Decentralised solar electricity for agri-food value chains in the Hindu Kush Himalaya region

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Foreword

The Hindukush Himalayan region spans more than 3 500 km and is a home to around 240 million people. Faced with the increasingly severe impacts of climate change and food insecurity, there is an urgent need to secure smallholder livelihoods among the communities of the region.

Clean and affordable decentralised renewable energy can strengthen the resilience of these vulnerable populations, helping them to adapt to the growing impacts of climate change by improving agricultural productivity.

Viable decentralised photovoltaic (PV) solutions to power key food value chains across all eight countries of the Hindukush Himalayan region offer the chance to significantly improve agro-based livelihoods, bringing opportunities to establish safer, healthier lives for the region's communities.

Francesco La Camera
IRENA Director-General

Socio-economic development in the mountains is constrained by a host of challenges and specificities, such as fragility, marginality and limited accessibility. Mountain communities are highly dependent on natural resources and remain very vulnerable to the impacts of climate change.

Government policies and programmes must therefore deliberately transform these challenges into mountain-specific opportunities by creating an enabling environment where innovation is encouraged, and a distributed renewable energy system is incentivised. This will bolster food value chains through automation and modernisation, resulting in better development outcomes.

Solar PV solutions look beyond mitigation to help mountain societies strengthen their resilience and adapt as they tackle the ever-increasing impacts of climatic hazards. This report - which assesses the scope and feasibility of using decentralised renewable energy solutions in selected food value chains - provides recommendations for policy, regulations, skill building and financial support.

The report indicates that an innovative, contextualised ecosystem development approach incorporating decentralised, energy-efficient solar-powered solutions will need to be embraced, wherein all ecosystem actors come together, synergise their efforts and take full ownership of the outcomes.

Dr Pema Gyamtsho
ICIMOD Director-General

Energy is a key driver for development, as it can lead to increased productivity and incomes, reliable infrastructure for health and improved connectivity and well-being. Access to clean and reliable energy according to a needs-based timeline is critical in improving livelihoods for the poor.

Despite their inherent challenges, hilly terrains such as that of the Hindukush Himalayan region present unique opportunities for innovation in renewable energy system design as well as efficiency of productive use, appliance and dissemination models.

SELCO Foundation, together with IRENA and ICIMOD, has explored the role of decentralised renewable energy in some of the most critical value chains in the Hindukush Himalayan region. Populations engaged in those value chains are amongst the most climate vulnerable in the world; in order to meet the development needs such regions, the optimisation of solutions through a user-centric and systemic approach is critical.

The solutions explored in this paper can be considered the foundations for building on much needed renewable-energy-driven innovations for productive use in hilly terrains.

Harish Hande
CEO, SELCO Foundation

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Abbreviations

°C	degrees Celsius
AC	alternating current
DC	direct current
HKH	Hindu Kush Himalaya
hp	horsepower
ICIMOD	International Centre for Integrated Mountain Development
IRENA	International Renewable Energy Agency
kWp	kilowatt peak
LPG	liquefied petroleum gas
PV	photovoltaic
Wp	watt peak

A traditional potato farm land at Kathmandu, Nepal.
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Executive summary

This report presents analysis, findings and recommendations on the use of decentralised solar photovoltaic (PV) solutions for selected food value chains in the Hindu Kush Himalaya (HKH) region. It is a joint publication resulting from the strategic partnership between the International Renewable Energy Agency (IRENA) and the International Centre for Integrated Mountain Development (ICIMOD). SELCO Foundation, building on its extensive experience in solar energy-powered agricultural solutions and under the guidance of IRENA and ICIMOD, carried out the required analysis of suitable solar PV solutions for the selected value chains in the local contexts.

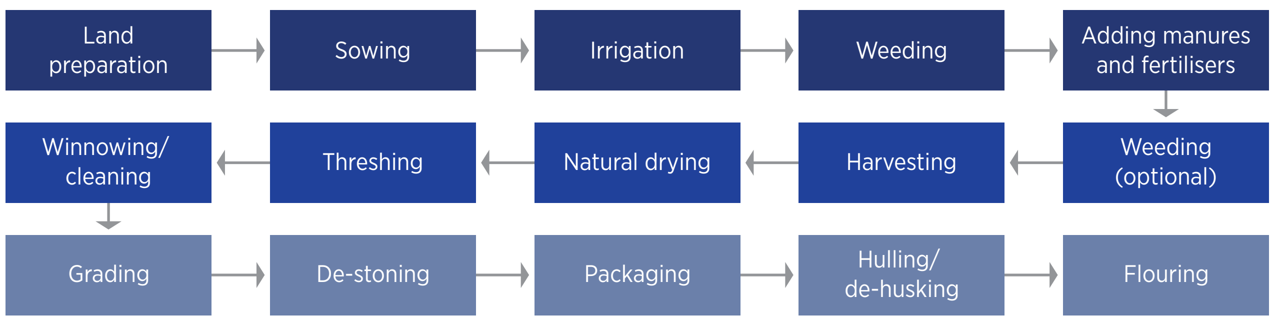
The communities inhabiting the mountainous areas of the HKH region rely mainly on agriculture and farming for their food security and livelihoods. Tackling poverty in mountain areas – where poverty rates are usually higher than in the plains – will require greater attention to raising the incomes of these communities. There is also an urgent need to strengthen the resilience of smallholder livelihoods, which face increasingly severe impacts from climate change. Access to reliable and affordable energy is a key infrastructure input to improve agricultural productivity, reduce losses and capture value creation opportunities through processing and enhanced market access. Proven methods have been used to improve processes within the food value chain, where the provision of electricity to operate efficient equipment increases productivity, leading to income generation.

The present study was carried out to assess the viability of solar PV solutions to meet energy needs at different nodal points in four selected food value chains of economic importance across the high-altitude areas of the HKH region – namely, buckwheat, yak milk, potato and other vegetables. Despite the prevalence of mini and micro hydropower in the region, many of these units are unable to fully meet the electricity requirements of the selected value chains. This is because, in many cases, trends such as the recent increase in power demand due to population growth and productive uses were not fully considered at the time of development of hydropower projects. Also, in some cases, the food value chains are located far from the hydropower sites, and the expansion of distribution lines is not a viable option. As a consequence, a considerable amount of electric power demand is not met by existing hydropower projects. Additionally, the seasonal variability in the water flow and subsequent drop in hydropower production strengthens the case for diversifying energy sources to meet growing demand.

The aim of the study was to assess and identify viable decentralised solar PV solutions to power key food value chains that are common across all eight countries of the HKH region. Survey-driven data from Bhutan and Nepal,[1] and analysis based on these data, reflect the ongoing practices and the nodal energy entry points that could drive key processes within these value chains. The solar PV-based solutions suggested here have been designed based on proof-of-concept, deployed systems for similar farming processes. The viable mechanised equipment required to automate the production processes for each of the four food value chains are discussed in the following paragraphs and also summarised in Table 1.

- For the buckwheat production process (Figure 1), techno-commercial equipment powered by solar PV has been proposed for the following activities: irrigation, insecticide spraying, threshing and winnowing, grading, de-stoning, hulling, milling (for flour) and packaging.

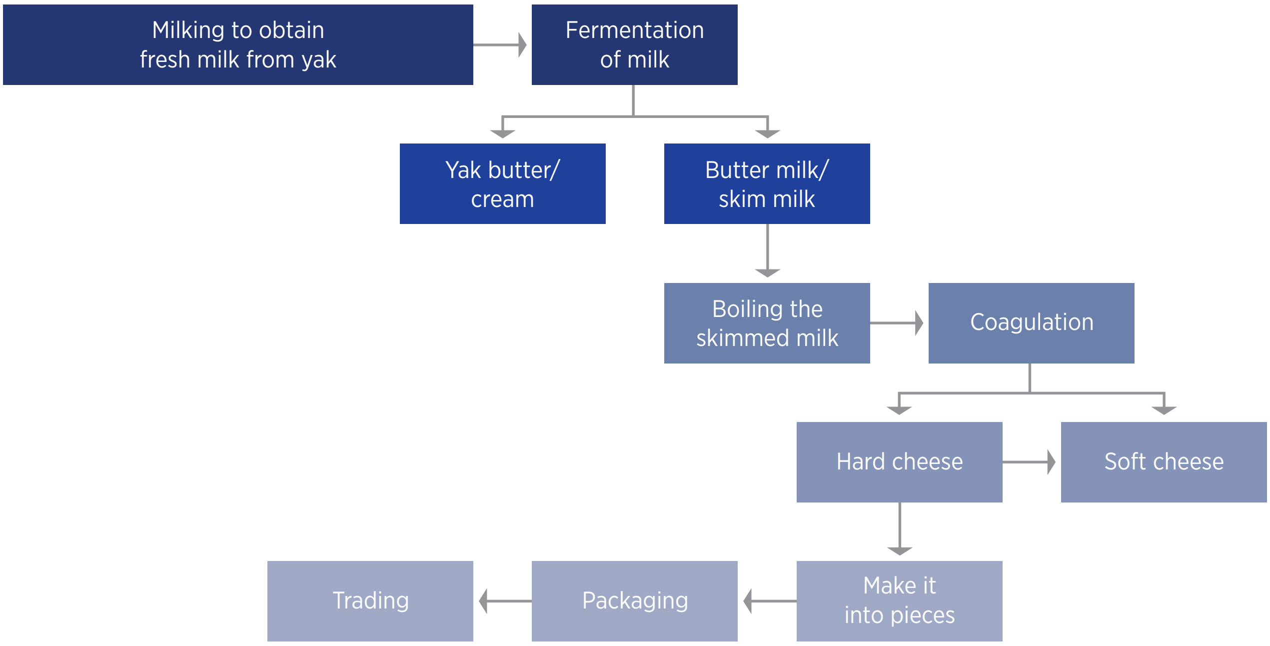
Figure 1 Flow diagram of the serial set of processes to produce buckwheat



[1] The COVID-19 pandemic and the resulting travel limitations restricted the selection of food value chains and the primary data collection to two countries, Bhutan and Nepal.

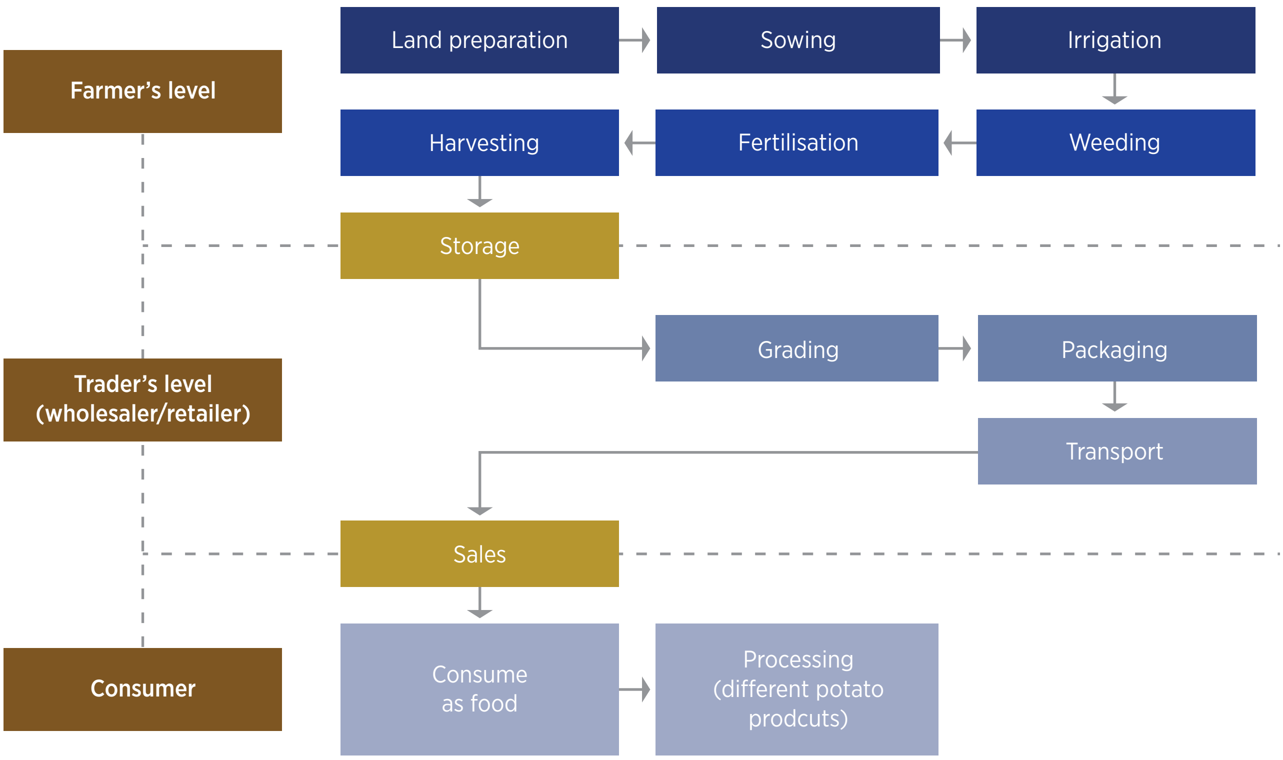
- For the yak cheese production process (Figure 2), techno-commercial solutions driven by solar PV have been proposed for the following activities: yak feed management, shelter lighting for yak milking, machines for milk extraction, milk testing and weighing machines, bulk milk chillers, butter churning machines, cream separator machines and yak dung log making machines (to prepare the dung for use as cooking fuel).

Figure 2 Flow diagram of steps taken to produce yak cheese



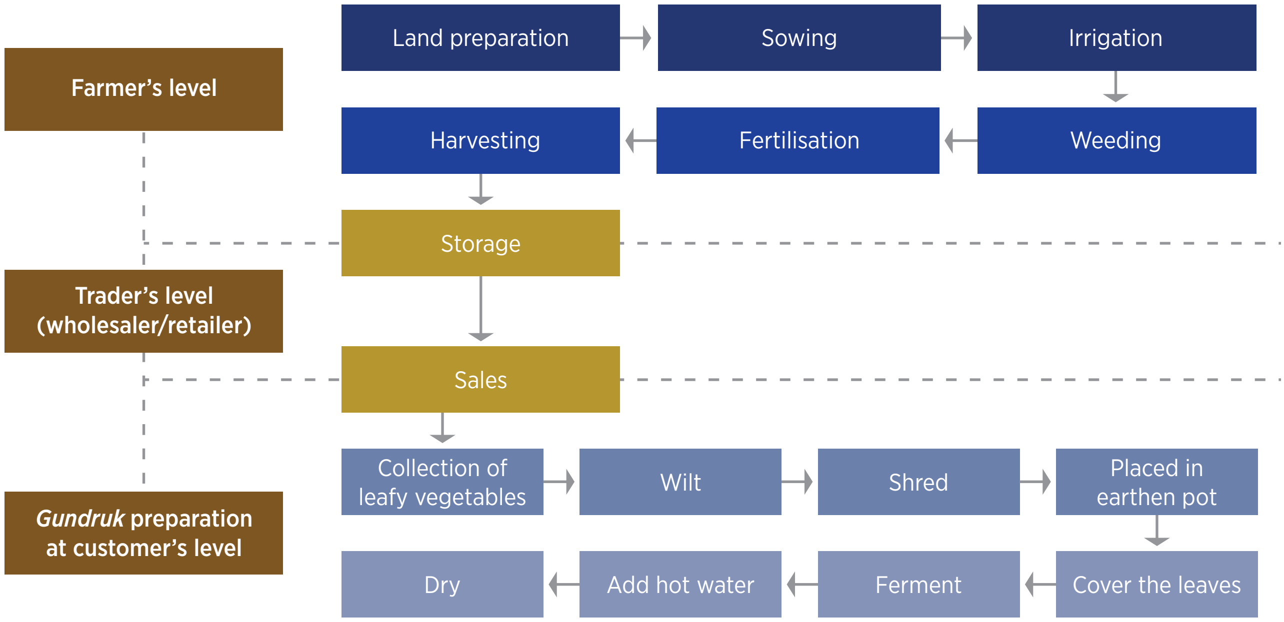
- For the potato production process (Figure 3), techno-commercial solutions driven by solar PV have been proposed for the following activities: irrigation, insecticide spraying, fencing solutions, cold storage, grading machines, potato peeling and chip making machines, and packet sealing machines.

Figure 3 Flow diagram of steps followed to grow potatoes and market them for processed products



- For the vegetable production process (specifically, the process of producing fermented and dried vegetable products known as *gundruk*) (Figure 4), techno-commercial solutions driven by solar PV have been proposed for the following activities: irrigation, insecticide spraying, fencing solutions, cold storage, drying and packaging.

Figure 4 Flow diagram of stages in the cultivation, harvesting and processing of vegetables to make *gundruk*



Gundruk
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Table 1 Consolidated set of technological recommendations for the four food product value chains studied

Buckwheat value chain	1	2	3	4	5	6	7	8
Solution proposed	Solar powered portable irrigation pump (1 hp)	Weeding machine	Solar powered agricultural insecticide sprayer	Solar powered thresher (3 hp) and winnower (2/3 hp)	Solar powered grader with aspirator (1 hp), de-stoner (2 hp), and huller (2 hp) and sealing (200 Watt)	-	-	-
Solar capacity	900 Wp	N/A	100 Wp	5 kWp	5 kWp	-	-	-
Cost of solar + unit (wherever applicable)	USD 2 000	USD 27	USD 315	USD 10 100	USD 12 290	-	-	-
Yak value chain	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Solution proposed	Solar powered chaff cutter (2/3 hp)	Solar powered DC luminaries for milking	Solar powered single cluster milking machine (for yak)	Solar powered milk tester and weighing machine	Solar powered bulk milk chillers	Solar powered butter churning machine	Solar powered electric cream separator machine	Solar powered yak dung log making machine
Solar capacity	6 kWp	60 Wp	100 Wp	150 Wp	5.2 kWp	75 Wp	500 Wp	3.6 kWp
Cost of solar + unit (wherever applicable)	USD 9 740	USD 425	USD 970	USD 1 375	USD 6 675	USD 330	USD 1 775	USD 8 275
Potato value chain	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Solution proposed	Solar powered drip irrigation pump (5 hp)	Weeding machine	Solar powered agricultural insecticide sprayer	Solar powered fencing solution	Solar powered cold storage unit	Solar powered potato grading machine	Solar powered potato peeler and chips making machine	Solar powered polythene sealing machine
Solar capacity	4 800 Wp	N/A	100 Wp	100 Wp	14 kWp (10 MT)	5 kWp	600 Wp	300 Wp
Cost of solar + unit (wherever applicable)	USD 7 670	USD 27	USD 315	USD 3 135	USD 41 380	USD 14 680	USD 3 065	USD 1 027
Vegetable value chain (Gundruk)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Solution proposed	Solar powered drip/sprinkler irrigation pump (2 hp)	Solar powered hydroponics technology	Weeding machine	Solar powered agricultural insecticide sprayer	Solar powered fencing solution	Solar powered monkey repellant	Solar powered cold storage unit	Solar powered drying and sealing unit
Solar capacity	2 000 Wp	60 Wp	N/A	100 Wp	100 Wp	60 Wp	7 kWp (5 MT)	1 kWp
Cost of solar + unit (wherever applicable)	USD 4 250	USD 210	USD 27	USD 315	USD 3 135	USD 310	USD 18 355	USD 2 360

Note: hp = horsepower; Wp = watt peak

The assessment and analyses based on the collected data and on the regional knowledge of the partners is the basis for recommending actions to promote the deployment of decentralised solar PV solutions for remote mountain communities in the HKH region. The recommendations are intended to guide the region in planning at the national and sub-national levels to ensure food security and strengthen livelihoods by building resilience in agricultural practices. The goal is to move towards the achievement of practices that, by tapping into renewable resources such as solar PV, allow for mechanisation that brings efficiency and innovation, and is climate resilient.

Recommendations

Replace outdated techniques with automation of processes in food value chains

Assessments based on feedback from local producers and enterprises – in terms of production volume, energy intervention, and market demand in the food value chains of buckwheat, yak milk, potato and other vegetables – show that communities in the region continue to rely on conventional fuels, including traditional biomass fuels such as yak dung and firewood for thermal needs, as well as diesel fuel (mainly for transport). This reliance impacts agricultural production and contributes to wastage of yield (due to lack of cold storage) and limited market supply (SELCO Foundation, 2021).

Access to electricity from renewable energy technologies using solar PV at different nodal points of the value chain can add value through automation and modernisation processes, resulting in reduced manual labour, increased yield, reduced wastage and greater market reach in the region and beyond.

Support the shift from subsistence farming and local merchandising towards enterprise development as scale and productivity increase

Mountain communities in the region have limited access to mainland markets. Innovation and modernisation through electrification – resulting in increased productivity of food products – allows for greater enterprise development. Government policies and programmes can drive this development by providing fiscal incentives such as tax breaks and financial support such as subsidies. This support would attract investors and start-ups to create ecosystems in which supply chains are established, storage is modernised and efficient transport enables local products to reach wider markets. Local entrepreneurship can be encouraged through entrepreneur skill development, financial support for initial investments and seed money. Special status can also be given to women-owned/-operated enterprises and their product sales.

Improve local skills and capacities to promote and scale the use of solar PV in the sector

As solar PV solutions in the agriculture and farming sector begin to show beneficial impacts and are further promoted through conducive policies and regulations, this needs to be supported by increasing the capacity and skills of local communities. Skills training and certification for renewable energy jobs created in sourcing, installing, operating and maintaining renewable solutions need to be actively promoted. Setting up training facilities with standard curricula and teaching methods will provide for the sustained use of solar PV solutions, with the additional benefit of creating a renewable energy job market to absorb the skilled labour force in the region. Given the difficulty in accessing these communities, it is imperative that a critical mass of trained persons is available at the local level to ensure proper operations and the possibility for troubleshooting and repairs.

Enhance the commercial viability of local food products

Deploying solar PV solutions for the agriculture sector and food value chains is considered technically viable based on the requirements and analysis of the value chains studied. This is reaffirmed by similar solutions being employed in other parts of the world. The commercial viability of this deployment is dependent on government and public sector support in the form of concessional loans, tax credits and subsidies to encourage private sector investment. Governments can prioritise the sale of products from local communities and thereby support them in increasing their market share. Reduced sales tax and duties on purchase of equipment and machinery can further attract enterprises in these food value chains.

Build awareness and inform local communities about policies and programmes

Local producers are largely unaware of the existing policies, regulations and programmes that incentivise the local production and supply of food produce. Public sector enterprises, in partnership with non-governmental organisations and development partners, should engage with local communities and initiate awareness campaigns targeting remote and isolated communities to make them aware of the available tools and options to deploy solar-powered solutions in their food value chains.

Promote solar PV solutions to support climate resilience and adaptation

The ever-growing impacts of climate change add to the vulnerability of mountain communities. Decentralised renewable energy solutions powered by solar PV can further strengthen climate resilience and need to be considered as an adaptation strategy in addition to helping to mitigate carbon emissions. Countries' policies and action plans, Nationally Determined Contributions and Long-Term Low Emission Development Strategies need to prioritise actions such as the deployment of solar PV in food value chains as a climate-resilient pathway for these communities. It is also important to ensure that plans and policies aimed at climate action do not exclude those communities that are most vulnerable to climate change.

Develop a project pipeline

This assessment study serves as an entry point towards developing a dynamic market for solar PV products and services in food value chains of economic importance in the HKH region. To this end, government functionaries, development partners and locally active development financial institutions need to apply the most viable projects and begin activating the market by developing appropriate risk mitigation tools and concessional financing instruments. These actions would need to be supported by active outreach with potential entrepreneurs from the region who may be encouraged to start offering the required energy services and promote joint ventures with private companies that are offering products and services based on decentralised renewable energy in the mainland. Through such actions, a robust pipeline of projects can be developed and widespread deployment of solar PV can be achieved to add value in these food value chains. Furthermore, such actions will provide local communities with opportunities for entrepreneurship and skills enhancement in the decentralised renewable energy sector.

This would enable entities such as IRENA and other development partners to further support the market through appropriate risk mitigation, project facilitation and technical assistance interventions.

Yaks in Nepal, Himalayas
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1. Introduction

Section 1

The Hindu Kush Himalaya (HKH) region is home to the three highest mountain ranges in the world – the Hindu Kush, the Karakorum and the Himalayas – and is renowned for its beauty and unique ecological setting. The region is also one of the most vulnerable to climate change and extreme weather, with communities residing in harsh living conditions in difficult, hard-to-reach terrain. The region spreads across 3 500 kilometres and spans eight South Asian countries: Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal and Pakistan. The mountain areas of these eight HKH countries host 9% of the collective population of these countries.[2]

Poverty and climate risk are two important issues that are decreasing social sustainability in the HKH region and leading to growing disparities across geographies. The region is one of the world's poorest, and poverty alleviation and eradicating hunger are priority agendas. To achieve these goals, political prioritisation and effort are needed to bring substantive socio-economic growth to the region. The Human Development Index (HDI) rankings for the eight HKH countries show that, aside from China, which falls under the "high" HDI category, six of the countries are in the "medium" category and still face a long road towards improving the living conditions of their citizens; meanwhile, Afghanistan, with a low HDI, needs to accelerate growth and bring an equitable share of the returns to all its citizens (Table 2) (UNDP, 2020).

Table 2 Human Development Index values and average annual economic growth for the eight HKH countries

Country	Human Development Index (HDI) value (2019)	Change in ranking (2014-2019)	Average annual % growth (1990-2019)
China	0.761	12	1.47
Bangladesh	0.632	8	1.64
Bhutan	0.654	1	–
India	0.645	1	1.42
Nepal	0.602	0	1.54
Myanmar	0.583	3	1.86
Pakistan	0.557	2	1.13
Afghanistan	0.511	-5	1.83

High HDI Medium HDI Low HDI

Source: UNDP, 2020.

The HKH countries are committed to the United Nations' 2030 Agenda for Sustainable Development and support the Sustainable Development Goals (SDGs). SDGs 1 and 2, on ending poverty and hunger, respectively, are greatly interlinked and require integrated efforts by governments. Replicable ecosystem processes, banking on sustainable energy solutions that enable various income-generating activities for remote populations, can help address poverty and the climate crisis. Sectoral interdependencies among energy, food, climate and water, and their cross linkages, are significant in fragile mountain regions.

In the HKH region, food security and livelihoods depend mainly on agriculture. The nature of food security and livelihoods in mountain regions differs from that in the plains because of differences in the physical environment, the scale of production (mainly niche farming), transport and communications infrastructure, remoteness and seasonality. Mountain environments are characterised by limited accessibility, a high degree of fragility, and marginality (Hussain *et al.*, 2016; Jodha, 2000; Rasul and Hussain, 2015). Agriculture in such regions faces the severe challenges of climate change, agricultural land abandonment, lack of production and post-harvest

[2] ICIMOD database.

technologies, and insufficient access to markets (Rasul *et al.*, 2019). Issues such as loss of productivity, lack of market access and economies of scale lead many inhabitants to look for other livelihood options and/or to out-migrate (Hussain *et al.*, 2021; Maharjan *et al.*, 2018).

With most of the rural population in the HKH region depending on agriculture, economic growth and the transformation of rural economies is of critical importance. To expedite this transformation, sustainable productivity, efficient post-harvest management and environmentally friendly agro-enterprises are crucial (ICIMOD, 2020). Agricultural value chains involving the use of renewable energy are among the most appropriate solutions to transform rural economies in the region. Currently, non-sustainable production practices, low productivity, and high post-harvest food losses are among the key reasons for the poor contribution of mountain agriculture to local and national economies and food security in the HKH countries. In particular, the share of post-harvest losses of vegetables is 30-40% and of fruits is 20-60%, with variations within and among countries (Rasul and Hussain, 2015).

Support for agricultural entrepreneurship by promoting productive uses of decentralised renewable energy within the food value chain will contribute to the incomes of farmers and other involved enterprises (collectors, distributors, processors and retailers) (Adhikari *et al.*, 2018; Shrestha *et al.*, 2015). It will also help reduce the dependence of mountain areas in the HKH region on external food supplies. Currently, most hilly and mountainous areas in the region depend heavily on the plains areas to meet their local food demand. In Pakistan, an estimated 30-60% of food demand in mountain areas is met by food items supplied from the plains (Hussain and Routray, 2012).

The high dependence on external food supplies leaves mountain regions vulnerable to climactic and non-climatic shocks. In the case of climate-induced hazards (*i.e.* floods, heavy snowfall and landslides) or price hikes in the supplied products, a significant proportion of mountain populations may be pushed into transitory food insecurity (Rasul *et al.*, 2019). Therefore, strengthening mountain food systems through the pathway of decentralised renewable energy for food value chains is critical for bolstering local production and consumption.

To ensure the equitable distribution and preservation of food sources and to strengthen food security, it is imperative to enhance and mechanise local agricultural practices. This in turn will increase productivity and reduce losses and drudgery, with modern energy as a key driver. Use of technology allows for enhancement of production, loss reduction, product diversification and value addition. In the HKH region, around 40% of farm households face frequent labour shortages during the critical periods of agricultural activities due to rampant out-migration of active household members, particularly youth (Hussain *et al.*, 2016). Female members of the household take on the additional responsibility of agricultural activities. This additional workload on women can lead to the abandonment of agricultural land (Hussain *et al.*, 2021; Rasul *et al.*, 2019). The adoption of renewable energy to operate smart machinery will help communities cope with the challenge of labour shortages and reduce the workload of women farmers.

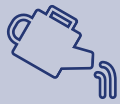
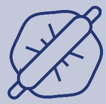
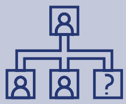
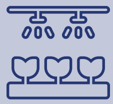
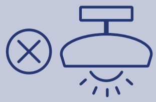
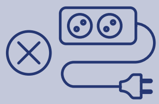
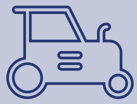
The strategic partnership between the International Renewable Energy Agency (IRENA) and the International Centre for Integrated Mountain Development (ICIMOD) aims to accelerate the pace of renewable energy adoption across the HKH region to strengthen economic value chains and assist in the development of resilient enterprises. IRENA, with its mandate to promote renewables across the globe, has been pursuing this initiative to ascertain the suitability of decentralised solar photovoltaic (PV) solutions in the context of adding value to existing food value chains. ICIMOD strives to bring about sustainable and resilient development, thus enabling improved and equitable livelihoods for remote mountain communities in its eight member states: Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal and Pakistan. SELCO Foundation complements this effort with its knowledge and experience in promoting decentralised renewable energy solutions in the agri-food sector. SELCO's robust and sustainable models have helped to improve the economic quotient of current livelihoods and create new ones across a range of sectors – agriculture, health and education – for rural and remote communities.

To achieve the objective of the current study, a scoping exercise was carried out in 2019, followed by a consultative workshop that identified the food sector as one of the areas in which to intervene to substantially enhance livelihoods in the region. The co-operation between IRENA and ICIMOD led to identifying decentralised renewable energy solutions as the key stepping stone to not only achieve broader energy access (SDG 7) but also other SDGs, primarily SDG 1 (poverty alleviation), SDG 2 (zero hunger), SDG 3 (health), SDG 4 (education), SDG 6 (water) and SDG 8 (livelihoods).

While the scope of the study extended across the HKH region, the limitations imposed by the COVID-19 pandemic and the subsequent inability to travel restricted the partners to collecting data and analysing the food-energy nexus for only two of the eight countries, Bhutan and Nepal. The selection of these countries for the study was guided by their similarities in: 1) ecological mountain and hill zones; 2) agro-ecological, climatic and terrain conditions; and 3) access to renewable energy. The data collection and subsequent analysis, however, apply to all eight of the HKH countries due to similarities in agriculture and farming practices and to the limited - or lack of - energy access throughout the region.

Farming practices in mountain terrains are observed to be on fragmented lands, using traditional and manual methods. There is limited or no use of technology in horticulture and animal husbandry, and the limited produce that is harvested serves the food needs of the family or the small communities alone. Challenges that are common and can be traced across food value chains in the region are summarised in Table 3.

Table 3 Challenges facing the agriculture and food production sectors as observed in Bhutan and Nepal

Challenge	Icon
Manual irrigation practices with poor access to water availability	
Limited or no use of technology in food processing	
Shortage of labour and limited youth involvement in agriculture and food processing sectors	
Limited resources and data for strong mapping and planning of food value chains	
High production costs for growing crops/rearing animals	
Poor electricity supply in rural areas, with sporadic and low-quality supply affecting mechanised food processing	
Lack of electricity access for remote and off-grid communities	
Use of old, inefficient machinery in farming, limiting productivity	
Lack of policy and a programmatic approach to incentivise the sector	

The assessment study evaluated current production processes for four selected food products – buckwheat, yak milk, potatoes and other vegetables – and examined the technical viability and estimated costs of decentralised renewable energy solutions for electricity provision in food value chains. The rationale for selecting these four food value chains and the approach and methodology adopted to carry out the assessment are elaborated in section 2.

2. Methodology and approach

2.1 Value chain approach

For any livelihood, it is possible to determine the gaps and requirements at every stage if examined through the lens of a value chain approach. In contrast, any solution viewed in isolation ignores the holistic nature of the problem at hand. For agriculture, the broad stages of any value chain that must be studied to map gaps and the interconnectedness of issues are pre-farming, farming, processing and market level. Considering that farming communities face challenges in procuring basic amenities due to the economic gap, value chain mapping can help develop understanding around possible areas of intervention to reduce production costs by increasing the value of products. Energy might not be the only area of intervention, but collaboration with an array of stakeholders can promote solutions by using the ecosystem approach.

A major hindrance facing agriculture-based livelihoods is the lack of appropriate farming technologies across the value chain, specifically for small and marginal farmers. Such technologies are either severely lacking in terms of access or completely missing from the value chain of products, services and systems available to farmers (IRENA and SELCO Foundation, 2022). Efficient, need-based productive assets can improve productivity, increase incomes and maintain well-being through removal of drudgery, increased savings and product diversification. Decentralisation presents the opportunity to maintain maximum value at farm and farmer level. This, combined with efforts to strengthen value chains via sustainable technologies, can go a long way towards enhancing the social, financial and environmental sustainability of small and marginal farmers.

A typical food value chain has a minimum of four functions embedded within it – production, processing, aggregation/transport, and marketing and sales – with the relevant actors being producers, processors, wholesalers and retailers. Energy is required at every stage of a food value chain (see Table 4 for a typical set of tasks that require energy).

Table 4 Tasks across different nodal points of the food value chain

Production	Processing	Aggregation/transport	Marketing and Sales
Land preparation	Washing/cleaning	Collection	Packaging/labelling/branding
Sowing	Sorting/grading	Cold storage/warehousing	Marketing
Irrigation	Grinding/milling	Transport	Selling/bulk selling
Harvesting	Other processing		
	Heating/boiling/cooking		
	Drying and dehydration/ fermenting		
	Grinding/milling		
	Value addition		

As illustrated in Figure 5, a cereal value chain can be mapped in a broad manner. The technologies driven by decentralised renewable energy could be applicable to any cereal commodity, from the input and farm level, to post-harvest processing, to distribution and food processing. The equipment that is mapped needs to be contextualised based on the availability of the technology type and benchmarked for efficiency and solar adaptability.

Figure 5 **Mapping of a cereal value chain**

2.2 Assessing the food value chains

Selection of food value chains

The choice of the selected food value chains for the study was based on criteria guided by four key dimensions and their indicators: 1) potential for mountain communities; 2) low risk of climate change and potential for use of renewable energy; 3) potential for empowerment of youth and women; and 4) potential to leverage expertise and resources. Scoring based on these criteria resulted in the selection of four food value chains: buckwheat and vegetables for Nepal, and yak milk and potatoes for Bhutan.[3]

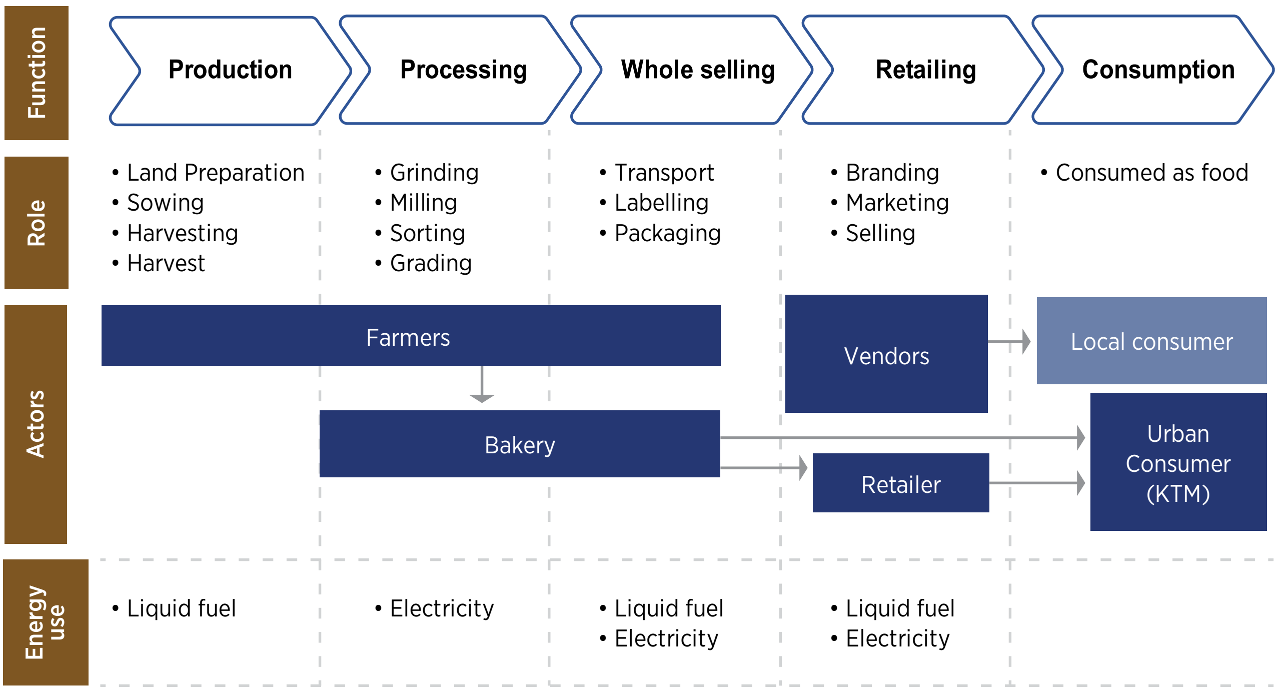
Buckwheat value chain

In Nepal, there is limited involvement in buckwheat cultivation and production, as farmers have not been able to commercialise this product in the mountain context. Farmers produce buckwheat for self-consumption alone or use it as cattle feed. The farming community producing buckwheat is involved in all four key functions: production, basic grinding/milling, sale to wholesalers or retailers, and consumption (Figure 6). The common practice is for producers to sell the buckwheat directly to retailers. The processed buckwheat is of lesser quality than the buckwheat coming to the urban market from neighbouring countries. One possible reason for this could be the use of outdated technologies, such as for grinding, at the study sites.

In Kathmandu, there is a small market for buckwheat, where retailers procure the grain from wholesalers to produce and sell breads and cookies. According to the survey, demand for buckwheat is slowly developing in city areas as people become more health conscious and value its nutritional content. In terms of the value chain, the buckwheat market lies mostly with local consumers, as the current scale of production is too low to make the transport cost worthwhile.

Liquid fuel is used to operate tractors, mostly for land preparation in the field at production scale. Buckwheat does not require irrigation and is mostly rain fed; therefore, it consumes little energy. Some producers-cum-processors use electricity to run grinding machines, which is also done at a low scale, to produce buckwheat flour. Wholesalers use liquid fuel mostly for transporting the product, and retailers use electricity to run their stores. However, there is potential to diversify buckwheat products into cookies, breads, muffins etc., which will also increase energy consumption along the chain.

Figure 6 Buckwheat value chain



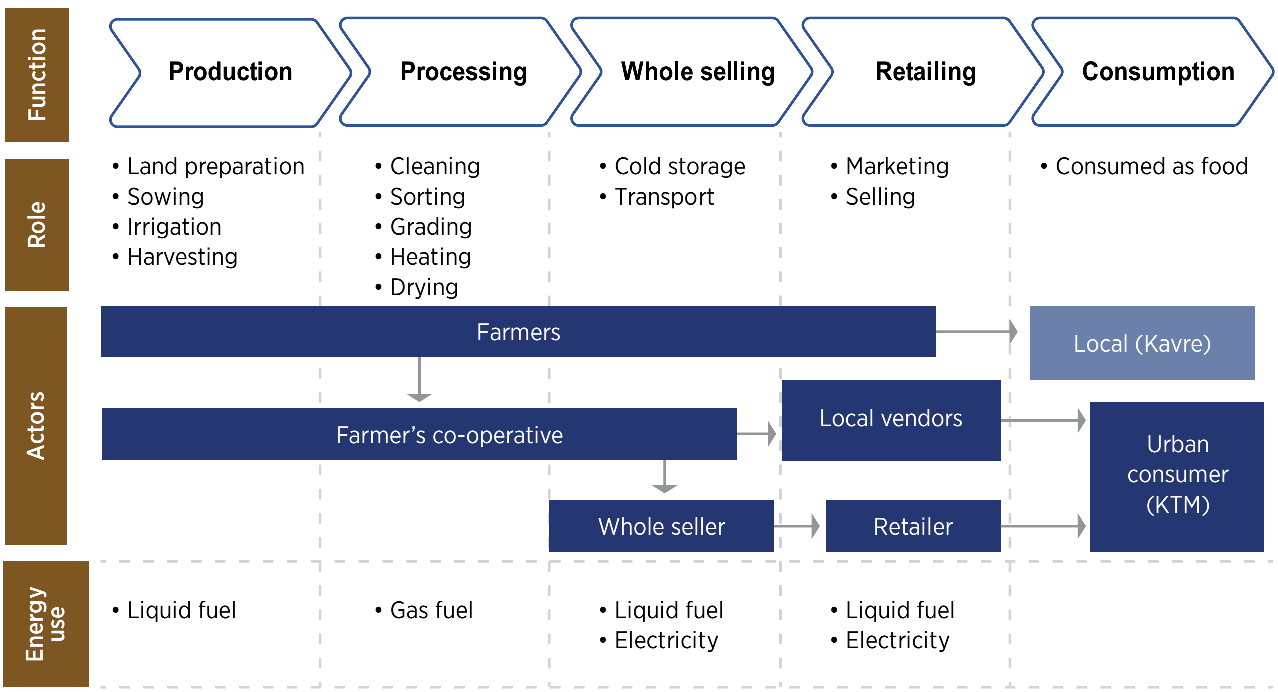
[3] Although current energy consumption is low or minimal in the value chains of the four selected food products, provision of electricity will increase productivity and enable market reach.

Vegetable value chain

Vegetable production is rapidly increasing as an important income source in Nepal, and several government schemes promote commercial vegetable production in the country. The vegetable value chain requires functions such as land preparation, sowing, irrigation and harvesting, which are done mostly at the producer level (Figure 7). At the processing level, activities such as cleaning, sorting, and grading are done, mostly by individual farmers. Nonetheless, enterprise co-operatives are very popular in Nepal, where some level of processing is done prior to selling products at the wholesale level. Vegetables are mostly sold fresh, and most producers sell their products directly to retailers in the market. Only in some cases are the products sold to retailers via wholesalers or their own co-operatives that play the role of wholesaler. There is a huge demand for clean, cut and frozen vegetables in the urban market. However, this market remains untapped due to a lack of vehicles equipped to transport frozen vegetables.

In places where current practices are mostly manual, energy use is minimal. In the case of buckwheat, tractors that operate on liquid fuel are used for land preparation and sowing. Some producers practise traditional methods of processing such as sun drying vegetables to produce fermented and dried products (*gundruk*), which is limited to the subsistence scale, and small quantities sell in the market. Cleaning, sorting and grading activities do not use energy under the current methods followed. It is observed that enterprises use liquefied petroleum gas (LPG) for heating purposes. Both electricity and liquid fuel are used for transport, packaging and selling of products. All surveyed enterprises had access to electricity, which they used primarily for lighting, except for one producer. To preserve vegetables, enterprises prefer sun-drying methods over freezing as this does not require additional energy or equipment. Solar dryers are yet to be adopted in mountain regions, as transporting and setting them up at households has been a challenge.

Figure 7 Vegetable value chain



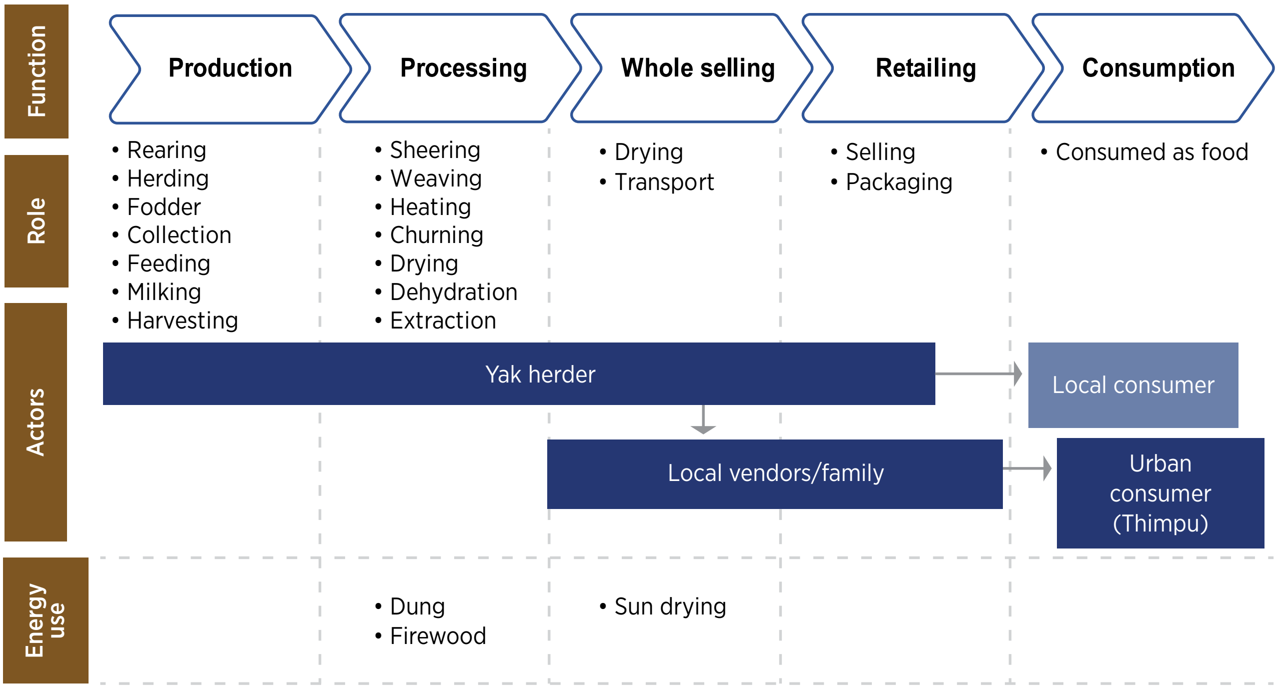
Yak value chain

The yak value chain is the least developed of the four value chains studied (Figure 8). At least three actors are required to run a value chain, and in the case of yak almost every producer fulfils all four functions that ready the produce for consumption. Yak herders/producers follow a transhumance practice, moving to higher altitude with their animals when summers approach due to the abundance of grass, and descending in winters. Due to the lack of collective processing centres and storage facilities, yak milk is processed at an individual level to make three main products that have a longer shelf life: soft cheese, hard cheese and butter.

No specific yak enterprises have been set up, as yak rearing is taken up as a family livelihood. In the past, the transhumance practice was nomadic, where the family as a whole would move to higher altitudes; however, the trend is changing whereby only men travel with their animals. Other family members are involved in the sale of yak products directly to local consumers or to wholesalers. One by-product is yak wool, extracted to make ropes, although this mostly serves consumptive uses.

Current practices in the yak value chain use minimal energy. To process dairy products, the herders/producers mostly use fuel wood or yak dung for heating, boiling, churning, drying and dehydrating the milk. Survey data show no other energy forms being used in the food value chain.

Figure 8 Yak value chain



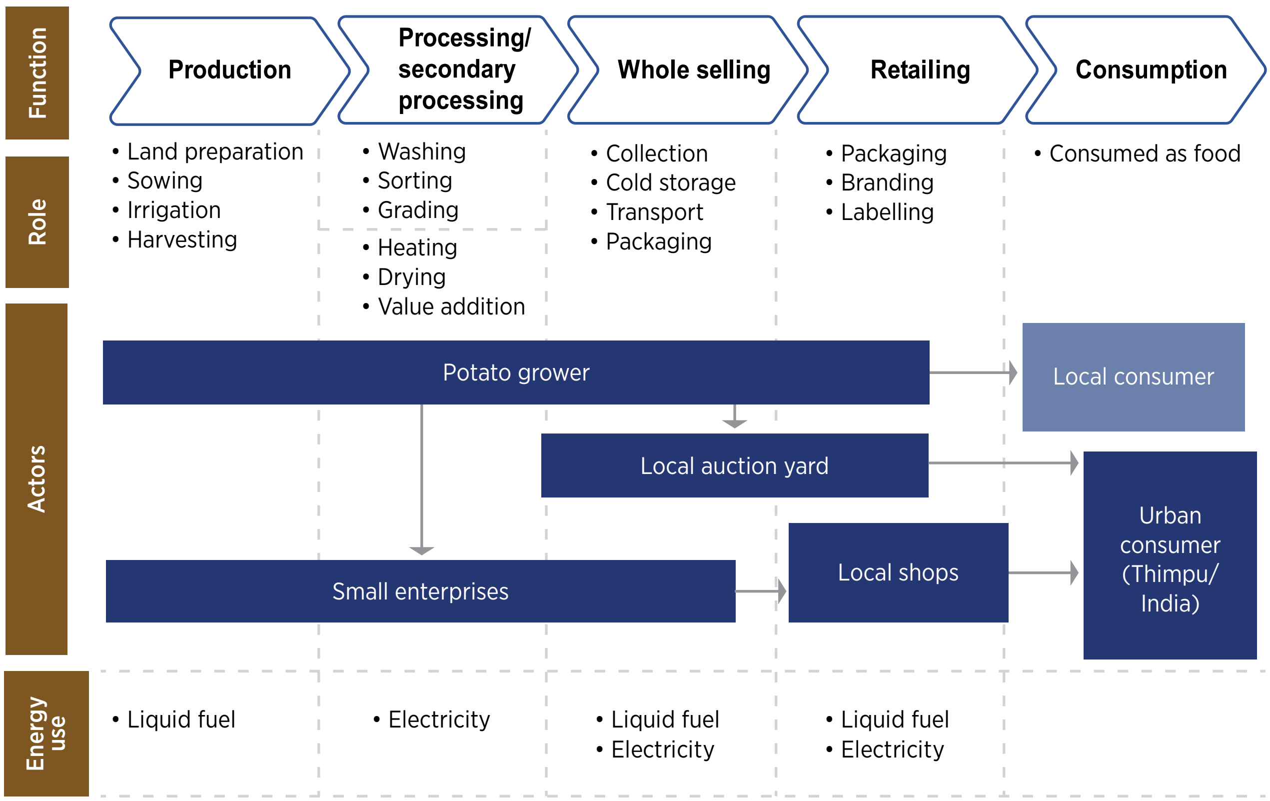
Potato value chain

Potato is a popular crop grown in Bhutan. Producers themselves perform most of the production functions in the potato value chain (Figure 9). Potato-based enterprises are small and privately owned, and a few aggregators operate at a medium scale. The most common processing activities are washing, sorting and grading of the produce. Only a few processors are engaged in diversifying products such as potato chips and potato flour. Most potato growers sell their products directly to the customer or to the local market. Where wholesalers are involved, the produce goes to the auction market and is sold to neighbouring markets such as India.

The international brand for potatoes is well established and marketed in Bhutan, where considerable investment is made in branding and promotion. This has made it difficult for local enterprises to compete in the market. Because the demand for Bhutanese potatoes is considerable in neighbouring markets, the farmers prefer to sell their potato produce fresh rather than as value-added products. However, the government of Bhutan is encouraging people to develop potato-based enterprises, and local entrepreneurs have begun developing value-added products such as potato chips and powder.

The two most common forms of energy used in the potato value chain are liquid fuel and hydropower. Liquid fuel is used to operate tractors for land preparation and sowing as well as to transport potatoes to collection centres and to wholesalers and retailers. Electricity is used mostly at the processing level to produce value-added products such as chips. Equipment for packaging and cold storage operates on grid-based electricity.

Figure 9 Potato value chain



2.3 Establishing the energy baseline in food value chains

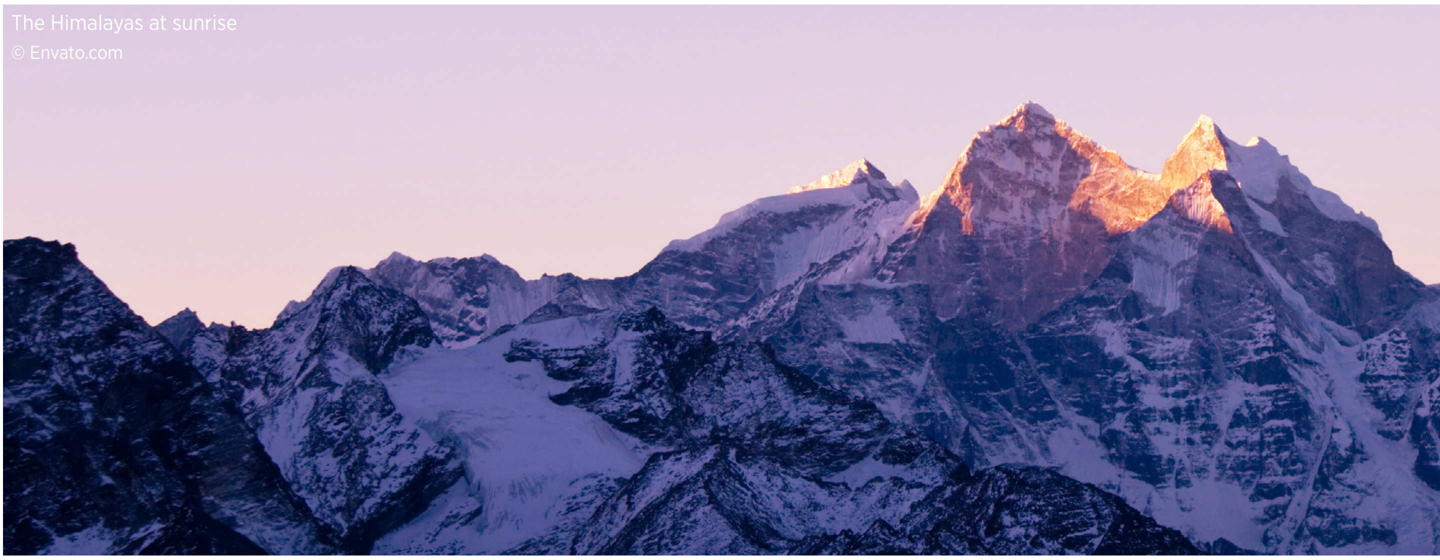
The use of decentralised renewable energy solutions, particularly solar PV, is limited in the HKH region. This is mainly because of ineffectively designed solar systems, a lack of linkages to livelihoods in previously designed PV programmes, and a lack of packaged solutions with effective financing and supply chains in place. The biggest source of energy in the region, however, has been hydropower, with much of it being small-scale, run-of-the-river hydropower. Although small and micro hydropower are defined as decentralised renewable energy, in the context of the target communities, located in hilly and high-altitude areas, these technologies have had limited success. The region's remoteness, low population density, difficult terrain and seasonal hydrological changes do not allow for micro hydro units to be used effectively in a decentralised manner. This section elaborates on the existing energy use in the four selected food value chains in the surveyed countries, Bhutan and Nepal.

In Nepal, the most common source of electricity available to communities is grid-based hydropower, although its reliability is seasonal and varies across regions. Also, the use of electricity in food value chains across the region is limited, as noted for buckwheat and vegetables. Diesel and petrol are used for transport and are procured mainly from petrol pumps (usually private). Very few enterprises have reported the use of solar power as it has not been widely adopted.

In Bhutan, grid-based hydropower is the most common source of energy. Due to the abundance of hydropower supplying a relatively small population, the electricity supply in the country is reliable. The remote communities growing potatoes and engaging in yak farming, however, do not have a reliable electricity source. Electricity in the potato value chain is used mostly for processing, storing and packaging. Since the government of Bhutan has made the first 100 units of electricity supply free, household spending on electricity has decreased. For yak herders, although electricity is available in settlement areas, it is not available in the remote locations that herders travel to during transhumance. Liquid fuel is used mainly for transport and is purchased from private petrol pumps. Yak herders usually use dung and firewood for processing purposes, in the absence or insufficiency of affordable modern energy.

Energy access and use among the surveyed enterprises

Most of the enterprises surveyed rely on electricity from the grid and on liquid fuel for activities in the buckwheat, vegetable and potato value chains (Table 5). Some vegetable enterprises use LPG as well for some processing activities. Yak-related enterprises use fuelwood for most energy-based activities. One of the enterprises indicated using solar energy, although this was for a short duration for lighting purposes.



The Himalayas at sunrise

Table 5 Different sources of energy used by the surveyed enterprises in the four food value chains studied

Kind of energy used by enterprise	**Buckwheat** (10 enterprises surveyed)	**Vegetable** (11 enterprises surveyed)	**Potato** (10 enterprises surveyed)	**Yak** (10 enterprises surveyed)	**Total** (41 enterprises surveyed)
	Number of enterprises reporting the particular energy source*				
Electricity from grid	6	7	4	0	17
Electricity from generator	0	0	0	0	0
Electricity from micro hydropower	0	0	0	0	0
Electricity from solar energy	0	0	0	1	1
Electricity from wind	0	0	0	0	0
Liquid fuel (petrol or kerosene)	5	8	8	0	21
Gaseous fuel (methane from tank, biogas)	0	1	0	0	1
Coal or charcoal	0	0	0	0	0
Vegetable- or animal-based fats or oils	0	0	0	0	0
Candle, paraffin wax or battery-powered source (*e.g. tukki*)	0	0	0	0	0
Dung	0	0	0	2	4
Wood, sawdust, grass or other natural material	0	0	0	10	10
Other	0	0	0	0	0

* In the survey, each enterprise had the option to report multiple energy sources.

Section 2

Energy is used at different stages of food value chains. The majority of the enterprises use energy for some production activities. Liquid fuel is the most commonly used fuel to drive tractors and tillers. Buckwheat, vegetable and potato-based enterprises use energy for processing activities (Table 6). Electricity is used mostly for buckwheat and potato processing, whereas the vegetable value chain relies on LPG. Diesel and petrol are the most commonly used energy sources for transport. Some enterprises use electricity for the labelling, branding, marketing and selling (*e.g.* for sealing, lighting and cooling) of processed products.

Table 6 Use of energy in different stages of the buckwheat, vegetable and potato food value chains

Value chain stages	Activities requiring energy	Buckwheat	Vegetable	Potato
		Number of enterprises reporting		
Production	Land preparation	3	4	2
	Sowing	0	0	0
	Irrigation	–	0	0
	Harvesting	0	0	0
Processing	Washing/cleaning	–	–	0
	Sorting/grading	–	–	1
	Grinding/milling	3	–	–
	Other processing	1	–	–
	Heating/boiling/cooking	–	1	2
	Drying and dehydration/fermenting	–	0	1
	Grinding/milling	–	–	1
	Value addition	–	0	1
Aggregation/transport	Collection	–	–	4
	Cold storage/warehousing	–	–	2
	Transport	1	1	4
Labelling, branding, marketing and selling	Packaging/labelling/branding	1	1	2
	Marketing	1	–	0
	Selling/bulk selling	0	7	0

In yak milk enterprises, traditional fuels are used for processing activities due mainly to the lack of access to electricity supply (Table 7). Fuelwood and other traditional biomass (*e.g.* crop residue) energy sources are used for boiling and heating processes. This exposes community members, particularly women and children, to air pollution from smoke and also adds to their drudgery due to the need for biomass collection.

Table 7 Use of energy in different stages of the yak milk food value chain

Value chain stages of yak milk	Activities requiring energy	Number of enterprises reporting
Production	Rearing/breeding	0
	Fodder collection (livestock based)	0
	Feeding (livestock based); extracting/milking (livestock based)	0
Processing	Shearing	0
	Weaving	0
	Heating/boiling	10
	Drying and dehydration	7
	Extraction	0
	Churning	0
Aggregation/transport	Collection	0
	Transport	0
Labelling, branding, marketing and selling	Selling/bulk selling	0

Barriers for enterprises to use or switch to renewable energy

The majority of the surveyed enterprises indicated considerable barriers to using renewable energy in their value chain processes (Table 8). Among the barriers mentioned were lack of knowledge about renewables, a limited renewable energy market, high investment cost and limited technical skills.

Lack of access to the renewable energy market was a major barrier in Bhutan. In Nepal, the reported barriers were a high renewable energy investment cost and the limited or no availability of credit facilities, compared to the easy availability and low cost of non-renewable energy (grid electricity). Enterprises in Nepal perceived the use of renewable energy to have a low impact on productivity.

Overall, enterprises in Nepal reported more factors that hindered them from using renewable energy compared to Bhutan. In Bhutan, the constraints to using/deploying renewable energy by enterprises were problems such as a lack of skilled staff and technical support, and high operation and maintenance needs. However, none of the surveyed enterprises have had experience in deploying renewable energy technologies (aside from solar for lighting purposes) and so could not report on issues with its operations.

The study of the four food value chains, including analysis of the production steps and findings from the surveys, clearly shows that the present use of energy is primarily from fossil fuels, and that differing stages of food production could benefit from the use of electricity or thermal energy to mechanise processes. This in turn would increase the yield and reduce the drudgery of manual labour. The following section explores the possible types of solar-powered equipment that could help to mechanise and optimise production in the four selected food value chains.

Table 8 Barriers for surveyed enterprises to use or switch to renewable energy

Barriers	**Buckwheat** (10 enterprises surveyed)	**Vegetable** (11 enterprises surveyed)	**Potato** (10 enterprises surveyed)	**Yak** (10 enterprises surveyed)	**Total** (41 enterprises surveyed)
	Number of enterprises reporting particular barriers*				
Lack of knowledge of renewable energy	7	6	0	5	18
Lack of access to renewable energy	1	2	0	10	13
Lack of trustworthy suppliers	0	0	0	1	1
Complicated technology	1	1	0	0	2
Not suitable for context/activities	6	9	6	8	29
Frequent breakdowns/not durable	0	1	0	2	3
Lack of technical support	4	5	0	4	13
Current energy source (non-renewable) is cheap and easy to use	5	7	0	0	12
High investment cost	8	7	1	0	16
Low/slow return on investment	0	1	1	0	2
Low impact on productivity	3	3	0	0	6
Lack of credit facility available	3	1	0	0	4
Other	1 (no incentive to switch)	0	1 (alternative not available)	1 (alternative not available)	3

* In the survey, each enterprise had the option to report multiple barriers.

3. Applicability of decentralised renewable energy for the livelihoods studied

3.1 Inclusive ecosystem approach

Most innovations in the agri-food sector have focused on centralised, industrial-scale set-ups. However, the benefits of such set-ups to rural and marginalised communities have been limited. To offer solutions to these communities, innovations need to be tailored to the rural context and to be decentralised. Such innovations need to be diversified, with a focus not simply on technology but also on ownership models, financial models, supply chain models, and service delivery models, which allow for sustained impact from the design and deployment of the technology.

These missing ecosystem factors need to be catalysed and enhanced in order to demonstrate the linkage between sustainable energy and development – thus demonstrating the capability of decentralised energy to transform communities. While the potential to enhance and decentralise agriculture value chains through energy is huge, financing has been a barrier to scaling. All aspects of the ecosystem need to be developed for any solution to be self-sustainable and a long-term investment.[4]

To address the value chain issues at hand and for the solutions to be long term and self-sustainable, the diverse arms of the ecosystem need to be in place. The key parts of the ecosystem include:

- **Technology and design of machinery**, solar, implementation and social design.
- **Finance**, which should be appropriately designed for comfortable uptake of the solutions by the stakeholders based on studying the inputs, outputs, cash flows and mitigation of any issues.
- **Training** of stakeholders in the use of machinery, solar systems, basic maintenance and other recommended best practices.
- **Policy** and government schemes that can be tapped to ensure uptake of solutions and financial support by various allied government agencies.
- **Ownership and linkages** with on-the-ground organisations to build an interconnected support system for stakeholders.

[4] IRENA-ICIMOD analysis.

3.2 Methodology

Figures 10 and 11 illustrate the processes to be followed for data collection as well as the steps for analysis to arrive at what would be a viable technical and financial solution. This is a generic process that can be used to evaluate which of the decentralised renewable energy solutions are best suited for each of the selected food value chains studied.

Figure 10 Approach and methodology for data collection

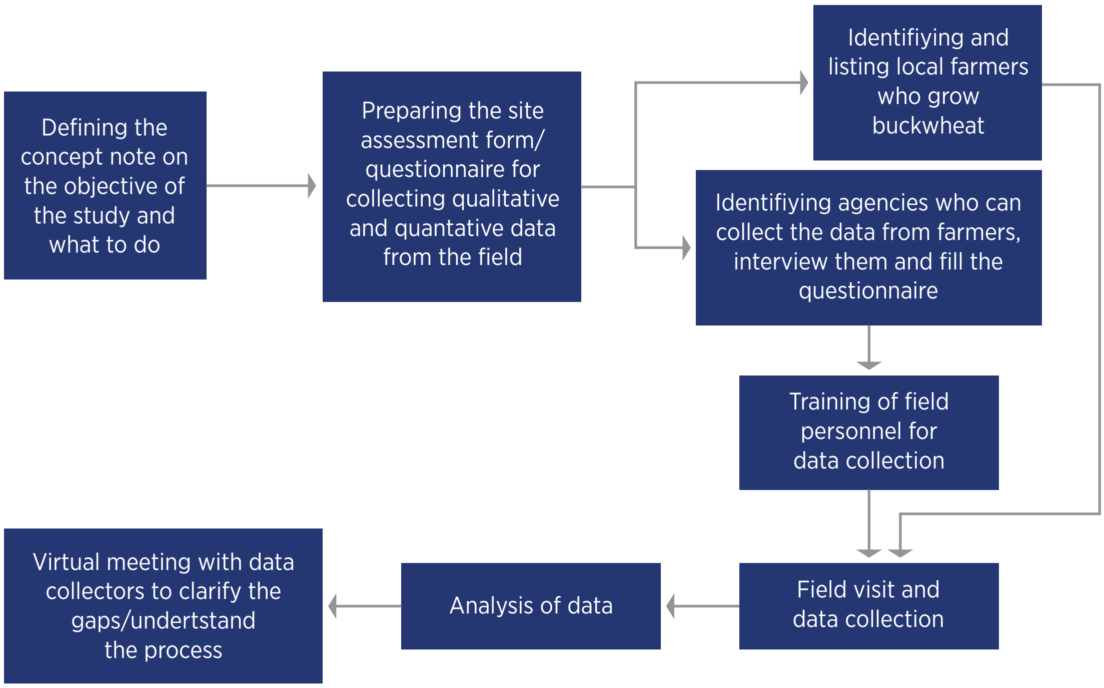
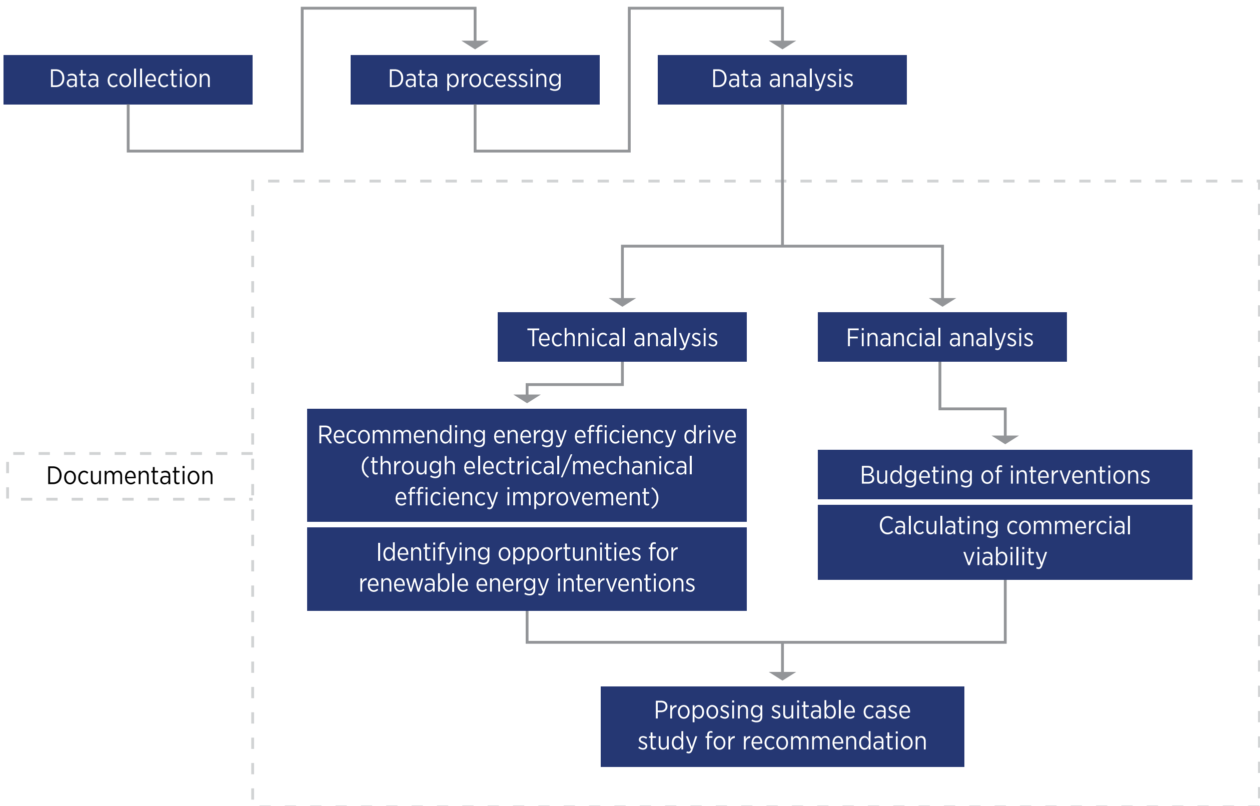


Figure 11 Process flow diagram that describes the steps to take for evaluating a technically and financially viable decentralised renewable energy solution



3.3 Energy entry points in the production processes of the selected food value chains

Buckwheat

Buckwheat is a common crop in Nepal and Bhutan, cultivated mainly for human consumption because of its nutritional value. It grows easily in higher altitudes, even in poor soil conditions or on rocky land. It is frequently cultivated for its edible seeds and leaves. Buckwheat can produce a seed crop in 100 days from sowing and needs less care compared to other crops such as rice or maize. In Nepal, it is one of the top six staple food crops, while in Bhutan it is an indispensable food, particularly in non-rice growing areas and other highlands where people have limited access to growing other cereals due to the diverse agro-geo climate of the country.

Based on the field data collected in Nepal, the following stages in the buckwheat value chain are energy entry points where solar PV-based solutions can be implemented:

Irrigation: Small and marginal farmers with small and fragmented landholdings are unable to benefit from the advantages of solar PV water pumps due to the high cost of ownership. A human- or animal-powered pedal-driven, rear-loading cargo tricycle with a portable direct current (DC) solar pump can be a great solution for marginal farmers on a rental or pay-per-use basis. This would ensure higher water flow at lower head, easy modular set-up, suitable daytime application and low operational cost. An entrepreneur-based portable pumping model can operate on a rotation basis from one farmland to another. Portable solar water pumps are a well-tested technology that has been demonstrated in various parts of the world. It has had success when ownership and financial models are based on local needs and contexts.

Weeding: In both Nepal and Bhutan, due to frequent power cuts in rural areas, using electricity-driven machines for weeding is not feasible. Nor are these machines easily available. Solar-powered de-weeding equipment has been used in parts of South India to efficiently remove weeds between rows of paddy crop.

Agricultural insecticide spraying: So far, agricultural insecticide sprayers have not been used in the study regions. However, this equipment can be introduced considering the unforeseen issues related to agricultural pests. This would be made solar powered.

Threshing and winnowing: Buckwheat threshing is currently being done manually. Machines are available that can be installed with a solar-powered single-phase motor, at a location where multiple farmers can come for threshing activities. Similarly, for winnowing, a solar-powered motor would make the process of separating the grain from the chaff smoother.

Grading, de-stoning, aspiration, hulling and packaging: Nowadays, for most process industries, the graders, de-stoners and aspirators are combined as a package. This solution reduces the time and effort to process millet or any other grain. For buckwheat value chain processes, a combination of four energy-efficient devices can be recommended: a millet grader with aspirator, a millet de-stoner, a millet huller and a packet sealing machine.

There is an opportunity to expand the market by building the capacity to grow a higher tonnage of buckwheat with additional support from modern use of technology, integrating renewable energy wherever applicable to reduce conventional fuel expenditure (such as diesel, kerosene, etc.) and incorporating machinery in farming and food processing when labour availability is a challenge.


Off grid solar irrigation pump
©Envato.com

Yak farming

Yak farming has been a family business for a long time in Bhutan and Nepal. An average family has around 50 yaks, which provide resources including milk, meat, leather (for rugs), hair (for ropes and clothes) and excrement (for fuel). Yak milking as well as butter and cheese production are all performed manually. These products are highly nutritious in fat, protein, essential minerals and healthy polyunsaturated fatty acids.[5] Hence, their demand is increasing in both domestic and international markets. Meanwhile, yak farming is in decline in both Bhutan and Nepal because of the rigorous manual labour and because the younger generation is increasingly attracted to contractual jobs in mainstream sectors.

Yak farming processes can be made simpler and more effective with mechanisation in the value chain, so that producers can continue to meet the market demand. The different processes of the yak farming value chain are as follows:

- Shelter and grooming
- Feeding
- Breeding
- Milking (female yak) and processing milk products
- Cleaning and maintaining hygiene
- Vaccination (if available)
- Shearing
- Utilising different yak by-products (*e.g.* yak dung)


Yak
© Envato.com

In the life cycle of yak milk production, entry points of energy provided by decentralised renewable energy solutions apply to the milking segment and to the processing of yak by-products.

The yak milk value chain can be described as follows:

Input → Production → Collection and retail → Processing

The following are the proposed techno-commercial solutions for each of these value chain processes:

INPUT - feed management: Yak prefer to graze wherever grass is available; however, in months when grass is less available, mechanical chaff cutters can be used to cut straw or hay into small pieces so that it can be mixed with other forage grass to be fed to yak. The cutting of crop residues increases the consumption and palatability of feed and reduces wastage.

PRODUCTION - shelter and milking machines: A solar home lighting system provides illumination while milking yak in the early morning hours. Generally, this is done once a day. For a small shed, two lights with one mobile charger would be sufficient.

Since yak milking is done manually in most cases, portable machines may reduce the labour involved. This is an efficient way of milking animals when the use of static milking machines is limited (such as milking in the field, or in the barn) or for small herds or sick animals in remote pens. It can be explored if the vacuum level and pulsing patterns are matched. Normally, there are one or two clusters for a portable milker. Since the frequency of milking is less for yak, a single cluster can be recommended for a single farmer.

5 These fatty acids play an important role in membrane fluidity and many physiological functions, some of which include inflammation, blood clotting, regulation of blood pressure and cell signaling in humans.

COLLECTION AND RETAIL - solar-powered milk testing and weighing machines, and bulk milk chillers: This can be a plan for the future once a yak milk co-operative is established that collects milk from each of the farmers. Milk testing and weighing would be crucial steps in this process.

Additionally, solar-powered bulk milk chillers can be installed for community use. Depending on the chiller's capacity, around 12-50 farmers can be linked to each bulk milk chiller. The unit cools milk from 350 degrees Celsius (°C) to 40°C and also ensures that the milk remains within the desired temperature (40°C) until the time it reaches dairy processors.

PROCESSING -solar-powered butter churners and electric cream separator machines: A solar-powered butter churner provides a one-stop solution to all blending, churning and chopping issues in mountain areas at a low cost. The labour involved can be reduced further by providing an electric cream separator machine with a 0.25 horsepower (hp) alternating current (AC) single-phase motor[6] that has the capacity to separate the cream from the milk quickly. As a yak's milk production varies between 200 litres and 500 litres of milk during the six-month lactation cycle (depending on the location and breed), a butter churner that is able to churn around 20 litres of milk at a time would be suitable for a yak-herding household or small enterprise.

Using yak dung as an efficient fuel for cooking: Each year, a yak produces 3-4 times its own weight in dung, which is a valuable source of warmth and is used mainly as a fuel for cooking and heating (Rhode *et al.*, 2007). The dung is also used for plaster and manure and for construction and is sometimes traded or sold. A dung log making machine produces cow dung in the form of a long bar that can be used as fuel. These machines are available in single-phase and three-phase in different capacities.

A main challenge in the yak value chain continues to be the lack of dairy equipment such as display fridges and vacuum packing machines.

Potatoes

Potatoes are widely grown in Nepal and are considered the country's second staple food crop, after rice. Nepal's per capita potato consumption has almost doubled since 1990 to 51 kilograms a year. One of the reasons that potato has become widely accepted by farmers in Bhutan and Nepal is that its high yield in a cool climate is well suited to the production of seed tubers for sale at lower altitudes.

The role of sustainable energy was analysed in the potato value chain. The uses of energy-efficient agricultural machines that will help improve the productivity and incomes of smallholder farmers are as follows:

Irrigation: Typically, 2-3 acres of land can be irrigated with a 5 hp solar-powered pump.

Weeding: In both Bhutan and Nepal, due to frequent power cuts in rural areas, using electricity-driven machines for weeding is not feasible. Nor are these machines easily available. In these cases, either a mechanical (non-electricity driven) weeding machine can be used or a solar-powered de-weeder can effectively work.

Agricultural insecticide spraying: Pests such as the potato tuber moth pose a huge problem for potato farmers. The use of pesticide sprayers would reduce these difficulties, and the machines can be solar powered at a reasonable cost.

Crop protection: Solar-powered fencing is similar to barbed wire fencing with multiple strands of plain wires and metal/cement/wooden posts to hold the strands in position. When activated, the wires carry high-voltage current that gives a non-lethal shock to the intruder and creates fear against fence tampering. The alarm alerts everyone in the protected area. It causes no physical harm, is highly reliable as it is off-grid, and has a low maintenance cost.

Solar-powered cold storage for potatoes: This would enable farm-level cooling for perishable commodities. The solar energy is stored in a thermal storage system for cooling during non-solar hours. It stores energy in the form of ice, which is one of the most reliable, cost-effective and non-hazardous forms of energy storage. Cooling is transferred from the thermal storage system to cold storage through the use of a refrigerant (also known as DX

[6] A yak can produce between 150 and 500 litres of milk, and a 0.25 hp butter churner should be able to churn 20 litres at a time in around 20-30 minutes, making it ideal for household or small business use. Correspondingly high-capacity butter churners can be installed based on the need.

cooling). In both Bhutan and Nepal, the average production of potato is 5 000 kilograms per acre. A 10 tonne cold storage unit is suggested so that at least 4-5 farmers can store potatoes via a co-operative model, with a shelf life of up to 30 weeks.

Solar-powered fruit and vegetable grading machine: Grading potatoes by size is an important activity for preparing tubers for commercial purposes. Mostly, this is done as manual labour, and the process is slow and expensive. A solar-powered fruit and vegetable grading machine can address this challenge.

Solar-powered potato peeler and chip-making unit (with sealing facility): This machine can improve the finances of families that are interested in making potato chips and selling them in the market. The chips can be packaged into polythene packets and sealed using an electric sealing machine. The recommendation is to have a 10 tonne cold storage unit to effectively store the produce to prevent losses that may inhibit further distribution as needed.

Local vegetables – *gundruk*

Gundruk is an important and popular food in Nepal. It is a mix of leafy vegetables – consisting of mustard greens, radish, spinach, cauliflower and more – that is fermented and then sun dried. Nepal produces around 2 000 tonnes of *gundruk* per year, mostly at the household level. For a farmer, the value chain for making *gundruk* is similar to that of potato. The applicable techno-commercial solutions are as follows:

Drip and sprinkler irrigation methods powered by solar energy: Both of these methods are practised in growing vegetables, typically on small farmlands where 2 hp surface or submersible pumps will be sufficient to irrigate 1-2 acres of land with drip or sprinkler irrigation methods. If the land area is larger, the pump's capacity must be increased to achieve high pressure.

Weeding: In both Bhutan and Nepal, due to frequent power cuts in rural areas, using electricity-driven machines for weeding is not feasible. Nor are these machines easily available. In these cases, either a mechanical (non-electricity driven) weeding machine can be used, or a solar-powered de-weeder can effectively work.

Agricultural insecticide spraying: Pests pose a huge problem for vegetable farmers. Spraying pesticides with a mechanical sprayer would reduce these difficulties, and the machine can be solar powered at a reasonable cost.

Crop protection: Solar-powered fencing solution: This solar-powered fencing solution is similar to barbed wire fencing. The high-voltage current from solar gives a non-lethal shock to the intruder and creates fear against fence tampering. When activated, the alarm alerts everyone in the protected area. It causes no physical harm, is highly reliable as it is off-grid, and has a low maintenance cost.

Solar-powered monkey repellent: This emits effective high-intensity ultrasonic soundwaves that help to eliminate problems caused by monkeys.

Solar-powered cold storage for vegetables: A similar off-grid cold storage solution as for potato storage can be recommended for a group of farmers.

Solar drying of vegetables needed to prepare *gundruk* and packaging: Drying vegetables typically takes 6-7 days. This process can be accelerated through a solar drying method. Solar drying and then packaging in polythene bags through the use of a sealant can be useful for any enterprise where *gundruk* is made and sold to the market.

Summary of technical and financial implications

All technical specifications and cost estimations provided in this section are based on generic designs, with maximum and minimum cost figures given. The design and costs of the systems could vary based on site-specific measures, number of hours of operation, etc.

Buckwheat value chain

Solar-based interventions increase the income-generating options for farmers in the buckwheat value chain. Solar interventions have a faster breakeven period than alternative options operating on fossil fuels. For example, if an agricultural water pump that runs on diesel is replaced by a solar water pump, the estimated payback period is between five and seven years (considering the high cost of diesel in the region). Some of the proposed renewable energy (solar) based solutions in the buckwheat value chain are outlined in Table 9.

Table 9 Proposed solar-based interventions in the buckwheat value chain

Buckwheat value chain steps	Value chain process	Rationale for solar-powered alternatives	Solution proposed	Solar capacity proposed	Cost of solar plus unit* (where applicable)
1	Irrigation	The cultivation process is dependent on natural rainfall. Nepal's agricultural sector of late has become vulnerable to erratic monsoon patterns. Unreliable rainfall compounded with cycles of drought have threatened crop yields in recent years. Irrigation solutions using portable solar pump sets can irrigate the farms using surface water sources such as streams, rivers or lakes.	Solar-powered portable irrigation pump (1 hp)	900 Wp to 5 kWp solar system with customised balance of systems (depending on the number of hours of operation)	USD 2 000 to USD 6 000
2	Weeding	Weeding is done manually on small-sized farmlands. The drudgery can be eliminated by using a solar-powered de-weeding machine.	Solar powered de-weeder	N/A	USD 27
3	Adding manure and fertiliser	In current practice, farmers do not use chemical fertiliser. In most cases, buckwheat is grown right after harvesting maize, and the agro-residue of the maize is used as a natural fertiliser. In the future, for pest control and improving yields, an insecticide sprayer that is solar powered can be used to kill pests and as part of a disinfection process.	Solar-powered agricultural insecticide sprayer	100 Wp solar system with customised balance of systems (depending on the number of hours of operation)	USD 315
4	Threshing and winnowing	The manual method of threshing** is laborious, time-consuming and costly due to the high demand for labour and increasing labour costs. A portable solar-powered buckwheat thresher reduces time, labour and grain losses.	Solar-powered thresher (3 hp) and winnower (1 hp or 2 hp)	5-10 kWp solar system with customised balance of systems (depending on the number of hours of operation)	USD 10 100 to USD 18 000
5	Grading, de-stoning, hulling, flouring, packaging	Grading† can be mechanised using a solar-powered grader with an aspirator and executed during the pre- and post-hulling stages in small millet processing. A solar-powered de-stoner‡ can replace manual labour in segregating the grains from impurities and is carried out during pre- and post-hulling. The buckwheat hulling machine is especially used to remove the triangle buckwheat shells. This is a common processing step that presently is undertaken in nearby cities where electricity is available. These machines can be powered with stand-alone solar systems. Buckwheat milling, to mill the grain to flour, can be carried out locally (instead of transporting the grain to flour mills in cities). All forms of packaging can use solar-powered sealant machines in local granaries and store houses.	Grader with aspirator (1 hp to 3 hp), de-stoner (2 hp to 4 hp) and huller (2 hp to 4 hp)	5-10 kWp solar system with customised balance of systems (depending on the number of hours of operation)	USD 12 000 to USD 18 000

Note: Wp = watt peak; kWp = kilowatt peak; N/A = data not available.

* The solar systems have been designed according to the average sunlight insolation available in Nepal. The pricing is calculated on the basis of 2018 market prices in the country.

** Threshing is the process of loosening the edible part of the grain from the straw. It is the first step in grain preparation after reaping the crop.

*** Winnowing is the process that separates the grain from the chaff.

† The grading process separates materials by size and is an important step in small millet processing.

‡ A de-stoner is used to remove stones, mud balls, sand and other heavier materials from buckwheat grains.

Yak value chain

As with the buckwheat value chain, solar interventions in the yak value chain would have a breakeven point of between five and seven years, compared to the expenses borne while using a diesel generator. Some of the proposed renewable energy (solar) based solutions in the yak value chain are outlined in Table 10.

Table 10 Proposed solar-based interventions in the yak value chain

Yak value chain steps	Value chain process	Rationale for solar-powered alternatives	Solution proposed	Solar capacity proposed	Cost of solar plus unit* (where applicable)
1	Managing feed for yak	During the lean periods when grazing grass is limited, solar-powered mechanical chaff cutters can be used to chop straw and hay substitutes for crop residues to be fed to cattle along with other forage grass. This helps to reduce the drudgery that the task demands and reduces dependency on local labour.	Solar-powered chaff cutter (2 hp or 3 hp)	6 kWp solar system with customised balance of systems (depending on the number of hours of operation)	USD 9 740
2	Lighting provision in milking sheds	Milking yak is undertaken as an activity in the early hours of the morning, requiring the shed to be well lit. For a small shed, two lights would be sufficient.	Solar-powered DC light bulbs for milking	60 Wp solar system with customised balance of systems (depending on the number of hours of operation)	USD 425
3	Milking machine for yak	Yak milking is done manually in most cases. For reduced drudgery, milking can be managed by portable machines. Portable milking machines (portable milkers) for cows are viable and commercially used. This is a mechanised means of milking animals in cases when the use of static milking machines is not possible (milking in the field, milking in the barn) or when attending agricultural shows, for small-size herds or sick animals in remote pens.** So far, a milking machine for yaks has not been put to use, but this can be explored if the vacuum level and pulsing patterns are matched.	Solar-powered single-cluster milking machine (for yak)	100 Wp solar system with customised balance of systems (depending on the number of hours of operation)	USD 970
4	Milk testing and weighing machines	Milk testing and weighing machines are essential equipment that serve the milk collection process. Once yak milk co-operatives are formed to take on the tasks of collecting and retailing sales of yak milk from individual farmers, solar-powered milk testing and weighing machines can be deployed for use.	Solar-powered milk testing and weighing machines	150 Wp solar system with customised balance of systems (depending on the number of hours of operation)	USD 1 375
5	Bulk milk chiller	Solar-powered bulk milk chillers can also be used by milk co-operatives. Capacities range from 150 litres to 2 000 litres. Based on the capacity of the bulk milk chiller, around 12-50 farmers can be linked to each bulk milk chiller. A bulk milk chiller cools milk from 35°C to 4°C.	Solar-powered bulk milk chillers	5.2 kWp solar system with customised balance of systems (depending on the number of hours of operation)	USD 13 000
6	Butter churning machine	Butter churners can be a useful within the yak milk value chain. A solar-powered churner can serve as a one-stop solution to carry out blending, churning and subsequent chopping of butter blocks in mountain areas at low cost.	Solar-powered butter churning machine	75 Wp solar system with customised balance of systems (depending on the number of hours of operation)	USD 330

7	Electric cream separator machine	An electric cream separator machine with a 0.25 hp AC single-phase motor*** has the capacity to separate the cream from milk quickly. Using a solar-powered machine brings mechanisation to the traditional manual practice.	Solar-powered electric cream separator machine	500 Wp solar system with customised balance of systems (depending on the number of hours of operation)	USD 1 775
8	Utilising yak dung as an efficient fuel for cooking	Each year, a yak produces three to four times its weight in dung, which is used as fuel for cooking and heating purposes. Dung is also used to plaster house walls, as manure in farming, and for the construction of fences, civic works of shrines, and storage rooms. Given its multi-purpose uses, yak dung is traded or sold to obtain other essential commodities. Yak dung is a valuable source of warmth for herdsmen on the move. A solar-powered dung log making machine can be designed and used, similar to the commercially available machine used for cow dung.	Solar-powered yak dung log making machine	3.6 kWp solar system with customised balance of systems (depending on the number of hours of operation)	USD 8 275

Note: Wp = watt peak; kWp = kilowatt peak.

* The details of balance of systems are not included in this document as they will change according to the hours of sunshine, the number of days of autonomy and the number of operating hours.

** For example, portable milking machines from Livestock Production Management.

*** The machine has a capacity of 300 litres per hour (rated) and 200-250 litres per hour (actual), a hopper size (at-a-time input capacity) of 25 litres and a processing time of 5-8 minutes per load.

Solar PV in the Himalayas

Potato value chain

Taking inspiration from some of the work done in the potato-growing regions of India, various types of interventions based on decentralised renewable energy have much quicker paybacks in potato value chains. The primary assumption is that there is a stable market linkage to the end products. For example, in a mature ecosystem a renewable energy (solar) based solution for potato chip making activity has a payback between three and five years. Some of the proposed renewable energy (solar) based solutions in the potato value chain are outlined in Table 11.

Table 11 Proposed solar-based interventions in the potato value chain

Potato value chain steps	Value chain process	Rationale for solar-powered alternatives	Solution proposed	Solar capacity proposed	Cost of solar plus unit* (where applicable)
1	Irrigation	Availability of water is a major factor that determines the yield and quality of potato. Potatoes are grown under rain-fed conditions or using traditional irrigation methods. In water-scarce areas or in response to the vagaries of weather, solar-based irrigation pumps can be deployed with drip irrigation systems.	Solar-powered drip irrigation pump (5 hp)**	4.8 kWp solar system with customised balance of systems (depending on the number of hours of operation)	USD 7 670
2	Weeding	Weeding is done manually on small-sized farmlands. The drudgery can be eliminated by using a solar powered de-weeding machine.	Weeding machine	N/A	USD 27
3	Adding manure and fertiliser	In current practice, local farmers do not add manure or chemical fertiliser. Solar-powered agricultural insecticide sprayers can be used for pest management and for disinfecting farmlands.	Solar-powered agricultural insecticide sprayer***	100 Wp solar system with customised balance of systems (depending on the number of hours of operation)	USD 315
4	Crop protection	Damage to crops by wild pigs and monkeys is a serious problem for potato growers in many places. Around 6% of the crop is damaged by wild animals every year (Bhutan National Food Security Strategy Paper 2006). Solar-powered electric fencing is a harmless way to deter animals from entering fenced farmlands.	Solar-powered fencing solution (1 acre would require 300 metres of fencing)†	100 Wp solar system with customised balance of systems (depending on the number of hours of operation)	USD 2 000 to USD 4 000
5	Storage	Potato storage is an important step in its food value chain. Potatoes are stored for a maximum period of 4-5 months, mainly for seed purposes, home consumption and domestic sale. The surveys revealed that Bhutanese farmers export their excess harvested potatoes to India due to a lack of centralised potato storage units. A solar-powered potato cold storage unit helps to provide a steady supply of potatoes to meet the demand around the year, as witnessed in Bhutan and Nepal.	Solar-powered cold storage unit	External body: 12.2 m X 2.4 m X 3 m	USD 41 380
6	Grading	Farmers grow potatoes of mixed sizes. A grader helps to segregate the potatoes by small, medium and large sizes. Electricity-powered potato graders can be replaced with solar-powered ones that can be used by individual farmers of (say) a farmer co-operative.	Solar-powered potato grading machine‡	5 kWp to 10 kWp solar system with customised balance of systems (depending on the number of hours of operation)	USD 14 700 to USD 20 000

7	Packaging	Potatoes are packed in a 50 kilogram nylon bag, and a manual sealing process is employed. A solar-powered sealing machine can speed up the process and reduce the manual drudgery.	Solar-powered polythene sealing machine	600 Wp solar system with customised balance of systems (depending on the number of hours of operation)	USD 3 065
8	Processing (potato chips)	Potato chips are a popular snack across all regions. A local potato chip making machine (powered by solar energy) can provide additional revenue from the sale of chips and works well as a way to commercialise excess yield that is not sold as a vegetable.	Solar-powered potato peeler and chip making machine	300 Wp solar system with customised balance of systems (depending on the number of hours of operation)	USD 1 027

Note: Wp = watt peak; kWp = kilowatt peak; N/A = data not available.

* The details of balance of systems are not included in this document as they will change according to the hours of sunshine, the number of days of autonomy and the number of operating hours.

** The pump can irrigate 5 acres of cultivable plain land with 50 000 litres per day using drip/sprinkler type irrigation; If the source is a bore well, around 146 meters depth is the maximum; If it is an open well, the maximum depth is 15-18 meters.

*** Hand sprayers range from 1 litre to 16 litres.

† 5-10 acres (500 metres to 1 kilometre perimeter; single-lined fence).

‡ 3 tonnes per hour (3 hp machine for 6 hours of usage).

Vegetable value chain

Across the developing world, smallholder farmers growing vegetables face challenges in selling their produce at the right time. Lack of storage forces them to be in what is seen as a perpetual distress sale mode. Investment in a 5 tonne cold storage can help local and marginal farmers preserve their vegetables for longer times and obtain a better profit from selling them. Some of the proposed renewable energy (solar) based solutions in the vegetable value chain are outlined in Table 12.

For reference, some recommendations for the storage life period of vegetables and minor fruits are provided in Table 13.

Table 12 Proposed solar-based interventions in the vegetable value chain

Vegetable value chain steps	Value chain process	Rationale for solar-powered alternatives	Solution proposed	Solar capacity proposed	Cost of solar plus unit* (where applicable)
1	Drip/ sprinkler irrigation	Vegetable farming in the surveyed regions does not need huge quantities of water, but it requires a reliable supply over the cropping period. Solar-based pumps that can draw water from low-delivery surface or submersible pumps are a possible solution to irrigate with available water sources.	Solar-powered drip/sprinkler irrigation pump (2 hp)	2 kWp solar system with customised balance of systems (depending on the number of hours of operation)	USD 4 250
2	Weeding	Weeding is done manually on small-sized farmlands. The drudgery can be eliminated by using a solar-powered weeding machine.	Solar-powered weeding machine	N/A	USD 27
3	Adding manure and fertiliser	Current farming practices in the region do not use manure or chemical fertiliser. Solar-powered agricultural insecticide sprayers can be used to kill pests and disinfect farmlands.	Solar-powered agricultural insecticide sprayer**	100 Wp solar system with customised balance of systems (depending on the number of hours of operation)	USD 315

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4	Crop protection	Vegetables such as cauliflower, cabbage, tomato, spinach and radish attract wild animals to farmlands. Hindrances from monkeys are common to the region. Low-powered electric fencing has proven to be a harmless way of deterring animals from entering vegetable patches.	Solar-powered fencing solution	100 Wp solar system with customised balance of systems (depending on the number of hours of operation)	USD 3 135
			Solar-powered monkey repellent	60 Wp solar system with customised balance of systems (depending on the number of hours of operation)	USD 310
5	Storage	Storage is an important means to preserve vegetables. Most of the vegetables are sold in market immediately, but mini cold storage (5 tonne) units that are solar powered can be planned for storing vegetables to maintain a balance between demand and supply.	Solar-powered cold storage unit	7 kWp solar power for a 5 tonne cold storage	USD 18 355
6	Drying vegetables and packaging them for sale	Sun drying of vegetables takes 6-7 days. This can be accelerated through a solar drying method. A solar dryer removes unnecessary moisture from the vegetables while retaining the original colour and taste. Unlike natural drying, it protects the produce from dust, dirt, and animal and bird droppings.[†] Solar-based dryers can be used with additional sealing machines for packaging. A solar-powered sealing machine can be easily installed.	Solar-powered drying and sealing unit[‡]	1 kWp solar system with customised balance of systems (depending on the number of hours of operation)	USD 2 360

Note: Wp = watt peak; kWp = kilowatt peak; N/A = data not available.

* The details of balance of systems are not included in this document as they will change according to the hours of sunshine, the number of days of autonomy and the number of operating hours.

** Hand sprayers range from 1 litre to 16 litres.

† For example, a solar box type dryer from Radha Energy Cell.

‡ Cabinet-type dryers can dry a batch of 50 kilograms; the best-case drying period is 1-2 days.

Table 13 Some recommendations for the storage life period of vegetables and minor fruits (for reference)

Commodity	Temperature (°C)	Relative humidity (%)	Storage period (weeks unless otherwise noted)
Artichoke, Jerusalem	-0.5 to 0	90-95	4-5 months
Basil	10	90-95	1
Bean sprout	0	95-100	0.5-1
Bitter melon, bitter gourd	10	85-90	1-2
Bok choy	0	95-100	2
Cactus leaf	5-10	90-95	2-3
Cactus fruit, prickly pear	5	85-90	2-3
Calamondin orange	9-10	85-90	2-3
Carambola (starfruit)	5-10	85-90	3-4
Cassava (yucca root)	0-5	85-90	4-8
Chard, Swiss	0	95-100	1-2

Chayote	7	85-90	85-90
Cherimoya (custard apple)	9-10	85-90	1-2
Cherry, sour	0	90-95	½-1
Chicory, witloof (Belgian endive)	0	95-100	2-4
Chinese cabbage	0	95-100	6-10
Chinese date (Jujube)	10	85-90	8-10
Chives	0	90-95	2-3
Cilantro, Chinese parsley	0	95-100	2
Citron citrus (Medica)	13	85-90	6-8
Clementine	5-7	85-90	6-8
Collard	0	95-100	1-2
Dasheen (Taro)	7-10	85-90	16-20
Elderberry	0	90-95	1-2
Ginger	13	65-75	16-24
Guava	7-10	85-90	2-3
Jicama	13-18	65-70	4-8
Kale	0	90-95	2-3
Kiwano (horned melon)	10-13	85-90	85-90
Kumquat	4-5	85-90	2-4
Loquat	0	85-90	2-3
Lychee	1-2	90-95	3-5
Mandarin orange	3-4	85-95	2-4
Mangosteen	13	85-90	2-4
Parsley	0	90-95	2-3
Passionfruit	7-10	90-95	3-4
Persimmon, Japanese	0-2	90-95	7-16
Pomegranate	5-10	90-95	8-10
Radicchio	0-1	90-95	3-4
Sapota, turning	15-20	85-90	2-3
Sapota, ripe	0-2	85-90	1-2
Tamarillo	3-4	85-90	6-8
Tamarind	2-7	90-95	3-4
Tangerine	3-4	85-95	2-4
Tomatillo, husk tomato	5	90	2-3
Water chestnut	1-2	90-98	4-8
Watercress	0-1	90-95	2-3
Yams (Dioscorea spp.) – not to be confused with sweet potato	16	70-80	12-24

4. Recommendations

The objective of the study was to assess the scope and potential feasibility of using decentralised renewable energy solutions in selected food value chains in the Hindu Kush Himalaya region. Despite being a significant source of livelihoods for many households in the region, agriculture still relies on traditional practices and often lacks access to modern energy sources. Decentralised solar-powered solutions and energy-efficient machinery have the potential to transform food value chains where mechanisation of processes and increased scale will help communities commercialise their produce and make the leap beyond subsistence farming. This transformational change needs to be brought about while preserving the socio-cultural patterns of the region, ensuring that development is guided along green pathways and sustainable livelihoods and in response to the short- and long-term needs of communities.

On another front, mountain regions are exposed to diverse hazards, including "fast-onset" ones such as landslides, floods and avalanches from extreme precipitation and earthquakes from active tectonic plates. These regions and their communities are also exposed to slow-onset hazards, which unfold more gradually but can be equally destructive. Such hazards include increasing temperatures, reduced precipitation, melting glaciers, desertification and changing ecosystems. The impact of the hazard on societies is proportional to their vulnerability and exposure to it.

In the HKH region, where societies depend heavily on farming, food production is generally expected to be negatively affected as a result of changes in the timing and duration of monsoons, higher rainfall variability, and increased extreme events, including floods and droughts. It is imperative to build resilience and adaptation to changes brought about by climatic impacts, including through climate-smart agriculture with improved irrigation, agricultural biodiversity and the use of resilient crop varieties. In addition, the policies and planning of the energy sector must be addressed, considering changing hydrological regimes, extreme climate events and possible ecological impacts (UNEP and Grid-Arendal, 2018).

Solar PV solutions look beyond mitigation to help mountain societies strengthen their resilience and adapt as they tackle the ever-increasing impacts of climatic hazards. The following set of recommendations covers the four overarching drivers – policy, regulations, skill building and financial support – that have been proven to promote and scale the use of renewables.

Replace outdated techniques with automation and processes in food value chains

Assessments based on feedback from local producers and enterprises – in terms of production volume, energy intervention, and market demand in the food value chains of buckwheat, yak milk, potato and vegetables – show that communities in the region continue to rely on outdated techniques and methodologies, resulting in lower production, wastage of yield and limited market supply. Energy access from solar-powered renewable energy technologies at different nodal points of the value chain can automate and modernise processes, resulting in reduced manual labour, increased yield, facilities for cold storage and greater market reach in the region and beyond.

Support the shift from subsistence farming and local merchandising towards enterprise development as scale and productivity increase

Mountain communities in the region have limited access to mainland markets. Innovation and modernisation through electrification – resulting in increased productivity of food products – allow for greater enterprise development. Government policies and programmes can drive this development by providing fiscal incentives such as tax breaks and financial support such as subsidies. This support would attract investors and start-ups to create the ecosystems where supply chains are established, storage is modernised, and efficient transport enables local products to reach wider markets. Local entrepreneurship can be encouraged through entrepreneur skill development, financial support for initial investments and seed money. Special status can also be given to women-owned/-operated enterprises and their product sales.

Improve local skills and capacities to promote and scale the use of solar PV in the sector

As solar PV solutions in the agriculture and farming sector begin to show beneficial impacts and are further promoted through conducive policies and regulations, this needs to be supported by increasing the capacity and skills of local communities. Skills training and certification for renewable energy jobs created in sourcing, installing, operating and maintaining the renewable solutions need to be actively promoted. Setting up training institutions, standard curricula and teaching methods will provide for the sustained use of solar PV solutions, with the additional benefit of creating a renewable energy job market to absorb the skilled labour force in the region. Given the difficulty in accessing these communities, it is imperative that a critical mass of trained persons is available at the local level to ensure proper operations and the possibility for troubleshooting and repairs.

Enhance the commercial viability of local food products

Deploying solar PV solutions for the agriculture sector and food value chains is assessed to be technically viable based on the requirements and analysis of the food value chains studied. This is reaffirmed by similar solutions being employed in other parts of the world. The commercial viability of this deployment is dependent on government and public sector support in the form of concessional loans, tax credits and subsidies to encourage private sector investment. Governments can prioritise the sale of products from local communities and thereby support them in increasing their market share. Reduced sales tax and duties on purchase of equipment and machinery can further attract enterprises in these food value chains.

Build awareness and inform local communities about policies and programmes

Local producers are largely unaware of the existing policies, regulations and programmes that incentivise the local production and supply of food produce. Public sector enterprises, in partnership with non-governmental organisations and development partners, should engage with local communities and initiate awareness campaigns targeting remote and isolated communities to make them aware of the available tools and options to deploy solar-powered solutions in their value chains.

Promote solar PV solutions to support climate resilience and adaptation

The ever-growing impacts of climate change add to the vulnerability of mountain communities. Decentralised renewable energy solutions powered by solar PV can help to further strengthen climate resilience and need to be considered as an adaptation strategy in addition to helping to mitigate carbon emissions. Countries' policies and action plans, Nationally Determined Contributions and Long-Term Low Emission Development Strategies need to prioritise actions such as the deployment of solar PV in food value chains as a climate-resilient pathway for these communities. It is also important to ensure that plans and policies aimed at climate action do not exclude those communities that are most vulnerable to climate change.

Develop a project pipeline

This assessment study serves as an entry point towards developing a dynamic market for solar PV products and services in food value chains of economic importance in the HKH region. To this end, government functionaries, development partners and locally active development financial institutions need to apply the most viable projects and begin activating the market by developing appropriate risk mitigation tools and concessional financing instruments. These actions would need to be supported by active outreach with potential entrepreneurs from the region who may be encouraged to start offering the required energy services and promote joint ventures with private companies that are offering products and services based on decentralised renewable energy in the mainland. Through such actions, a robust pipeline of projects can be developed and widespread deployment of solar PV can be achieved to add value in these food value chains. Furthermore, such actions will provide local communities a good opportunity for entrepreneurship and skills enhancement in the decentralised renewable energy sector.

This would enable entities such as IRENA and other development partners to further support the market through appropriate risk mitigation, project facilitation and technical assistance interventions.

5. Snapshot of mechanised solutions at various stages of the food value chains studied

In the study, four food value chains were assessed for processes that could potentially be mechanised and transformed through decentralised renewable energy solutions: buckwheat, yak milk, potato and other vegetables. Table 14 provides a quick snapshot of the proposed solutions powered by solar energy.

Table 14 Proposed solar-based interventions in the four food value chains studied

Food produce	Process for mechanisation	Suggested solution(s)
Buckwheat	Irrigation	Portable solar system to drive a solar surface pump
	Weeding	Mechanical weeding machine (non-electric)
	Insecticide spraying	Agricultural insecticide sprayer driven by a mounted solar system with storage
	Threshing and winnowing	Mechanised thresher and winnower machine powered by a mounted solar system with storage
	Grading, de-stoning, aspiration, hulling, packaging	Mechanised machines for each process powered by solar systems with storage
Yak milk	Yak feed management	Mechanised chaff cutter powered by a mounted solar system with storage
	Production: • Shelter for yak milking • Milking machine for yak	• Solar home lighting system with sufficient capacity • Milking machine (designed along the lines of a cow milking machine) powered by a solar panel with storage
	Collection and retail: • Milk testing and weighing machines • Bulk milk chillers	• Electrical machines powered by solar panels with storage • Chillers powered by solar panels with storage
	Processing: • Butter churning machine • Cream separator machine	• Electrical butter churner for blending, churning and chopping, powered by a solar panel with storage • Electric cream separator machine powered by a solar panel with storage
	Yak dung as cooking fuel: • Dung log making machine	• Electrical yak dung log making machine powered by a solar panel with storage

Potato	Irrigation	Drip irrigation fed by a solar-powered surface pump
	Weeding	Mechanical weeding machine (non-electric)
	Agricultural insecticide spraying	Agricultural insecticide sprayer driven by a mounted solar system with storage
	Crop protection	Electric fencing solution powered by a mounted solar panel with storage
	Cold storage	Solar-powered cold storage that runs on a thermal storage system, used for cooling during non-solar hours
	Potato grading machine	Electric potato grading machine powered by a mounted solar panel with storage
	Potato peeler and chip making machine	Integrated potato peeler and chip making machine powered by a mounted solar panel with storage
	Packet sealing machine	Electric sealing machine powered by a mounted solar panel with storage
Vegetable (gundruk)	All processes similar to potato value chain	Same solar-powered solutions as for respective processes of the potato value chain
	Vegetable drying and packaging	Solar-powered dryer and sealant machine powered by a mounted solar panel with storage


Yak cheese
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Section 5

Appendix

The strengths, weaknesses, opportunities and threats (SWOT) associated with the four food value chains studied are outlined in Table 15.

Table 15 SWOT analysis of the four food value chains studied

Value chain	Outcomes of SWOT analysis
Buckwheat (high-altitude mountains of Nepal)	Strengths • Nutritious crop • Adaptive to extreme climatic conditions • Native to Hindu Kush Himalaya • Culturally acceptable
	Weaknesses • Inadequate policy support • Grown by relatively poor, small and marginal farmers • Negligible research on genetics and breeding • Low market value • Buckwheat stubble adds very little organic matter to the soil when loose • Considered to be the food of the poor
	Opportunities • Potential for value chain development for food and cosmetics, and for the use of renewable energy • Adaptability in extreme conditions and early maturity • Research focus by national institutions • Potential multiple uses of buckwheat plant and grains • Rising demand for high-yielding varieties
	Threats • Wild bird attacks on the buckwheat crop • Highly sensitive to wind, heavy rainfall and excessive soil nitrogen (likely to cause lodging)
Vegetables (hilly regions of Nepal)	Strengths • Key to crop diversity and nutritional health • Shorter crop life cycle • Women-labour friendly • Adaptable to diverse ecological zones in the hills and mountains • Relatively less wildlife intrusion compared to cereals
	Weaknesses • High post-harvest losses • Low uptake of required innovation and technology • High water requirements in the field • Low price for local vegetables • Low seed quality and lack of competitiveness
	Opportunities • Governmental area of interest • Potential for off-season production • High potential for value chain development and the use of renewable energy • Potential for climate-smart practices • High chances of increased investment in technology
	Threats • Inadequate financial services • High vulnerability to climatic shocks • Vulnerability to pest attacks • High labour requirements

Yak (high-altitude mountains of Bhutan)	Strengths • Highly suitable to high-altitude mountains • High nutritional value of products • Important source of income for high-altitude communities • Closely tied to social customs of herders and communities • Indigenous knowledge and expertise of yak rearing
	Weaknesses • Declining interest of youth in yak raising • High dependence on high land pastures • Inadequate market access • Inadequate protection of open pasture grazing animals
	Opportunities • Policy support for livestock production • Potential for product diversification through value chain development and the use of renewable energy • Potential to engage youth and women in the value chain development activities • Increasing market demand for products due to uniqueness
	Threats • Increasing labour shortage • High mortality due to climate-induced erratic events and new diseases • Increased impacts of climate change on rangelands • Inadequate yak research and development • Inadequate incentives for yak herders/communities
Potato (hilly areas of Bhutan)	Strengths • Highly suited to high-altitude mountains • High nutritional value of products • Important source of income for high-altitude communities • Closely tied to social customs of herders and communities • Indigenous knowledge and expertise of yak rearing
	Weaknesses • Declining interest of youth in yak raising • High dependence on high land pastures • Inadequate market access • Inadequate protection of open pasture grazing animals
	Opportunities • Policy support for livestock production • Potential for product diversification through value chain development and the use of renewable energy • Potential to engage youth and women in the value chain development activities • Increasing market demand for products due to uniqueness
	Threats • Increasing labour shortage • High mortality due to climate-induced erratic events and new diseases • Increased impacts of climate change on rangelands • Inadequate yak research and development • Inadequate incentives for yak herders/communities

Source: Based on expert consultation, 2020.

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