few private entities tied to economic powers. Thus, the governance of global goods, such as peace, climate, health, oceans, etc. will progressively weaken to the detriment of sustainable agrifood systems.	When the failure of Agenda 2030 becomes evident, multilateral institutions will manage to act on a limited number of social targets. Some countries, pressured by collective action, will address the political economy challenge to reach compromises among citizens, parliaments and private lobbies, and will manage to address some trade-offs and reinforce regulations to reduce GHG emissions, improve food safety, control chemicals' use and safeguard biodiversity. In other countries, conflicts of interest between public decision-makers and private lobbies, big agrifood companies and small-scale farmers, will prevent substantial changes from taking place. Lack of global coordination, power asymmetries and systemic governance weaknesses will hamper results at national and global scales.	Governments, steered by elites acting under the influence of few powerful actors, will increasingly become more authoritarian. Private sector companies will be closely allied with governments, as they will create rules that favour said companies. Governance of global issues will progressively weaken to favour economic interests of the elites over environmental and social ones, while few attempts of civil society movements to oppose this system will fail. International organizations will be diverted from their original goals through underfunding, thus forcing them to embrace dubious public-private global partnerships and fictitious "global alliances' that progressively will replace them. Thus, global commons will drastically degrade with dramatic consequences.	The mobilization of real and representative civil society and other organizations will lead to the emergence of more effective participatory and novel, multilevel governance models resulting in a balanced power distribution across the state, civil society organizations, the United Nations, academia, trade unions, farmers organizations and private corporations. To address global challenges, the world will reverse the piecemeal governance of the early decades of the century to adopt a more integrated approach by strengthening transparency and through the provision of public goods at global, regional and national levels. Although setting and enforcing global agreements on GHG emissions and sustainable agriculture standards will be difficult, owing to the implied costs of adopting new technologies, some success will be achieved, with long-run positive impacts on agrifood systems.

[cj] Some "triggers" identified bear direct linkages with key drivers highlighted here, such as the trigger "Income and wealth distribution" through which inequalities are expected to be addressed. Other triggers, such as "Institutions and governance" are more systemic in nature and may trigger first round impacts on different sets of drivers.

Table 3.1 (cont.) Triggers and scenarios

Scenarios / Triggers	MORE OF THE SAME (MOS)	ADJUSTED FUTURE (AFU)	RACE TO THE BOTTOM (RAB)	TRADING OFF FOR SUSTAINABILITY (TOS)
Consumer awareness	Consumers will be induced by advertising campaigns to consume foods alleged to be healthy and sustainable. However, limited verifiable information will prevent consumers' associations from acting as effective counterparts. Regulations for increasing transparency will be biased thanks to lobbying. Despite some awareness, low-price, highly processed foods with poor nutritional value will be massively consumed because of limited incomes of many people.	Governments, to accommodate an increasing request of transparency on the quality, and social and environmental sustainability of food from the public and consumers' associations, will reinforce measures regarding labelling and traceability. Consumers' associations will attempt to induce behavioural changes. However, food transnationals, claiming excessive costs, will manage to water down such initiatives. The lack of global coordination favoured the avoidance of norms, thus limiting overall results.	Consumer awareness about the quality and sustainability of foods will progressively shrink, owing to the progressive reduction of public goods such as education and freedom of expression. Consumers' associations will be purposely weakened, including through legal prosecution, as they will tell uncomfortable truths regarding the quality of food and the sustainability of food production. Thus, the removal of citizens' power will fully deactivate a key trigger of transformation.	Consumer awareness will increase, thanks to a combination of coordinated public policies, including education and critical thinking in schools, and behavioural changes generated by consumers' associations. Through an organized movement at global, national and local levels, citizen consumers will gain power to become an active party in the transformation of agrifood systems. Despite initial attempts to disqualify the consumers' movements favouring sustainable production, transnationals will realize that collaboration with consumers will actually pay off.
Income and wealth distribution	Improving income and wealth distribution would be a must, given the food price increases caused by the tightening natural resources and the billions of people that cannot afford healthy diets. Unfortunately, income and wealth distribution will worsen, given the diminished fiscal space that will entail the reduction of publicly funded social protection programmes along with the privatization of basic public goods such as education, health care services, and security. Additionally, the reduction of jobs, wages and trade unions' strength, owing to increasing capital and information intensity of production processes, will compound the dire situation.	Faint-hearted taxes on profits of transnationals in information and communication technology and "big oil", and to some extent on fiscal dumping, will be imposed. These will bring mixed results, owing to diverging interests of various countries. However, both in low- and middle-income countries (LMICs) and high-income countries (HICs), some fiscal space will be created to fund last-minute actions for SDGs 1 and 2, and to act against the mounting inequalities resulting from a jobless growth in some sectors, and a rampant gig economy elsewhere. Trade unions will regain strength to adjust to labour market asymmetry in negotiating power. Overall, poverty, hunger and food insecurity will decrease around 2030, but only temporarily.	Fiscal competition, and fear of losing investment capital and associated jobs, will continue to discourage governments from billing the richer classes. In this context, rent-seeking from transnationals, including in agrifood systems, will be exacerbated. Very weak institutions at all levels will allow power accumulation and extraction of huge rents from agrifood value chains, while wages and job security will be sacrificed, also because of the non-existent trade unions. Owing to all that, income and wealth distribution will dramatically worsen. Dysfunctional agrifood systems will exhibit increasing food prices with disastrous consequences on poverty, food security and hunger.	Although in a context of limited economic growth because of the transition from fossil fuels to renewables, and in a context where investment in new sustainable technologies was favoured compared to household consumption, some achievements to reduce hunger will materialize thanks to social protection policies strictly targeting the neediest social groups. In the long run, equitable taxation, aware trade unions, improved public services and well-designed social protection programmes as well as the development of novel, accessible and sustainable technologies will help reduce inequality, poverty and hunger in a sustainable manner.

Table 3.1 (cont.) Triggers and scenarios

Scenarios / Triggers	MORE OF THE SAME (MOS)	ADJUSTED FUTURE (AFU)	RACE TO THE BOTTOM (RAB)	TRADING OFF FOR SUSTAINABILITY (TOS)
Innovative technologies and approaches	Science will progress and support innovation, but investment will be concentrated in a few HICs. A fragmented and ever more competitive multipolar system will facilitate the acceptance of doubtful biotechnologies, owing to neglected precautionary principles and weak global regulations. Agroecological and other environment-friendly approaches will be developed only to a limited extent. Artificial intelligence (AI) and machine learning will facilitate agricultural robotics, and soil and crop monitoring. However, the few investors controlling these technologies will have no incentives to transfer or adapt them to multi-cropping or small-scale systems.	Science and innovation will contribute to eliminate the risk of a quite likely collapse. Although the emphasis put in the 2020s on digitalization will prove to be excessive, some applications, such as soil, crop and animal monitoring through remote sensing and other Internet of Things (IoT) applications, will prove to be very useful. However, to quickly ensure affordable healthy diets by increasing land and water productivity, LMICs will become the experimental field for strong genetic manipulations. However, insufficient testing and lack of knowledge of the systemic implications will prove most of them to be unsustainable and will give way to more controllable biotechnologies.	Instead of facilitating the adoption of sustainable techniques, digitalization will be increasingly used to control value chains at all levels. Digital equipment will be increasingly provided almost for free to smallholders by a few transnationals controlling big data and AI systems to obtain strategic digital information. Private investment in agrifood systems will mainly originate from export-oriented transnationals in global value chains to take over smaller national businesses and make mass land acquisitions. Thus, in many instances, large numbers of farmers will become landless and jobless, and forced to urbanize or migrate abroad. The pioneering attempts to adopt integrated agroecological and agroforestry approaches will become remote dreams.	After a period of uncertainty, digitalization, IoT and AI worked for people and sustainable development thanks to a new global governance of big data generation, use and ownership. This process, demanded by civil society, independent academia and some governments, will be fully supported and facilitated by the relevant United Nations bodies. The gains from technological innovation will not only prioritize previously neglected populations in LMICs, but also sustainable, resilient and integrated agrifood systems. Thus, priority will be given to scientific research and development geared towards approaches that meet the needs of the great variety of agroecological and social conditions.

Source: Authors' elaboration.

3.2.1 Institutions and governance

Achieving transformational changes to redirect agrifood systems towards sustainable, resilient and inclusive development requires identifying and managing trade-offs to maximize economic, environmental and social benefits. This involves having to make difficult choices, which are likely to produce winners and losers. Transformative processes thus require – as a precondition (upstream enabler) – much stronger and more transparent and accountable institutions and governance, including adaptive and effective regulatory governance.

Currently, as stated in the document:

> "the institutional vacuum is particularly felt in the discrepancy between the global level of issues at stake, such as international capital flows, global climate issues, international conflicts or local conflicts fed by external dynamics, big data generation, storage, use and control, on one side, and the increasing weakness of most of the sovereign countries to govern such issues, on the other side. With few exceptions, the size of most countries is clearly too small to influence, at least to some extent, these global dynamics" (FAO, 2021, p. 10).[3]

Better institutions and governance are required both within and outside agrifood systems, because governance and institutions influence all the drivers and the channels that link the various elements of agrifood systems with the other systems. FAO defines governance as referring to formal and informal rules, organizations, and processes through which public and private actors articulate their interests and make and implement decisions.[5, ck] This definition points to the dual nature of governance as simultaneously being a set of rules, structures and procedures that guide or influence individual and collective behaviour and an activity that seeks to alter or sustain those very same rules, structures and procedures. Examples are: processes and rules for climate change, and other disaster and crisis risks and emergencies; policies and legislative frameworks related to agrifood systems at all levels (food production and processing food trade, food safety, food quality and food consumption, etc.); mechanisms for conflict prevention and solving; and institutions for poverty and hunger eradication. Given the multiple issues at stake and their interrelationships, clear, specific, well-designed governance and institutional mechanisms with effective compliance rules need to be in place.

Policy and governance are closely interrelated yet different. Policy, in essence, is a commitment to a designated goal and course of action to attain that goal. It is a selection among several options, and a choice of means and instruments to achieve the selected objectives. Whereas governance is about mobilizing and concentrating the collective will to achieve a given policy objective, and about providing means, instruments and resources necessary to support effective implementation of those policy objectives. In short, both a policy and its impact on the ground are an output and outcome of governance processes.[6]

More specifically, better understanding of key governance challenges and efforts towards improved/strengthened institutions and governance are needed across all the domains of agrifood systems and their socioeconomic and environmental contexts, comprising those listed here.[cl]

1. **New technologies.** Governance and regulations for "new technologies" (e.g. genome or gene editing, etc.) are considered preconditions for the prevention of undesired side effects of research and development in this field, and to govern issues regarding ownership (intellectual property rights) and societal benefits sharing (who gains, who loses).
2. **Big data.** The implications of big data, their dynamics and concentration for economic growth, reduction of poverty and income inequality have not been fully explored. Regulations addressing the independent generation, transparent accumulation, storage, use, dissemination, property rights and confidentiality of big data are definitely required. United Nations international organizations have a role to play in governance in order to influence big data, including those generated by and needed for agriculture, fisheries and forestry.
3. **Land and water.** The importance of governance regarding ownership of land, water and other natural resources, as well as water accounting, cannot be overstated: laws and policies that enable security of formal and informal tenure and rights to land, fisheries, forestry, and water use and control are a solid incentive to stimulate long-term investment in production and ensure resilient and sustainable protection and conservation of the environment and natural capital. Securing land tenure and formal recognition of traditional, customary rights related to natural resources will increase incentives to boost productivity in land use, while protecting the environment and enhancing land-related investments. Largely as a result of poor systems of water governance there is increasing competition for scarce water resources between different sectors (agriculture, energy, tourism, etc.) as well as within sectors (e.g. big farmers vs small-scale farmers).

[ck] A more articulated definition separates institutions, governance and regulatory governance: a) institutions are intended as the body of norms, rules, habits, etc., recognized by most, if not all, parties in a society, as broadly intended; b) governance is intended as the processes of governing (decision-making, implementing, assessing, monitoring, evaluating and enforcing processes) by using (applying and respecting) institutions; and c) regulatory governance refers in particular to the setting and use of binding (and enforceable) rules to govern the behaviour of parts of a society (an economic sector, groups of citizens, etc.).

[cl] These domains requiring better governance were identified during the Internal Expert Consultation (IEC). Further analyses, better articulation and the identification of ways forward to address them were recommended by participants in the IEC.

4. **Sustainable development.** Governance frameworks (policy, legal and institutional) and arrangements that take multiple risks into account and allow for key trade-offs between economic, environmental and social objectives to be addressed, should direct changes to drive inclusive, resilient and sustainable development. Their presence is necessary to ensure that there are rules and processes in place to adequately address and enforce the sustainable use of agrifood systems, including natural resources for food production. Their absence signals possible emerging problems for sustainable agrifood systems in the medium and long run.
5. **Private vs public sector.** In recent decades, nation states appear to be increasingly less capable, vis-à-vis the private sector, of governing markets and curbing inequalities. Governance systems seem to be driven/dominated by private sector players rather than public institutions, with skewed outcomes for global and individual well-being. New social pacts may be needed to ensure that no one is left behind. Innovative communities, including those for agrifood systems and energy, may be built through improved governance.
6. **Conflicts.** Solving and preventing conflicts require strengthening socio-environmental and economic governance as well as political will and commitment on the part of policymakers and political leaders. This comprises governance frameworks that allow for the participation and engagement of Indigenous Peoples and other vulnerable groups (Indigenous Peoples-conscious or gender-conscious focus) in order to address the hurdles these groups face.
7. **Employment and job conditions.** Stronger institutions and improved governance, at all levels, is particularly needed to address issues related to labour markets and job conditions. While, on the one side, capital and information intensification, other things being equal, reduce labour intensity of production processes, thus impacting on job opportunities, population growth, particularly of youth in sub-Saharan Africa (SSA) and South Asia (SAS), increases labour supply, thus engendering risks for fair labour market competition and decent job conditions. This also increases the risk of "social dumping" on international product/service markets, with negative "cascade" effects on labour markets globally.
8. **Migrations.** Understanding and addressing governance related to migration processes is of crucial importance to facilitate access to decent work. This is particularly relevant in the process of recovery from the COVID-19 pandemic, which may enable migrants to find new opportunities. Governing the jobs of migrants, which are fundamental for agrifood systems, including in HICs, is not only key in ensuring decent employment conditions, but also to protect/increase remittances and engage diasporas in development processes. Plus, forced migrations/displacement require better governance.
9. **Public goods.** Deforestation, overfishing, overuse of groundwater, soil and land degradation, etc. – these are often public or commonly owned resources under inefficient governance systems, often complicated by the transnational and dynamic nature of some of these resources.
10. **Food safety.** The exponential growth of big data in the coming years will be of relevance to food safety decision-making. Both governments and industry need to learn how to generate, use and interpret data. While this is an opportunity for improved transparency along food value chains, challenges will remain with regard to the interpretation of data, integration of diverse datasets, and with regard to data confidentiality and ownership. Furthermore, to avoid exclusion of SMEs from market access because of food safety issues, it will be important to ensure that they form part of the data-generated knowledge systems and to promote policy-science-people interfaces.
11. **Multilateralism and global imbalances.** In addressing global issues, the international community and multilateral fora show fragmentation, poor accountability and lack of political commitment. This raises questions regarding rules for global governance: regional and intraregional bodies are challenged by resurgent nationalisms while the human rights agenda is not prioritized.
12. **Market power and concentrations.** Consolidation and specialization in food and agricultural production, processing and distribution channels have led to enormous gains in efficiency, but also led to the concentration of market power in increasingly fewer enterprises. All this may have been achieved at the expense of resilience, biodiversity and inclusiveness. Trade-offs of concentration processes need to be better understood, and policies and innovative governance arrangements devised to maximize benefits across multiple agrifood systems outcomes and actors.

13. **Intergenerational equity.** Equitably meeting the needs of present and future generations, that is, achieving intergenerational equity by taking into account the rights of future generations, for example, on climate justice, is becoming urgent in light of increasingly degrading natural resources and climate. A recent paper by the United Nations High-level Committee on Programmes identifies insufficient knowledge-gathering capacities, demographic trends, inequalities, skewed political and economic incentives, insufficient governance and insufficient legal rights as challenges to meeting intergenerational equity.7 A key point for any measures taken to address this issue and its challenges is to support a concerted normative and legal push to enshrine a global responsibility towards future generations, with legal standing in international law.

Having 'good' policies and regulatory frameworks in place, implementing and enforcing them, and achieving expected outcomes will be possible if other governance factors are managed by considering actors' influence and pressures, addressing tensions between different objectives, rebalancing power asymmetries and reconciling conflicting interests.

Overall, the discrepancy between the global relevance and nature of issues at stake, such as international capital flows, global climate issues, biodiversity and natural resources depletion, international conflicts or local conflicts fed by external dynamics, big data generation, storage, use and control, and the limited power of most sovereign countries that are definitely too small to influence these global dynamics, need to be filled by stronger international and global organizations. Thus, in this context their role is expected to expand significantly.

3.2.2 Consumer awareness

The need to increase and leverage consumer awareness regarding the type, quantity and safety of food to consume, and the sustainability of related production and distribution processes, as well as food waste and other broader impacts of consumption choices, is underlined as a trigger to directly influence selected outcomes of agrifood systems and, via feedback effects, also selected drivers. Increasingly, in HICs, groups of younger generations appear eager to actively participate in changing current realities, for instance, in face of climate change.

The educated segment of the youth might progressively lead development and policy processes, becoming a trigger of change for: environmental problems (the impacts of consuming certain food items on climate change and GHG emissions, and on natural resources conditions); social problems brought about by certain food production processes (inequalities, including gender imbalances, and decent working conditions or remunerations); and structural problems (e.g. concentration of input-output markets). Consumer awareness regarding food, as well as non-food consumption, is important in light of existing sectoral and cross-country interdependencies.

- Social media is increasingly playing multiple roles in shaping up consumers' views and behaviours. On the one hand, they ease the contact between governments and citizens, including in emergency situations like the outbreak of COVID-19, or enable better linking between consumers and producers. On the other hand, they allow businesses to influence or manipulate consumer preferences through targeted advertising, based on personal information unconsciously shared or snatched thanks to a lack of enforceable regulations. Social media may also contribute to channelling "fake news" for political consensus gathering and/or other malicious ends.
- Food producers, whether local, national or transnational, will have not only to react to pressure coming from consumers but will need to anticipate them, thus favouring transformative processes. In fact, the ability to anticipate the evolution of consumers, rather than reacting to it or, even worse, preventing or diverting it through misleading advertising campaigns or other stealth marketing techniques, constitutes and important competitive advantage for private companies.

3.2.3 Income and wealth distribution

The urgency of improving income and wealth distribution among and across societies is seen as a channel through which inequalities, and urban and rural poverty, can be reduced as well as a means to achieve economic growth, macro-stability and manageable urbanization. Food security and nutrition outcomes are difficult to achieve if income and wealth distribution are not improved.[cm] On the one hand, for example, there is increasing attention on the affordability of nutritious diets and evidence showing that billions of people cannot afford them.[cn] On the other hand, large portions of global wealth and incomes are appropriated by very small fractions of the population and in few countries. Reducing cross- and within-country inequalities may reduce geopolitical instability.

Providing more income and income-generating opportunities to people implies that channels through which income is distributed throughout the economic system are enlarged and maintained active even during economic downturns. Remunerative green employment opportunities across all economic sectors have to be ensured for wage workers, while equitable profit sharing is required for capital owners. The latter is particularly important given the ongoing capital intensification of many production processes within and outside agriculture, that increasingly rely on automation, innovations implying intellectual property rights, and information/data dense production processes and capacities to generate, handle, store, use and control big data and related platforms and technologies.

The cost of health expenditure is increasing at an alarming rate because of unhealthy foods and related non-communicable diseases, affecting the poorest families. These inequalities are disproportionately borne by women around the world, depending on where they are born, their age, disability status, whether they belong to an Indigenous Peoples group or to other minority groups, thus limiting the potential of around half the world's population. Redistributive channels based on fiscal measures, including channels for intra-household redistribution, and public funding involving various aspects of social and economic life are also perceived as essential to achieving corporate goals. To date, most distributional actions have been implemented by nation states through the fiscal system.

The economic space is increasingly extending beyond traditional boundaries of nation states. Hence, it is increasingly less clear who has the incentives and the power to enforce fiscal redistribution and redistribution actions become more problematic. The public interventions triggered by the outbreak the COVID-19 pandemic were mainly focused on income support, and just confirm the importance of mechanisms to redistribute real income in all countries, such as increasing the amount and effectiveness of public expenditure on basic public goods, such as education, health care services, food safety, security and justice, food safety, and basic and applied research, including that for agrifood systems. Equitable and effective fiscal systems, also regulated through international agreements, form the necessary counterpart to all of this in order to avoid excessive governments' indebtedness, which would impinge on national sovereignty and future generations.

3.2.4 Innovative technologies and approaches

A great deal of reliance and hope are placed on technologically innovative solutions to: produce more with the same or less resources (save water, reduce land degradation, reduce food loss and the use of inputs, conserve biodiversity, etc.); reduce food and agricultural prices, including the cost of nutritious food; and reduce the risks of epidemics and pandemics. Innovative technologies are also expected to increase transparency in transactions, create new earning opportunities and boost the overall technical progress while promoting social inclusion. Further breakthroughs, including in biotechnologies and "systemic" technologies such as conservation and integrated, precision agriculture, agroforestry, agroecology and accessible applications are also seen as an entry door to support the development of emerging sectors, such as the Blue Economy'.

Digitalization and biotechnologies, such as genome editing (or gene editing), in particular CRISPR-Cas,[co] or synthetic biology, where the genetic material of an organism can be synthesized, are seen as catalysts for food and agriculture. Emphasis is also put on:

- **Circular bioeconomy, organic agriculture, and food loss and waste reduction along the whole food systems.** This is seen not only as a way of producing food, but also of addressing GHG emissions and improving the overall footprint of food systems.

[cm] SDGs 1 and 2 and related targets.

[cn] See, for instance, *The State of Food Security and Nutrition in the World 2021*.[8]

[co] CRISPR-Cas represents a relatively new set of techniques for making precise changes to the genetic makeup of a living organism without transferring transgenes across species boundaries.

- **Microbiome.** Understanding how the microbiome can provide integrated perspectives for food, human and environmental health.
- **Vertical farming.** This option is seen as particularly important if urbanization processes continue as per recent trends.
- **Lab-grown meat**, and the provisions of food through bioreactors.
- **Green and clean energy**, especially solar energy, including in low-income countries (LICs). In SSA, in particular, solar energy may power irrigation systems as well as cooking, which could reduce the use of biomass and wood, thus reducing deforestation and GHG emissions.
- **Downstream applications.** Technological innovations may extend beyond food production, to include:

  - biodegradable packaging that enhances the shelf-life of foods beyond conventional packaging and changes physical characteristics as it nears its shelf-life.
  - traceability of supply chains and international trade geared up by digital technology.
  - Remote sensory data and Geographic Information Systems, to, among other things, improve the fight against Illegal, unreported and unregulated (IUU) fishing.
  - Artificial Intelligence and digital solutions for e-commerce such as digital marketplaces, etc. The potential of digital solutions is also seen for e-leaning processes at various levels (educational, professional and social) or agricultural extension services, particularly where people are connected via the Internet or other digital networks.

The blurring boundaries between food and medicine, thanks to advances in genomics, food processing, drug design/formulation, etc., may increasingly lead to personalized foods to address health conditions. This is an area that is in rapid evolution where regulatory guidance and oversight would be challenging, but much needed.

However, further research, in addition to better governance, is also needed to address structural issues, such as the excessive concentration in big data ownership, use and control, and improving income distribution through better profit-sharing. Technology can be an enabler, but if ownership and dissemination develop unevenly, the technological divide of many strata of societies, including smallholder farmers, may dramatically increase because of the high investment costs of digital technologies and inaccessible economies of scale.

3.3 Strategic policy options

Triggers of change need to be exploited through context-specific actions that require a clear evidence-based design, effective implementation, and constant monitoring of processes and outcomes. Selected strategic policy options to move agrifood systems towards sustainability – not only for the relatively short term of Agenda 2030, but beyond it (to 2050 and 2100) – emerged during the CSFE. This exercise also catalysed strategy and policy proposals already expressed in recent FAO flagship reports, documents from Regional Conferences and other corporate documents.

Selected strategy and policy options are proposed in this section, with no pretence at being exhaustive. They are organized according to the main trigger of change they are likely to activate, notwithstanding the fact that trigger strategies and policies are intertwined in most practical contexts, and therefore a single strategic option may activate more than one trigger.[cp]

3.3.1 Strengthening institutions and governance

Transforming agrifood systems requires a substantial effort in terms of taking concrete actions that pertain to institutions and governance, an overarching trigger that impinges on almost all strategies and policy options. Establishing these governance and institutional foundations helps overcome political economy hurdles, goes beyond vested interests that support conventional

[cp] Most of these strategic policy options were identified in the technical papers provided as background documents to this report by technical divisions. Others refer to recent corporate reports, FAO flagship publications and documents of Regional Conferences.

development paradigms, and weakens troublesome power structures. The following are some strategic and policy options that either may contribute to strengthen institutions and governance, or may benefit aspects of agrifood systems by strengthening institutions and governance.

- **Food standards legislation.** Regulatory measures, such as food standards legislation through food product reformulation, taxes on sugar-sweetened beverages, control of advertising targeting children and in schools, as well as informative food labels, including simple front-of-pack nutrition labelling can be introduced to help reduce sugar, salt and fat intake, and eliminate transfats in urban centres.
- **One Health approach and early warning systems.** National and international integrated One Health systems for human, animal, plant and environmental health through improved pest and disease prevention, early warning and management of national and global health risks, including antimicrobial resistance, would help prevent diseases and pandemics (see Section 1.15).
- **Capacity building for extension and advisory services.** In general, there are insufficient human resources and training on non-chemical pest and disease management techniques to support farmers. Farmers largely rely on other farmers or local pesticide distributors for advice. Provision of best practices guidance through the use of digital technologies and by linking to improved services would be helpful.
- **Afforestation and conservation of forests** can maintain and improve soil organic carbon sequestration, which can contribute to offset GHG emissions, but require solid governance at all scales, also to balance the costs and benefits of afforestation and conservation within and between countries.
- **Financial mechanisms for "blue transformation".** Blue bonds, credit default swaps and other financing mechanisms that distribute risks and engage stakeholders, play a critical role in financing the transition towards a "Blue Economy" (see Section 1.18). Initiatives such as the United Nations' Sustainable Blue Finance Initiative and the World Bank's ProBlue fund are examples of mechanisms to finance the transition. For ethical and sustainable investment, the Sustainable Blue Economy Finance Principles,[9] and the Principles for Investment in Sustainable Fisheries,[10] provide a framework for investors. Governments have the option to include the principles set in these guidelines into their legislation to make them compulsory and enforceable.
- **Managing the risks of conflicts associated to decarbonization.** A Green Economy agenda that ensures reforms for a cleaner global economy needs to be complemented by transparent and accountable governance mechanisms for the production and commerce of strategic minerals requiring low-carbon technologies. Their value chains must be governed in a responsible, accountable and transparent way. In addition, Parties to the Paris Agreement could engage with fragile states, dependent on oil revenues, to support more stable transition processes.
- **Public-private partnerships for innovation.** The OECD-FAO Guidance for Responsible Agricultural Supply Chains helps enterprises observe existing standards for supply chain risk mitigation in agriculture,[cq] and is recommended by many governments as the first point of call in understanding how businesses (including small-, medium- and large-sized enterprises) can operate to reduce their adverse impacts while supporting development. The guidelines also promote responsible business conduct in agrifood systems, considering issues related to innovation, access to innovation, data and technology, and business impacts on society and the environment (for example, National Action Plans on Responsible Business Conduct). Governments have the option to include the principles set in these guidelines into their legislation to make them compulsory and enforceable.
- **Private investment regulation and promotion.** Beyond public spending in agriculture, governments have the option to adopt policy and regulatory measures needed to mobilize more private investment in agrifood systems (see Section 1.10). For example, regulations aimed at

[cq] These standards include the *OECD Guidelines for Multinational Enterprises*,[11] the *Principles for Responsible Investment in Agriculture and Food Systems*,[12] and the *Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests in the Context of National Food Security*.[13]

reducing unnecessary procedures, and increasing fair, clear and enforceable fiscal measures, as well as the transparency of the banking sector, can enable greater private financial flows into food systems.

- **Early warning systems for conflicts.** These systems would give existing bodies in the more stable, multilateral world system (including the United Nations Security Council, the African Union, Regional Economic Communities and other multilateral entities charged with maintaining peace and security) the best possible chance to prevent, manage and contain conflicts.
- **Risk-management governance.** National governments and strategic partners have the option to develop inclusive and coherent risk and regulatory policies, strategies and plans to enhance resilience to shocks and stressors across sectors and levels in a systematic way (see Section 1.6). This includes multi-stakeholder coordination platforms and mechanisms (including for advocacy), and conflict-sensitive efforts to build socioeconomic capabilities and resilience.
- **Conflict prevention strategies.** Preventing violence requires seeking inclusive solutions through dialogue, adapted macroeconomic policies, institutional reform in core state functions and redistributive policies (see Section 1.5). Inclusive decision-making is fundamental to sustaining peace at all levels, as are long-term policies to address economic, social and political aspirations. This involves the participation of young people and women in all aspects of peace and security, including in peace processes.
- **Data transparency on impact investments.** One of the difficulties in distinguishing between investments that may have positive developmental impacts on agrifood systems from those that have negative ones is the lack of standardized metrics and consistent data to measure their social and environmental impacts (see Section 1.10). Enhancing data through better standards, transparency and additional data collection will encourage more impact investments and investments aligned with environmental, social and governance (ESG) metrics, including those aimed at climate change mitigation.
- **Regulations on intellectual property.** Technologies and innovations need to be complemented and guided by enhanced human capital, governance and institutions. Innovations depend on a working societal model that ensures that civil rights are enforceable, while penalties and reparations can be attained. Ownership (including intellectual property rights) needs to be regulated through transparent rules, while a judicial and penal system must ensure their enforceability. For this to take place, a high degree of competence in governance is a prerequisite.
- **Land and water tenure rights.** Responsible governance of tenure rights ensure that informal, customary rights are recognized and respected, and that laws are enforced correspondingly. In turn, this helps prevent and solve conflicts, and ensures more transparent and legitimate decision-making processes, while also promoting enhanced land information and regulatory measures.
- **Territorial governance: intermediary cities.** They play a primary role in connecting important rural and urban areas to basic facilities and services, and can provide opportunities for migration to rural populations seeking employment or as a step towards migration to large cities. They can act as regional market centres or hubs, offering innovative green employment opportunities for residents of smaller cities, and connect traders and producers with customers and farmers' markets in larger metropolitan areas.
- **Urban space governance: farmers’ marketplaces and outlets.** There is a need to ensure a balance of retail outlets, i.e. ensure that outlets that sell predominantly fresh and nutritious-dense food, such as farmers’ markets, open-air municipal markets and small food vendors are not crowded out by other outlets (e.g. convenience stores and supermarkets), particularly in low-income areas.
- **Urban space governance: zoning laws.** These are regulations that, for instance, attempt at incentivizing the reduction of the density of fast-food restaurants and food swamps, or fast-food restaurants near schools. These are being explored as a mechanism to reduce/prevent obesity and associated non-communicable diseases, complemented by food retail policies and incentives to increase the availability of healthy foods.
- **Industrial governance: incentivizing in agroprocessing.** Agrifood systems go beyond the agriculture sector. Bearing in mind how the manufacturing and service sectors fit into agrifood

systems would help in increasing the vertical coordination of different sectors. For example, agroprocessing plays an important role in ensuring food security. Governments have the option to encourage investment in processing facilities in a sustainable and green manner.

- **Business models for biocontrol.** Biopesticides and biological control agents are not readily available to farmers in most locations in LMICs. The costs for classical biocontrol and augmentative biocontrol are usually shouldered by governments. Operations are often inefficient, and funding is unsustainable in the long run. An improved organizational and institutional set-up could enhance the sustainability and efficiency of biocontrol activities.
- **Research funding.** The number of researchers focused on natural enemies of pests have been fast declining. This discrepancy in research funding between genetic engineering, chemical pesticides and big data solutions vs nature-based solutions (biological control and preventative agroecological measures), impacts both the state of the art in the research, as well as its delivery and dissemination.
- **Managing the impact of monocultures.** Monoculture systems typically weaken natural pest regulation mechanisms and make production systems more vulnerable to pest and disease outbreaks, maintaining pesticide use high. Institutional arrangements to manage these aspects could help to move towards more sustainable integrated approaches.
- **Regulation of use of antibiotics and pesticides.** Antibiotics and pesticides (especially highly toxic, broad-spectrum pesticides with immediate knockout effects on pests) are often used as a quick and easier pathway for farmers and for governments to demonstrate fast action in cases of large pest or disease outbreaks. However, the negative externalities on human and environmental health are often not taken into account in the pesticides' market price. This requires solid institutions and enforceable regulations.
- **Climate-smart agriculture, agroecology, regenerative agriculture.** Research suggests that nature-based solutions (NbS) could provide around 30 percent of the cost-effective mitigation that is needed by 2030 to stabilize warming to below 2 °C,[14] and most of the NbS are linked with reductions in the agriculture, forestry and other land use (AFOLU) sectors (see Section 1.16). But, as with many new approaches, products and services, institutional arrangements are needed to identify actors, define standards, establish property rights, set up incentives and regulate their delivery.
- **Procurement procedures through cities and regions.** Through procurement procedures, cities and regions can support the transition towards more sustainable, healthy and low-carbon food that is affordable and accessible for all and reflective of culture, geographical specification and local traditions.
- **Partnerships with fisheries' private sector.** Large and small fisheries and aquaculture firms, retailers and global supermarket chains hold substantial capacity to catalyse the transformation of "blue food" systems (see Section 1.17). Financial firms also hold significant potential to invest in fisheries and aquaculture with "green/blue" investment funds and continue to increase their portfolios. This makes it all the more urgent to ensure adoption of ESG metrics, including for climate change mitigation, and to adhere to them for investment choices and monitoring.
- **Diversity of actors and of responses of agrifood systems.** This determines their resilience. Diversity provides a network for learning and transformation, for preventing risks and buffering shocks, and for ensuring agility in responding to varying needs and opportunities. Diversity and stability in trade is another key element that has emerged.[15]
- **Investing in human capital to strengthen governance capacities.** Strengthened capacities in governments and their partners to analyse governance issues and implement necessary reforms across different sectors can accelerate agrifood systems transformation.
- **Context-specific approach to strengthening institutions and governance.** For support to countries to be effective and inclusive, programmes and actions need to be based on a good understanding of both national and local agrifood systems governance (i.e. both national and local institutions as well as political economy). In addition, it is important to recognize that the uneven nature of local landscapes: (i) make policy work differently in different countries, and in different places within a country; and (ii) shapes possibilities leading to whether one can implement a successful policy or not.

3.3.2 Increasing consumer awareness

Consumers are the largest stakeholders in decision-making processes regarding agrifood systems. They are increasingly making complex choices about the sustainability, nutritional content and safety of what they eat. Dietary patterns with better nutritional, environmental and social outcomes are possible. Their adoption has a huge transformative potential to deliver benefits on a scale not otherwise achievable. It may be, therefore, that consumers hold the power to shift demand towards more environmentally and socially responsible and nutritious foods, provided the right mix of information, support and regulation is in place, thereby possibly leading to deep changes in production systems. Thus, their opinions and ensuing consumption choices act as natural and powerful triggers for transformation (see Section 1.14).

The following are some strategic and policy options that may increase awareness of consumers so that they can act as a trigger of change.

- **Education for consumer awareness.** While governments can incentivize producers to share information with consumers regarding agrifood production processes, they can also increase consumers' critical thinking capacities through school curricula, to increase their awareness regarding the implications of consumption choices.[16] Regulations and dietary guidelines can complement education to encourage people to adopt healthy diets based on sustainably produced foods.
- **Public communication campaigns on agrifood systems.** Public campaigns aimed at sharing information regarding agrifood systems help increase awareness on specific issues. Focus could be placed on the functioning of agrifood systems and their implications for sustainable development, including, for instance, the implications of producing and consuming certain products or adopting certain production processes, compared to others, with respect to natural resource use, biodiversity or climate change.
- **Food labelling policies.** All packed food in almost all countries requires a label that displays certain mandatory information, depending on designated national laws. In general terms, food labelling must be accurate and not misleading. However, the quality, type and scope of information to be mandatorily provided on labels is a politically sensitive matter. Producers may claim that disclosing information on the product can reduce their competitive advantage, while information on production processes and related impacts is even more controversial, pending the definition and/or acceptance of common standards for measuring social and environmental impacts through, for instance, life cycle assessments. Governments could extend the content and scope of labelling, possibly starting with pilot initiatives, to explore how to effectively incorporate social and environmental dimensions of food production processes. Consumers would receive stronger signals to help orientate their choices.
- **Advertising bans and negative campaigning.** While there are potential challenges to identifying the effectiveness of a single policy measure on consumer behaviour, some studies show that well-targeted and selected advertising bans can help orient consumption choices away from selected categories of goods that may be detrimental to one's health or to other developmental objectives. However, designing and implementing such policies may be difficult both on technical and political grounds. On technical grounds, the measures need to actually affect targeted people (children, obese persons with specific health problems, etc.), correct the behaviour that actually causes the problem (e.g. targeting sugar consumption while obesity is mainly generated by lifestyles) and be coherent (synergetic) with other measures that aim at the same goal. On political grounds, banning advertisements or negative campaigning may be perceived in some instances as a limitation of individual freedom, both by producers and consumers. Despite these difficulties, advertising bans and negative campaigning may be considered to be an item in a policy toolbox for orienting consumer behaviour and increasing consumer awareness.
- **Favouring direct producer-consumer linkages.** Policies that facilitate direct links between farmers and consumers and promote local food systems can leverage increased consumer awareness, sense of agency and interest, often related to production practices with lower environmental impacts, to upscale to the adoption of more sustainable technologies, even if

they may entail higher unit production costs and consumer prices because they avoid the use of chemicals or require greater labour intensity.

- **Increasing capacities for consumers' advocacy.** Strengthening consumers' capacities to adequately advocate for improvements in the food environment implies furthering their knowledge on how agrifood systems work both at national and international levels. Incentivizing media, public authorities and independent academia to share with consumers independent information and implement scientific dissemination programmes may help improve the technical soundness, pertinence and effectiveness of actions carried out by consumers' associations, thus improving and upscaling the impacts of their claims regarding the sustainability and resilience of food systems.
- **Food loss and waste policies and dietary change.** Awareness about reducing food loss and waste could contribute to the reduction of energy use and GHG emissions from agriculture, transport, storage and distribution, and reduce land demand.
- **Partnerships with civil society, private companies and businesses, cities and regions.** Faced with growing challenges and global trends, many stakeholders are actively engaged in transforming food systems and natural resources at local and global levels. Non-state actors can help shape and influence the transformation of food systems and play a considerable role in initiating changes in shaping public policy.
- **Social protection programmes to reach consumers.** Linking social protection programmes to grassroots initiatives that promote healthy diets from sustainable food systems could help engage the most vulnerable producers and consumers, and increase their awareness regarding the health, social and environmental implications of their consumption choices.
- **Youth engagement.** Youth in agrifood systems is key to transforming conventional unsustainable agriculture, fisheries and aquaculture practices. Engaging young consumers in adopting more sustainable agrifood practices entails life-long behavioural changes with long-term impacts on food systems, as well as having a cascade impact on households they belong to. It is also essential to bring the concerns and requests of youth into climate-related policymaking and planning. Political commitment is needed to ensure mainstreaming intergenerational equity issues into the climate and resource management agendas.

3.3.3 Improving income and wealth distribution

At a time when systems are yielding great wealth and income for the few, and, conversely, members of the precarious middle class are increasingly struggling to access healthy and nutritious diets, while persistent poverty and revamped food insecurity and hunger grow, improving income and wealth distribution is a major trigger for transformation as it allows leveraging simultaneous impacts on agrifood systems both on the demand and supply sides.

Based on the analyses outlined in Chapter 1, regarding recent possible future food price trends, and the need to internalize externalities and to bring current and future food production within the boundaries of the planetary resources (see, for example, Section 1.2 on an ecological economics perspective, and Section 1.8 on food prices), it is likely that – despite the much needed and plausible future technological improvements that could increase production and productivity – prices of agrifood commodities and food may further increase. In such a context, the only way to ensure access to healthy diets based on sustainably produced food, and counteract resurgent food insecurity and hunger, is to increase the purchasing power of people. In addition, as highlighted in a FAO report on investments needed to achieve Zero Hunger and eliminate extreme poverty,[17] improving income distribution would entail a virtuous circle of savings and investment, with positive impacts not only on people's well-being, but also on territorial economic development, reduced distress urbanization and migrations, and improved resource management.

Most of the measures to improve institutions and governance mentioned above, if effectively implemented, are expected to have positive impacts on cross- and within country income distribution. In addition, some policy options exist that take into consideration specific aspects of agrifood systems. Acknowledging that these are not comprehensive, given the multiple and multifaceted instruments that can be adopted to reduce within and between country inequality (see Section 1.7), and specifically to leveraging changes in agrifood systems, some strategic and policy options that may improve income and wealth distribution are put forward hereafter:

- **Territorial approach for rural development.** The development of inclusive value chains and territorial markets for agrifood products from small-scale producers offers opportunities for both agricultural and non-agricultural jobs, including in tourism, energy and natural resource management. The small urban centres house important components of the food systems (local governments, SMEs for inputs and implements, extension services, veterinary inputs, machinery sales and repair, logistics, traders and transporters) which link farmers to regional or national wholesale markets for fresh products and to food processing industries. Unmanaged, or even distress, urbanization and migration can be prevented or reduced if conditions for better livelihoods in small urban centres improve.[18]
- **Multi-sectoral approach to poverty reduction.** Investing to increase the social protection coverage in rural areas, and adopting policy packages that encompass actions to expand credit to smallholder farmers, along with investments to expand access to basic water infrastructure, especially in semi-arid regions, and in school feeding programmes linked to public procurement contribute to triggering a virtuous circle of material and immaterial capital formation, including human capital, with long-term impacts on well-being. This is of particular relevance for SSA, where building resilience and ending poverty is a major priority that guides policy-making.[19]
- **Repurposing government expenditure on agriculture (GEA).** Countries have the option to reallocate GEA to favour transformation without compromising macroeconomic stability. As discussed in Section 1.3, a FAO report shows that, globally, USD 540 billion of annual GEA is allocated to support farmers through many policy measures that incentivize inefficient and unsustainable agricultural activities.[20] Reallocating these resources within agrifood systems may contribute to achieving sustainable development outcomes. In fact, some modest, but well-prioritized, public investments in productive infrastructure may result in higher gross domestic product (GDP) growth and poverty reduction (see the cases of Uganda and Mexico),[21,22] while retargeted incentives may help move along more sustainable and resilient production and consumption patterns.
- **Green job opportunities in rural areas.** Part of repurposed funds could be used to protect the emergence of "infant industries" adopting organic or agroecological practices. Such practices may be comparatively more labour-intensive than conventional agriculture, with beneficial impacts on employment. However, on the one side, a workforce with higher skills will need to be fostered by public action and have access to relevant advisory services and procurement of specific inputs. On the other side, advisory services to establish markets for such products and complementary campaigns (see the sub-section above) may be needed.
- **Increasing the fiscal space, including tracking and stopping illicit financial flows.** Increasing fiscal revenues by broadening the fiscal base and making the fiscal system more progressive, including by tracking and stopping illicit financial flows that unduly drain financial and fiscal resources, particularly of LICs, facilitates a widening of the fiscal space to support inclusive and sustainable development policies, without jeopardizing the macroeconomic stability of countries (see Sections 1.2. and 1.3). However, this would only be possible if public bodies are able to effectively and equitably trade off potentially contrasting objectives, such as enforcing taxes to increase the fiscal space and incentivizing investment.
- **Public procurement measures.** The demand for local foodstuffs by public schools, hospitals and other public institutions, can support poverty reduction. Indeed, in some local contexts this procurement may constitute such a significant portion of local food demand that, if properly targeted, it could reduce the uncertainty faced by small producers and trigger the local propensity to invest in agrifood activities.
- **Competitiveness of international and national markets.** International trade is essential for sustainably expanding food availability in countries where the population is expected to increase significantly. Trade plays a central role in income generation and distribution within and across countries. This implies that commercial agreements have to be set within a solid institutional context that ensures the respect of all stakeholders, including future generations.

However, commodity dependence of LICs has to be broken by investing in economic diversification within and outside agrifood systems (see Sections 1.3). Basing decisions on what to produce and trade only based on narrowly set short-term comparative advantages, may well lead to distorted decisions. More holistic assessments that are based also on achieving resilience and sustainability are required, as recent pandemics and conflicts show. Strong global and national institutions are also needed to prevent rent seeking behaviours owing to market concentration at national and international levels (see Section 1.12), coordinate efforts across countries and prevent unfair competition with countries that adopt more stringent environmental social and fiscal regulations.

- **Market access for smallholders.** Small-scale producers face barriers in accessing markets. Policies should aim at establishing short circuits of food commerce and commercialization by strengthening rural and urban linkages, and developing spaces and infrastructure to promote producer-to-consumer marketplaces, such as public markets, traditional marketplaces and local grocery stores.
- **Labour markets formalization.** The formalization of micro- and small-sized enterprises, and sector-based approaches to formalization that address sector-specific characteristics could be helpful. Policies to support their formalization need to address the structural causes of informality by extending social security coverage, improving compliance with the law and implementing integrated approaches to formalization, while working in collaboration with labour market institutions and organizations of informal workers and employers. This is of particular importance for the Latin America and the Caribbean region, where building inclusive rural societies is a priority for policymaking, given the high level of informality. [23]
- **Green finance.** Access to financial services to smallholders, based on natural resource management incentives, is an innovative solution to supporting agricultural production and natural resource management simultaneously. While these programmes have clear positive environmental impacts, if they are complemented by schemes for the payment of environmental services, they also contribute to diversifying income sources from agricultural activities, thus increasing income and resilience of smallholders. This is of particular importance to the Asia and the Pacific region, where accelerating sustainable natural resources management for biodiversity conservation and climate action is a priority guiding policymaking.[24]
- **Transport, water and electricity in rural areas.** Better coverage and quality rural infrastructure is a fundamental prerequisite for economic inclusion, food security and better nutrition in rural areas. Rural transport and roads play an important role in facilitating access to essential services, including education and health, as well as to markets and income-generating opportunities. Access to water has a direct impact on health and food security, reducing child mortality and households' health expenses,[25] and positively impacting school attendance.[26] This is particularly important for the Near East and North Africa region, where greening agriculture, addressing water scarcity and ensuring environmental sustainability and climate action is a major priority guiding policy.[27] Access to electricity allows for extended studying and working hours, increased production and avoids the use of non-healthy electricity sources such as kerosene. However, under a shifting development paradigm based on renewable energy sources, the conventional concept of electrification of rural areas, intended as terminals of carbon-intensive energy produced in a centralized way, may need revisiting. Rural areas are already increasingly becoming sources of renewable energy both for local uses and potentially to service urban areas. If this shift is further pursued, positive implications for income generation and diversification may be expected.
- **Rural women's economic activities.** Putting in place financial services targeting rural women's economic activities and facilitating smallholders' access to markets by addressing mobility constraints, transportation restrictions and market disruption, and by adopting specific measures to protect and support women's labour-market participation, *inter alia*, helps towards reducing gender inequalities. To better design and monitor such measures and inform future policy interventions it is important to collect sex-disaggregated, qualitative and quantitative data in order to produce analytical evidence. Investing in women's leadership and supporting their formal and informal networks would indeed contribute to increasing the economic, social and

environmental resilience of agrifood systems, as has been the case in response to the COVID-19 pandemics and their consequences.[28]

- **Education for income source diversification.** Increasing capital intensity in all segments of agrifood value chains may well limit future labour demand. In addition, the mechanization and digitalization of primary production may lower profits and eventually marginalize farmers who cannot invest in overhauling their capital assets. The COVID-19 pandemic may have boosted digitalization and automation trends, thus increasing the likelihood of further job losses. In this context, training small producers who stay in agriculture, or leave it during structural transformation processes, to participate in capital ventures through cooperatives or company stockholding may become increasingly important, as long as this is associated with the development of institutions that grant protection to savings and assets.[29] Young farmers, more inclined to adopting digital and other innovations, can increase their material and immaterial capital ownership only if they have access to finance, training and capacity development.[3]
- **Universal basic income and new social pacts.** If capital and information intensification of production processes continues, inequalities between capital owners and job losers may increase. Inequalities, economic insecurity and diminished consumption could pave the way to the emergence of universal basic income schemes, starting with HICs and upper-middle-income countries. In this context, completely new "social pacts" regarding labour and social responsibility may need to be implemented to maintain active citizenship and participation.

3.3.4 Boosting innovative technologies and approaches

The expected global population growth, as highlighted in Section 1.1, will entail a significant expansion of food demand, particularly if food consumption patterns are not adjusted towards less resource-intensive food items. Unfortunately, global production and consumption activities within agrifood systems are already exceeding planetary boundaries, and several technologies currently applied in agrifood systems contribute to the degradation of natural resources (see Sections 1.2, 1.14, 1.15 and 1.16). Tangible negative consequences on agrifood, social and environmental systems are already observable. The potential of innovative technologies and approaches as triggers of change needs to be exploited to the maximum extent possible, to pursue the general objective of producing more with less. Just as one example, "AgBots" (agricultural robots), sorts of small farm vehicles, can identify and remove weeds without using chemical herbicides; robots can thus reduce the cost of weeding and protecting the environment. AI and cloud solutions can detect pest-infested areas using drone imaging and guide farmers with regard to irrigating, planting, fertilizing, etc. (see Section 1.9). However, gains from innovation and science need to reach everyone and contribute to economic inclusivity. In addition, and probably even more importantly, monopolies exerted by the few big data platforms that accumulate, process and sell the information collected by myriads of sensors, need to be framed within solid and enforceable rules. The following are some strategic and policy options that may boost innovative technologies and approaches along with their inclusiveness:

- **Co-creation of knowledge on innovative technologies by multiple stakeholders.** Identifying and developing innovative technologies, adapting them to local contexts and making them affordable in such contexts, requires Indigenous Peoples' knowledge and local knowledge. The latter is a key input for their development. The involvement of small-scale producers in innovating is essential for the co-creation of knowledge.[30] Taking into account local and traditional knowledge systems would improve foresight, ease the identification of solutions, address trade-offs and stimulate collective buy-in. Governments can create incentives and regulatory frameworks to encourage innovation based on Indigenous Peoples' knowledge- and local knowledge, and build human capital accordingly.
- **Access to data and science.** Science can play a crucial role in elucidating the complexity of agrifood systems, analysing their performance, identifying spatial and temporal synergies and trade-offs. Improving the availability, quality, accessibility and use of data to inform actions for enhancing productivity, increasing access to safe and nutritious food and reducing inequalities in agrifood systems are vital. Connecting existing initiatives and innovation actors and practices

across regions and countries, while providing an environment that encourages new innovation possibilities, is going to become increasingly more important.[31]

- **Public investments for smallholders and SMEs in information and communication technology (ICT).** Although SMEs and smallholders make up the largest number of actors in agrifood systems, they do allocate adequate investment to ICT. This is because of information asymmetries regarding the benefits of ICT between small- and large-scale actors, lack of economies of scale and scope, limited capacity to invest and other challenges. Public support can play a role in overcoming some of these constraints, so that more investment targets these actors.[32]
- **Open-source technologies for digital public goods.** The need to shift from proprietary data to open data is becoming more and more evident as long as the importance of data analytics for decision-making increases. Open-source technologies, with the help of crowd or publicly funded research and/or user-friendly software, could pave the road for innovative uses of big data to encourage marginalized stakeholders to reclaim their data ownership and regain their autonomy. As the United Nations Digital Cooperation Roadmap advises,[33] a concerted global effort to encourage and invest in the creation of digital public goods is required: open-source software, open data, open AI models and open standards, all funded and developed by public-private sector joint forces. A variety of projects that support collaborative networks to access data for research on agrifood systems may need to be promoted and incentivized.
- **Capabilities for data-driven agrifood systems.** Developing human resources to generate store, handle, control, and analyse big data in agrifood systems is a prerequisite for distributing the benefits of digitalization across and within countries and communities. Without data experts and educated stakeholders, data will become more and more powerful, but may potentially harm the sustainability, resilience and inclusiveness of agrifood systems. Capacities in national statistical systems and consumers awareness need to be built on data harvesting, storage, management and control, to ensure country-driven, independent, transparent and accountable data generation, validation and utilization processes, as well as their conversion into statistics.[34]
- **Data interoperability and data portability.** The workflow and ease of data use need to be streamlined. It is critical that the ICT industry, while developing the most advanced software systems, be incentivized to refine technical solutions that ensure data interoperability: that is, the ability of a system to work with other systems without special effort on the part of the user. Agrifood systems would benefit from interoperability because, as users would not be tied to a particular system or platform but could move across suppliers of services, they would avoid the costs of resetting ICT applications and potentially losing information and being exposed to monopolistic behaviours.
- **Legal, ethical and technical governance frameworks.** New business models arise in a data-driven economy, creating enormous opportunities but, at the same time, posing important risks. The creation of a digital ecosystem that not only gathers data from farmers but provides them with readymade solutions to their problems, for example, matching their supply with a certain demand, reduces marketing times and efforts. If full transparency is not granted and ensured by a solid and enforceable legal framework, the risks of manipulation of the choices increase and, ultimately, the agency and freedom of farmers become jeopardized (see Section 1.4). It is important for national governments and international agencies to understand how to set rules to legally frame the work of large technology companies that gather, store, control large amounts of data and sell data-informed services. Legal frameworks and their enforcement must ensure that public benefits are maximized, while the rights of farmers and consumers, the primary data generators and owners, are ensured. Legal mechanisms for data governance could take different forms, from international treaties, to national legislation, to licensing practices. The transitional co-existence of various data governance frameworks would be probably still preferable to what is today's lack of data governance.
- **ICT for access to information.** ICT adapted to the scale of operations of the users, including smallholders, can provide tools for detecting early risk signals, making timely forecasts, adopting early warning strategies and implementing response diversification. ICT and digital tools can also dramatically increase access to information in the agriculture sector, opening the way to substantially improve the effectiveness of agricultural extension, advisory services and learning.

Ensuring access to the ICT, training and financial support needed to adopt agroclimatic early warning systems is key to making these systems accessible to small-scale producers.[15]

- **Market and financial inclusion.** Further digitalizing trade procedures and supply chain operations, if properly governed, could potentially: 1) improve transparency in markets and policies; 2) ease international governance and coordination mechanisms; 3) help reduce asymmetry of information in food availability, stocks and trade flows; and 4) promote coordination of policy responses. Flexible and diversified financial products could also be leveraged through financial institutions and the banking system, in synergy with government agencies and relevant sectoral ministries. Digital technologies can facilitate accessing customized products and financial services, including making payments on e-commerce platforms, and collecting money from various sources.[35] These means need to be incentivized, however, in parallel, public authorities will need to ensure data protection, privacy and control over the use of big data generated by financial transactions and accumulated on a few big data platforms.

3.4 Concluding remarks

Transformative processes will most certainly require long-term commitment, persistency and perseverance. Acceptance of long-termism by citizens and their governments is required, meaning transformative action needs to start now. Whether that will happen or not, will determine one of the possible futures of agrifood systems. The factors that influence the decisions of citizens and governments regarding the future of agrifood systems are multiple, including the urgency to satisfy immediate needs, ethical and cultural values, the social contexts within which decisions will be made, as well as current and future – political, economic, social, cultural and military power structures. Stakeholders interested in transforming agrifood systems along sustainability and resilience patterns will have to increase their awareness, enlarge their agency space and "outsmart" political economy constraints that have thus far prevented the move towards the targets of Agenda 2030.

Sustainably nourishing close to 10 billion people by 2050, while preserving natural resources and increasing the resilience of agrifood systems to the inevitable shocks and "unknown unknowns" that will materialize along the way, is an unprecedented challenge. It requires addressing the trade-offs that have been highlighted in this report. All of them deserve further analyses through a holistic approach for guiding contextualized actions. However, for some of them, win-win solutions are not possible, as highlighted in the scenario "trading off for sustainability". For others, win-win solutions may not even be currently imaginable, given the boundaries of the planetary resources available. The readiness to give up something today, particularly by better-off citizens and more powerful actors, to the advantage of others and of future generations, might end up being the only option to ensure sustainable and resilient agrifood systems that positively contribute to intra- and intergenerational equity.

This corporate strategic foresight report forces one to strategically prepare for different outlooks, including those considered more pessimistic. It has been said: "I feel very optimistic about the future of pessimism".[cr] This sentence could be interpreted in different ways. Of course it could also support a pessimistic view of the future. Indeed, given that trends and human behaviour have not changed significantly despite many warnings, inconvenient truths, recommendations, Millennium Development Goals and SDGs, assuming that paths will not change for the better would be a fairly safe bet.

Most human beings desire improved lifestyles and well-being, more real income, a fulfilling income-generating occupation, a better house, a better mode of transportation, travel, to eat at the best restaurants, enjoy improved public services, top quality health care facilities, top quality education facilities, sophisticated services, and solid and durable infrastructures.

Understandably, most humans desire all of this at the lowest price possible. This is true for humans in HICs and LMICs. These aspirations and lifestyles come at a cost as they require substantial resources, which are being exhausted at a fast pace. Even when confronted with this reality,

[cr] Jean Rostand, French biologist and philosopher (1894–1977).

most humans would not give up on pursuing their dreams and aspirations. Plus, there would be a fear of free-riding from others who would not comply with a potential pact. Therefore, most citizens and their governments might not activate triggers nor deal with tough trade-offs. Technological advancements eventually might not be capable of solving the problem.

Ultimately, a strategic foresight report has also to convey unfortunate, but plausible, scenarios such as a "more of the same" or even or worse. But one could also recall that "…my mind is pessimistic, but my will is optimistic. Whatever the situation, I imagine the worst that could happen in order to summon up all my reserves and will power to overcome every obstacle".[36, cs]

The story of mankind should be one of gradually learning as much as possible from the past in order to avoid repeating crises, and to dare to imagine – and push for – an "impossible" improved future. Hopefully, this strategic foresight report is a contribution in that direction.

[cs] Antonio Gramsci, Italian philosopher, political scientist and politician (1891–1937).

NOTES – CHAPTER 3

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Annexes

Annex 1. Regions and countries as defined in this report

Table A1.1 Countries by region as defined in this report

HIGH-INCOME COUNTRIES (HICS)	EAST ASIA AND THE PACIFIC (EAP)	EUROPE AND CENTRAL ASIA (ECA)	LATIN AMERICA AND THE CARIBBEAN (LAC)	NEAR EAST AND NORD AFRICA (NNA)	SOUTH ASIA (SAS)	SUB-SAHARAN ASIA (SSA)
Andorra	American Samoa	Albania	Anguilla	Algeria	Afghanistan	Angola
Antigua and Barbuda	Cambodia	Armenia	Argentina	Djibouti	Bangladesh	Benin
Aruba	Cook Islands	Azerbaijan	Belize	Egypt	Bhutan	Botswana
Ascension, Saint Helena and Tristan da Cunha	Democratic People's Republic of Korea	Belarus	Bolivia (Plurinational State of)	Iran (Islamic Republic of)	India	Burkina Faso
Australia	Fiji	Bosnia and Herzegovina	Brazil	Iraq	Maldives	Burundi
Austria	Indonesia	Bulgaria	Colombia	Jordan	Nepal	Cabo Verde
Bahamas	Kiribati	Channel Islands	Costa Rica	Lebanon	Pakistan	
Bahrain	Lao People's Democratic Republic	Georgia	Cuba	Libya	Sri Lanka	Cameroon
Barbados	Malaysia	Kazakhstan	Dominica	Morocco		Central African Republic
Belgium	Marshall Islands	Kyrgyzstan	Dominican Republic	Palestine		Chad
Bermuda	Mayotte	Montenegro	Ecuador	Syrian Arab Republic		Comoros
British Virgin Islands	Micronesia (Federated States of)	North Macedonia	El Salvador	Tunisia		Congo
Brunei Darussalam	Mongolia	Republic of Moldova	Greater Antilles	Yemen		Côte d'Ivoire
Canada	Myanmar	Russian Federation	Grenada			Democratic Republic of the Congo
Cayman Islands	Nauru	Serbia	Guatemala			Equatorial Guinea
Chile	Niue	Svalbard and Jan Mayen Islands	Guyana			Eritrea
Croatia	Norfolk Island	Tajikistan	Haiti			Eswatini
Cyprus	Papua New Guinea	Türkiye	Honduras			Ethiopia
Czechia	Philippines	Turkmenistan	Jamaica			Gabon
Denmark	Samoa	Ukraine	Lesser Antilles			Gambia

Table A1.1 (cont.) Countries by region as defined in this report

HIGH-INCOME COUNTRIES (HICS)	EAST ASIA AND THE PACIFIC (EAP)	EUROPE AND CENTRAL ASIA (ECA)	LATIN AMERICA AND THE CARIBBEAN (LAC)	NEAR EAST AND NORD AFRICA (NNA)	SOUTH ASIA (SAS)	SUB-SAHARAN ASIA (SSA)
Estonia	Solomon Islands	Uzbekistan	Mexico			Ghana
Faroe Islands	Thailand		Nicaragua			Guinea
Finland	Timor-Leste		Paraguay			Guinea-Bissau
France	Tokelau		Peru			Kenya
French Guiana	Tonga		Saint Lucia			Lesotho
French Polynesia	Tuvalu		Saint Vincent and the Grenadines			Liberia
Germany	Vanuatu		Suriname			Madagascar
Greece	Viet Nam		Venezuela (Bolivarian Republic of)			Malawi
Greenland	Wallis and Futuna Islands					Mali
Guadeloupe						Mauritania
Guam						Mozambique
Hungary						Namibia
Iceland						Niger
Ireland						Nigeria
Isle of Man						Rwanda
Israel						Sao Tome and Principe
Italy						Senegal
Japan						Sierra Leone
Kuwait						Somalia
Latvia						South Africa
Liechtenstein						South Sudan
Lithuania						Sudan
Luxembourg						Togo
Malta						Uganda
Martinique						United Republic of Tanzania
Mauritius						Western Sahara
Montserrat						Zambia
Netherlands						Zimbabwe
New Caledonia						
New Zealand						
Northern Mariana Islands						
Norway						
Oman						
Palau						

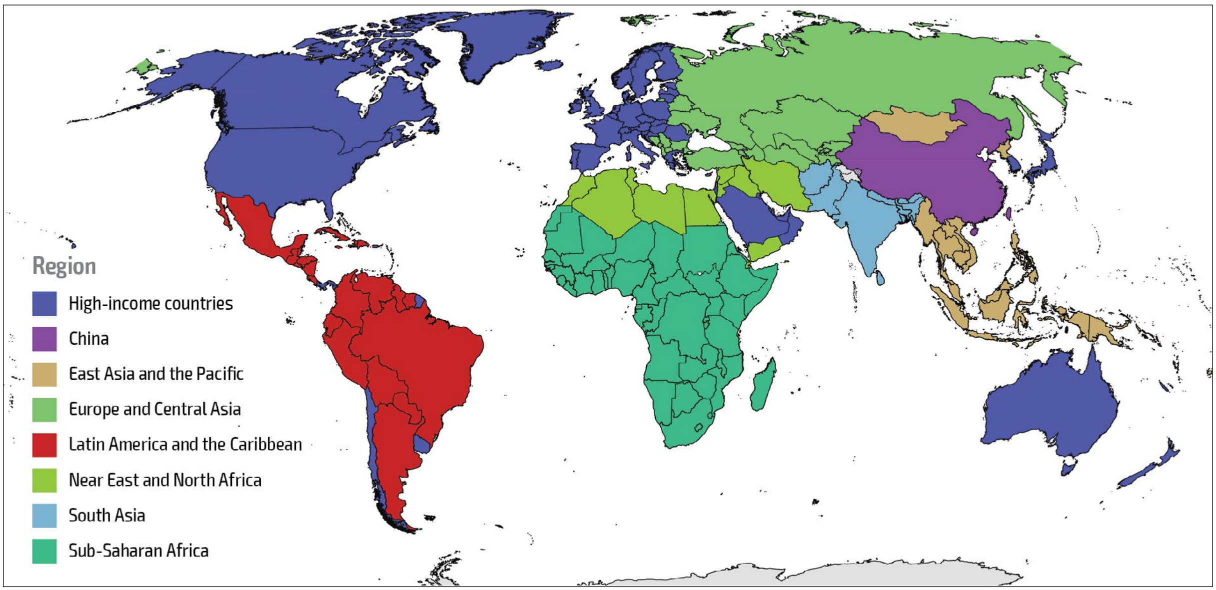
Table A1.1 (cont.) **Countries by region as defined in this report**

HIGH-INCOME COUNTRIES (HICS)	EAST ASIA AND THE PACIFIC (EAP)	EUROPE AND CENTRAL ASIA (ECA)	LATIN AMERICA AND THE CARIBBEAN (LAC)	NEAR EAST AND NORD AFRICA (NNA)	SOUTH ASIA (SAS)	SUB-SAHARAN ASIA (SSA)
Panama						
Poland						
Portugal						
Puerto Rico						
Qatar						
Reunion						
Republic of Korea						
Romania						
Saint Kitts and Nevis						
Saint Pierre and Miquelon						
San Marino						
Saudi Arabia						
Seychelles						
Singapore						
Slovakia						
Slovenia						
Spain						
Sweden						
Switzerland						
Trinidad and Tobago						
Turks and Caicos islands						
United Arab Emirates						
United Kingdom of Great Britain and Northern Ireland						
United States of America						
United States Virgin Islands						
Uruguay						

Notes: High-income countries (HICs) are classified in a single group, regardless their geographical location. All other countries, qualified as low- and middle-income countries (LMICs), are classified by geographical region, notably Europe and Central Asia (ECA), East Asia and the Pacific (EAP), South Asia (SAS), Latin America and the Caribbean (LAC), Near East and North Africa (NNA) and sub-Saharan Africa (SSA). If not otherwise specified, LMICs and EAP exclude China, which is singled out as one country which comprises the Special Administrative Regions (SARs) of Taiwan, Hong Kong and Macao. Country groups and China are generally referred to as "regions" in this report.

Source: World Bank. 2021. *World Bank list of economies (June 2020).* Washington, DC. Cited 22 June 2022. https://databank.worldbank.org/data/download/site-content/CLASS.xls

Figure A1.1 Regions as defined in this report



Notes: Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties. Final boundary between the Sudan and South Sudan has not yet been determined. Final status of the Abyei area is not yet determined.

Source: Authors' elaboration based on World Bank. 2021. *World Bank list of economies (June 2021)*. Washington, DC. Cited 22 June 2022. https://databank.worldbank.org/data/download/site-content/CLASS.xlsx

Annex 2. Economics of technology and growth[ct]

This annex, that supports Section 1.11 Capital and information intensity of production, introduces several topics related to this section. The material is mathematically intensive, so although the concepts are central, it is placed outside of the main text. The presentation starts with the concept of a production function and demonstrates some standard results. It then proceeds to some well-established, but often neglected, critiques of the production function approach.

A. The production function approach

Most discussions within economics over the inputs to production are carried out by reference to production functions. A production function, $F(\cdot)$, relates quantities of inputs, in terms of a suitable metric, to a quantity of output. The key inputs are capital, K (measured, e.g. by replacement cost) and labour, L (e.g. as hours of work). Other inputs – such as fuels, land, water or fertilizer – are unspecified and will be denoted by $x_1, x_2, \dots x_n$. In addition to depending on quantities of inputs, the production function can change over time through "autonomous" or exogenous processes. Denoting output by Y, the general expression is

$$Y = F\,(K, L, x_1, x_2, \dots, x_n; t) \tag{1}$$

The change in output, denoted ΔY, is, to first-order changes in the inputs,

$$\Delta Y = \Delta t\,\frac{\delta F}{\delta t} + \Delta K\,\frac{\delta F}{\delta K} + \Delta L\,\frac{\delta F}{\delta L} + \sum_{i=1}^{n} \Delta x_i\,\frac{\delta F}{\delta x_i} \tag{2}$$

The proportional change is equal to $\Delta Y/Y$. Because Y is also equal to F, calculated at the current level of inputs from Equation (1), the proportional change can be written,

$$\frac{\Delta Y}{Y} = \Delta t\,\frac{1}{F}\,\frac{\delta F}{\delta t} + \frac{\Delta K}{K}\left(\frac{K}{F}\,\frac{\delta F}{\delta K}\right) + \frac{\Delta L}{L}\left(\frac{L}{F}\,\frac{\delta F}{\delta L}\right) + \sum_{i=1}^{n} \frac{\Delta x_i}{x_i}\left(\frac{x_i}{F}\,\frac{\delta F}{\delta x_i}\right) \tag{3}$$

In each term except the first, the ratio of the input to itself (e.g. K/K) has been inserted. That ratio is equal to one, so it does not affect the result, but it does presume that all inputs are non-zero.

In Equation (3), the expressions in parentheses are elasticities of output with respect to a change in input. Denoting them by α, β, and ε_i, and the coefficient on Δt by γ, the equation can be written

$$\frac{\Delta Y}{Y} = \gamma \Delta t + \alpha\,\frac{\Delta K}{K} + \beta\,\frac{\Delta L}{L} + \sum_{i=1}^{n} \varepsilon_i\,\frac{\Delta x_i}{x_i} \tag{4}$$

Returns to scale

Consider a counterfactual change in which all inputs are increased by the same factor, a, but at a fixed moment in time. In that case,

$$\Delta t = 0, \text{ while } \frac{\Delta K}{K} = \frac{\Delta L}{L} = \frac{\Delta x_1}{x_1} = \dots = \frac{\Delta x_n}{x_n} = \frac{\Delta a}{a} \tag{5}$$

Substituting into Equation (4) then gives

$$\frac{\Delta Y}{Y} = \left(\alpha + \beta + \sum_{i=1}^{n} \varepsilon_i\right)\frac{\Delta a}{a} \tag{6}$$

[ct] This annex and related Section 1.11 draws upon Kemp-Benedict (2021).[1]

If the expression in parentheses sums to one, then Y grows by the same factor as all of the inputs. In that case, the production function is said to exhibit constant returns to scale. If it is less than one, the production function exhibits decreasing returns to scale. Finally, if it is greater than one, production exhibits increasing returns to scale.

The existence of increasing returns to scale are certainly observed, and help to explain the phenomena of mergers and firm growth.[2] However, prior to the emergence of new growth theory, increasing returns to scale proved technically problematic to formalize when carrying out optimization calculations. More commonly, constant returns to scale have been assumed, so that the elasticities in Equation (6) sum to one.

Profit maximization

Every input to production has a corresponding price. Denote the price of capital (the return to capital) by r, the average wage by w, and the prices of input i by p_i. Then the cost of production, C, is

$$C = rK + wL + \sum_{i=1}^{n} p_i X_i \tag{7}$$

If the output is sold at a price P, then profits Π are equal to

$$\Pi = PY - C \tag{8}$$

Now, substitute $F(\cdot)$ in place of Y, and substitute for C, to get an expression for profits in terms of the inputs,

$$\Pi = PF\left(K, L, x_1, \ldots, x_n; t\right) - rK - wL - \sum_{i=1}^{n} p_i X_i \tag{9}$$

Suppose that at each instant in time (so that t is not changing), firms choose inputs to production so as to maximize profits. Every firm is assumed to be a price taker, so they do this while leaving all prices fixed, including the price of their own product. The firm reaches an optimum when

$$\frac{\delta \Pi}{\delta K} = \frac{\delta \Pi}{\delta L} = \frac{\delta \Pi}{\delta x_1} = \ldots = \frac{\delta \Pi}{\delta x_n} = 0 \tag{10}$$

That implies that

$$r = P\,\frac{\delta F}{\delta K},\ w = P\,\frac{\delta F}{\delta L},\ p_1 = P\,\frac{\delta F}{\delta x_1},\ \ldots,\ p_n = P\,\frac{\delta F}{\delta x_n} \tag{11}$$

Substituting Equation (11) into Equation (7) and factoring out P gives:

$$C = P\left(\frac{\delta F}{\delta K}K + \frac{\delta F}{\delta L}L + \sum_{i=1}^{n} \frac{\delta F}{\delta x_i}x_i\right) \tag{11a}$$

Using Equation (1) to multiply and divide the right-hand-side of the Equation (11a) gives:

$$C = PY\left(\frac{K}{F}\frac{\delta F}{\delta K} + \frac{L}{F}\frac{\delta F}{\delta L} + \sum_{i=1}^{n} \frac{x_i}{F}\frac{\delta F}{\delta x_i}\right) \tag{12}$$

The terms inside the parentheses in Equation (12) are the elasticities introduced earlier.

Substitution shows that

$$C = PY\left(\alpha + \beta + \sum_{i=1}^{n} \varepsilon_i\right) \tag{13}$$

That is, when profits are maximized, i.e. when the (10) holds, costs are equal to the returns-to-scale factor (the sum of elasticities of the output to each input), multiplied by the value of output. In the case of constant returns to scale, all of the value is paid out in proportion to the elasticities, so that each input – known as a "factor of production" – is paid its marginal contribution to output.

This is a key result in neoclassical theory. It is a justification for income distribution based on marginal productivity theory.

Growth accounting

In a growth accounting exercise, Equation (4) is applied to data, where the elasticities are presumed, based on the profit optimization calculation that results in Equation (13), to be equal to cost shares. Given observed real economic growth and changes in real inputs, this gives an expression for γ,

$$\gamma = \frac{1}{Y}\frac{\Delta Y}{\Delta t} - \alpha\frac{1}{K}\frac{\Delta K}{\Delta t} - \beta\frac{1}{L}\frac{\Delta L}{\Delta t} - \sum_{i=1}^{n} \varepsilon_i \frac{1}{x_i}\frac{\Delta x_i}{\Delta t} \tag{14}$$

This is known as the "Solow residual". It is equal to growth in output that is not explained by growth in inputs, and is also called "total factor productivity" (TFP) growth.

Some comments on growth accounting are called for. First, the residual normally dominates other terms, so that most growth remains unexplained by this method. Unexplained growth in output is presumed to follow from technological change. The "new growth theory" seeks to explain this term, which is why it is also called "endogenous" growth theory.

Second, growth accounting exercises are very frequently applied to the whole economy, although they may be applied to a sector, including agriculture. For those exercises to retain all of the assumptions and consequences of the neoclassical production function, Equation (13) must be derivable from an economy-wide production function – the *aggregate* production function. However, a very well-established, but rarely acknowledged, result is that the aggregate production function does not exist.[3] Perhaps the mathematically most direct and irrefutable demonstration (although technically the most demanding) was provided by Fisher (1965, 1969).[4,5] He showed that the only way an aggregate production function could exist would be if every firm (or production unit within a firm) had a production function of the same form. But this is clearly not the case. To take just two of the numerous possible examples, the production function of an oil refinery will be quite different from that of a pet store.

Third, as an accounting identity within the national accounts, the value of output is equal to the sum of factor payments. Imposing this requirement implies that the expression in parentheses in Equation (13) must equal one. That is why increasing or decreasing returns to scale is problematic in the neoclassical production function approach. Equation (13) was derived by assuming a particular behaviour: that firms maximize profit in each time period by adjusting inputs at fixed prices. If the assumption holds, then we have a potential contradiction. However, there is no reason to believe that it will hold: firstly, firms may pursue other goals, such as growth and longevity, rather than short-run profit maximization;[6] secondly, they face difficulties adjusting inputs in the short run;[7] and thirdly, prices are largely administered by firms.[8]

An alternative approach to examining productivity and input costs that does not share the limitations of the production function is described in the next section. The new endogenous growth theory, which is discussed in the final section, seeks to address the first limitation, but not the second or third.

B. The accounting approach

The alternative approach presented here does not have a formal name, but will be referred to in this annex as the "accounting approach". In the national accounts, the value of output is equal to the sum of costs, so

$$PY = rK + wL + \sum_{i=1}^{n} p_i x_i \tag{15}$$

Taking the first-order variation in each term gives

$$\Delta PY + P\Delta Y = \Delta rK + r\Delta K + \Delta wL + w\Delta L + \sum_{i=1}^{n} (\Delta p_i x_i + p_i \Delta x_i) \tag{16}$$

Dividing Equation (16) through by PY gives:

$$\frac{\Delta PY + P\Delta Y}{PY} = \frac{\Delta rK}{PY} + \frac{r\Delta K}{PY} + \frac{\Delta wL}{PY} + \frac{w\Delta L}{PY} + \sum_{i=1}^{n} \left(\frac{\Delta p_i x_i}{PY} + \frac{p_i \Delta x_i}{PY} \right) \tag{16a}$$

To clearly separate cost shares in the accounting approach from elasticities in the production function approach, lower-case Roman alphabet letters will be used rather than Greek letters, so that a is the capital share, b is the labour share and e_i is the cost share for input i. Then,

$$a = \frac{rK}{PY},\ b = \frac{wL}{PY},\ e_1 = \frac{p_1 x_1}{PY},\ \ldots,\ e_n = \frac{p_n x_n}{PY} \tag{17}$$

Expressing the result in terms of cost shares and inserting in each term of the right-hand side the ratio of each input or its unit cost to itself (e.g. *r/r*, *K/K*, etc.) gives:

$$\frac{\Delta P}{P} + \frac{\Delta Y}{Y} = a\frac{\Delta r}{r} + a\frac{\Delta K}{K} + b\frac{\Delta w}{w} + b\frac{\Delta L}{L} + \sum_{i=1}^{n} \left(e_i \frac{\Delta p_i}{p_i} + e_i \frac{\Delta x_i}{x_i} \right) \tag{18}$$

Next, define a new factor, $g\Delta t$, that collects some of the terms in this expression,

$$g\Delta t = a\left(\frac{\Delta r}{r} - \frac{\Delta P}{P}\right) + b\left(\frac{\Delta w}{w} - \frac{\Delta P}{P}\right) + \sum_{i=1}^{n} e_i \left(\frac{\Delta p_i}{p_i} - \frac{\Delta P}{P}\right) \tag{19}$$

After factoring out $\Delta P/P$, $g\Delta t$, can also be written as:

$$g\Delta t = -\frac{\Delta P}{P}\left(a + b + \sum_{i=1}^{n} e_i\right) + a\frac{\Delta r}{r} + b\frac{\Delta w}{w} + \sum_{i=1}^{n} \frac{\Delta p_i}{p_i} \tag{19a}$$

After substituting $g\Delta t$, and recalling that the factors a, b, and e_i are cost shares and, therefore, sum to one by definition, Equation (18) becomes:

$$\frac{\Delta Y}{Y} = g\Delta t + a\frac{\Delta K}{K} + b\frac{\Delta L}{L} + \sum_{i=1}^{n} e_i \frac{\Delta x_i}{x_i} \tag{20}$$

This equation is precisely parallel to Equation (4), with α = a, β = b, and $\varepsilon_i = e_i$. In other words, this looks like the variation in a production function with constant returns to scale. Moreover, because the cost shares sum to one, it provides a basis for growth accounting.

It is important to note, however, that Equation (20) is *not* derived from a production function or profit maximization – rather, it is derived by manipulating an accounting identity. It has no content beyond that identity. This result has been discovered and rediscovered multiple times.[3,9,10,11]

Explaining the Solow residual

Purely as an algebraic result arising from the accounting identity in Equation (15), the Solow residual (or TFP growth) is given by Equation (19), divided by Δt, to give

$$g = a\left(\frac{1}{r}\frac{\Delta r}{\Delta t} - \frac{1}{P}\frac{\Delta P}{\Delta t}\right) + b\left(\frac{1}{w}\frac{\Delta w}{\Delta t} - \frac{1}{P}\frac{\Delta P}{\Delta t}\right) + \sum_{i=1}^{n} e_i\left(\frac{1}{p_i}\frac{\Delta p_i}{\Delta t} - \frac{1}{P}\frac{\Delta P}{\Delta t}\right) \quad (21)$$

This is the sum of the growth rates of different real prices, weighted by the corresponding cost shares. They are 'real' in that the growth rate of the general price level, P, is subtracted from them. In the first parenthesis, is the growth rate of the real return on profit; in the second, is the growth of the real wage; and in the last, is a sum of terms for the real price of each input.

It is possible to go further. Consider the profit share,

$$a = \frac{rK}{PY} \quad (22)$$

Taking the first-order variation and dividing by a on the left-hand side (LHS) and rK/PY on the right-hand side (RHS) gives[cu]

$$\frac{\Delta a}{a} = \frac{\Delta r}{r} + \frac{\Delta K}{K} - \frac{\Delta P}{P} - \frac{\Delta Y}{Y} \quad (23)$$

This means that, after rearranging the Equation (23) and dividing through by Δt to calculate growth rates rather than total changes, the expression in the first set of parentheses in Equation (21) can be written

$$\frac{1}{r}\frac{\Delta r}{\Delta t} - \frac{1}{P}\frac{\Delta P}{\Delta t} = \frac{1}{a}\frac{\Delta a}{\Delta t} - \frac{1}{K}\frac{\Delta K}{\Delta t} + \frac{1}{Y}\frac{\Delta Y}{\Delta t} \quad (24)$$

Analogously, a parallel expression to the (24) can be worked out for the share of wages b:

$$b = \frac{wL}{PY} \quad (24a)$$

Taking the first-order variation and dividing by b on the LHS and wL/PY on the RHS gives

$$\frac{\Delta b}{b} = \frac{\Delta w}{w} + \frac{\Delta L}{L} - \frac{\Delta P}{P} - \frac{\Delta Y}{Y} \quad (24b)$$

By rearranging the (24b), the expression in second set of parentheses in Equation (21) can be written:

$$\frac{1}{w}\frac{\Delta w}{\Delta t} - \frac{1}{P}\frac{\Delta P}{\Delta t} = \frac{1}{b}\frac{\Delta b}{\Delta t} - \frac{1}{L}\frac{\Delta L}{\Delta t} + \frac{1}{Y}\frac{\Delta Y}{\Delta t} \quad (24c)$$

[cu] The first-order variation of a, Δa, is calculated as its total differential, say, the sum of the first-order partial derivatives of a with respect to each RHS variable times the variation of such variable: $\Delta a = \frac{\delta a}{\delta r}\Delta r + \frac{\delta a}{\delta K}\Delta K + \frac{\delta a}{\delta P}\Delta P + \frac{\delta a}{\delta Y}\Delta Y$. Calculating each addend on the RHS and mutually dividing LHS and RHS by $a=rK/PY$ yields the (23).

Finally, parallel expressions to the (24) can be worked out for intermediate inputs' shares e_i:

$$e_i = \frac{p_i x_i}{PY} \tag{24d}$$

Taking the first-order variation and dividing by e_i on the LHS and $p_i x_i/PY$ on the RHS gives

$$\frac{\Delta e_i}{e_i} = \frac{\Delta p_i}{p_i} + \frac{\Delta x_i}{x_i} - \frac{\Delta P}{P} - \frac{\Delta Y}{Y} \tag{24e}$$

By rearranging the (24e) and dividing through by Δt, the third set of parentheses in Equation (21) can be written:

$$\frac{1}{p_i}\frac{\Delta p_i}{\Delta t} - \frac{1}{P}\frac{\Delta P}{\Delta t} = + \frac{1}{e_i}\frac{\Delta e_i}{\Delta t} - \frac{1}{x_i}\frac{\Delta x_i}{\Delta t} + \frac{1}{Y}\frac{\Delta Y}{\Delta t} \tag{24f}$$

Substituting (24), (24c) and (24f) into Equation (21) and rearranging terms gives

$$g = \frac{\Delta a + \Delta b + \sum_{i=1}^{n} \Delta e_i}{\Delta t} + a\left(\frac{1}{Y}\frac{\Delta Y}{\Delta t} - \frac{1}{K}\frac{\Delta K}{\Delta t}\right) + b\left(\frac{1}{Y}\frac{\Delta Y}{\Delta t} - \frac{1}{L}\frac{\Delta L}{\Delta t}\right) + \sum_{i=1}^{n} e_i \left(\frac{1}{Y}\frac{\Delta Y}{\Delta t} - \frac{1}{x_i}\frac{\Delta x_i}{\Delta t}\right) \tag{25}$$

But the first term sums to zero; as the cost shares sum to one, the total change in all of the cost shares must be zero. The remaining terms are productivity growth rates. For example, if capital productivity is denoted by κ, then, by definition,

$$\kappa = \frac{Y}{K} \tag{26}$$

Its growth rate is

$$\frac{1}{\kappa}\frac{\Delta \kappa}{\Delta t} = \frac{1}{Y}\frac{\Delta Y}{\Delta t} - \frac{1}{K}\frac{\Delta K}{\Delta t} \tag{27}$$

and similarly for the other inputs. The expression on the right-hand side of this equation is the expression in the first set of parentheses in Equation (25). Denoting labour productivity by λ and productivity for the input i by πi, the residual is seen to equal

$$g = a\,\frac{1}{\kappa}\frac{\Delta \kappa}{\Delta t} + b\,\frac{1}{\lambda}\frac{\Delta \lambda}{\Delta t} + \sum_{i=1}^{n} e_i \frac{1}{\pi_i}\frac{\Delta \pi_i}{\Delta t} \tag{28}$$

The Solow residual is then seen to equal the sum of the productivity growth rates weighted by their corresponding cost shares.

Equation (28) is an essential result. It is the final missing expression in the growth accounting exercise, and shows that the Solow residual is not, in fact, unexplained. Note that it is derived entirely from an accounting identity, with no theory whatsoever. To say something about economic processes, it is necessary to say how productivities might change. This is discussed below under the rubric of cost share-induced technological change.

Before completing this section, it is helpful to record two expressions. Starting with the basic accounting balance in Equation (15) and dividing through by PY,

$$1 = \frac{rK}{PY} + \frac{wL}{PY} + \sum_{i=1}^{n} \frac{p_i x_i}{PY} \tag{29}$$

Each term is a cost share as defined in Equation (17), so this expression is (trivially) equivalent to

$$1 = a + b + \sum_{i=1}^{n} e_i \tag{30}$$

That is, the cost shares sum to one.

But Equation (29) can also be written in terms of productivities as

$$1 = \frac{r}{P\kappa} + \frac{w}{P\lambda} + \sum_{i=1}^{n} \frac{p_i}{P\pi_i} \tag{31}$$

This expression shows that cost shares will remain constant if real prices and compensation rise in line with productivities. Thus, an unchanging labour cost share means that real wages are rising in line with labour productivity. Conversely, if the wage share is falling, then real wages are growing more slowly than labour productivity.

The Kaldor-Verdoorn Law

A strong regularity that can be seen in data on productivity and growth is that average labour productivity growth accelerates when the manufacturing growth rate increases. This was first observed by Verdoorn (1949, 2002),[12,13] and later raised to the status of a 'law' by Kaldor (1966).[14] It has withstood criticism,[15,16,17] and has been confirmed (with some extensions) multiple times.[18,19,20,21] Magacho and McCombie (2018)[22] further found the law to hold for countries at all levels of income, although the coefficients changed in a systematic way, with greater impact from low-tech manufacturing in lower-middle-income countries and greater impact from high-tech manufacturing in higher-middle-income countries.

It is worth emphasizing that arguments for why the Kaldor-Verdoorn Law should hold constitute a theory of endogenous technological change that long predates the new endogenous growth models of the 1980s, which are discussed below. The law is explainable in terms of economic processes, including increasing returns to scale.[18] It is motivated by empirical observation and does not depend on a production function.

Cost share-induced technological change

In the accounting approach, a full theory of distribution requires both a theory of compensation and a theory of productivity change. Since it relies on national accounts, the accounting approach must be consistent with any theoretical approach, including one based on production functions. In the production function approach, cost shares are equal to elasticities, which are determined by the technical coefficients in proposed production functions. Thus, distribution is effectively set exogenously.

A different theoretical starting point is that firms increase productivity in response to costs. There are a number of such theories.[23,24,25] One particular model will be presented here. It takes its inspiration from evolutionary economics,[26] and classical economic theory,[27] and proposes that firms seek innovations in the neighbourhood of their current technology, but only accept those innovations that will increase their profitability at prevailing prices.[28,29] That model was further developed by the author of this annex,[30,31] and was shown to be compatible with the Kaldor-Verdoorn Law.

A key feature of the classical-evolutionary cost share-induced technological change model is that technological change that features faster labour productivity growth than capital productivity growth – so-called "directed" or "biased" technological change – is explained by income distribution. The requirement that only innovations that increase firms' profitability at prevailing prices will be accepted, means that productivity growth rates across different inputs must satisfy the condition that, for any candidate innovation, the sum of the product of cost shares with proportional increases in the corresponding productivities must be positive. Given the likelihood of finding any particular combination of changes in productivities (e.g. rising labour productivity normally, but does not necessarily, entail an increase in energy inputs), this criterion imparts a bias to the direction of technological change.

An implication of the theory is that productivity growth rates depend on cost shares through expressions that can be derived from a "generating function" $G(a, b, e_1, e_2, \ldots, e_n)$, which is homogeneous of order one in the cost shares (while satisfying some additional requirements),[31] through

$$\frac{1}{\kappa}\frac{\Delta\kappa}{\Delta t} = \frac{\delta G}{\delta a}, \quad \frac{1}{\lambda}\frac{\Delta\lambda}{\Delta t} = \frac{\delta G}{\delta b}, \quad \frac{1}{\pi_i}\frac{\Delta\pi_i}{\Delta t} = \frac{\delta G}{\delta e_i} \tag{32}$$

While exceptions can occur in some unusual (and normally transient) circumstances, in most cases the aggregate effect of an increase (decrease) in a cost share – say, the labour share, b – is a rise (fall) in the corresponding productivity, in this case, labour productivity λ. However, after labour productivity rises, the real wage may be changed in response. If labour has strong bargaining power, then the real wage may tend to rise in line with labour productivity, leaving the cost share unchanged. If the real wage fails to rise with labour productivity, then the cost share will fall. In the latter case, the falling cost share will then, through Equation (32), slow the rate of increase in labour productivity.

For an input to production, for example, an agricultural raw material, a rise in price will lead to a rise in the cost share, which will then lead to more rapid efficiency of use of the raw material, thereby leading to higher raw material productivity. With no change in the price, that will offset the rise in the cost share. With no change in output, it will also reduce demand pressure on the resource. Production may also respond to the temporarily higher price. Together, reduced demand and increased production will tend to lower the price, and therefore further lower the cost share. Such feedbacks tend to drive cost share-induced technological change models towards equilibria characterized by constant cost shares and steady productivity growth rates.[30] Those equilibria may never be reached in practice, but cost share-induced technological change introduces a stabilizing dynamic.

C. The new endogenous growth theory

The various growth models that seek to explain the Solow residual within the production function approach are sometimes called "new" growth models and sometimes "endogenous" growth models. Yet, as Kurz and Salvadori (2003)[32] have pointed out, endogenizing growth is nothing new, although these models do it in a different way. This annex therefore refers to such models as "new endogenous" growth models.

To discuss the new endogenous growth models, it is useful to start with a particular production function, the Cobb-Douglas, which is characterized by constant elasticities. Setting inputs other than capital and labour aside for the moment, the standard Cobb-Douglas model is

$$Y = F(K, L) = A(t)\, K^{\alpha} L^{1-\alpha} \tag{33}$$

This function exhibits constant returns to scale, a condition which is enforced by setting the elasticity of output with respect to labour equal to one, minus the elasticity of output with respect to capital. Taking the first-order variation, and dividing by the expressions on either side of the equation, gives

$$\frac{\Delta Y}{Y} = \frac{\Delta A}{A} + \alpha\frac{\Delta K}{K} + (1-\alpha)\frac{\Delta L}{L} \tag{34}$$

The first term on the right-hand side, $\Delta A/A$, is the Solow residual.

Endogenizing the Solow residual

One approach to endogenizing the residual, suggested by Romer (1987, 1994),[33,34] is to say that A depends on the capital-labour ratio K/L and, specifically (for purposes of calculation), that the dependency exhibits a constant elasticity γ. That is,

$$A = A_0\left(\frac{K}{L}\right)^{\gamma} \tag{35}$$

However, the adjustment of A to the new capital-labour ratio takes time. When firms make their profit-maximizing allocation of labour and capital, they hold A fixed and use Equation (33). The capital cost share is therefore α, while the labour cost share is $1 - \alpha$. However, for growth accounting purposes, the coefficient is given by $\beta = \alpha + \gamma$, because, after substituting from Equation (35) into Equation (33),

$$Y = A_0 \left(\frac{K}{L}\right)^{\gamma} K^{\alpha}L^{1-\alpha} = A_0 K^{\alpha+\gamma}L^{1-\alpha-\gamma} = A_0 K^{\beta}L^{1-\beta} \tag{36}$$

Romer found that a value for β of around 0.8 would reconcile his model to observed patterns (note that Romer's β is equal to one minus the value used here).

A further model proposed by Mankiw, Romer (a different Romer) and Weil (1992)[35] (see also Romer, 1994),[34] proposed a further factor of production – human capital H – which enters into the production function with its own cost share. That is,

$$Y = AK^{\alpha} H^{\beta} L^{1-\alpha-\beta} \tag{37}$$

Using secondary school enrolment as a proxy for human capital, they showed that setting $\alpha = \beta = 1/3$ can explain growth patterns without leaving an unexplained residual.

A model in the same spirit, although not by authors associated with the new endogenous growth theory,[36] proposes that both capital and labour are enhanced by energy inputs, so that

$$Y = F\,(Ke_K \varepsilon_K, Le_L \varepsilon_L) \tag{38}$$

where e_K and e_L are energy intensities of capital and labour, while ε_K and ε_L convert those energy inputs into useful energy equivalents.

Directed technological change

The models above beg the question of the direction or bias of technological change. As noted earlier, the classical-evolutionary model of cost share-induced technological change does explain directed technological change. Acemoglu (2002)[37] proposed a model for directed technological change within the production function approach. In his model, firms purchase machines from technology monopolists, who are led to produce machines that save on one input or another depending on: the relative abundance of inputs; the degree of substitutability or complementarity of the inputs; and the state of the market.

Throughout Section 1.11, reference is made to the different sections of this annex. They present theories of technological change from different traditions, which are used to interpret observations and put forward policy recommendations.

NOTES – ANNEXES

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