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Decentralised renewable energy for agriculture in Nepal

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The cover page photograph by Siddhartha Shrestha shows a village powered by a solar mini-grid in the mountainous Upper Dolpo region of Nepal.

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Abbreviations

ADBN	Agricultural Development Bank Nepal
AEPC	Alternative Energy Promotion Centre
capex	capital expenditure
CHC	custom hiring centre
CO_2	carbon dioxide
DRE	decentralised renewable energy
EPC	engineering, procurement and construction
FAO	Food and Agriculture Organization of the United Nations
FGD	focus group discussion
FWEAN	Federation of Woman Entrepreneurs Associations of Nepal
FY	financial year
GDP	gross domestic product
GHG	greenhouse gas
GRB	gender responsive budgeting
GWh	gigawatt hour
ha	hectare
hp	horsepower
ICIMOD	International Centre for Integrated Mountain Development
IRENA	International Renewable Energy Agency
ISPS	institutional solar photovoltaic system
IWMI	International Water Management Institute
kg	kilogramme
KII	key informant interview
kVh	kilovolt hour
kW	kilowatt
kWh	kilowatt hour
kWp	kilowatt peak
LPD	litres per day
MHP	micro-hydro power
MoAD	Ministry of Agriculture Development
MoALD	Ministry of Agriculture and Livestock Development
MoEWRI	Ministry of Energy, Water Resources and Irrigation
MoLESS	Ministry of Labour Employment and Social Security
MW	megawatt
NACCFL	Nepal Agriculture Co-operative Central Federation Ltd.
NARC	National Agriculture Research Council
NCF	National Cooperative Federation of Nepal
NEA	Nepal Electricity Authority
NGO	non-governmental organisation
NPR	Nepalese rupee
O&M	operations and maintenance
PJ	petajoule
PMAMP	Prime Minister Agriculture Modernization Project
PPP	public private partnership
PSLP	Priority Sector Lending Programme
PV	photovoltaic
tCO_2eq	tonnes of carbon dioxide equivalent
TJ	terajoule
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States dollar
V	volt
WECS	Water and Energy Commission Secretariat

Executive summary

Nepal's agricultural sector accounts for 24% of the country's gross domestic product (GDP) and supports the livelihoods of 62% of its population. The country has a diverse landscape and climate, enabling a wide variety of food crops and livestock to be cultivated. This produce is essential in ensuring the food security of the population.

Several challenges, however, have hindered the development of the sector. In particular, high youth unemployment has led to significant outward male migration, leaving a growing burden on women, who already carry a heavy responsibility for domestic and farming activities.

In addition, Nepal's terrain, which varies greatly from flat plains in the south to high mountains in the north, is highly vulnerable to climate change. Extreme weather events, such as heavy rainfall and drought, are becoming increasingly common, threatening important food crops.

Mechanisation, which involves the introduction of farming equipment to improve productivity, has the potential to improve climate resilience. It can also help address many of the other factors hindering the sector's development. Currently, however, the level of mechanisation in Nepal's agricultural sector is very low. This is especially the case among smallholder farmers, who represent 27% of the total farm population.

While many factors lie behind this, limited access to reliable and affordable energy is one of the most pressing. The agricultural sector relies heavily on diesel, making up 91% of the total energy consumed, while grid-based electricity only supplies 1.6%. Meanwhile, renewable energy integration is still in its infancy and contributes only 0.3% of total energy consumed. Most of this is generated by solar photovoltaic (PV) panels.

This study makes an initial assessment of the energy needs of Nepal's agricultural sector and identifies opportunities for mechanisation through the introduction of decentralised renewable energy (DRE) systems. It concentrates on four important agri-food value chains: maize, apples, fish and millet.

The study was led by the International Renewable Energy Agency (IRENA), in collaboration with Nepal's Alternative Energy Promotion Centre (AEPC) and the Ministry of Agriculture and Livestock Development (MoALD). The work is part of IRENA's Empowering Lives and Livelihoods: Renewables for Climate Action initiative.[1]

The findings show that the greatest opportunities for decentralised renewable energy (DRE) solutions lie in powering non-mobile equipment, such as water pumps for irrigation, and processing equipment, such as shellers, mills, dryers and aerators. There is also great potential for the application of DRE in powering cold storage chains, which could further enhance farmer income by reducing produce spoilage.

In addition, the study found that many existing renewable energy mini-grids within the country are under-utilised and could be reconfigured to supply affordable and reliable energy for agricultural needs.

Alongside these potential areas for implementation, the study concluded that planning for grid compatibility in the medium to long term is very important. Nepal's national electricity grid is rapidly expanding, with rural electrification remaining a top priority for the government. Therefore, it is critical to examine how these systems will continue to operate and remain productive after the grid extends to the areas identified – or when the energy quality provided by the grid is improved.

Based on an energy needs assessment and the demand for mechanisation with the introduction of DRE solutions, the study estimated the potential carbon dioxide (CO_2) emissions reduction in tonnes of CO_2 equivalent (tCO_2eq). It also calculated the level of investment necessary to realise this outcome, in United States dollars (USD) (see Table 1).

1 *For details, see https://www.irena.org/Energy-Transition/Partnerships/Empowering-Lives-and-Livelihoods-Renewables-for-Climate-Action*

Table 1 Estimated CO_2 emissions offset and investment required in DREs

Estimated potential of overall CO_2 emissions offset per year (replacing the use of diesel and petrol)	206 722 tCO_2eq*
Estimated investment requirement in DREs to offset the fossil fuel energy in the short term, within five years for:	
Maize	USD 87 million
Apples	USD 1.1 million
Fish	USD 1.2 million
Millet	USD 24 million

Notes: *See Appendix E; tCO_2eq = tonnes of carbon dioxide equivalent.

The report concludes with a series of recommendations to scale up the introduction of DRE systems into the four agri-food value chains examined. These recommendations are broken down into two types: measures that apply across all the technologies considered; and technology-specific measures, with a focus on DRE-powered dryers, irrigation and cold storage, along with the extension of existing mini-grids for agricultural purposes.

Recommendations applicable across all technologies

a. **Enhance government co-ordination**

Collaboration between MoALD, which oversees the Nepalese agricultural sector, and the Ministry of Energy, Water Resources & Irrigation (MoEWRI), which is responsible for overseeing the scaling of renewable energy integration, is essential in realising the desired outcomes. This collaboration should include joint planning, knowledge-sharing and a dedicated budget for joint initiatives. There is also a need to better involve provincial and local government stakeholders to improve the introduction of programmatic interventions. These stakeholders' involvement should also be accompanied by an upskilling of local staff and dedicated budgets for any activities which they will oversee.

b. **Focus attention on high potential opportunities for DRE integration**

Much of Nepal's farming equipment, such as tractors and their attachments, is diesel powered. While replacing these technologies could serve to further reduce emissions, there is currently no commercially viable alternative. Therefore, the report concludes that the focus should be on non-mobile equipment that is either: 1) already powered by electricity from the grid, but not run productively due to the unreliability of the power; or 2) equipment that is run on diesel-powered generators, which could be replaced by DRE systems.

Additionally, the study concludes that to achieve the greatest long-term impact, it is important to focus on projects that are underpinned by strong business models and have sustainable revenue sources, as well as available options for operations and maintenance (O&M). Without these two critical elements, systems will likely fall into disrepair or be underutilised. Working with enterprises that are already engaging multiple end-users will be an important entry point for DRE integration, as increased usage of DRE equipment will ultimately translate into improved business viability.

c. **Build awareness of the benefits of mechanisation and enhance capacity around the use of DRE**

It is important to educate end users about the potential benefits of mechanisation. This will serve to drive demand for DRE and DRE-powered equipment and help to ensure the economic viability of projects that are introduced. Such benefits include the prospect for improved crop yields, reductions in produce spoilage, increasing revenues, and lowering the requirement for manual labour input. Regional communications campaigns can help to raise awareness of these benefits and help to build interest in DRE solutions for agriculture.

It will also be critical to train end-users on the use of any technology introduced, as incorrect usage may lead to lessened impact or malfunction, which could ultimately translate into dissatisfaction with the new technology. Training on O&M provided at the local level can help to ensure the correct up-keep and utilisation of systems, as well as their sustainable operation over the long term. Additionally, it is critical that the introduction of any new DRE technology is accompanied by a strong business plan and the development of business skills to help execute that plan effectively. Without end-users and energy demand, DRE systems will not be economically viable.

d. **Capitalise on the opportunity for DRE integration to improve gender equality**

In Nepal, women carry the burden of many domestic and farming activities. The introduction of farming equipment can help to reduce the need for their manual labour, freeing up their time for other important social and economic activities. Without recognition and planning, however, this opportunity may not be maximised to its fullest potential.

As a starting point, women must be provided with a meaningful opportunity to contribute to needs assessments and must be equally engaged in all decision-making around prospective programmatic interventions. Additionally, any government-led interventions around DRE should provide specific support for female farmers and female-led agricultural enterprises and groups. This report highlights that post-production activities may hold the most potential to impact the livelihoods of women, as they are important players in these stages of the value chain, which include drying and packaging. This is also an opportunity to enhance women's participation in the O&M of DRE systems by engaging with educational institutions and scaling up the delivery of the necessary technical skills to female students.

Technology-specific recommendations

e. **Increase the adoption of solar and bioenergy dryers**

In many agri-food value chains, drying is an important practice for preservation and is a necessary step. In others, such as for fish or apples, it can enhance value addition and significantly reduce food spoilage. In Nepal, fish drying is already a common practice. Yet, it relies on the environmentally-degrading chopping and burning of wood. There is vast potential for the integration of solar or bioenergy-powered dryers to displace these methods, while also scaling up drying practices where there has been limited focus traditionally, such as in the apple value chain.

In order for systems to be economically viable they need to have a steady and reliable number of customers. Therefore, focusing their introduction on existing medium and large-scale agricultural enterprises, such as large-scale apple producers, or focusing on custom hiring centres that already serve a large number of farmers, may be important. It will also be critical to address some of the technical challenges associated with solar-powered drying, such as variability during the monsoon season.

f. **Continue to scale up solar irrigation nationwide**

Nepal has been successful in accelerating the uptake of solar irrigation pumps with the introduction of a government-led subsidy programme. It is suggested that this programme continue, alongside the necessary budget. System use and sustainability could be enhanced with improved O&M. This could be achieved by requiring that installation contracts include O&M, or by implementing training to build up local capacities to carry out O&M over the long term. It was also found that by achieving economies of scale, focusing on community-level installations could have a more far-reaching impact than one-off projects that serve individual farmers.

g. **Maximise the use of existing DRE-powered mini-grids for agricultural applications**

Nepal has a history of successful micro-hydro and solar mini-grid integration. While important for rural electrification, many of these systems, however, have been under-utilised. With efforts to map existing mini-grids against agricultural energy demands, it may be possible to enhance their use. Feasibility studies and communications campaigns will be necessary in order to realise this untapped potential.

h. Scale up DRE-powered cold storage

Cold storage is essential to reducing food spoilage, yet its uptake in Nepal has been limited up to now. There have been a number of pilot installations of DRE-powered cold chains, but most have run into disrepair or been under-utilised (or not utilised at all). The key challenge identified by this report has been the lack of a viable business model underpinning the introduction of such facilities.

Successful integration must therefore be demand driven. There is a need to better educate farmers about how they can increase their revenue through cold storage and encourage them to use these services. Use by farmers could also be enhanced through the introduction of a user-focused subsidy programme. On the other side of the equation, more support could be given to enterprises looking to implement cold storage, helping them design their business model and ensuring that their plans and technical designs align with farmers' needs.

1 Introduction

The primary objective of this study is to evaluate the energy deficit challenges in Nepal's agri-food value chains. In particular, the study considers those challenges affecting smallholder farmers, including women and youth, who struggle to modernise their farming practices.

The study is also part of a broader initiative from the International Renewable Energy Agency (IRENA) entitled Empowering Lives and Livelihoods: Renewables for Climate Action, which aims to connect people and livelihoods through renewable energy solutions in the agri-food sector.

The study focuses on the identification of energy gaps in four value chains: maize, apples, fish and millet. It looks at the opportunities each has to transition away from fossil fuels via the integration of decentralised renewable energy (DRE) systems. The study analyses the current energy consumption of agri-equipment and identifies opportunities where the integration of DRE could enhance equipment usage and/or promote more sustainable practices.

1.1 Data collection: Methods, sources and inputs

This study is based on primary data collected through key informant interviews (KIIs). These were conducted with three tiers of government units and projects, development partners working on agri-energy nexus efforts, private sector actors, individual farmers, commercial farmers, custom hiring centres, agri-enterprise owners, and research and training institutions.

In addition, focus group discussions (FGDs) were held to seek input from women and underserved communities. Additional data was gathered through interactions with people in the field, such as farming co-operatives, women's self-help groups and platforms that served the value chain with agri-food related services.

Data collected included the type of agri-equipment, work time (manual as opposed to that using equipment), ownership, gender-based usage, fuel use and power rating. This data aids in assessing potential DRE interventions for reliable power supply and calculating the drudgery reduction of mechanisation. Additional information from government records and published literature supplemented any gaps.

Agri-equipment is categorised as mobile (such as tractor-mounted rotavators and power tillers), or non-mobile (such as water pumps and flour mills). This classification helps us analyse which equipment can be powered by which DRE solution. Finally, the equipment investment in DREs required to offset the fossil fuel energy for the country is estimated for the short term (within five years). For a description of the investment estimation methodology, see Appendix A.

1.1.1 Selection of value chains and study sites

The criteria for selecting food value chains for the study were:

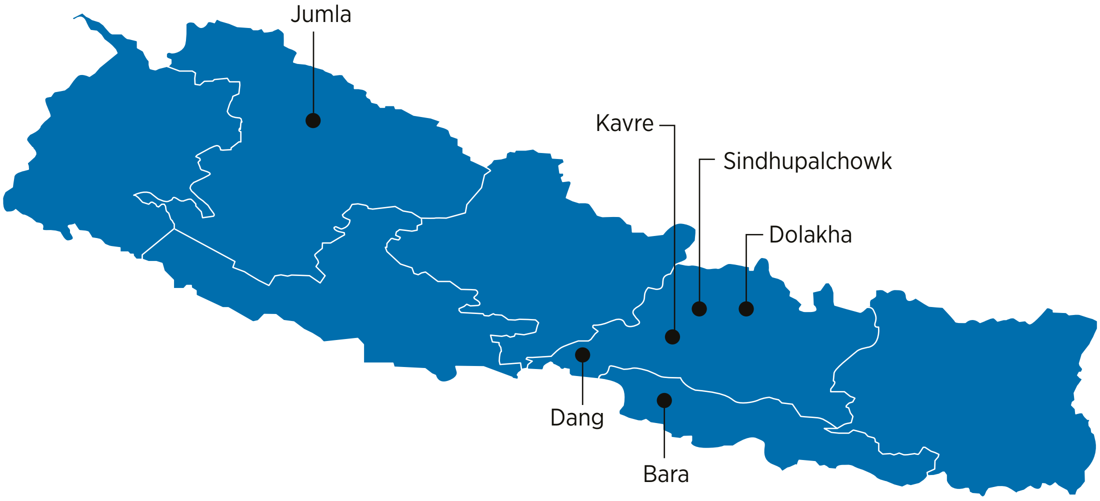
- That they align with government priorities for food security and improved nutrition.
- That they address climate resilience and gender roles.
- That they have the potential for improved production through mechanisation with reliable power.
- That they offer market potential for private sector investment in DRE solutions produced in off-grid or unreliable grid areas, where DRE options would be viable.

Field studies were conducted in areas where the selected food commodities are cultivated and that had been designated "super zones" under the Prime Minister Agriculture Modernisation Project (PMAMP).[2] These areas were chosen because of: 1) linkages with key players in the food value chain; 2) the availability of complementary project data for detailed energy gap analysis; and 3) their emphasis on mechanisation and understanding agri-equipment usage with reliable electricity.

The districts reviewed were Dang for maize, Bara for fisheries, Jumla for apples, and Dolakha, Sindhupalchowk and Kavrepalanchowk for millet (Figure 1). The commodity selection matrix is shown in Table 2.

2 As defined by the PMAMP, "super zones" are large commercial agricultural production and industrial centres (see section 3.1).

Figure 1 Locations visited for the study



Source: (Bhattarai, 2020).

Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply the expression of any opinion on the part of IRENA concerning the status of any region, country, territory, city or area or of its authorities, or concerning the delimitation of frontiers or boundaries.

The section below provides a brief description of each food commodity in the context of Nepal.

- **Maize:** This is the second most cultivated crop in Nepal after rice. The crop relies heavily on rainfall and is produced annually from March to May. Production increased by 9% in the financial year (FY) 2021 to FY 2022 period, compared to FY 2019-2020 (MoALD, 2023), but further improvements in production face challenges such as labour shortages and drought (Thapa, 2021). Under the PMAMP, maize has been prioritised as a staple food and for its nutritional value.
- **Apples:** The PMAMP prioritises apple production within its import substitution strategy. This is because of the immense potential the crop has for enhanced yields and value addition into items such as juices, jams, and pickles. Apples are cultivated in all provinces except Madhesh.
- **Fish:** Fish production increased 10% between 2021 and 2022 (MoALD, 2023). Under the PMAMP initiative, fish farming has been prioritised as part of the import substitution category and is a critical source of protein for the local population.
- **Millet:** Millet production experienced a slight, 4% increase between 2019 and 2022. Finger millet is the most popular variety grown. Due to its nutritional value, it is a staple crop and food product for hill and mountain communities.

Table 2 Selected food commodity value chain analysis matrix

Indicators	1. Maize	2. Apples	3. Fish	4. Millet
Current national priority (food security)	High	High	High	Medium
Nutritional values	Medium	High	High	High
Potential for productivity gains attracting the private sector (market value of crops at national scale)	High	High	High	Low
Improvement of added value for smallholder farmers by gaining access to DRE solutions	High	High	High	Medium
Provision of mechanisation reduces drudgery, building long-term resilience	High	High	High	Medium
Most suitable application of DRE	Irrigation, harvesting, threshing, processing, recipe diversification	Plantation, storage, processing, packaging, marketing	Water quality management, harvesting, cold storage, drying, transportation	Harvesting, threshing, milling

Source: (AEPC, 2023).

Notes: The qualitative grading is based on post-discussion inferences with respective government agencies. No specific, score-based gradings have been made.

2 The agriculture and energy landscape in Nepal

2.1 Socio-economic context within a changing climate

Nepal's agrarian community is highly exposed to the impact of climate change and its associated vulnerabilities. Agriculture contributes 24% of gross domestic product (GDP) (NewBiz Report, 2023), while for 62% of the population, the sector supports their livelihood through income and food provision.

Over half of farmers have an average farm size of less than 0.5 hectares (ha) (Table 3), while women comprise 64.8% of the sector's employment (MoALD, 2021). Data further show that 32% of households in Nepal are headed by women. In terms of ownership of land, house or both, 24% of total households are owned by women (National Statistics Office, 2023).

Table 3: Farmer categories and average land holdings

Farmer categories	Average land holding	Percentage of total farm population	Percentage of total available land
Small commercial farmers	1-5 ha and above	20%	53%
Subsistence farmers	0.5-1 ha	27%	28%
Landless/near landless farmers	<0.5 ha	53%	19%

Source: (GC and Hall, 2020).
Note: ha = hectares.

Nepal classified as a "low-income food deficit country" ranks 73rd in food security out of 117 food-importing nations (FAO *et al.*, 2022). Approximately 45 out of 77 districts face food insufficiency (MoALD, 2023). Progress has been made in recent years, however, with undernourishment decreasing from 16.0% in 2006 to 6.1% in 2020 (Global Hunger Index, 2020), while per capita grain production met its target of 376 kilograms (kg) in FY 2019-2020 (MoALD, 2023).

Gender and youth dimensions to the agricultural sector

The role of youth and their participation is pivotal for the agricultural sector to grow, and for the country to achieve food security. In Nepal, however, migration among the employable labour force is high, with many youths taking this path. Indeed, nearly all migrant workers are young adults and from the economically most productive age group of 18 to 44. Around half are between the ages of 25 and 34 years (MoLESS, 2022). In 2021-2022 alone, a total of 630 000 new and renewed labour approvals for migration were issued by the government. Of these, approximately 92% were male and 8% female.

Migration therefore often results in women taking on the primary role in the household and attending to most agrarian responsibilities until the produce reaches market. The introduction of new technologies has vast potential to help these women manage these tasks and improve efficiency (Aryal and Kattel, 2019). Although the federal level recognises the need to make the sector more gender-sensitive,[3] including via the use of agri-equipment, gender inequalities persist, particularly in accessing, adopting and using technologies and machinery (MoAD, 2017).

While gender responsive budgeting (GRB) in government programmes was once commonplace, the Ministry of Agricultural and Livestock Development (MoALD) budget for this shrank from 76.4% in FY 2012-2013 (FAO Nepal, 2019) to 18.3% in FY 2020-2021 (MoALD, 2021).

In the agricultural context, gender responsiveness is understood as: 1) women operating machines by themselves; 2) women mobilising mechanisation services through other operators; and 3) representation of women in the decision-making related to mechanisation-specific policies, programmes and budgeting, as well as in oversight mechanisms.

3 *The Gender Strategy, 2017, developed by MoALD, envisioned inclusive policies, mechanisms and capacity in value chains, along with the enhancement of small and medium-sized enterprises through improved research and extension services (MoAD, 2017).*

2.2 Policy landscape for agricultural mechanisation

The Constitution of Nepal outlines the right to food as a fundamental human right and places the responsibility for ensuring national food security on the state. The Agriculture Mechanisation Promotion Policy (2014) is central to this objective. It is designed to address challenges in the wider introduction of farming equipment. Some of the key features of the policy are:

- Provision of reliable electricity at subsidised tariffs for the agricultural sector.
- Promotion of clean energy technologies and fuel-efficient agri-machinery that also serve multi-purpose uses.
- Provision of capital subsidies via access to low-interest, collateral free loans for the purchase of agri-machinery.
- Provision of tax exemptions for imported and locally manufactured agri-machinery, along with the encouragement of public-private partnerships in the supply chain.
- Provision for individuals and groups to rent machinery from co-operatives and private entities.

This policy is complemented by the Agriculture Development Strategy, 2012-2035, which outlines a national plan for how mechanisation can enhance the sector's productivity and contribution to enhanced economic growth.

Another important programme designed to support agri-equipment is the PMAMP, which provides additional subsidies, alongside technical support. The PMAMP is the largest, nationwide federal government-led initiative and is now in the seventh of its ten-year project period.

The PMAMP has identified 15 food commodities classified under three major themes: 1) food and nutrition security; 2) import substitution; and 3) export promotion. The project, which seeks to improve productivity using modern and sustainable methods, is being implemented through different administrative units. These are defined according to farming areas, or numbers of livestock – graded small to large – and defined as "super zones", "zones", "blocks" or "pockets", while covering all 77 districts of Nepal.

2.3 Decentralised renewable energy, electricity access and demand in the agricultural sector

In Nepal, the largest share of electricity generation comes from hydropower, which contributed around 95% of total generation capacity in 2023 (NEA, 2023). In line with the reporting approach taken by the sole utility, Nepal Electricity Authority (NEA), all renewable energy projects that are operational, but not reported as grid connected capacity (as their primary point of delivery), are categorised as DRE projects. These include renewable energy systems such as micro/mini-hydro and solar mini-grids, off-grid solar, biomass-based gasification systems, and biogas plants, among others.

The Alternative Energy Promotion Centre (AEPC), which comes under the Ministry of Energy, Water Resources and Irrigation (MoEWRI), is responsible for the promotion of renewable energy technologies. The number of these deployed in the period up to 2023 and their capacity in kilowatts (kW) are shown in Table 4.

Adding thrust to the use and uptake of DRE, there are also programmes driven by development partners, some of which have a specific focus on agriculture and related livelihoods.

Table 4 AEPC's DRE system deployment status (up to 2023)

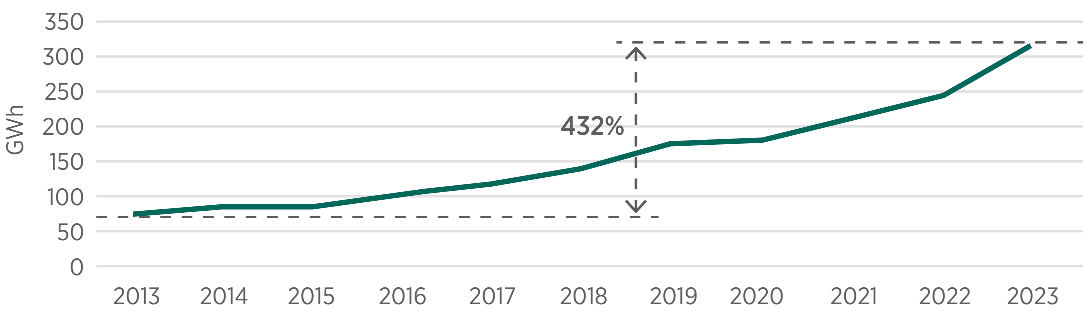
Technology	Capacity	Number deployed
Solar mini-grid	2 707 kW	-
Micro/mini-hydro	38 842 kW	-
Improved water mill	-	11 104
Solar water pump (drinking water and irrigation)	-	3 342
Institutional solar power system	-	4 021
Institutional, urban and commercial biogas plant	-	357
Solar dryer and cooker	-	2 464

Source: (AEPC, 2023).
Note: kW = kilowatt.

In 2023, 95% of Nepal's population had access to the electricity grid. That year, total generation capacity stood at 2 685 megawatts (MW).

In 2023, the percentage of consumers receiving power for irrigation was 4.3% (Ministry of Finance, 2023) (NEA, 2023).The NEA provides a subsidised electricity tariff for water supply and irrigation, with sales of electricity for this purpose rising over the past decade (Figure 2). Between 2013 and 2023, there was a four-fold increase (432%), to 315 gigawatt hours (GWh) (NEA, 2023). The tariff for irrigation purposes is USD 0.017[4] per kilowatt hour (kWh) in low-voltage connections.[5]

Figure 2 Electricity sales for water supply and irrigation (GWh), 2013-2023

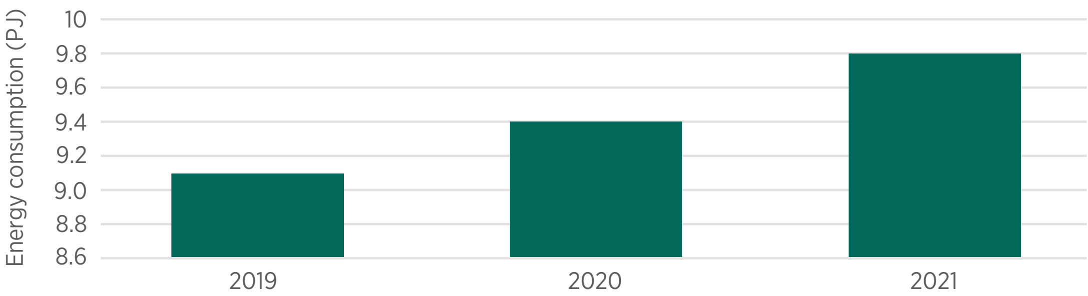


Source: (NEA, 2023).

4 *Converted from Nepalese rupees (NPR), at NPR 2.25/kWh.*
5 *Low voltage means 230 volts (V)/400V.*

Similarly, growing demand for power shows up in agricultural sector energy consumption, calculated in petajoules (PJ), which has been growing over the last few years (Figure 3).

Figure 3 Agricultural sector energy consumption (PJ), 2019-2021



Source: (WECS, 2022).
Note: PJ = petajoules.

The agricultural sector accounts for only 1.6% of total energy consumption. Most energy is consumed in the residential sector (63.2%), followed by the industrial (18.3%) and commercial sectors (7%) (WECS, 2022).

Diesel accounts for most energy consumption in the agricultural sector, at 91% (2 475 GWh). This is attributed to the fuel needs of essential farming equipment, such as tillers, harvesters, threshers and water pumps. Only a small percentage – 7.4% (WECS, 2022) – of farm machinery, including water pumping for irrigation, runs on electricity. Renewable energy currently accounts for a very small percentage of energy consumed in the sector, at 0.3%. this is primarily derived from solar energy (WECS, 2022).

Grid access at the study locations

According to the NEA Distribution and Consumer Services Directorate report of 2019, the electrification status of the districts visited for the study was 93.3% for the district of Dolakha, 79.9% for Dang, 77.4% for Bara and 5.6% for Jumla (NEA Distribution & Consumer Services Directorate, 2019). The government provides smallholder farmers with agricultural meters, called Krishi Meters, and provides electricity at subsidised rates (USD 0.017 /kWh[6] with no additional monthly demand charges) (NEA, 2023). However, in the fisheries sector, meters are not provided.[7]

The study responses indicated that within the districts examined, electricity from the national grid does not provide reliable and uninterrupted power for agricultural purposes. Co-operatives,[8] individual farmers and enterprises[9] indicated strongly that key power-dependant agricultural activities, such as pumps for irrigation, cold storage and threshing machines, are often rendered inoperable due to low voltages and frequent power outages. As a result, the use of fossil-fuel sources such as diesel generators and diesel water pumps have become commonplace to ensure reliable energy supply. Similarly, where thermal energy is required, for example in drying, either firewood (for fish drying) or open sun drying (for apple slices) is used as the primary means.

In Bara, the PMAMP supports diesel generators for the hatcheries of fish farms. There is a need for a continuous flow of water in these fishponds, requiring a reliable and uninterrupted electricity supply to power the water pumps.

6 Converted from NPR 2.25 /kWh.
7 Source: KII with NEA, Lamahi, Dang district.
8 Source: KIIs with co-operatives in Dang, Dolakha and Jumla.
9 Source: KIIs with enterprises in Dang, Bara and Jumla.

3 Energy use patterns and estimated investments in selected agri-food value chains

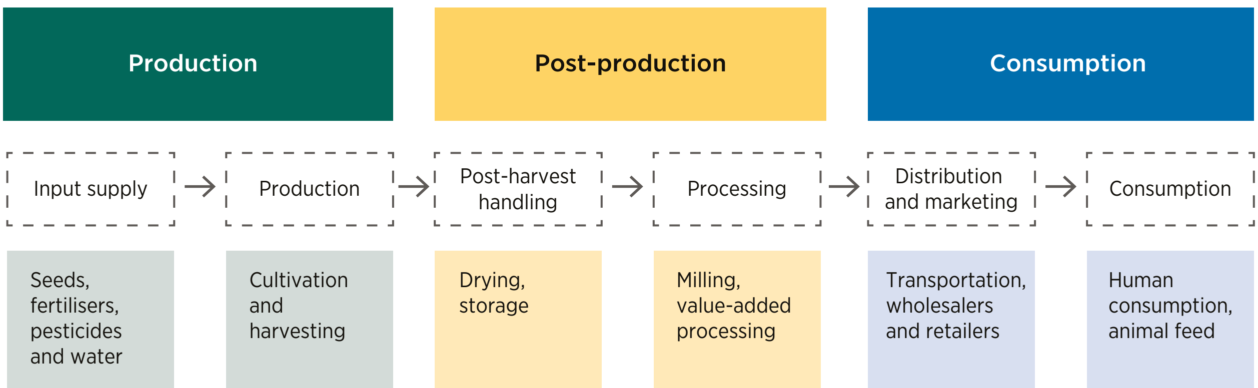
With the development of policies, strategies and accompanying programmes, there is a growing awareness of the benefits of mechanisation and increasing interest among farmers to make use of equipment. The following sections describe current energy use patterns in the four agri-value chains studied.

3.1 Maize

Maize serves as a staple diet to a large population, primarily the people of the mid-hills region and is also the main source of fodder and feed for the livestock and poultry.

Figure 4 shows the maize value chain from input supply to consumption. The major stages of the value chain can be divided into production, post-production and consumption. Under each stage, different nodes of the value chain where agri-equipment is used have been detailed.

Figure 4 Maize value chain



To identify the agri-equipment used across the maize value chain, the study in Dang district identified a list of equipment, its gender-based use, primary fuel, ownership type, and its typical power rating in horsepower (hp). This information, which was gathered from co-operative-run custom hiring centres (CHCs – see Box 1) and individually-run CHCs, was then used to evaluate the DRE potential for each intervention (Table 5).

Table 5 Use of equipment/manual labour in the maize value chain[10]

Equipment	Mobile/ non-mobile	Manual work time (without equipment) per hectare of land	Equipment work time per hectare of land	Percentage of drudgery reduction[11]	Ownership	Use by gender (majority)	Fuel	Typical power rating
Power tiller	Mobile	60 person hours	9 person hours	85%	Co-operative	Male and female	Diesel	18 hp
Rotavator	Mobile	47 person hours	2 person hours	95%	Individual and co-operative	Male	Diesel (powered by tractor)	Generally powered by 55 hp tractor
Tractor	Mobile	(subject to accessory attached)	(subject to accessory attached)	-	Individual and co-operative	Male	Diesel	Range of 25 hp-60 hp
Harrow	Mobile	60 person hours	1.5 person hours	98%	Co-operative	Male	Diesel (powered by tractor)	Generally powered by 55 hp tractor
Maize spreader	Mobile	48 person hours	1 person hour	98%	Co-operative	Male	Diesel (powered by tractor)	Generally powered by 55 hp tractor
Seed drill	Mobile	47 person hours	1.5 person hours	97%	Individual, farmer group and co-operative	Male and female	Diesel (powered by tractor)	Generally powered by 55 hp tractor
Seed grader and treater machine	Non-mobile	-	1 person hour for 1 tonne	-	Co-operative	Male	Grid	2 hp
Weeder machine	Mobile	235 person hours	23.5 person hours running the machine	90%	Individual, farmer group and co-operative	Male and female	Diesel or grid	5 hp
Jab planter	Mobile	94 person hours	47 person hours	50%	Co-operative, farmer group	Female	(manual)	-
Water pump	Non-mobile	-	8 person hours for 0.34 ha	-	Individual, co-operative	Male and female	Grid and solar	Electric pump: 2 hp Solar pump: 3 hp
Corn sheller	Non-mobile	8 person hours for 100 kg	0.5 person hours for 100 kg	94%	Individual, co-operative	Male and female	Grid	Range of 0.48 hp-1.5 hp
Maize thresher (without husk)	Non-mobile	16 person hours for 100 kg	1 person hour for 7 000 kg (0.01 person hours for 100 kg)	99.9%	Co-operative	Male	Diesel	Generally powered by 55 hp tractor
Maize thresher (with husk)	Non-mobile	16 person hours for 100 kg	1 person hour for 3 000 kg (0.03 person hours for 100 kg)	99.8%	Co-operative	Male	Diesel	Generally powered by 55 hp tractor
Sheller mill	Non-mobile	-	-	-	Farmer group, co-operative	Male	Grid	5 hp
Cold storage	Non-mobile	No data (Cold storage under construction)			Co-operative	No data	Grid	No data

Notes: In Dang, the cost of 1 litre of diesel is USD 1.30 when converted at a rate of NPR 170 per litre; ha = hectares; hp = horsepower; kg = kilogramme.

10 *The equipment use in the table is not exhaustive. The listing is based on in-field experience and literature reviews.*
11 *Drudgery reduction is the person-hours reduced by use of the equipment, compared to manual work.*

Seed drill

Maize thresher

Most of the equipment was found to be powered by diesel. This is because the mobile equipment used at the production stage mostly consists of accessories attached to tractors. In the maize value chain, some of the equipment, such as corn shellers and seed graders (Table 5) is powered by the national grid. However, the reliability and power quality of the grid were found to be poor in areas away from market centres and urban areas.

The CHCs reported that grid-powered equipment struggles to operate in certain areas of Dang district (especially for farms that are far from the transformer), with low voltage issues common. Due to seasonal cropping, the demand for grid-powered equipment peaks when all the farmers are using equipment, further causing low voltage issues. Consultations with CHCs and farms also revealed that only water pumps were being powered by solar electricity.

Box 1 What is a CHC?

In Nepal, a CHC is an entity that provides agricultural equipment for rent. These are commonplace across the country and serve an important role in providing access to machinery that farmers would not be able to acquire outright on their own. While their offerings vary from entity to entity, they will typically provide a variety of machinery needed along the value chain, from ploughing and planting, harvesting to processing. These entities are sometimes government run and operated, while others are private businesses or co-operatives run by a group of farmers (FAO, 2021).

Furthermore, the data gathered from the study shows that the use of the machines significantly reduces drudgery. Indeed, the average drudgery reduction was more than 90% when compared with manual work (see Table 5).

When asked about the CHC's interest in new equipment in the Dang maize super zone, those surveyed expressed a demand for equipment related to packaging, seed drills, corn shellers and drying technologies. This shows that although diesel-powered machinery (mainly tractors and tractor-mounted equipment, such as rotavators, seed drills and other related equipment) is currently popular, demand for new equipment mostly includes post-production equipment that can be powered by electricity – and is therefore suitable for a DRE intervention.

Based on the literature review and field visits, a non-exhaustive list of agri-equipment in the maize value chain has been prepared. Each piece of equipment is categorised as mobile or non-mobile.[12] This labelling is used to help choose the agri-equipment that potentially can be powered by DRE solutions. The proposed DRE solution for each piece of agri-equipment is shown in Table 6, which is further categorised into short-term and long-term intervention. "Short term" implies equipment that has the potential for DRE intervention within five years, whereas, "long term" means equipment that will likely require more than five years for a DRE intervention to be taken up.

12 *Mobile equipment is that which needs to be physically moved while doing work – for example, tractor-mounted rotavators and power tillers. Similarly, non-mobile equipment is that which remains stationary while working – for example, water pumps and mills.*

Table 6 DRE evaluation of equipment in the maize value chain

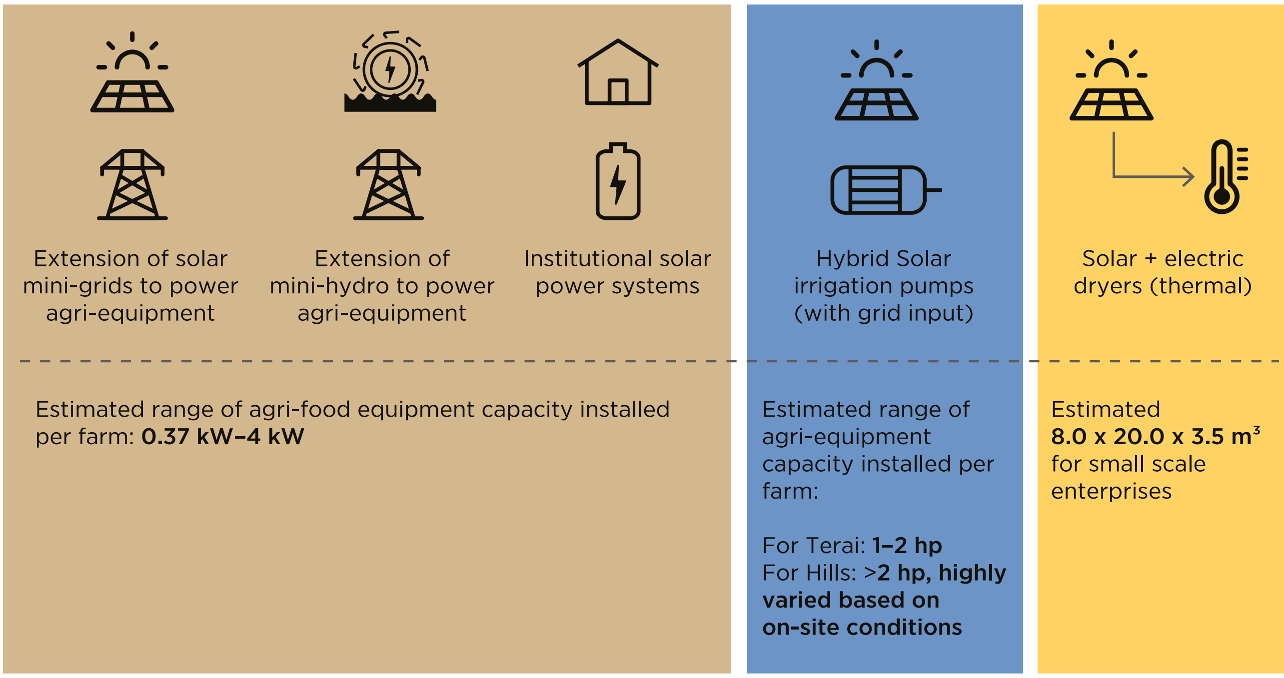
DRE technology	Equipment	Value chain stage	Equipment type	Short term/ long term
Electric power tiller charged using DRE[1]	Power tiller	Production	Mobile	Long term
Electric rotavator charged using DRE[1]	Rotavator	Production	Mobile	Long term
Electric tractor charged using DRE[1]	Tractor	Production	Mobile	Long term
Powered by tractors	Harrow	Production	Mobile	Long term
	Seed drill	Production	Mobile	Long term
	Maize thresher (without husk)	Post-production	Non-mobile	Long term
	Maize thresher (with husk)	Post-production	Non-mobile	Long term
Charged using DRE[1]	Maize spreader	Production	Mobile	Short term
	Sprayer	Production	Mobile	Short term
	Weeder machine	Production	Mobile	Short term
Solar mini-grids, solar-wind hybrid systems, institutional solar PV systems (ISPS) and mini-hydro	Seed grader and treater machine	Post-production	Non-mobile	Short term
	Corn sheller	Post-production	Non-mobile	Short term
	Sheller mill	Post-production	Non-mobile	Short term
	Weighing scales	Post-production	Non-mobile	Short term
	Packaging machine	Consumption	Non-mobile	Short term
	Labelling machine	Consumption	Non-mobile	Short term
Solar water pumps and mini-hydro	Water pumps	Production	Non-mobile	Short term
Solar-powered cold storage, micro/mini-hydro	Cold storage	Post-production	Non-mobile	Short term
Solar + electric dryers	Dryers	Post-production	Non-mobile	Short term
Manual labour	Jab planter	Production	Mobile	-

Note: [1] Such as solar mini-grids, institutional solar PV systems (ISPS) and mini-hydro; PV = photovoltaic.

As Table 6 shows, in the short term, the majority of the equipment that has the potential for DRE intervention falls under post-production and consumption. Few established DREs, such as water pumping, fall in the production stage.

PMAMP has identified 15 maize growing districts (zones) around Nepal, with these located in each of the country's three geographical regions – Terai, the mid-hills and the Himalayan Mountains. Taking into account the DRE technologies relevant to agri-equipment that AEPC is already implementing in these districts, and after using a project-based approach to evaluate which DRE interventions are realistic, the DRE solutions shown in Figure 5 are now proposed.

Figure 5 Maize value chain: Potential DRE interventions in the short term



Based on: The Noun Project (thenounproject.com); solar + electric dryers estimate based on (Udomkun *et al.*, 2020).
Notes: kW = kilowatt; hp = horsepower; m^3 = cubic metres.

Estimated investments: Maize

To quantify the estimated investments required for DRE in the maize value chain, the methodology described in Appendix A is followed.

Estimated annual energy consumption based on production areas of maize	2 330 terajoules (TJ)[13]
Estimated annual DRE-based energy equivalent to offset fossil fuel energy in the short term after factoring in the efficiency of internal combustion engines	435 TJ, equivalent to 120 751 210 kWh1
Estimated equipment investment required in DREs to offset the fossil fuel energy for maize in Nepal (in the short term):	USD 87 million (for detailed calculation, see Appendix D)

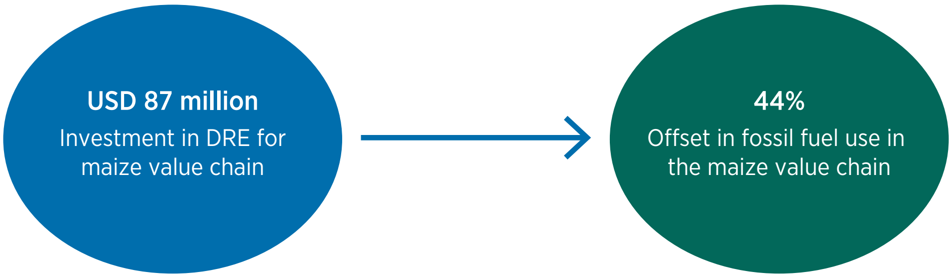
To estimate the percentage of agri-equipment that could potentially be DRE-powered, first, an inventory of agri-equipment supported by PMAMP in the 2021-2022 period was obtained. Then, the amount of equipment on the inventory with the potential for DRE intervention in the short term was determined.

For maize, the resulting figure was 44%, or 4 367 pieces of equipment out of the 9 938 pieces on the inventory supported by PMAMP in the 2021-2022 period that were applicable to the maize value chain. The types of equipment included sprayers, weighing scales, water pumps, mills and corn shellers.

Investing in DRE to power agricultural equipment for maize therefore represents a substantial opportunity to decrease dependency on fossil fuels within Nepal's maize value chain. This study estimates that an investment of USD 87 million could potentially reduce current fossil fuel usage by up to 44%.[14]

13 For details, see Appendix B.
14 Refer to Appendix B and Appendix D for full calculations conducted and assumptions used to arrive at the estimates presented here.

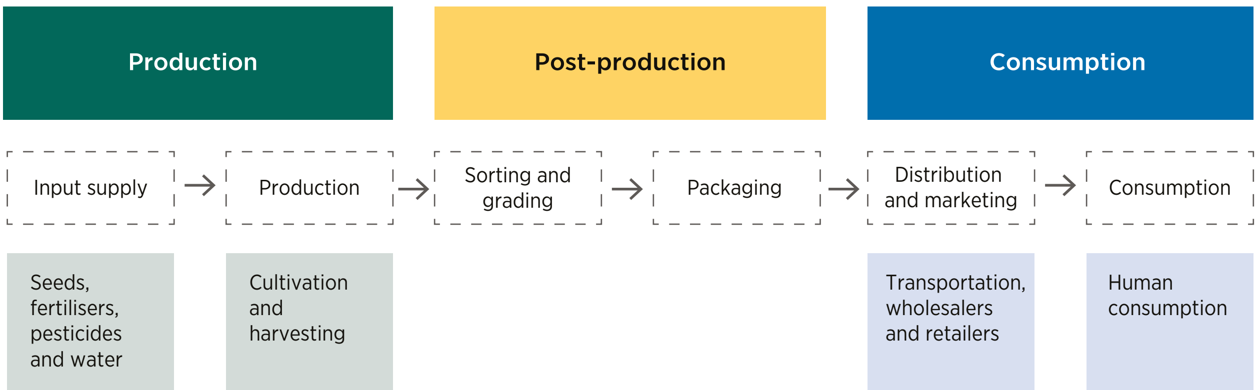
Figure 6 Maize value chain: Investment and percentage fossil fuel offset



3.2 Apples

Apple cultivation is an important economic activity in the mountainous regions of Nepal. Figure 7 shows the apple value chain.

Figure 7 Apple value chain



The Jumla district study identified a list of agri-equipment, its gender use, primary fuel source, ownership type and typical power rating. This information was then used to calculate the potential for DRE intervention at each stage of the value chain (Table 7). The information was gathered from commercial enterprises.

Table 7 Use of equipment/manual labour in the apple value chain[15]

Equipment	Mobile/non-mobile	Manual work time (without equipment)	Equipment work time	Percentage of drudgery reduction[16]	Ownership	Use by gender (majority)	Fuel	Power rating
Mini tiller	Mobile	-	20 person hours /ha	-	Private company	Male and female	Diesel	7 hp
Power tiller	Mobile	-	24 person hours /ha	-	Private company	Male and female	Diesel	-
Tractor	Mobile	1 200 person hours /ha	10 person hours /ha	99.2%	Private company	Male	Diesel	65 hp
Manually driven tractor	Mobile	1 200 person hours /ha	80 person-hours /ha	93.3%	Private company	Male	Diesel	7 hp
Apple grader (small)	Non-mobile	500 person hours for 100 cartons	3.33 person hours for 100 cartons	99.3%	Private company	Male and female	Electric equipment (diesel generator powered)	2 motors of 1 hp each + ancillary motors
Apple grader (large)	Non-mobile	191 person hours per tonne	0.27 person hours per tonne	99.9%	Private company	Male and female	Electricity	4 motors of 1 hp each + ancillary motors
Spray machine	Mobile	Manually pumped spray, 100 person hours /ha	25 person hours /ha	75.0%	Private company	Male and female	Petrol	1 hp
Juice maker	Non-mobile	Up to 40 litres in 1 person hour	Up to 170 litres in one person hour	76.5%	Private company	Male and female	Electric equipment (diesel generator powered)	-
Apple slicer	Non-mobile	6 person hours for 100 kg	-	-	Private company	Male and female	Manual	-
Submersible pump (river water pump to reservoir tank)	Non-mobile	-	-	-	Private company	Male and female	Electric equipment (diesel generator powered)	-
Surface pump (reservoir tank to drip irrigation system)	Non-mobile	-	-	-	Private company	Male and female	Electric equipment (diesel generator powered)	

Notes: In Jumla, the cost of 1 litre of diesel is USD 1.50 when converted at a rate of NPR 200 per litre; /ha = per hectare; hp = horsepower.

15 The equipment use in the following table is not exhaustive. The listing is based on in-field experience and literature reviews.
16 Drudgery reduction is calculated as the reduction in person hours caused by the use of the equipment, compared to manual work.

Apple grader machine (large)

Juice maker

Most of the equipment identified in the study was powered by diesel, the primary fuel for tractors, mini-tillers and power tillers. In addition, equipment such as apple graders and water pumps were being run on electricity produced by diesel generators due to the poor reliability of the electricity grid throughout the district (Box 2).

Box 2 The impact of national grid power interruptions

Interruptions in power provided by the national grid significantly impact agricultural value chain processes. In Jumla, for example, one apple enterprise reported grid outages and poor power quality as a common occurrence and, as a result, found it very difficult to plan any of its electricity-dependent processing activities. Machines such as apple graders could only be operated intermittently, depending on when electricity was accessible from the grid. If reliable and uninterrupted power was available, the enterprise would be able to drastically improve its operational efficiency.

In addition, due to grid unreliability, many enterprises currently resort to diesel generators to provide power during outages, or to maintain more consistent production schedules. Diesel generators are not only polluting, but also add expense to production, limiting profits.

A reliable energy source is essential for powering equipment in the apple value chain, especially when comparing the efficiency of machinery to manual labour. The study showed that utilisation of machines notably diminished tedious work, resulting in an average reduction of over 90% in drudgery (see Table 7).

Following a similar method to that used for the maize value chain, a non-exhaustive list of agri-equipment matching each stage of the apple value chain was then prepared. Each type of equipment was also categorised as mobile or non-mobile. The potential DRE solution for powering each type of agri-equipment can be seen in Table 8, which is further categorised into short-term and long-term intervention.

Table 8 DRE evaluation of equipment in the apple value chain

DRE technology	Equipment	Value chain stage	Equipment type	Short term/ long term[17]
Electric mini-tiller charged using DRE[1]	Mini tiller	Production	Mobile	Long term
	Power tiller	Production	Mobile	Long term
	Tractor	Production	Mobile	Long term
Manually-driven electric tractor charged using DRE[1]	Manually-driven tractor	Production	Mobile	Long term
Solar water pumps and mini-hydro	Water pumps	Production	Non-mobile	Short term
Charged using DRE[1]	Spray machine	Production	Non-mobile	Short term
Solar mini-grids, solar-wind hybrid systems, ISPS and mini-hydro	Apple grader (small)	Post-production	Non-mobile	Short term
	Apple grader (large)	Post-production	Non-mobile	Short term
	Apple slicer	Post-production	Non-mobile	Short term
	Weighing scales	Post-production	Non-mobile	Short term
	Packaging machine	Consumption	Non-mobile	Short term
	Labelling machine	Consumption	Non-mobile	Short term
	Juice maker	Consumption	Non-mobile	Short term
Solar powered cold storage, micro/mini-hydro	Cold storage	Post-production	Non-mobile	Short term
Solar + electric dryers	Dryers	Post-production	Non-mobile	Short term

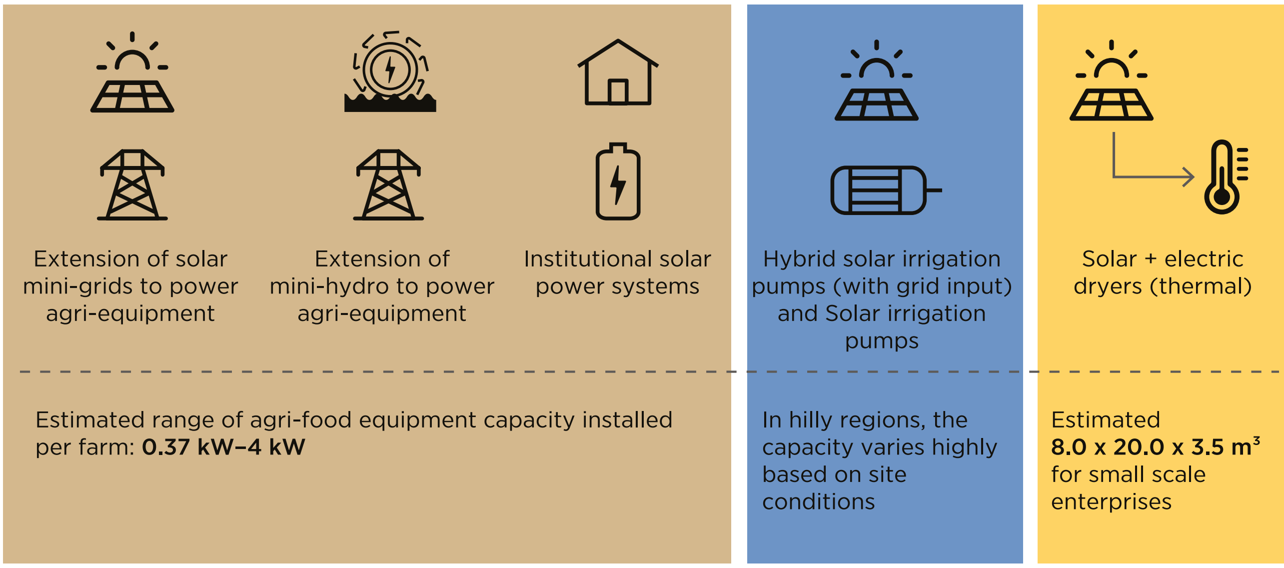
Note: [1] Such as solar mini-grids, ISPS and mini-hydro

As Table 8 shows, most of the equipment with DRE potential in the short term falls under the post-production and consumption stages, with only some, such as that used for water pumping, falling under the production stage.

PMAMP categorises 11 districts, or zones, as apple growing. Taking into account the DRE technologies relevant to agri-equipment that AEPC is already implementing in these districts, and after using a project-based approach to evaluate which DRE interventions are realistic, the DRE solutions shown in Figure 8 are now proposed.

17 *"Short term" implies equipment that has the potential for DRE intervention uptake within five years. Similarly, "long term" means equipment that will likely require more than five years for the uptake of DRE intervention.*

Figure 8 Apple value chain: Potential DRE interventions in the short term



Based on: The Noun Project (thenounproject.com); solar + electric dryers estimate based on (Udomkun *et al.*, 2020).
Notes: kW = kilowatt; m^3 = cubic metres.

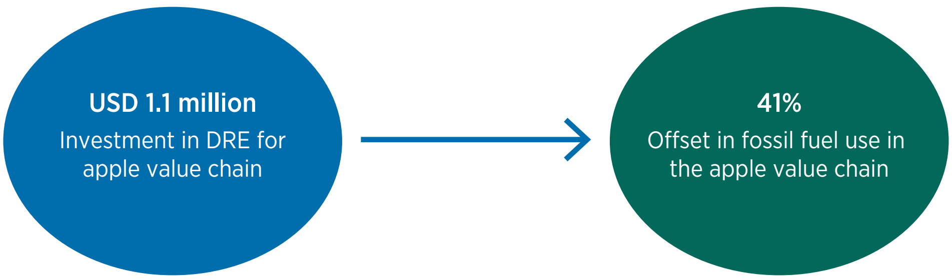
Estimated investments: Apples

Estimated annual energy consumption based on apple production areas	32 TJ[18]
Estimated annual DRE-based energy equivalent to offset the fossil fuel energy of 41% of apple agri-equipment in the short-term, after factoring in the efficiency of internal combustion engines	5.5 TJ, equivalent to 1 538 406 kWh
Estimated equipment investment required in DREs to offset fossil fuel energy for apples in Nepal (in the short term)	USD 1.1 million (for detailed calculation, see Appendix D).

As with the maize value chain, an inventory of agri-equipment supported by PMAMP in the 2021-2022 period was obtained. It was then determined which of the equipment in that inventory had short-term DRE potential, for more information see Appendix A and C.

For apples, 3 845 pieces of equipment out of the 9 438 applicable to the apple value chain supported by PMAMP during the period, or 41%, had DRE potential. The types of equipment included sprayers, weighing scales, water pumps, solar dryers, juice makers and apple slicers.

Figure 9 Apple value chain: Investment and percentage fossil fuel offset



18 *For details, see Appendix B.*

3.3 Fish

Fish production in the country's inland waters is dominated by pond-based carp polyculture. Some 94% of these ponds are in the Terai region. Figure 10 shows the fish value chain from input supply to consumption.

Figure 10 Fish value chain

Production		Post-production		Consumption	
Fish farming →	Water and health management →	Post-harvest handling →	Processing →	Distribution and marketing →	Consumption
Aquaculture facilities, feeding and nutrition	Optimum water quality, disease prevention and control	Seining and netting	Cleaning, gutting and packaging	Transportation, wholesalers and retailers	Human consumption

To identify the agri-equipment used across the value chain, the Bara district study gathered information from individual farmers, farmers' groups and private enterprises. It identified the types of equipment, their gender use, primary fuel, ownership type and typical power rating, in horsepower (hp) or kilovolt amps (kVA). This information was then used to calculate the DRE potential of each type of agri-equipment (see Table 9).

Table 9 Use of equipment/manual labour in the fish value chain[19]

Equipment	Equipment work time	Ownership	Use by gender (majority)	Fuel	Power rating
Fish feed	-	Individual	Male and female	Grid electricity	5.3 hp
Water pump for hatchery	8 hours (1 day) to fill a tank (tank size is subject to the size of the hatchery)	Individual	Male and female	Grid electricity, or powered by diesel generator	Electric pump: 7 hp Diesel generator: 10 kVA to 15 kVA
Water pump for air circulation	8 hours continuous run	Individual	Male and female	Electric and solar	2 hp
Aerator	4 hours daily for a 1016 m^2 fish pond	Individual	Male	Grid	1 hp

Note: The manual work time is not given because the equipment is mechanical by default and manual labour is not generally used; hp = horsepower; kVA = kilovolt amps; m^2 = square metre.


Fish feed machine


Solar water pumping system for fishpond top-up


Aerator powered by 1 hp submersible pump

19 *The equipment use in the table is not exhaustive. The listing is derived from in-field experience and literature reviews.*

With a high grid connection rate in the Terai region, most of the equipment in the fish value chain uses grid electricity. Due to frequent grid outages, however, many fish farms have installed diesel generators. This is particularly in order to ensure continuous water supply for the hatchery. Similarly, solar water pumps are used so that fishponds can maintain their water levels.[20] The opportunity for solar dryers was also identified for enterprises that produced dried fish. Such enterprises currently use firewood for this purpose.

Box 3 Opportunity for DRE-based dryers

During the study, a visit was made to a business that supplies dry fish to large markets (mostly in Kathmandu). The fish were dried using firewood, as shown in the accompanying photograph. Entrepreneurs said that while the smoky flavour of the dried fish (the result of firewood-based drying) is preferred by a portion of consumers, there is demand for dry fish without a smoky flavour. Hence, this shows an opportunity for DRE-based drying solutions in drying fish.

Dry fish production at a private enterprise

A non-exhaustive list of agri-equipment in the fish value chain was also prepared, linking each type to a particular stage. Each piece of equipment was then categorised as mobile or non-mobile. The DRE potential for each was assessed, then further categorised as either short-term or long-term, as shown in Table 10.

Table 10 DRE evaluation of equipment in the fish value chain

DRE technology	Equipment	Value chain stage	Equipment type	Short term/ Long term[21]
Extension of solar mini-grids in areas with no electricity,	Feeder	Production	Non-mobile	Short term
	Aerators	Production	Non-mobile	Short term
Solar + grid-connected ISPS	Weighing scales	Post-production	Non-mobile	Short term
	Packaging machine	Consumption	Non-mobile	Short term
	Labelling machine	Consumption	Non-mobile	Short term
Solar + electric dryers	Dryers	Post-production	Non-mobile	Short term
Solar + grid-connected water pumps	Water pumps	Production	Non-mobile	Short term

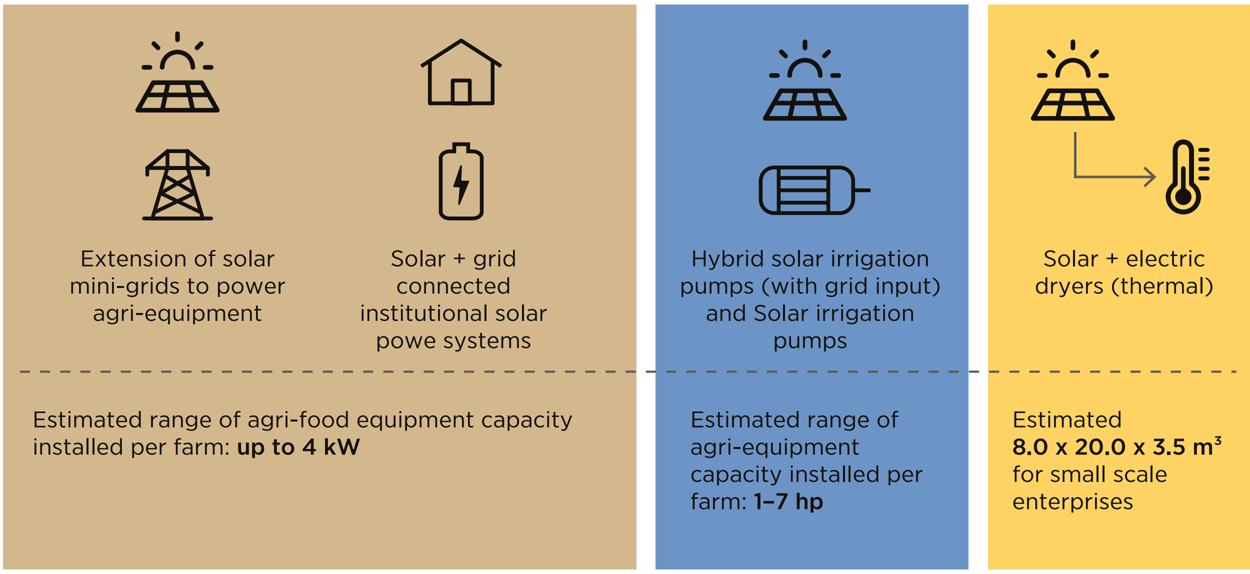
As can be seen in Table 10, all the equipment identified as having potential for DRE intervention in the short term is used in the production, post-production and consumption stages of the fish value chain.

PMAMP counts nine districts, or zones, as fish producing, with all of them in the Terai region. Taking into account the DRE technologies relevant to agri-equipment that AEPC is already implementing in these districts, and after using a project-based approach to evaluate which DRE interventions are realistic, the DRE solutions shown in Figure 11 are now proposed.

20 *The percentage drudgery reduction in fisheries could not be determined because manual labour is not otherwise used in the absence of the equipment (such as for pumping, aeration etc.).*

21 *"Short term" implies equipment that has the potential for DRE-based uptake within five years; "Long term" means equipment that will likely require more than five years for DRE-based uptake.*

Figure 11 Fish value chain: Potential DRE interventions in the short term



Based on: The Noun Project (thenounproject.com); solar + electric dryers estimate based on (Udomkun *et al.*, 2020).
Notes: kW = kilowatt; hp = horsepower; m^3 = cubic metres.

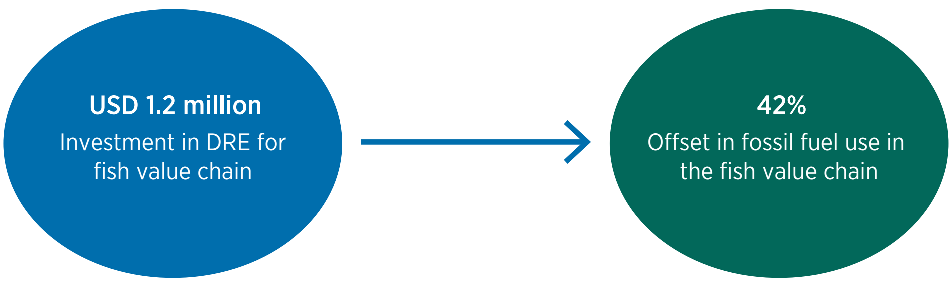
Estimated investments: Fish

Estimated annual energy consumption based on fish production areas	33 TJ[22]
Estimated annual DRE-based energy equivalent to offset the fossil fuel energy of 42% of fish agri-equipment in the short term after factoring in the efficiency of internal combustion engines	5.8 TJ, equivalent to 1 620 152 kWh1
Estimated equipment investment required in DREs to offset the fossil fuel energy for fish (in the short term)	USD 1.2 million (for a detailed calculation, see Appendix D).

As with the other value chains, an inventory of agri-equipment supported by PMAMP in the 2021-2022 period was obtained. The equipment in the inventory were identified as short-term DRE potential or long-term DRE potential, for more information see Appendix A and C.

For fish, this amounted to 1 047 pieces of equipment out of the 2 511 pieces applicable in the fish value chain – or some 42% of the total. The types of equipment included weighing scales, aerators, feeders and labelling machines.

Figure 12 Fish value chain: Investment and percentage fossil fuel offset

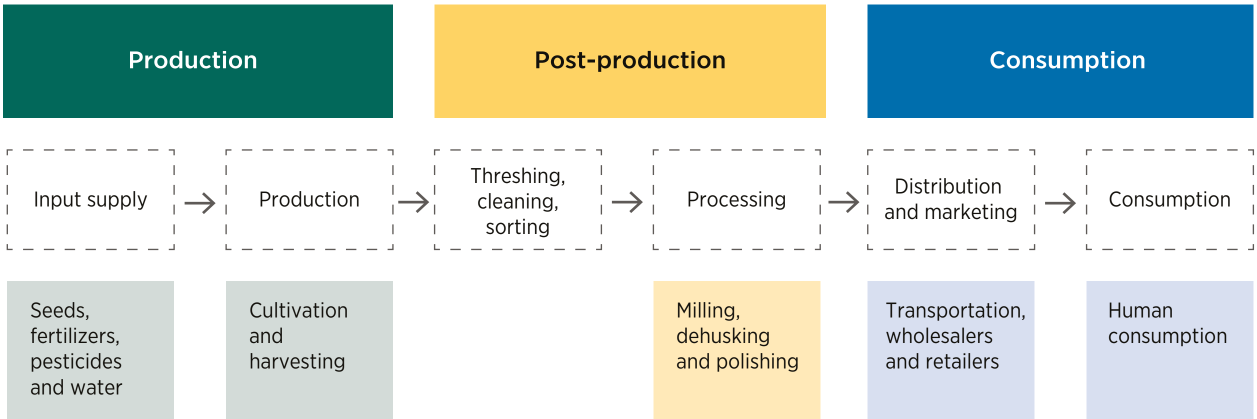


22 *For details, see Appendix C.*

3.4 Millet

Millet is the fourth ranked cereal crop in Nepal, grown mostly on hillsides. Figure 13 shows the millet value chain, from input supply to consumption.

Figure 13 Millet value chain



To identify the agri-equipment used across the value chain, the study in the Dolakha, Sindhupalchowk and Kavre districts gathered information from farmer co-operatives and government research institutions. The study identified the types of equipment, their gender use, primary fuel, ownership type and typical power rating. This information was then used to calculate the DRE potential of each type of agri-equipment (see Table 11).

Table 11 Use of equipment/manual labour in the millet value chain[23]

Equipment	Ownership	Use by gender (majority)	Fuel	Power rating
Mini-tillers	Individual, co-operative	Male and female	Diesel	6 hp-7 hp
Thresher: small	Co-operative	Male	Grid	1 hp
Thresher: large	Co-operative	Male	Diesel (powered by tractor)	Generally powered by 55 hp tractor
Mills	Co-operative	Male	Grid	3 hp

Note: hp = horsepower.


Mini-tiller


Electrically powered millet thresher

While the primary fuel used by mini-tillers is diesel, equipment such as mills and small threshers are operated with electricity from the grid.

As with the other food value chains studied here, a non-exhaustive list of agri-equipment in the millet value chain was also prepared, linking each type to a particular stage. Each piece of equipment was categorised as mobile or non-mobile. The DRE potential for each type was then assessed and categorised as either short term or long term, as shown in Table 12.

23 *The equipment use in the table is not exhaustive. The listing is based on in-field experience and literature reviews.*

Table 12 DRE evaluation of equipment in the Millet value chain

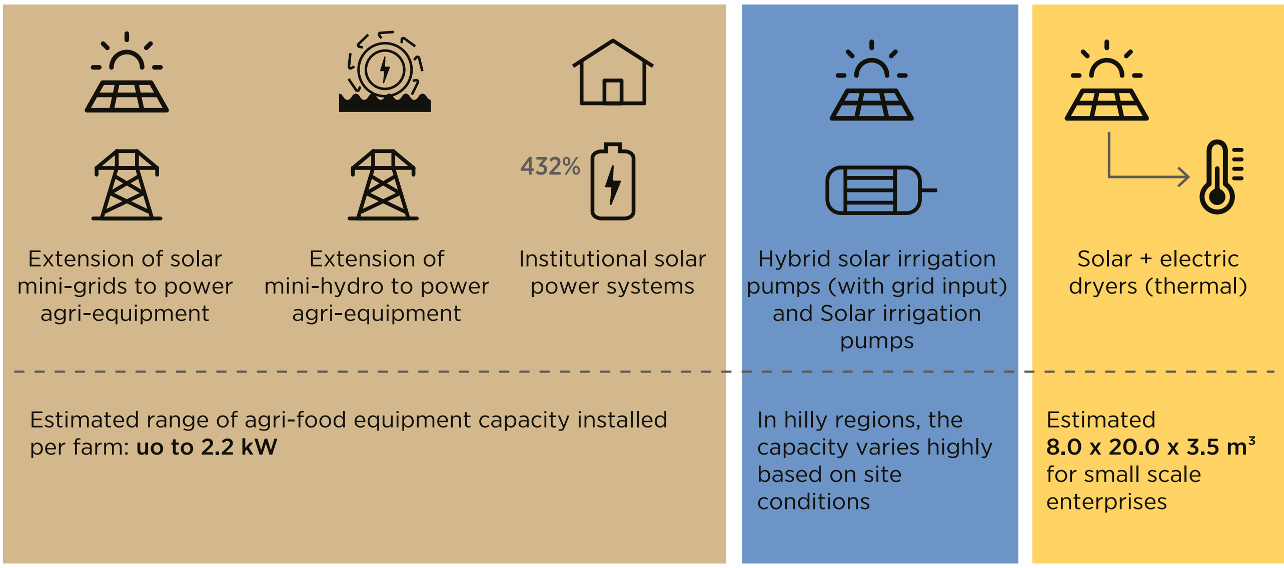
DRE technology	Equipment	Value chain stage	Equipment type	Short term/long term[24]
Electric mini-tiller charged using DRE[1]	Mini-tillers	Production	Mobile	Long term
Solar water pumps and mini-hydro	Water pumps	Production	Non-mobile	Short term
Solar mini-grids, solar-wind hybrid systems, ISPS and mini-hydro	Threshers	Post-production	Non-mobile	Short term
	Mills	Post-production	Non-mobile	Short term
	Grader	Post-production	Non-mobile	Short term
	Weighing scales	Post-production	Non-mobile	Short term
	Packaging machine	Consumption	Non-mobile	Short term
	Labelling machine	Consumption	Non-mobile	Short term
Solar + electric dryers	Dryers	Post-production	Non-mobile	Short term

Note:[1] Such as solar mini-grids, ISPS and mini-hydro

As Table 12 shows, most of the equipment with potential for DRE intervention in the short-term fell into the post-production and consumption stages, with a few established DREs, such as water pumping, falling into the production stage.

Millet is grown in the hilly and mountainous regions of Nepal (Gyawali, 2021). Taking into account the DRE technologies relevant to agri-equipment that AEPC is already implementing in these districts, and after using a project-based approach to evaluate which DRE interventions are realistic, the DRE solutions shown in Figure 14 are now proposed.

Figure 14 Millet value chain: Potential DRE intervention in the short term



Based on: The Noun Project (thenounproject.com); solar + electric dryers estimate based on (Udomkun, *et al.*, 2020).
Notes: kW = kilowatt; m^3 = cubic metres.

24 *"Short term" implies equipment that has the potential for DRE uptake within five years. Similarly, "long term" means equipment that will likely require more than five years for DRE uptake.*

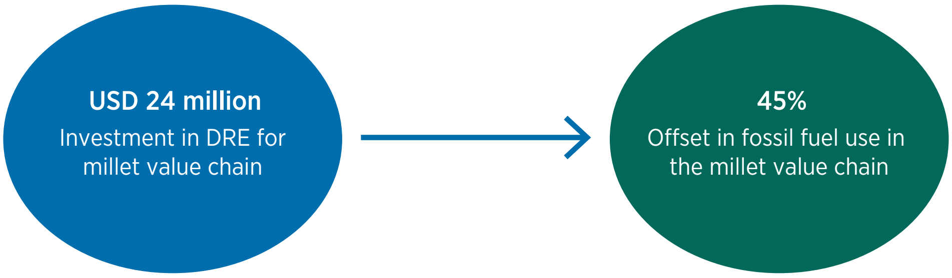
Estimated investments: Millet

Estimated annual energy consumption based on production areas of millet	631 TJ[25]
Estimated annual DRE-based energy equivalent to offset the fossil fuel energy of 45% of millet agri-equipment in the short term, after factoring in the efficiency of internal combustion engines	119 TJ, equivalent to 33 168 529 kWh1
Estimated equipment investment required in DREs to offset the fossil fuel energy for millet in Nepal (in the short term):	USD 24 million (for a detailed calculation, see Appendix D).

As with the other value chains, an inventory of agri-equipment supported by PMAMP in the 2021-2022 period was obtained. This report identified the equipment in the inventory that had short-term DRE potential, for more information see Appendix A and C.

For millet, 4 464 pieces of equipment out of 10 018 applicable in the millet value chain had this potential (around 45% of the total).

Figure 15 Millet value chain: Investment and percentage fossil fuel offset



25 *For details, see Appendix C.*

4 Key renewable energy powered technology and equipment options for enhancing agri-food value chains

Most mobile agricultural equipment, such as mini-tillers and tractors, are powered by fossil-fuel sources. The fuel used is mostly diesel, as there are limited electric options, with these currently not deemed commercially viable within the context of the Nepalese market. Small or non-mobile equipment, such as solar water pumps for irrigation, are more viable options, as is the extension of the existing DRE infrastructure (such as micro-hydro and ISPS) to include power production and processing machines, such as corn shellers, mills, aerators and small threshers.

Upon identifying the suitable equipment for DRE intervention in each value chain, Table 13 shows the specific DRE technology that is suitable to power the range of equipment identified.

Table 13 Potential DRE solutions

DRE technology	Agri-food value chain stage	Examples of use	Approximate power capacities of load	Geographical relevance
Extensions of mini-grids (solar, solar-wind hybrid, mini-hydro)	Production and post-production	• Grading machines • Mills • Small threshers • Juice makers • Sprayers • Cold storage	For Terai: 1-2 hp For Hills: >2 hp, highly varied, based on site conditions	Terai and Hills
Solar water pumps with grid compatibility	Production	• Irrigation	Subject to crop water and head requirements	Terai and Hills
		• Fishpond top-up	Subject to pond characteristics	Terai
ISPS (off-grid) and solar, grid-tied systems	Post-production	• Grading machines • Seed grader and treater machines • Corn shellers • Mills • Small threshers • Juice makers • Sprayers • Cold storage	Up to 4 kW	Terai and Hills
	Production	• Aerators	Up to 1 hp	Terai
Solar + electric hybrid dryers	Post-production	• Dry maize grains • Dry fish • Dry apple	Subject to drying requirements	Terai and Hills

Notes: kW = kilowatt; hp = horsepower.

In the sub-sections below, we elaborate further on the key DRE technical solutions to powering agri-food value chains.

4.1 Cold storage

The introduction of more cold storage in Nepal could serve multiple objectives, including increasing food security by ensuring more of the total agricultural production is consumed, and increasing profits to farmers by allowing them to maximise the sale of their products.

Despite this potential, cold storage has had very limited success in Nepal to date, with only a handful of pilot projects being implemented. There are a variety of reasons why implementation has not been more successful and has not led to wider adoption. Some key findings gathered through field visits and KIIs include:

- A disconnected market, meaning that farmers' sales are limited to the local region. If they were able to tap into a wider network of markets, cold storage might become more lucrative.
- Limited awareness among farmers about the opportunity and benefits of cold storage. In addition, wholesalers buy directly from farmers, so the technology does not attract a sufficient number of farmers.
- Lack of technical knowledge in pilot projects. Some facilities, for example, were designed to store only one product (*e.g.* potatoes), but due to insufficient capacity building, multiple products were stored in the same chamber. This sped up spoilage, rather than the reverse, and led to misconceptions about the efficacy of the systems.
- To power them, cold storage units face high operating electricity costs. Farmers also encountered difficulties as a result of an unreliable supply of electricity from the grid. For example, In Jumla, a 20-tonne cold store was installed with government backing for the storage of apples (costing approximately USD 13 097, equivalent to NPR 1.75 million). Respondents rated the reliability and quality of the grid supply as poor, leading to underutilisation, despite significant investment in building these storage facilities.
- Facilities that were designed with solar PV and battery storage also encountered challenges, including issues with the degradation of batteries.

Combined, these factors led to most units becoming dysfunctional or closing. A more concentrated effort to promote appropriate technologies and delivery models is therefore needed.

Box 4 Solar cold storage pilots

The International Centre for Integrated Mountain Development (ICIMOD) is currently piloting solar cold storage, in which solar energy is utilised to make ice during the day. The ice, regulates and maintains the temperature throughout the night (negating the need for batteries). The pilot project is currently in progress and has shown promise. Final results, however, have yet to be determined.

4.2 Solar dryers

The field visits and KIIs undertaken for this study confirmed a strong interest in solar drying among farmers and agricultural enterprises. Drying is a key process across all four agri-food value chains studied here. In some instances, such as with maize, it is an essential process for preservation. With others, such as apples or fish, it is an optional step to enhance value creation and reduce spoilage.

In Nepal, open air drying is a common practice. This method holds several challenges such as contamination from dust, loss to birds, insects and animals, product discolouration, and hardening (Aacharya *et al.*, 2024). In the fish value chain, drying with wood fires is also commonplace.

Currently, AEPC provides subsidies to assist with the upfront cost of solar dryers. These subsidies range from 40% to 75% of the upfront cost, depending on the dryer capacity and the location of the installation. Despite this, uptake has been low to date, with approximately 2 464 units installed, as of 2023. Nowadays, AEPC reports that growth in uptake is nearly stagnant. In the 2020-2021 period, only 0.3% more units were deployed compared to 2021-2022, with no additional units deployed at all in 2022-2023 (AEPC, 2023).

Field visits and KIIs also revealed several other key findings with regards to solar and bioenergy dryers:

- The technologies available are more effective for drying small quantities of produce with low moisture content. Produce with high moisture content has posed challenges, as has seasonal variability in Nepal, leading to issues with solar dryers during the monsoon season.
- In Bara, an important region for the fisheries sector, solar dryers could potentially reduce the need for immense quantities of firewood.
- Hybrid dryers, which have solar PV systems, but can also be connected to the grid, were highlighted as a viable technology to address the above challenge. Such an arrangement can help to ensure a dependable energy supply year-round and enhance the consistency of the drying process.
- Despite the availability of the AEPC subsidy, high upfront costs were still documented as a barrier to adoption. This highlights a greater need to link farmers to other sources of finances, asides subsidies.
- To be economically viable, solar dryers need to have a great enough volume of produce to be dried and require year-round utilisation. For example, in Dang, the fuel cost of a 3 tonne solar dryer is approximately USD 19 in a single batch (achieving up to 15% moisture content). However, it was observed that the machine almost never reached its 3 tonne capacity. As a result, the cost to the farmers was deemed high for most and they instead opted for manual drying.
- The finding above pointed to the greatest opportunities existing at the commercial scale, rather than single farm installations. These units are likely to be the most economically viable because they can ensure the most consistent operations.
- Finally, farmers often do not understand the value and importance of drying. This was specifically observed in the maize value chain, where lowering the moisture content of the grain is important for preservation. Greater awareness is needed to enhance the uptake of solar drying.

4.3 Solar irrigation pumps

The total number of solar water pump systems for irrigation in Nepal reached 3 342 in FY 2022-2023 (AEPC, 2023). Between FY 2018-2019 and FY 2022-2023, the yearly rates of increase in installation were 38%, 29%, 28% and 7%, respectively (AEPC, 2023). The AEPC provides a 60% subsidy on solar water pumps for irrigation, not exceeding USD 15 000, with the remaining 40% paid by the end-user (individual owners, private company or user committee). In addition, provincial and local governments also support solar water pumps for irrigation. There is, however, a lack of data on their involvement and progress.

In terms of geographical distribution, the majority of solar irrigation pumps are installed in the Terai, where there are high groundwater reserves and very fertile lands.

Irrigation in the hills is mostly achieved using the gravity flow method. There are big terraces and plains, however, that have developed as a result of rivers changing course. These areas are typically not irrigated and instead rely on natural rainfall. There is a significant untapped potential here to make use of solar water pumps for lifting water from rivers, especially as many of these areas lack grid access or have poor grid quality. Surface water from flowing rivers and rock aquifers where the river gradient is high can also be utilised for lift irrigation in the hills.

Key observations from field visits and KIIs included:

- Farmers have taken advantage of the subsidies and judging by the applications received by AEPC, awareness of, and demand for solar irrigation pumps is high.
- The involvement of private companies is essential in co-ordinating subsidy applications, procurement and installation services for users whose subsidy applications are approved. AEPC receives more than 80% of its applications through private sector channels. Most private companies themselves do not develop and invest in solar water pump projects under the modality of water sales or fixed monthly tariffs to recoup investment. Ghampower®, a private company focused on solar energy systems, has partnered with micro-finance institutions to help farmers access finance for the 40% share of the system cost. Micro-finance institutions identify customers and provide lending, while Ghampower® is responsible for the system design, installation and after-sales service. More than 200 solar water pumping systems have been installed by the enterprise under this model.
- From field visits to the maize and fish super zones (Dang and Bara), the experience of farmers and local governments with solar water pumps was positive. However, users said there were challenges in the O&M of the systems. Co-operatives and farmers said that on average they spend USD 75 on O&M for each breakdown and had to rely on only a few service providers for repairs, compared to the multiple repair service options available with other equipment.
- From field visits, it appeared that solar irrigation systems are currently under-utilised, and only operational at 68% of their capacity.
- Women reported being comfortable operating solar irrigation pumps (the only DRE technology where this was observed to be the case).

Renewable energy with grid-connectivity option: In Bara, after installing a solar water pumping system, a farmer locally upgraded the configuration to also connect it to the grid. This enabled the farmer to use solar PV energy during the day and rely on the grid at night and in the early morning. In some areas, farmers have defaulted to electric pumps when there is grid availability and use solar water pumps as a back-up.

With NEA aiming for 100% electrification by 2025 (NEA, 2023), it is important to note that in the Nepalese market, there is a need for any DRE solution to consider its compatibility with the grid, as grid power quality improves. Institutions such as the International Water Management Institute Nepal (IWMI Nepal) call for a policy focus on grid-connected solar irrigation pumps to improve year-round energy utilisation (Shrestha, 2023). IWMI Nepal has also piloted such projects. While the findings from these pilots is yet to be documented, their existence shows the growing need to think of DRE and its grid-connectivity options from an early stage.

4.4 Renewable energy powered mini-grids

Solar mini-grids

The cumulative installed capacity of solar mini-grids and wind mini-grids in Nepal reached 2 707 kW in FY 2022-2023 (AEPC, 2023). Almost all solar mini-grids are highly subsidy-driven.[26] The involvement of private enterprises in solar mini-grid deployment is limited mostly to engineering, procurement and construction (EPC) contracts. Based on the study's consultations, compared to investing in a project, private players perceive their role as EPC contractor to be relatively low-risk, with their obligations limited to project construction and after-sales service.

AEPC has documented an increasing trend in the cumulative installed capacity of solar[27] and wind mini-grids. Deployment, however, is primarily as an off-grid electricity solution for last-mile electrification, rather than to supplement the grid power supply. Technologies such as solar mini-grids can, nonetheless, serve a community by powering agri-equipment and other productive uses of electricity.

Box 5 Case study of a productive end-use from a solar mini-grid

With AEPC support, in 2022, a 120 kilowatt peak (kWp) solar mini-grid was constructed in Mahabu Municipality, Dailekh district that serves more than 350 households. Prior to this project, these households had relied on solar home systems for lighting. Within three months of the construction of the solar mini-grid, three rice and wheat electric mills (3 hp capacity each) were purchased by two households. This demonstrates how access to reliable electricity can trigger productive end uses.

Micro/mini-hydro mini-grids

Nepal boasts abundant water resources, with its perennial rivers and steep terrain facilitating the development of micro and mini-hydropower (MHPs) projects for rural electrification.

As of FY 2022-2023, the cumulative installed capacity of MHPs in Nepal was 38 842 kW (AEPC, 2023). These projects received substantial subsidies.[28] In similarity with solar mini-grids, private company involvement in MHPs primarily occurs through EPC contracts.

The cumulative installed capacity of MHPs promoted by AEPC shows that the deployment rate[29] during the last decade has been moderate – much slower than the pace at which solar mini-grids have been deployed.

Studies also show that the electricity generation from several micro-hydro projects in Jumla and Dolakha, which serve adjacent communities, has been under-utilised (Kumar, 2015). These projects have moderate micro-hydro generation capacity, in the range of 620 kW to 1 546 kW. There is therefore a need to revive and optimise the use of existing hydro plants, which, in the given context, could power agri-equipment such as cold storage, as well as be made available for other productive, agrarian uses.

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26 *AEPC provides a capital expenditure (capex) subsidy of 90% with a ceiling of 250 kW in capacity. For local government projects, the balance of 10% is met from their budget. In public-private partnerships (PPPs), the project receives a 60% subsidy on upfront costs with a ceiling of 100 kW in capacity.*

27 *The rate of increase in installed capacity was 32% in FY 2018-2019, 70% in FY 2019-2020 and 132% in FY 2021-2022.*

28 *An up-front subsidy of 90% for capacities in the range of 10 kW-1 000 kW is available for local governments and user committees. For PPPs, the subsidy is tied to installed capacity, or the number of generation units.*

29 *From FY 2018-2019 to FY 2022-2023, the annual rates of increase in installed capacity were 8%, 3%, 5% and 3% respectively.*

5 Models for the provision of agri-equipment services

In Nepal, the most common way of using agri-equipment, especially among smallholders, is by renting a machine for a particular purpose. Typically, the rental equipment is owned by either a co-operative or a privately run enterprise. The hourly rental rates of these machines are based on the market rates (concurred through informal communication), with no regulatory mechanisms defining the level. Some of the rental models currently operating are expanded upon in the chapter below.

5.1 Co-operative, or privately-run custom hiring centres

A co-operative-run CHC is operated by a farmers' co-operative. Its primary purpose is to rent out agri-machinery to its members, who are entitled to discounted rental rates that are often lower than those offered by privately-run enterprises. Almost all of the agri-equipment in these CHCs is supported by the government through projects such as PMAMP.

The CHCs in the maize super zone (Dang) had dedicated staff for: 1) O&M of the equipment and machinery; 2) transportation; and 3) business management, along with other administrative and managerial functions. All the machines were operated by a driver employed by the co-operative.

Co-operatives share up to 25% of their annual profits among their members.[30] They do not have any other significant service provisions, except for lending small sums to members. These are typically in the range of USD 187 to USD 224 (NPR 25 000 to NPR 30 000). The KIIs found that the revenues generated by co-operative CHCs in both the Dang maize super zone (Figure 16) and the Dolakha millet super zone were only marginally adequate for CHC operation, leaving limited opportunities to scale.

Based on discussions during field visits, another model deserves consideration: a customised service centre.

Under the proposed model, the services of co-operative CHCs could expand beyond renting agri-equipment to provide other services, such as food produce sales and crop advisory support. This has the potential to broaden the co-operative's revenue sources, potentially boosting profits and facilitating the expansion of their service offerings.

In some co-operatives[31], members team up to produce fish or silage, with this then collectively sold to industries or large markets. Such co-operatives aim to bring more land and fishponds from their members into production in order to maximise output. Yet, what was observed at the co-operatives visited was that they had a weak influence on local industries and suffered from late payment for rentals and services. A co-operative's ambitions to expand would fall through and partnerships with industries would not materialise. This stems from the absence of co-ordinated efforts among farmers to achieve large-scale production, consequently limiting their optimal utilisation of agricultural equipment.

Co-operative-run CHCs were also not popular in the fish super zone (Bara), apple super zone (Jumla) and millet growing area in Dolakha. In Bara and Dolakha, the equipment used in the fish value chain and for growing millet were mostly individually owned. Similarly, in Jumla, the equipment used was owned by private enterprises or co-operatives.

Private CHCs are operated by individual farmers who rent out equipment. These centres often offer equipment that is not available through co-operatively run CHCs, which typically have a limited selection. Privately-run CHCs also offer quicker response times to farmers' demands due to decisions being made solely by the owner.

Typically, these centres start with a small selection of equipment rented out by an individual farmer and gradually expand to include larger, more expensive machinery, often with the support of government projects, such as PMAMP. Equipment O&M are handled by paid operators. However, initial observations suggest that privately-run CHCs offering a wide range of equipment are primarily accessible to wealthier farmers with better access to government and development support programmes.

30 Source: KII of Suryodaya Krishak Bahu-Udeshiya Sahakari Sanstha Ltd., Materiya, Dang.

31 Source: KII of Shree Badka Bagiya Krishi Sahakari Sanstha. The number of members of the co-operatives interviewed ranged from 42 members to 398 members.

Women working in fish drying enterprise, Bara

Guthichaur Agro Farm, Jumla

It was noted that women often hold leadership roles in managing the CHCs (see Box 6).

Box 6 CHCs benefiting women

The Harit Tarkari Udpadak Krishak Samuha Lamahi (Green Vegetable Producer Farmer Group, Lamahi), a women-led co-operative in Dang, says they benefit from the use of machines in producing vegetables, maize and rice. The equipment has helped reduce their farm-based workload and drudgery considerably, primarily in land preparation, plantation and the harvesting of crops.

5.2 Co-operative ownership

In the co-operative ownership model, close collaboration between the co-operative and local farmers establishes a hub for collecting, processing and accessing markets for agricultural commodities. This approach encourages greater use of agricultural equipment and allows small-scale farmers to capitalise on market access collectively.

Box 7 The co-operative model in the apple value chain

In Jumla, a central co-operative organisation, the Jilla Sahakari Sangh (Translation: District Cooperative Union), oversees the operations of nine smaller co-operatives, with a total of 83 members. The smaller co-operatives handle the collection of apples from farmers, processing and packaging, while the umbrella co-operative helps in the provision of equipment, seeking government support for items such as diesel generators, cellar stores, grading machines and juice makers. Profits are divided among farmers, co-operatives and the umbrella organisation at a ratio of 40:40:20, respectively.

5.3 Commercial enterprises and industries

To support their business operations, commercial enterprises and industries have a demand for agri-equipment. The Guthichaur Agro apple farm in Jumla, which has 22 ha of land, for example, has an annual production of 150 000 kg of apples, enabled by mechanised farming. The enterprise invested in the purchase of equipment, such as apple graders, with this significantly increasing processing efficiency (see Table 7 for a comparison between manual and mechanised equipment use). Similarly, another apple farm[32] visited in the study had invested in small agri-equipment, such as sprayers, juice makers and apple graders, with the support of government grants.

A common challenge to all these farms, however, remains the lack of reliable electricity supply from the national grid. This results in a need to depend on diesel generators to power equipment (see Table 7 for the details of electrical equipment powered by diesel generators).

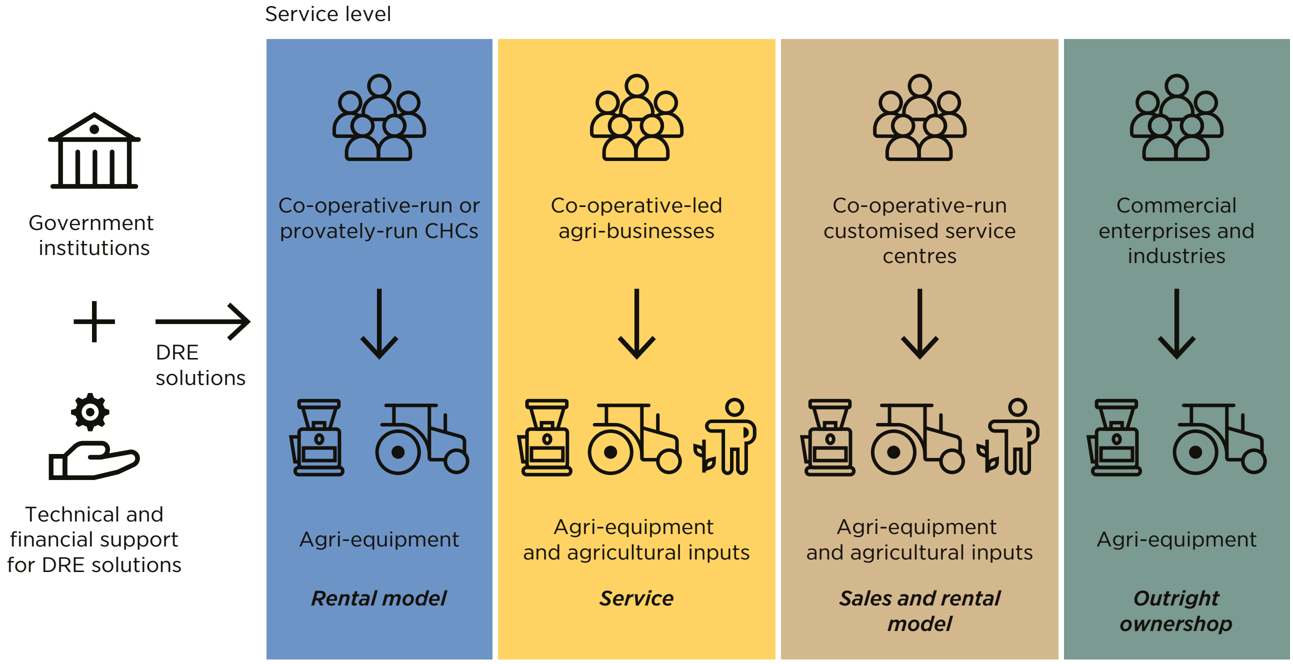
Each of the above three support modalities has its advantages and limitations. A comparison between them is shown in Table 14.

32 *The farm in question was the Aaankhe Krishi Paryatan Tatha Anusandhan Udhyog, Jumla.*

Table 14 Comparison of the operational modalities

Custom Hiring Centres (existing)				**Co-operative-led agri business** (existing)		**Co-operative-run, customised service centres**(new model proposed during consultations)		**Commercial enterprises and industries** (existing)	
Co-operative-run		**Privately-run**							
Advantage	**Limitations**	**Advantage**	**Limitations**	**Advantage**	**Limitations**	**Advantage**	**Limitations**	**Advantage**	**Limitations**
The model already exists, making integration of new initiatives easier.	Without carefully determined hourly rental rates and efficient management, the co-operative does not collect enough revenue to expand and upgrade its services.	The model already exists. However, it is limited to wealthy farmers.	Being a single owner, the choice of equipment is generally limited to small agri-equipment unless government and development programme support is received.	The model already exists, making integration of new initiatives easier.	Without a regulated mechanism of quality control and price negotiation with the farmers, the agri business may fail, resulting in the disposal of agri equipment and DRE.	Operated by co-operatives, keeping the operation centralised.	The model is based on a proposal from consultations. It requires a closer assessment of its risks and viability.	Utilisation of DRE to power agri-equipment and strengthen production, or post-production processes.	The number of large-scale enterprises and industries may be low, limiting the number of DRE interventions.
Operated by co-operatives or farmer groups, keeping the operation centralised.	The revenue source is limited to the renting of equipment with marginally adequate operating costs. This limits the CHC in upgrading and expanding its services.	Due to a single decision-maker, the response to farmer demand is quicker.		Operated by co-operatives, keeping the operation centralised.		Revenue streams are diversified beyond equipment rental services.		Better O&M, since the agri-equipment is tied to production efficiency and revenues.	
Better year-round utilisation of machines compared to individual ownership.		Better O&M, since the revenue is tied to renting of equipment.		Enables produce from smallholder farmers to reach the market via a centralised processing mechanism.		Better O&M, since diversified revenue streams enable timely O&M of DRE and agri-equipment.		May be more willing to financially contribute to DRE solutions to strengthen their process.	
Better O&M, since the revenue is tied to renting of equipment.				Better year-round utilisation of machines compared to individual ownership.					

Figure 16 Proposed support modality



Based on: The Noun Project (thenounproject.com).

Given the different agri-equipment support modalities observed during the study, the mobilisation of DRE should focus on: 1) institutionalised ownership; or 2) privately-owned DRE, but with multiple end users. Supporting DRE solutions for individually owned equipment is not recommended as a focus area (except in the case of solar irrigation). The priority DRE systems identified within this report (such as DRE-powered cold storage and DRE-powered dryers) rely on numerous end users and year-round use to maximise their economic viability. Therefore, operations that are already engaging numerous farmers and already own and operate a substantial amount of agricultural equipment, such as CHCs, will be a key entry point for DRE. These entities are also more likely to be able to effectively manage O&M over the long term.

5.4 Access to finance

With the exception of solar grid-connected systems for the commercial and industrial sectors, DRE in Nepal is heavily driven by support from the government, non-profits, few companies and development programmes.

The financing sector requires awareness and investment confidence, backed up by a technical team, to invest in DREs. In Nepal, only about 61% of the population have access to formal financial services, and of these people, only 40% are formally banked (Choudhary, *et al.*, 2021). Small-scale producers and agricultural enterprises often lack access to credit, while available sources are often informal and unregulated and come with unfavourable terms.

The Priority Sector Lending Programme (PSLP), run by the Nepal Rastra Bank, the central bank of Nepal, requires banks and financial institutions to allocate 10% of their loan portfolios to the agricultural sector. The scheme's guidelines say that loans shall be made available with a 5% interest subsidy on the base rates of the financial institutions. A cap of USD 454 000[33] for businesses and USD 136 000[34] for individuals is also set for producing, processing, and marketing agriculture and livestock commodities (Choudhary *et al.*, 2021).

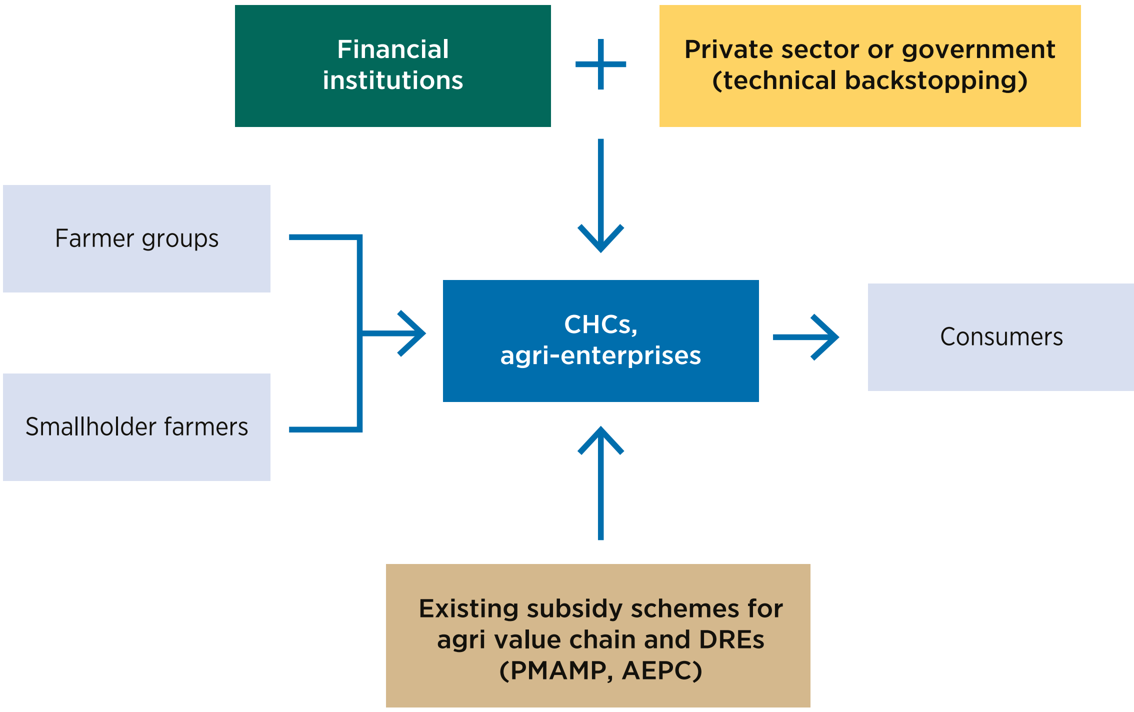
Uptake of this scheme has been poor, however. This is because:

- Financial institutions perceive agri-businesses as high risk.
- Businesses lack business plans – as was observed during this study's field visits in reference to cold storage, for example.
- Businesses lack the required accounting compliance.

To increase access to finance for agriculture enterprises, partial credit guarantees and risk-sharing facilities can be effective mechanisms. This is particularly so when they are accompanied by technical assistance provided to banks (Choudhary *et al.*, 2021).

Further analysis and study of lessons-learnt in implementation is necessary in order to better understand the financing of DRE in the agricultural sector. A potential model for implementation is shown in Figure 17.

Figure 17 Model for mobilising DRE finance in agri-enterprises



Notes: CHCs = custom hiring centre; DREs = decentralised renewable energy; PMAMP = Prime Minister Agriculture Modernization Project; AEPC = Alternative Energy Promotion Centre.

33 Converted from NPR 50 million.
34 Converted from NPR 15 million.

6 Key recommendations

6.1 Cross-cutting recommendations applicable across all technologies

Enhance government co-ordination

The successful implementation of all recommendations outlined below will rely on effective collaboration between MoALD and MoEWRI. This collaboration should focus particularly on PMAMP and AEPC and utilise the expertise of relevant government and non-government bodies.

Specifically, this entails:

- **The sharing of information:** MoALD and MoEWRI – and their respective sub-departments and programmes in particular – and AEPC should conduct joint studies, create mechanisms to share information in a streamlined manner, and engage in regular co-ordination meetings. Where deemed useful, other government entities should be brought in to provide their expertise in programme design and implementation. Such entities include:
  - the Centre for Agricultural Infrastructure Development and Mechanisation Promotion
  - the National Co-operative Federation of Nepal (NCF)
  - the Nepal Agriculture Co-operative Central Federation Ltd. (NACCFL)
  - the Federation of Woman Entrepreneurs Associations of Nepal (FWEAN)
  - the National Agriculture Research Council (NARC)
  - the Agricultural Development Bank Nepal (ADBN).

- **The allocation of budgets for DRE intervention in agri-food:** Joint efforts by both the above ministries to provide annual budgets for DRE. These budgets should enable incentives, technical assistance and capacity building for farmers and co-operatives in order that they can more effectively uptake technologies and improve their productivity.

- **Working closely with subnational governments:** There needs to be meaningful engagement with provincial and local governments to understand needs at the community level. In addition, capacity building and technical support should be given to build up knowhow among subnational government staff.

Ministry and relevant government body	Responsibilities
MoALD and PMAMP	• Identify the energy demands of agricultural enterprises. Focus on addressing energy gaps that are limiting yields and productivity. • Launch communications campaigns to build interest among end users. Improved efficiency and reduced drudgery must be highlighted as significant benefits.
MoEWRI and AEPC	• Focus on commercially viable solutions that can power non-mobile farming equipment. • Focus on supporting enterprises that already serve multiple end users. An existing customer base and round the clock usage will enhance the business case and economic viability of DRE systems. A CHC that rents out farming and post-production related equipment to many farmers within a region, for example, would be a good entry point for DRE systems. • O&M needs to be considered alongside any programme interventions, including an assessment of what technical skills exist at the local level already and how they can be enhanced to meet the needs of newly introduced technology. Poor maintenance can lead to unused or underused systems. • Providing business support to farmers and agricultural enterprises alongside any government subsidies will help to ensure that the planned interventions are economically viable before any substantial investments are made.

Integrate gender equality in scaling up DRE for agricultural mechanisation

To effectively support gender equality in the agricultural sector, it is essential to integrate gender considerations into all initiatives. It is also necessary to specifically assess the potential a given intervention has for improving the livelihoods of women. This involves ensuring women are actively involved in decision-making processes and providing targeted training and feasibility studies to facilitate women's participation in operating machinery.

The design of programmes should also be underpinned by feasibility studies to assess the interest of women in utilising DRE and/or DRE-powered equipment, along with their ability to do so.

Specifically, this entails:

- **Assessing the value chain for the greatest impact on women:** Assessing women's participation within the value chains at a more granular level would also help to identify areas for the greatest opportunity to improve women's livelihoods. Within this study, post-production activities were highlighted as having a very high level of female participation. Therefore, these areas could be prioritised for gender-specific interventions – for example, in DRE for drying and packaging. Introducing capacity-building programmes in post-production processing and new opportunities for product diversification could also serve to increase the demand for DRE, while also contributing greatly to the livelihoods of women.

Ministry and relevant government body	Responsibilities
MoALD and PMAMP	Ensure that any leadership teams taking decisions about DRE implementation for agricultural use include equal representation of women. Women must also be equally represented within teams that oversee implementation, monitoring and evaluation. Assess any challenges that women may face in utilising DRE-powered equipment. Design training programmes to address these gaps and empower women to participate. Conduct feasibility studies to further understand the greatest opportunities to reduce drudgery for women within agricultural value chains. Focus interventions on the key areas identified.
MoEWRI and AEPC	Design programmes that encourage female leadership in the area of DRE, including mentorship and scholarship opportunities for women. Work with educational institutions at the local level to understand how female students can support O&M efforts, or deliver capacity-building to end users. Opportunities to attract more female students to technical and engineering programmes should also be considered.

6.2 Technology-specific recommendations

Increase the uptake of solar and bioenergy dryers

While field assessments showed a strong level of interest in DRE-powered dryers, there has been very limited adoption of these technologies within the country to date (limited to a handful of pilot projects). Engagement with stakeholders also revealed limited knowledge about how to transition to solar or bioenergy-based drying. These findings point to the need for a holistic strategy – one which considers awareness and capacity building, business planning and technical support.

Specifically, this entails:

- **Building awareness:** Conducting educational programmes and outreach to inform farmers and enterprises about the benefits of solar drying will help to build demand and increase uptake. Such benefits include: cost savings; a positive environmental impact; and the potential for product diversification.

- **Collaborating with commercial-scale enterprises:** Focusing on integrating DRE-powered drying into commercial-scale operations, rather than small-scale pilot projects, would help enhance the economic viability of the DRE systems. Apple-producing enterprises in Jumla, for example, could diversify products and increase revenue through solar drying. Other value chains, such as in fisheries, should also be examined to see how they can be integrated to enhance overall drying demands and system use. For this, financing and delivery models needs to be considered.

- **Addressing technical challenges:** To ensure adequate drying is possible during the monsoon season, renewable energy-powered dryers (such as solar or bioenergy) could also be connected to the grid, or to existing mini-grids (solar/hydro). This would make it possible to utilise the grid, or mini-grid electricity, when solar resources are not sufficient. There is also a need for capacity building around the most suitable crops for drying, moisture control and quality assurance, in order to ensure effective drying.

Ministry and relevant government body	Responsibilities
MoALD and PMAMP	Map out enterprises that could benefit from the introduction of solar or bioenergy drying, with a specific focus on those that could enhance product diversification and create new revenue streams. Conduct an assessment of mapped enterprises to understand current drying activities, including the use of dryers powered by diesel generators, or those that use firewood.
MoEWRI and AEPC	Create an education campaign for identified enterprises to help them understand the benefits and business case for DRE-powered drying. Develop training programmes and other means to provide technical support to ensure that the systems that are introduced function effectively. Ensure that plans are in place for long-term and sustainable O&M. Help enterprises to access the subsidies that are currently available. These can cover USD 40 to 75% of the upfront costs of solar dryers.

Scale up solar pumping and irrigation

To date, the use of solar irrigation in Nepal has already been significant. This has largely been driven by two factors: the cost savings potential of shifting away from diesel use; and the AEPC-led subsidy programme that helps to cover a portion of the upfront system costs. In addition, the role of the private sector has been particularly helpful in co-ordinating applications and designing and installing systems. The private sector role could be increased by providing access to financing for the balance of system cost that must be provided by the end user, and to address O&M challenges.

The specific recommendations for this scale-up are:

- **Sustain and expand the subsidy and financing model:** The subsidy programme that is already in place should be continued, with the necessary budget allocated to increase deployment levels. This will require ongoing, dedicated budgets into the future, alongside increasing participation from the private sector. Furthermore, to cater to the high demand for solar pumping systems which the government subsidies alone cannot fulfil, affordable financing from financial institutions should be sought which can be potentially unlocked by fostering partnerships between financial institutions and technical partners to provide technical backstopping. This instils the financial institutions with investment confidence.

- **Achieve economies of scale:** Focusing on commercial-scale applications, or community-level implementations would help to achieve economies of scale and make systems more economically viable. It would also improve the long-term management of system maintenance. However, there are currently no incentives designed specifically for community-level installations; this is an area that could be explored further.

- **Address O&M challenges:** Concentrating expansion efforts in specific regions would allow for a more focused approach to the development of localised O&M support. A constraint for timely O&M observed during the field visits was that due to geographically scattered systems, private companies do not find it economical to allocate resources for timely O&M of solar pumping systems. The logistical cost also becomes a burden to users. Additionally, or alternatively, O&M services could be made a requirement in installation contracts that receive subsidies from AEPC and other government bodies. This could address the challenge of a shortage of O&M support available in remote communities, while ensuring long-term system reliability.

- **Scale up usage:** Field assessments revealed that solar irrigation systems that are already in use are under-utilised. Indeed, a capacity utilisation rate of only around 68% was encountered. Increasing usage would significantly improve the return on investment in these systems and improve their business case. Implementing capacity building programmes on integrated farming, where a variety of crops are rotated year-round, could help to scale up usage. Capacity building programmes could also assist farmers in connecting their solar irrigation systems to the grid, allowing them to take advantage of Nepal's net metering system. This would allow systems to send electricity into the grid when not utilised for their primary purpose. This would create a new revenue stream for farmers.

- **Build technical skills at the local level:** Rather than focus on building O&M skills among farmers, the focus should be on training existing local technical and maintenance businesses that already have adjacent skill sets. Such efforts would not only expand their skills base, but also create new revenue streams. Doing so will require a mapping of these individuals and businesses and assessing their level of interest. It could also involve collaboration with local technical schools and engineering colleges to involve students in O&M efforts. This would enhance local support and give students the opportunity for hands-on learning.

Ministry and relevant government body	Responsibilities
MoALD and PMAMP	Conduct assessments to analyse opportunities for the community-level solar irrigation systems to be implemented. Design a capacity building programme on integrated farming techniques to help farmers increase their crop rotations – and therefore increase their usage of solar irrigation systems.
MoEWRI and AEPC	Examine the potential for sustaining or expanding the current subsidy programme for solar irrigation, alongside the necessary budget for doing so. Assess the feasibility of introducing a specific subsidy scheme to encourage community-level systems, which will likely reduce O&M challenges in the long term and improve the overarching business case. Explore how subsidy contracts can be adjusted to ensure that O&M is considered from the outset. For example, consider that O&M must be included as a component of installation contracts. Work with the financial sector to explore how the remainder of the upfront system cost carried by the farmer/enterprise can be financed. Map all existing solar irrigation systems in order to assess the opportunity to introduce local O&M support in key focal areas. This would help to improve system functioning and build confidence in the technology for further uptake. Design training programmes that target local electrical and/or pump services shops. Examine the possibility of engaging local technical schools and colleges in capacity building initiatives. Provide training on how Nepal's net metering system functions and how farmers that already have solar irrigation systems that are underused can take advantage of the programmer and create a new source of revenue.

Scale up the use of existing mini-grids

While the number of mini-grids AEPC deploys annually is increasing, there are some that are under-utilised. A study of micro-hydro mini-grids, for example, shows that some of them operate at a capacity factor of around 20% (Shakya *et al.*, 2015) and as a result, many of these plants even have difficulty generating enough revenue to meet their operating costs. Field observations for solar mini-grids present a similar case.

The AEPC-led subsidy programme covers up to 90% of the cost of solar mini-grid systems with capacities up to 250 kW, if developed by local governments. The programme also covers up to 60% of the costs for systems up to 100 kW developed by private companies, PPPs, co-operatives or communities. The primary goal of the programme is to provide electricity to underserved populations. However, there is significant potential to scale up productive uses, particularly in the agricultural sector, by extending transmission and distribution lines to facilitate electricity use for activities such as irrigation and agri-processing.

Specifically, this entails:

- **Identifying opportunities for the use of existing mini-grids in agriculture:** Many mini-grids have organically attracted agro-processing mills and other operations due to access to affordable and reliable electricity. This trend can be further expanded through targeted communication and outreach campaigns, requiring co-ordinated efforts among professionals in irrigation, agricultural production and the energy sector.

- **Expanding transmission from existing mini-grids:** There is a need to conduct feasibility studies on the potential to expand transmission to identified agricultural zones/enterprises.

Ministry and relevant government body	Responsibilities
MoALD and PMAMP	Identify energy needs among the agricultural activities surrounding existing mini-grids. Build awareness among the farmers and enterprises identified within these areas on the potential to utilise electricity from these mini-grids for their agricultural processes.
MoEWRI and AEPC	Conduct a feasibility study on the potential to expand transmission from existing mini-grids to farmers and enterprises that have been identified within surrounding areas.

Scale up the use of DRE-powered cold storage

There is a significant need for cold storage in Nepal in order to reduce high food waste from spoilage. Despite government and NGO efforts, many pilot projects have failed due to a lack of farmer interest, awareness or familiarity with cold storage. Farmers are not used to storing products for sale later at potentially higher prices. To address this, cold storage implementation should be demand-driven, with a focus on increasing farmer awareness and interest.

Specifically, this entails:

- **Increasing awareness and education:** Conduct targeted awareness campaigns to educate farmers on the benefits of cold storage. These benefits include reducing spoilage and increasing profits by potentially selling produce at higher prices later. Training programmes should be implemented that demonstrate the practical use and advantages of cold storage facilities.

- **Focusing on demand driven projects:** Conduct thorough market research to understand farmers' needs and preferences regarding cold storage. Develop cold storage projects based on demand assessments, rather than top-down government directives.

- **Introducing subsidies for end users:** Develop a subsidy programme that offers financial support to farmers who utilise cold storage facilities. Promote the subsidy programme through agricultural extension services and farmer co-operatives.

- **Providing business support to cold storage owners:** Offer feasibility study support to assess the viability of cold storage projects before implementation. Provide technology support and training on modern cold storage systems and practices. Facilitate business planning workshops that cover key aspects, such as pricing, operations, maintenance and planning.

Ministry and relevant government body	Responsibilities
MoALD and PMAMP	Collaborate with agricultural co-operatives and non-governmental organisations (NGOs) to provide training on the benefits of cold storage, including opportunities to reduce spoilage and increase revenues. Engage end users (farmers/enterprises) to understand their specific cold storage needs. Work with these stakeholders to design and implement programmes that meet their unique needs. Assess the development of a subsidy programme designed to encourage farmers and agricultural enterprises to make use of cold storage. Ensure that efforts are made to streamline the process and provide support to applicants.
MoEWRI and AEPC	Work with enterprises that are interested in cold storage to develop viable business plans. Provide training where needed on topics such as pricing for storage and O&M.

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Appendix A: Methodology for estimated investments

For a broad estimate of the investment potential of DRE for the select agri-value chains, the following methodology has been applied:

- A nationwide cumulative data of agriculture mechanisation support provided by the PMAMP project for FY 2021-2022 was obtained.
- The agri-equipment was then put into two categories:
  - Those with potential for DRE intervention in the short-term (five years) respective to each commodity.
  - Those foreseen to be unrealistic for DRE intervention in the short-term respective to each commodity.

Based on the categorisation, the percentage of agri-equipment with potential for DRE intervention was obtained for each commodity.

- The percentage of agri-equipment with DRE potential was then used to estimate the energy required from DRE solutions and the total potential for fossil fuel offset of the select agri-value chains. In the conversion of diesel and petrol-based energy to the electrical energy required from DREs, a 46% efficiency rating for diesel engines was taken (Shakti Sustainable Energy Foundation and ICF International, 2014).
- Given that DREs include various technologies, the energy required from DRE solutions was further divided into energy required from specific technologies. This was done by dividing the energy based on the percentage of the number of systems per technology implemented by AEPC.

Table A1 Percentage share of DRE systems

Technology	Number deployed to date (AEPC figures)	Share of total systems deployed (%)
Solar mini-grid	37[35]	0.15
Micro/mini-hydro	3 300[36]	14
Improved water mill	11 104	46
Solar water pump (drinking water and irrigation)	3 129	13
Institutional solar power system	3 817	16
Institutional, urban and commercial biogas plant	355	1.5
Solar dryer and cooker	2 464	10
Total	**24 206**	

- Once the energy required from each technology was obtained, an estimation was made of the capacity of the technology required to fulfil the energy requirement. Then, based on the capacity of the technology, the cost of each technology was obtained and cumulatively formed the total estimated investment.

35 Estimated based on the projects implemented by AEPC.

36 Obtained from Techno-Economic Modelling of Micro-Hydropower Mini-Grids in Nepal to Improve Financial Sustainability and Enable Electric Cooking (Clements et al., 2021).

The following limitations and assumptions of the estimated investment derivation must be noted, however:

- The national inventory of agri-equipment support is based on PMAMP data and each item of equipment was further categorised based on its potential DRE intervention.
- The division of energy required from each technology was based on the number of systems deployed by AEPC. As provincial and local governments have also supported DREs, cumulative national data was not available.
- The calculation of energy required from respective DRE technologies assumes that the share of energy required was proportional to the percentage share of DRE technologies deployed by AEPC.
- Power line extensions of solar mini-grids and micro/mini hydro plants, and the estimated number of solar water pumps and institutional solar power systems, were considered for investment estimation.
- Solar dryers were excluded from the costs due to uncertainty over their capacity estimation, as this is specific to the end-use of the commodity.

Appendix B: The energy consumption of each commodity by fuel type

Table B1 Maize: Fossil fuel energy consumption

Share of energy consumption based on production area of maize	2 330 TJ

Fossil fuel energy consumption in the agricultural sector	
Diesel: 90.9%	2 118 TJ
Petrol: 1.4%	33 TJ
Total potential of fossil fuel offset (only diesel and petrol), excluding non-renewable electricity imported via grid	**2 151 TJ**

Note: The percentage of energy consumption by fuel type was obtained from the Nepal Energy Sector Synopsis Report, 2022 (WECS, 2022); Tj = terajoules.

Table B2 Apples: Fossil fuel energy consumption

Share of energy consumption based on apple production area	32 TJ

Fossil fuel energy consumption in the agricultural sector	
Diesel: 90.9%	29.1 TJ
Petrol: 1.4%	0.4 TJ
Total potential of fossil fuel offset (only diesel and petrol), excluding non-renewable electricity imported via grid	**29.6 TJ**

Note: The percentage of energy consumption by fuel type was obtained from the Nepal Energy Sector Synopsis Report, 2022 (WECS, 2022); Tj = terajoules.

Table B3: Fish: Fossil fuel energy consumption

Share of energy consumption based on production area of fish	33 TJ

Fossil fuel energy consumption in the agricultural sector	
Diesel: 90.9%	29.9 TJ
Petrol: 1.4%	0.5 TJ
Total potential of fossil fuel offset (only diesel and petrol), excluding the non-renewable electricity imported via grid	**30.4 TJ**

Note: The percentage of energy consumption by fuel type was obtained from the Nepal Energy Sector Synopsis Report, 2022 (WECS, 2022); Tj = terajoules.

Table B4 Millet: Fossil fuel energy consumption

Share of energy consumption based on production area of millet	583 TJ

Fossil fuel energy consumption in the agricultural sector	
Diesel: 90.9%	574 TJ
Petrol: 1.4%	9 TJ
Total potential of fossil fuel offset (only diesel and petrol), excluding the non-renewable electricity imported via grid	**583 TJ**

Note: The percentage of energy consumption by fuel type was obtained from the Nepal Energy Sector Synopsis Report, 2022 (WECS, 2022); Tj = terajoules.

Appendix C: Estimation of energy from DREs by commodity

In the conversion of diesel and petrol-based energy to the electrical energy required from DREs, a 46% efficiency rating for diesel engines was assumed (Shakti Sustainable Energy Foundation *et al.*, 2014). The efficiency of a petrol engine was ignored because the use of petrol in the agriculture sector is miniscule (1.4%), while the share taken by diesel fuel is 91% (WECS, 2022).

Table C1 Maize: Estimation of energy from DREs

Total energy consumed by commodities (diesel and petrol fuels)	597 378 322 kWh (equivalent to 2 151 TJ)	
Cumulative agri-equipment with potential for DRE intervention in the short term	44%	4 367 pieces
Cumulative agri-equipment not foreseen for DRE intervention in the short term	56%	5 571 pieces
Energy consumed by commodities in the short term	262 502 629 kWh (44% of 597 378 322 kWh)	
Energy required from DREs (with diesel engine efficiency taken into account)	120 751 210 kWh (46% of 262 502 629 kWh)	

Notes: kWh = kilowatt hours; TJ = terajoules.

Table C2 Apples: Estimation of energy from DREs

Total energy consumed by commodities (diesel and petrol fuels)	597 378 322 kWh (equivalent to 2 151 TJ)	
Cumulative agri-equipment with potential for DRE intervention in the short term	41%	3 845 pieces
Cumulative agri-equipment not foreseen for DRE intervention in the short term	59%	5 593 pieces
Energy consumed by commodities in the short term	3 344 361 kWh (41% of 8 209 123 kWh)	
Energy required from DREs (with diesel engine efficiency taken into account)	1 538 406 kWh (46% of 3 344 361 kWh)	

Notes: kWh = kilowatt hours; TJ = terajoules.

Table C3 Fish: Estimation of energy from DREs

Total energy consumed by commodities (diesel and petrol fuels)	8 446 910 kWh (equivalent to 30.4 TJ)	
Cumulative agri-equipment with potential for DRE intervention in the short term	42%	1 047 pieces
Cumulative agri-equipment not foreseen for DRE intervention in the short term	58%	1 464 pieces
Energy consumed by commodities in the short term	3 522 069 kWh (42% of 8 446 910 kWh)	
Energy required from DREs (with diesel engine efficiency taken into account)	1 620 152 kWh (46% of 3 522 069 kWh)	

Notes: kWh = kilowatt hours; TJ = terajoules.

Table C4 Millet: Estimation of energy from DREs

Total energy consumed by commodities (diesel and petrol fuels)	161 817 399 kWh (equivalent to 583 TJ)	
Cumulative agri-equipment with potential for DRE intervention in the short term	45%	4 464 pieces
Cumulative agri-equipment not foreseen for DRE intervention in the short term	55%	5 554 pieces
Energy consumed by commodities in the short term	72 105 497 kWh (45% of 161 817 399 kWh)	
Energy required from DREs (with diesel engine efficiency taken into account)	33 168 529 kWh (46% of 72 105 497 kWh)	

Notes: kWh = kilowatt hours; TJ = terajoules.

Appendix D: DRE investment required by commodity

Table D1 Maize: DRE investment required

Technology	Energy (kWh)	Annual energy available hours	Equivalent in kW	Average length of extension (metres)	Cost of system	Unit rates	Total cost (NPR)	Total cost (USD)
Solar mini-grid	181 433	1 35037	134	500	NPR 1 900 per metre	1.3 systems	1 276 753 (cost of power line extension)	9 579 (cost of power line extension)
Micro/mini-hydro	16 181 888	5 475	2 956	500	NPR 1 900 per metre	20 systems	18 718 775 (cost of power line extension)	140 436 (cost of power line extension)
Solar water pump (drinking water and irrigation)	16 387 839	1 350	12 139		NPR 494 45838 for 1 hp system (100,000 LPD, 10 metre head)	NPR 662 812 per kW	8 045 971 834	60 364 407
ISPS	19 717 385	1 350	14 605		NPR 468 6771 for 2 kW system	NPR 234 339 per kW	3 422 624 074	25 678 026
Solar dryer	12 082 476				NPR 92 8671 for 21 m^2 system	NPR 5.5 per kWh	65 964 923	494 898
						Total	**11 554 556 358**	**86 687 346 (Approx. USD 87 million)**

Notes: This estimation of the investment required is for the technologies listed that have the most potential for contributing to the objective of this report. The annual energy required is divided based on the percentage of technologies implemented by AEPC in the period 2021-2022; hp = horsepower; kW = kilowatt; kWh = kilowatt hour; LPD = litres per day; m^2 = square metre.

37 Given 300 days of sunshine and 4.5 peak sun hours.
38 Figures from AEPC price list, 2020-2021.

Table D2 Apples: DRE investment required

Technology	Energy (kWh)	Annual energy available hours	Equivalent in kW	Average length of extension (metres)	Cost of system	Unit rates	Total cost (NPR)	Total cost (USD)
Solar mini-grid	2 312	1 350	2	500	NPR 1 900 per metre	0.02 systems	16 266 (cost of power line extension)	122 (cost of power line extension)
Micro/mini-hydro	206 162	5 475	38	500	NPR 1 900 per metre	0.25 systems	238 483 (cost of power line extension)	1 789 (cost of power line extension)
Solar water pump (drinking water and irrigation)	208 786	1 350	155		NPR 494 458[39] for 1 hp system (100,000 LPD, 10 metre head)	NPR 662 812 per kW	102 508 053	769 060
ISPS	251 205	1 350	186		NPR 468 6771 for 2 kW system	NPR 234 339 per kW	43 605 240	327 146
Solar dryer	153 934				NPR 92,8671 for 21m^2 system	NPR 5.5 per kWh	840 413	6 305
						Total	**147 208 454**	**1 104 422 (Approx. USD 1.1 million)**

Notes: This estimation of the investment required is for the technologies listed that have the most potential for contributing to the objective of this report. The annual energy required is divided based on the percentage of technologies implemented by AEPC in the period 2021-2022; hp = horsepower; kW = kilowatt; kWh = kilowatt hour; LPD = litres per day; m^2 = square metre.

39 *Figures from AEPC price list, 2020-2021.*

Table D3 Fish: DRE investment required

Technology	Energy (kWh)	Annual energy available hours	Equivalent in kW	Cost of system	Unit rates	Total cost (NPR)	Total cost (USD)
Solar water pump (drinking water and irrigation)	219 880	1 350	163	NPR 494 458[40] for 1 hp system (100 000 LPD, 10 metre head)	NPR 662 812 per kW	107 954 976	809 926
ISPS	264 553	1 350	196	NPR 468 6771 for 2 kW system	NPR 234 339 per kW	45 922 271	344 529
Solar dryer	162 114			NPR 92 8671 for 21 m² system	NPR 5.5 per kWh	885 069	6 640
					Total	**154 762 316**	**1 161 095 (Approx. USD 1.2 million)**

Notes: This estimation of the investment required is for the technologies listed that have the most potential for contributing to the objective of this report. The annual energy required is divided based on the percentage of technologies implemented by AEPC in the period 2021-2022; hp = horsepower; kW = kilowatt; kWh = kilowatt hour; LPD = litres per day; m² = square metre.

Table D4 Millet: DRE investment required

Technology	Energy (kWh)	Annual energy available hours	Equivalent in kW	Average length of extension (metres)	Cost of system	Unit rates	Total cost (NPR)	Total cost (USD)
Solar mini-grid	49 837	1 350[41]	37	500	NPR 1 900 per metre	0.37 systems	350 705 (cost of power line extension)	2 631 (cost of power line extension)
Micro/ mini-hydro	4 444 920	5 475	812	500	NPR 1 900 per metre	5	5 141 764 (cost of power line extension)	38 576 (cost of power line extension)
Solar water pump (drinking water and irrigation)	4 501 491	1 350	3 334		NPR 494 458[42] for 1 hp system (100 000 LPD, 10 metre head)	NPR 662 812 per kW	2 210 106 617	16 581 189
ISPS	5 416 067	1 350	4 012		NPR 468 6771 for 2 kW system	NPR 234 339 per kW	940 143 002	7 053 365
Solar dryer	3 318 873				NPR 92 8671 for 21 m² system	NPR 5.5 per kWh	18 119 565	135 941
						Total	**3 173 861 653**	**23 811 701 (Approx. USD 24 million)**

Notes: This estimation of the investment required is for the technologies listed that have the most potential for contributing to the objective of this report. The annual energy required is divided based on the percentage of technologies implemented by AEPC in the period 2021-2022; hp = horsepower; kW = kilowatt; kWh = kilowatt hour; LPD = litres per day; m² = square metre.

40 *Figures from AEPC price list, 2020-2021*
41 *Given 300 days of sunshine and 4.5 peak sun hours.*
42 *Figures from AEPC price list, 2020-2021.*

Appendix E: Annual CO_2 emissions offset

For a broad estimate of the potential for carbon dioxide (CO_2) offset, the production area of each commodity and the energy consumption of the agricultural sector are taken as references.

First, the commodity production area is obtained and the share of the production area of each commodity is calculated (Table E1). Second, the total energy consumption of the agricultural sector is taken as a reference and the share in energy consumption of each commodity is calculated (Table E2). Third, the total energy consumption of the four commodities is divided into energy consumption in the agriculture sector by energy/fuel source, *i.e.* diesel, petrol, solar and grid. Then, the cumulative energy from diesel and petrol is considered as the basis for potential fossil fuel offset, as these are non-renewable sources and form the majority of the sector's energy consumption. The mix of non-renewable electricity imported via the national grid is excluded as it requires tracing of the electricity mix imported from India, which contributes an insignificant percentage of Nepal's agricultural energy use.[43]

The overall potential for fossil fuel offset for maize, apples, fish and millet is 2 793 TJ, as shown at the end of Table E3 and calculated based on the methodology described above. The potential fossil fuel energy offset is then converted to equivalent tonnes of CO_2 emissions using the United Nations Framework Convention on Climate Change (UNFCCC) greenhouse gas (GHG) emissions calculator. This results in the potential offset of 206 722 tonnes of CO_2 equivalent (tCO_2eq).

However, the following limitations of the CO_2 equivalent offset estimate must be noted:

- This represents a broad estimate of the national potential CO_2 offset from maize, apples, fish and millet.
- The calculation of energy consumption by commodity assumes that the share of energy consumption is proportional to the share of the production area for each commodity.

Table E1 Share of total agricultural land by commodity

Total agriculture land (cultivated and uncultivated): 4 121 000 ha	Share taken by maize production	979 776 ha (24%)
	Share taken by apple production	13 464 ha (0.3%)
	Share taken by fish production	13 854 ha (0.3%)
	Share taken by millet production	265 401 ha (6%)
	Total area (maize, apples, fish and millet)	**1 272 495 ha (30.9%)**

Source: (MoALD, 2023).
Note: ha = hectares.

43 *Grid electricity accounts for only 7.4% of the electricity in the agricultural sector. Furthermore, in FY 2022-2023, NEA imported only 14% of total system energy demand from India.*

Table E2 Share of total energy consumption by commodity

Total energy consumption in agricultural sector: 9 800 TJ	Share of energy consumption based on production area of maize	24%	2 330 TJ
	Share of energy consumption based on production area of apples	0.3%	631 TJ
	Share of energy consumption based on production area of fish	0.3%	32 TJ
	Share of energy consumption based on production area of millet	6%	33 TJ
Total energy consumed by the four commodities			**3 026 TJ**

Source: (WECS, 2022).
Note: TJ = terajoules.

Table E3 Deducing the potential energy offset of the selected commodities

Energy consumption in farms	
Total energy consumption (maize, apples, fish and millet)	**3 026 TJ**

Energy consumption in the agricultural sector by fuel type/energy source and percentage share of total		**Equivalent metric tonnes of fuel**[44]	**Equivalent litres of fuel**	**Equivalent tonnes of CO_2 emissions (tCO_2eq)**[45]
Diesel: 90.9%	2 751 TJ	63 970	75 258 585	206 722
Petrol: 1.4%	42 TJ	956	1 328 224	
Solar: 0.3%	9 TJ	-	-	-
Grid: 7.4%	224 TJ	-	-	-

Source: (WECS, 2022).

Potential for fossil fuel offset (only diesel and petrol), excluding non-renewable electricity imported via grid	**2 793 TJ**
Potential for CO_2 emissions offset	**206 722 tCO_2eq**

Notes: tCO_2eq = tonnes of carbon dioxide equivalent; TJ = terajoules.

44 Given that 1 000 tonnes of gas-diesel oil is equivalent to 43 TJ and 1 000 tonnes of motor gasoline is equivalent to 44.3 TJ.
45 Calculated using the UNFCCC GHG Emissions Calculator.

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