IRENA
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RENEWABLE ENERGY BENEFITS
DECENTRALISED SOLUTIONS IN THE AGRI-FOOD CHAIN

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ABOUT IRENA

The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future, and serves as the principal platform for international co-operation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity.

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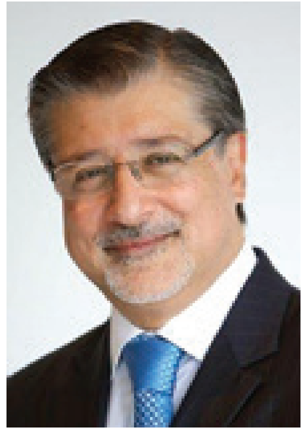
DISCLAIMER

FOREWORD



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The number of people without access to electricity is estimated at more than one billion, with almost 2.9 billion still relying on traditional biomass for cooking and heating. About 80% of those lacking modern energy access live in rural areas, which also host more than 70% of the world's poor, living on less than 1.25 USD a day.

Agriculture and related agri-food activities are at the heart of the rural economy, with a large percentage of households employed in harvesting, agro-processing, and the transport and marketing of produce. Yet, rural communities often struggle with the lack of access and affordability of resources, and they can be limited to producing low-quality goods with little variety.

Combined with high energy costs, this traps rural economies in developing countries in poverty. Without modern energy services, nearly one-third of produce can go to waste. This, in turn, compromises food security.

This publication, the latest from the International Renewable Energy Agency on the socio-economic benefits of renewables, provides a comprehensive analysis of the impact of deploying off-grid renewables in the agri-food sector.

The study finds that introducing these technologies in rural areas can boost agricultural productivity, reduce food losses, thereby improving food security and helping to address malnutrition, and increase resilience to climate variability.

Affordable energy services were recognized as essential ingredients of economic development in the Millennium Development Goals, including the eradication of extreme poverty. More recently, access to affordable, reliable, sustainable and modern energy has been included as one of the Sustainable Development Goals. Increasing access to cost-effective and environmentally sustainable energy services can have a broader development impact through better livelihoods, improved health, gender equality and enhanced education.

Efficient cookstoves, for instance, can cut indoor air pollution and help prevent diseases related to food and water contamination. Meanwhile, off-grid renewables can decrease costs, reduce drudgery, and save considerable time.

By reducing the need for firewood, modern renewables can relieve women, as well as children, of a laborious task. Less time out gathering allows more time for education.

All told, decentralised renewables offer an environmentally friendly and sustainable answer to energy poverty. They are well-suited to rural conditions, relatively easy to develop locally and cost effective compared to other energy solutions.

I am confident that the findings from this report will encourage policy makers from both the energy and the agricultural sectors to support renewable energy deployment. As part of the agri-food value chain, renewable provide an integrated solution to meet multiple sustainable development goals.

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INTRODUCTION

The number of people without access to electricity was last estimated at more than one billion in 2012, and nearly 2.9 billion people worldwide still rely on traditional biomass for cooking and heating. About 80% of those without access to modern energy live in rural areas (SEforALL, 2015) which host more than 70% of the world's poor people[1] (IFAD, 2011). The livelihood of most rural people relies on agriculture, for subsistence through household farming and also for income and jobs. Globally, the agricultural sector sustains the livelihood of nearly 40% of the population, many of whom live in poverty (UN, 2015). In rural areas, agriculture and related agri-food activities are at the heart of the economy, and a large percentage of households generate their income from employment in harvesting, agro-processing, transporting and marketing produce.

However, many rural communities struggle with lack of access and affordability of resources, and often are limited to producing low-quality goods with little diversity. The high cost of energy, vulnerability to price fluctuations and lack of access to modern energy services can trap rural economies in poverty, while affecting food security. Granting rural areas access to affordable, secure and environmentally sustainable energy along the different stages of the agri-food chain can support the development of communities through job creation, poverty reduction, improved health, enhanced access to water and food, better livelihoods and gender equality (IRENA, 2016a).

[1] People living on less than USD 1.25 a day.

This study analyses the impact of decentralised renewable energy solutions on the livelihoods of communities, covering technologies that can be used along the agri-food chain in: 1) primary production activities such as water pumping, 2) post-harvesting activities including agro-processing and food preservation for storage and transport through drying, milling, pressing and cooling, and 3) food preparation and cooking. Analysing the socio-economic benefits of the various applications can play a crucial role in guiding policy making towards adopting energy access approaches that support development in rural areas. This study provides a conceptual framework for presenting these benefits by collecting, analysing and describing the multifaceted impacts that can result from energy access initiatives in the presence of an enabling environment. The analysis (in chapter 1) is structured along a framework that groups the socio-economic benefits into economic, health, environmental and well-being dimensions (see figure 1)[2]. Conceptualising these benefits in a comprehensive framework can be challenging as there is a risk of double counting or overlapping benefits.

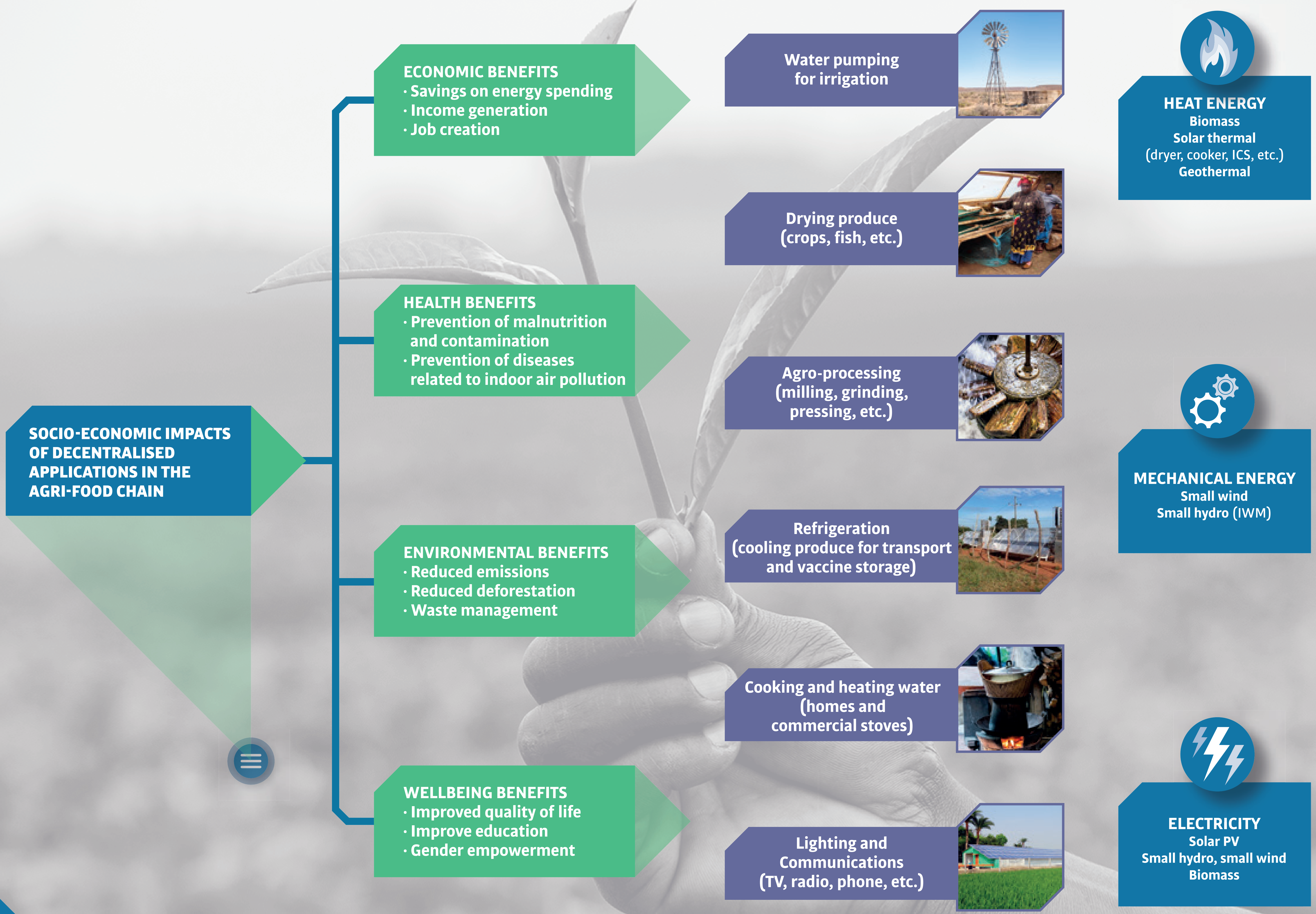
Figure 1 illustrates the different renewable energy technologies that can improve livelihoods along the steps of the agri-food chain. These technologies include: 1) biomass, solar thermal and geothermal energy that can produce heat for food production, drying, cooling and cooking; 2) water and wind mills that produce mechanical energy for agro-processing with the option to simultaneously generate electricity; and 3) solar photovoltaics (PV), small hydropower and small wind and biomass to generate electricity for lighting and powering all sorts of appliances for cooling, processing, and running information and communication technologies (ICT). The technical and practical aspects of each technology are described in chapter 2.

Chapter 3 presents two cases of where the introduction of decentralised renewable technologies resulted in socio-economic benefits for the communities. The first is the introduction of an improved water mill with electrification in a rural village in Nepal, and the second is a national programme for the introduction of biogas digesters in Vietnam. The case studies present data collected on the ground and contribute to the anecdotal evidence on the benefits of decentralised renewable energy.

[2] Different measures of socio-economic benefits exist, *e.g.*, the World Bank World Development Indicators, the UNDP Human Development Index and the UN Sustainable Development Solutions Network (UNSDSN) World Happiness Index. The selected ones meet the objectives of this report in the most appropriate way.

Finally, a conclusion section (chapter 4) provides recommendations to feed the policy discussion on these issues in an effort to maximise the socio-economic benefits of renewable technologies and support their scale-up in the agri-food chain.

FIGURE 1. SOCIO-ECONOMIC BENEFITS OF DECENTRALISED RENEWABLES IN THE AGRI-FOOD CHAIN



01 BENEFITS OF DECENTRALISED RENEWABLE ENERGY SOLUTIONS IN THE AGRI-FOOD CHAIN

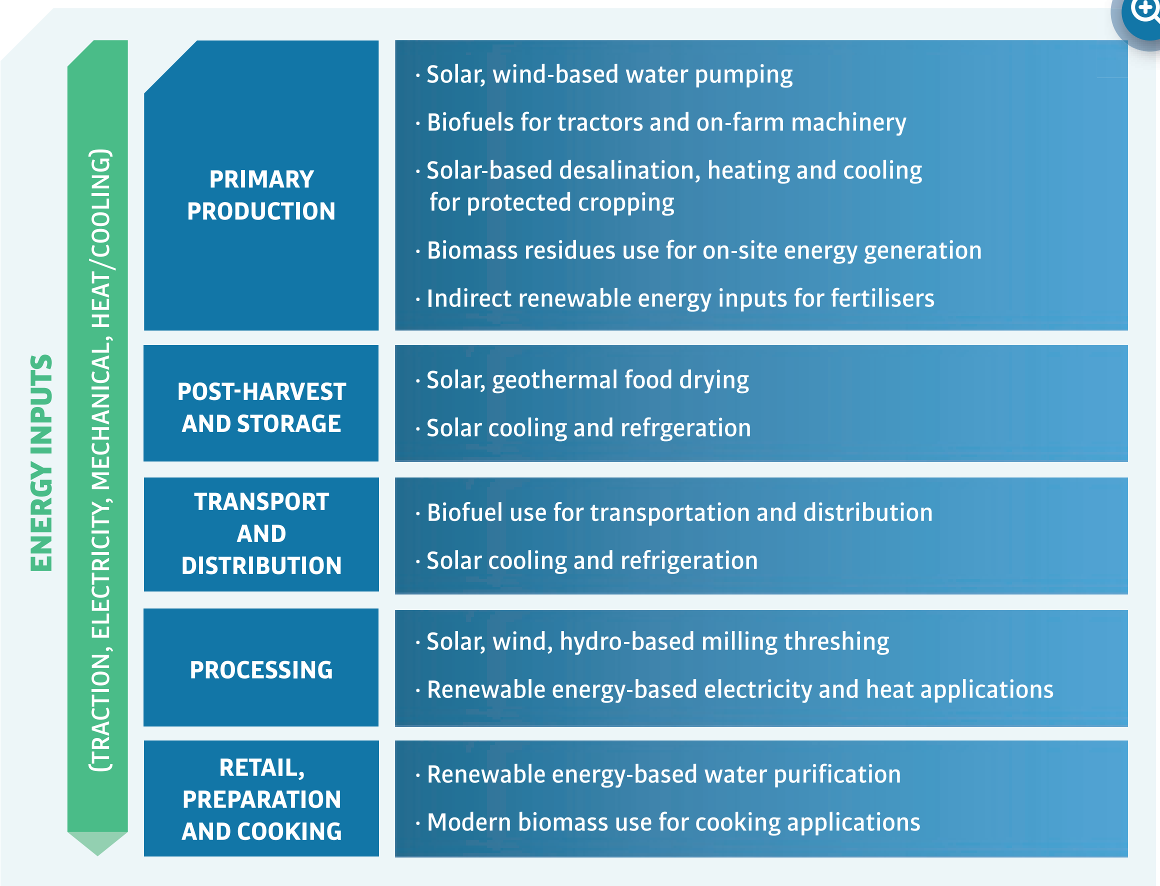
In past decades, food production, storage and processing have been fuelled largely by fossil fuels, and, in rural settings with limited access to fossil fuels, farmers traditionally have relied on animal and human labour or wood fuels. However, the high cost of conventional energy sources, vulnerability to their price fluctuation and the lack of access to energy can limit production in these communities to low-quality goods with little diversity. It is believed that access to affordable, secure and environmentally sustainable energy along different stages of the agri-food chain can support development.

The agri-food chain can be defined as the range of activities needed for a product of agricultural origin to be delivered as a final good to the consumer. It consists of the production and subsequent processing of raw food products into consumer products for local and export markets. The agri-food chain comprises the following stages (see figure 2):

- *Primary production*, which involves land preparation, irrigation, crop cultivation and harvesting and livestock farming.
- *Post-harvest and storage*, which immediately follows the harvesting of products (for crops) and involves cleaning, sorting, cooling and packing the produce. This is followed by the processing of produce when needed.
- *Transport and distribution*, when the raw product reaches the consumer or the processing site.

- *Processing*, which, when applicable, involves transforming the raw product into one that is adjusted to the needs of the consumer. Examples include drying, milling, grinding, pressing, shredding and de-husking.
- At times, the end product is transported again to the consumer and, in the last stage of *food retail, preparation and cooking*, the products are prepared for consumption.

FIGURE 2. ENTRY POINTS FOR RENEWABLE ENERGY IN DIFFERENT STAGES OF THE AGRI-FOOD CHAIN



Source: IRENA, 2015a

The introduction of decentralised renewable energy along the agri-food chain can offer multiple benefits including increased revenues, improved energy security, reduced greenhouse gas emissions and support for further sustainable development goals (FAO, 2011a).

These benefits have been studied widely over the past decade. Building on the existing literature and on the evidence provided by studies in the field, this chapter analyses the impacts that decentralised renewable energy

solutions can have on the livelihoods of rural communities that otherwise lack access to modern energy services. It should be noted that technological solutions for the provision of energy are only part of the solution; they do not guarantee rural development, and the realisation of benefits relies on an enabling environment that includes entrepreneurship, skills, access to markets, access to financing and support through public sector planning.

The following sections analyse the economic, health, environmental and well-being benefits of decentralised renewable energy solutions along the different stages of the agri-food chain.

1.1 ECONOMIC BENEFITS

Assessing the economic benefits of deploying decentralised renewable energy along the agri-food chain requires going beyond the "consumptive use" of energy (for household cooking) to explore its productive uses (see box 1).

BOX 1
PRODUCTIVE USES OF ENERGY

The literature presents different definitions for the term "productive uses" of energy. Some authors use the broader definition by including the use of energy for health and education or for other welfare-related activities that would eventually increase productivity, such as lighting, information and communications, and vaccine refrigeration (Kapadia, 2004). Although health and education do not contribute directly to income generation, they "aim at enhancing income generation opportunities and productivity in rural areas to improve quality of life and increase local resilience and self-reliance" (Etcheverry, 2003). Similarly, the term "productive biogas" has been used beyond the concept of generating income to include broader uses for development, such as health and environment (SNV and FACT Foundation, 2014).

Other authors employ a narrower definition of productive uses of energy, taking into account only uses that "create goods and/or services either directly or indirectly for the production of income or value" that can be achieved by selling products or services at greater than their cost of production, resulting in increased net income (GEF and FAO, 2003). A similar definition is used in the *Productive Use of Energy (PRODUSE) Manual* that defines productive uses of electricity as "agricultural, commercial and industrial activities involving electricity services as a direct input to the production of goods or provision of services" (GIZ *et al.*, 2013).

However, the distinction between productive and consumptive use is not clear. For example, it is not obvious whether preparing extra food for sale while preparing it for one's own consumption, or charging neighbours a fee to watch television, can be considered productive activities (IOB, 2013).

There is growing evidence that decentralised renewable energy solutions can lead to economic benefits in terms of **savings on fuel spending, income generation** and **job creation**, both in the renewable energy supply chain and in induced activities.

1.1.1 SAVINGS ON FUEL SPENDING

Decentralised renewables can enable significant savings on fuel spending, such as for fuel wood, charcoal, kerosene and diesel, especially in remote areas where more than half of the price of the fuel is spent on transporting it, and where most of the appliances used are not efficient (IRENA, 2014a). A study that evaluated the socio-economic impacts of 23 off-grid renewable energy projects to meet a variety of energy needs – including food preparation, lighting, electrification and irrigation – in more than 17 developing countries found that household spending on fuel wood, charcoal or kerosene decreased in 65% of the projects. The decrease was significant in 30% of the cases (a 40% reduction in the case of improved cook stove projects, for example) and was marginal in 35% of the projects (Terrapon-Pfaff *et al.*, 2014).

The potential for savings on fuel, however, is not straightforward. In instances where fuel wood or other energy sources, such as agricultural residues and dung, are collected rather than purchased, the savings can be reported only in terms of time saved on collection, and not in monetary terms. Moreover, the analysis of the potential for savings depends on the level of government subsidy offered to the different energy sources, and on the potential change in energy consumption patterns. A closer look at anecdotal cases in various communities can help provide an understanding of the savings realised from the introduction of renewables in the different stages of the agri-food chain.

- In **food production**, and specifically for irrigation, considerable savings have been reported from the replacement of diesel-powered pumps with renewables-based pumping systems. The use of solar pumps in particular has resulted in economic savings at the national/state level and at the farmer level, in light of the drastic drop in the cost of solar PV (see section 2.1.2). The economic savings of solar pumping solutions are realised at the national/state level and at the farm level.
  - At the national/state level, switching to solar pumps can reduce government spending on subsidies. In the Indian state of Rajasthan, the deployment of 4,000 solar pumps has enabled the saving of 2.4 million litres of diesel fuel, and, consequently, has led to annual savings in government subsidies on diesel of more than USD 350,000 (estimated at INR 24 million for a subsidy of INR 10 per liter of diesel)[3] (see table 3 in section 2.1.2) (Goyal, 2013).
  - At the farm level, savings on fuel spending also can be realised. In India, the replacement of two diesel-powered water pumps with solar pumps in salt farms resulted in annual savings of USD 1,277, enabling the recovery of the investment in three years (SEWA and NRDC, 2015).
- In **post-harvest, storage, transport and distribution,** significant savings can be achieved from the deployment of decentralised renewables for drying produce such as grains, tea, fish and tobacco (see section 2.2). Tea curing is one example, given the level of energy intensity of the process. In Sri Lanka, the production of 1 kilogram (kg) of tea requires 1.38 kg of fuel wood, which can be reduced by 15% if locally fabricated gasifiers are used (Jayah *et al.*, 1999). In Indonesia, the introduction of solar dryers for rubber drying resulted in the reduction of fuelwood consumption from 1.0-1.5 kg to only 0.3 kg of fuelwood per kg of rubber by connecting a solar air heater to the drying chamber (Breymayer *et al.*, 1993).
- In **processing,** considerable savings has been reported from the replacement of diesel generators with decentralised renewables for milling and grinding grains (see section 2.3). In Dokwala village in the Himalayas, the introduction of improved water mills (IWMs) has enabled savings on energy spending for agro-processing activities (rice de-husking) at both the farmer and the community levels (UNDP and Practical Action, 2009). At the farmer level, the tariff rates for agro-processing services using IWMs are almost three to five times less than using diesel-generated processing. Based on an annual output of 50 tonnes of rice, the total annual savings is estimated at around USD 750 per farmer. At the community level, around 420 litres of diesel fuel is saved annually, equivalent to almost USD 458 per year, considering the market price of diesel at the time the study was conducted (see section 3.1.2).
- In **retail, preparation and cooking**, there is heavy reliance on solid biomass such as, specifically in cooking. In most cases, this does not involve cash expenditure but requires significant time investment that can exceed five hours a day per household (Pachauri *et al.*, 2004) (see section 1.4). In

[3] Average exchange rate of USD 1 = INR 58.85 in 2013, when the study was conducted.

Nepal, the time savings realised following the deployment of off-grid technology was conservatively estimated at one hour a day (Malla *et al.*, 2011). In India, the average annual savings on fuelwood collection was estimated at 660 hours per household (Practical Action and GACC, 2014). The economic savings in such cases can be estimated using a monetary value on time spent gathering wood.

Some studies have estimated the savings from replacing traditional energy sources with modern ones. For example, a survey of 464 households in selected developing countries concluded that in Kenya and Sudan, annual savings on purchased fuel wood by introducing improved cook stoves and liquefied petroleum gas (LPG) could exceed USD 20 and USD 46, respectively, per household. This is significant relative to household income below the poverty line (around USD 456 a year). In some cases, however, the replacement of open-fire cooking with improved cook stoves has resulted in little or no savings. This can be due to higher energy consumption, known as the rebound effect (*e.g.*, from a change in cooking behaviour) (IOB, 2013).

In addition to savings achieved on fuel spending, the use of decentralised renewables can lead to opportunities for (additional) income generation along the stages of the agri-food chain.

1.1.2 INCOME GENERATION

The introduction of decentralised renewable solutions can lead to considerable income generation from downstream activities along the agri-food chain, in the form of increased productivity[4]; newly created income-generating opportunities; improved access to markets (through access to information); and reduced food imports. For community members to be able to benefit from this new income generation, however, there must be a demand for the new or additional products or services offered. There is a need to identify the most adequate produce to harvest, as well as to evaluate the right price along with other enabling conditions such as access to markets for the services and products offered, availability of skills required and access to finance (IDS *et al.*, 2015).

[4] Increased productivity is defined as the output of a product or service that can be sold per unit of time per cost of production (accounting for the reduced wastage of produce that can be sold).

Increased productivity

Renewables can boost productivity in the agricultural sector by 1) *enabling the production of higher-quantity and higher-quality outputs* that can be sold in the market, and 2) *reducing the time and cost* of preparing products for sale.

Increasing the marketable output can be done by increasing yields through improved irrigation using water pumps, or by reducing wastage through better storage such as cooling or drying or agro-processing such as making preserves (see table 4).

- In **food production**, renewables-based water pumping can increase yields by up to 300% (Energy4impact, 2016). In Zimbabwe, as a result of introducing solar pumps, household incomes increased by 286% for the very poor, 173% for the poor and 47% for middle-income groups (Oxfam, 2015).
- In **post-harvest, storage, transport and distribution,** decentralised renewable energy can offer solutions for food preservation (see section 2.2.1) and refrigeration (see section 2.2.2). The lack of proper handling causes estimated global losses of as high as 45% for fruits and vegetables and roots and tubers, 35% for seafood and fish, 30% for cereals and 20% for dairy, meat, and oilseeds and pulses (Fridgehub, 2014). Renewables-based storage methods allow farmers to extend the shelf-lives of perishable goods and to keep them in good condition, resulting in better prices and allowing for their transport to wider markets in neighbouring villages.

Reducing the time and cost of production can be facilitated through the use of decentralised renewables in every stage of the food chain, including agro-processing and cooking.

- In the **production** stage, introducing water pumps can reduce the time spent carrying water, and replacing diesel pumps with solar pumps can lead to savings on fuel spending (see section 2.1.2).
- In the **post-harvest and storage** stage, drying produce using solar dryers is much faster than drying it on shelves (see section 2.2.1).
- In the **agro-processing** stage, using machines (driven by renewable mechanical power in cases where electricity access is lacking) for activities such as grinding, de-husking and pressing saves time over performing those activities manually. Having access to the processing machines locally saves farmers the time needed to travel to a neighbouring village for the services (see section 3.1.2).

- In the **retail, preparation and cooking** stage, the cost and time saved from using improved cook stoves or biogas digesters as opposed to open-fire cooking is considerable (see section 2.4).

Table 1 presents additional examples of ways in which income was generated as a result of increased productivity following the introduction of renewables.

TABLE 1. EXAMPLES OF INCREASED INCOME AS A RESULT OF INCREASED PRODUCTIVITY FROM USE OF RENEWABLES IN THE AGRI-FOOD CHAIN

INCREASED PRODUCTIVITY DUE TO	INCREASED OUTPUT DUE TO	ACTIVITY IN THE AGRI-FOOD CHAIN	IMPACT ON INCOME GENERATION
Increased output that can be sold	Increased yields (quantity and quality)	Pumping for irrigation	Irrigation projects in India, Nepal and Tanzania were able to achieve higher incomes through increased agricultural productivity. One irrigation project triggered the establishment of a tree nursery producing seedlings that are sold in the region and beyond to farmer groups, companies and individuals (Terrapon-Pfaff *et al.*, 2014).
	Reduced waste through improved storage	Drying	A solar dryer in Malawi can dry 90 kg of maize grain per batch and has a payback period of less than one year if surplus grain is dried and sold in the market (World Bank *et al.*, 2011).
		Refrigeration	Off-grid refrigeration can save around 35% to 55% of food wasted on the supply chain due to the lack of refrigeration (Fridgehub, n.d.)
Reduced time	Reduced time and cost of agro-processing	Agro-processing	A rice thresher in sub-Saharan Africa produces 6 tonnes of rice/day compared to 1 tonne/day using a manual thresher (World Bank *et al.*, 2011).
Reduced cost	Reduced spending on traditional fuel	Agro-processing	Savings on diesel spending of USD 1,208 per year are realised by introducing an improved water mill in Nepal for grain processing (see section 3.1.2)

Newly created income-generating opportunities

Renewables can support newly established businesses and activities along all stages of the agri-food chain. The deployment of micro-hydropower plants in Indonesia, for example, enabled the development of businesses in egg hatchery, rice milling, coffee grinding and bread making (GIZ and NL Agency Ministry of Foreign Affairs, 2013). Moreover, renewables offer potential for income generation from the production of crops for bioenergy such as bagasse and biofuels.

Improved access to markets

Renewables can contribute to increasing income generation along all of the stages of the agri-food chain by improving access to information related to the market and the weather to ensure that the products are sold in the market, for example. In the **production** stage, access to information can support decision making in identifying market needs, and in the **retail** stage, access to information can help with marketing produce and establishing the right prices, customers, standards and grades of products. This can reduce dependence on traders for identifying the selling prices of produce, which can vary by day and week (Tadesse and Bahiigwa, 2015).

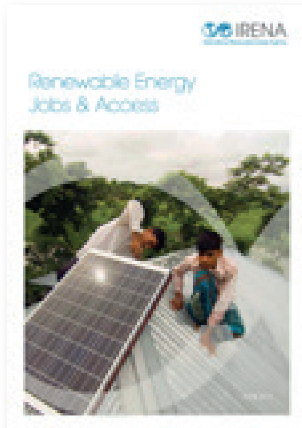
In **all stages of the agri-food chain**, mobile phones and the Internet can facilitate access to information related to advice, guidelines and best practices for improving relevant activities, as well as to risk alerts for drought, floods and diseases, as in the case of Kenya (World Bank, 2016). Mobile phones in rural areas also can facilitate banking activities (money transfer, micro-financing, etc.).

Reduced food imports

Increasing local food production can minimise the need for importing food, reducing import costs and resulting in economic savings.

Finally, the deployment of renewable energy solutions can trigger income generation in the renewable energy sector itself, creating ample job opportunities along the segments of the value chain of renewable energy projects (IRENA and CEM, 2014).

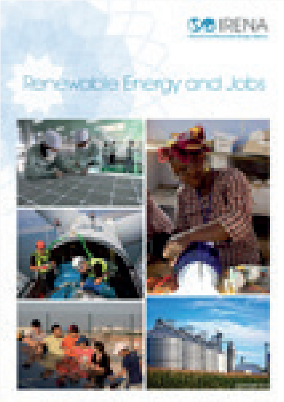
1.1.3 JOB CREATION



Renewable energy deployment can facilitate job creation on two fronts: in the value chain of the technology itself (direct and indirect jobs), and in the induced productive activities that it enables, including businesses related to food production and distribution.

Jobs in the renewable energy sector

The impact of renewable energy deployment on job creation in the rural context has been studied in IRENA's Renewable Energy Jobs & Access and Renewable Energy and Jobs reports. Both studies showcase suc-

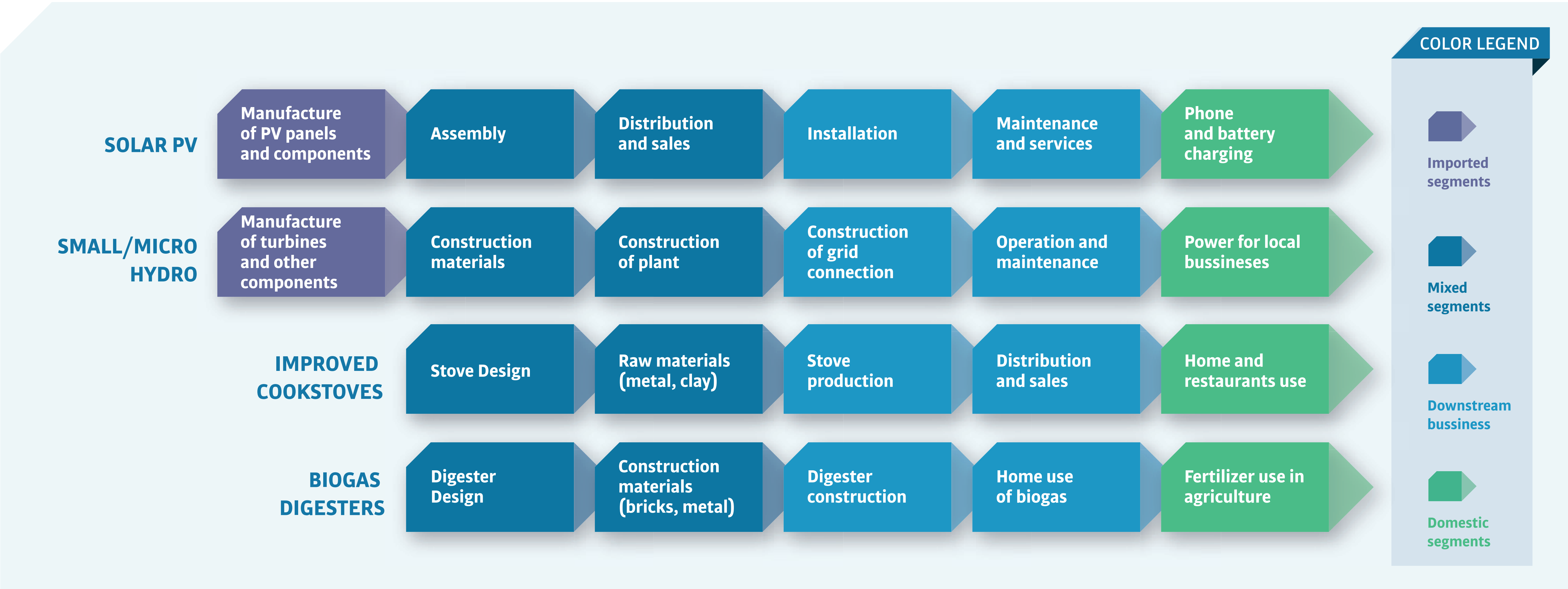


cessful projects and examine how the value chain for renewable energy projects can be integrated in the local economy and generate downstream employment. In the value chain of renewable energy technologies, IRENA estimates that reaching the objective of universal access to modern energy services by 2030 could create at least 4.5 million jobs in the off-grid renewables-based electricity sector alone (IRENA, 2014b).

Jobs can be created directly and indirectly in manufacturing and transporting the equipment, planning and installing the system, connecting it with households through a mini-grid (when applicable), operating and maintaining it, and decommissioning the project after its lifetime (see figure 3). The potential for domestic job creation is technology-specific and depends on the scale of the application (stand-alone or centralised) as well as on the extent of localisation (IRENA, 2012). The analysis of the potential job creation is based on selected technologies that are most widely adopted in rural areas.

- In most cases, solar PV systems are imported and then distributed to retailers, sold, assembled and installed on site, after which they create long-term jobs in maintenance. However, local companies increasingly are engaging in assembling and even manufacturing components, creating jobs in those segments. PV systems potentially could create a substantial number of jobs if locally produced. In Bangladesh, the installation of up to 4.5 million solar home systems led to the creation of jobs in installation, panel assembly and operations and maintenance, rising from 60,000 direct jobs in 2011 to around 127,000 in 2015 (IRENA, 2016b).
- For small hydropower, the main components (such as the turbine) typically are imported, and jobs are created mainly in the construction and installation

FIGURE 3. VALUE CHAINS OF SELECTED OFF-GRID RENEWABLE ENERGY TECHNOLOGIES



Source: IRENA, 2012

of the facilities, with some locally procured materials such as cement. For example, the construction and installation of a small hydropower project can employ 85 people for one year, with an additional 10 longer-term jobs in operation (Jianhe County Tianyuan Hydropower Dev. Co., Ltd, 2014). IRENA estimates that in 2015, around 204,000 people were employed in the sector globally (IRENA, 2016b).

- For biogas digesters, the average digester construction can take place domestically using local materials depending on the type, and it normally requires on average 4 people, including 1 mason team leader, 1.5 skilled masons and 1.5 untrained assistants for a total of 3.7 working days, implying 14.8 human-days per digester. This figure can be up to 30 human-days (6 days for a team of 5 masons) (see section 3.2.2). In addition, more people can be employed in collecting the feedstock in the case where it is considered a formal job.
- Improved cook stoves are more distributed in nature, and they tend to create jobs in manufacturing (in the case of clay stoves, for example) and distribution, rather than in installation and operation. The distributive nature of these applications presents women with job opportunities. For example, 54% of the 76,000 people employed in the improved cook stoves sector by the partners of the Global Alliance for Clean Cookstoves in 2012 were women (GACC, 2012).

To maximise the economic benefits of decentralised renewable energy deployment, the provision of energy access should go beyond meeting basic needs to include energy services for productive uses and creating the potential for induced jobs in all sectors, including activities in the agri-food chain.

Induced jobs in the agri-food chain

Decentralised applications of renewables can have both positive and negative impacts on induced jobs along all stages of the agri-food value chain. Among the positive impacts, the availability of a reliable source of energy can enable new businesses and productive uses that create induced jobs in the longer term. In Ghana, for example, an EnDev project that aims to provide access to modern energy services for productive uses in agriculture and small-scale manufacturing and processing (including solar PV pumps and improved cook stoves) resulted in the development of 1,000 micro, small and medium-sized enterprises and in the creation of 3,000 employment opportunities (EnDev, n.d.).

Another positive induced effect stems from the increased spending capability of the workforce that is employed, directly or indirectly, in the renewable energy sector. The job creation translates into rising incomes and increased spending and consumption of goods and services, resulting in increased economic activity as well as job creation in other economic sectors such as retail, hotels, agriculture and transport.

However, a potential negative effect is that as markets transition from traditional energy sources (diesel, fuel wood) to renewables-based sources, the labour requirements are reduced and workers risk losing their jobs. In the agri-food chain, technologies that mechanise farming operations (such as pumping and grain milling) increase productivity and enable greater output per unit of human labour. In Vanuatu, for example, the grating and grinding of coconut and cassava using solar-powered machinery can take just a few seconds, whereas processing the same amount with manual grinders would take up to 20 minutes (IRENA, 2014c). While this reduces the drudgery of manual farm work, it may also reduce on-farm employment.

In Ethiopia, government action to substitute fuel wood with other fuels for cooking led to unemployment of woodcutters and resulted in a loss of livelihood for 92% of wood providers. The number of people employed in woodcutting dropped from 42,000 to 3,500, and only 2,000 new jobs were created in improved cook stoves. In response to the job losses, the government supported the development of an association to provide alternative employment for female fuelwood gatherers, including as forest guards, in reforestation and water supply projects, and in forestry stewardship positions (UNEP, 2014).

Estimating the potential for job creation from renewable energy deployment in the rural context, including along the agri-food chain, faces specific challenges. Information on the number of jobs created is available only for some programmes or countries and normally lacks detail on, for example, the types of jobs (formal and informal, temporary and permanent), salaries, etc. The informal and temporary nature of many of these jobs makes economic accounting and reporting difficult, although approximations can be obtained using employment factors for different technologies estimated from case studies (IRENA, 2014b).

An important requirement for the successful deployment of decentralised renewable energy technologies that creates opportunities for job creation is the availability of financing and skills. Renewable energy projects should be well integrated with local commercial activities, and local enterprises play an important role in extending access through the adoption of innovative business models that cover financing and capacity building. Most of the technical and commercial skills needed can be developed domestically, thereby strengthening local economic activities and contributing to community development. The transition of manual unskilled labour towards more skilled and commercially oriented occupations (such as those in the renewable energy sector) can be facilitated through education and training and by adopting a forward-looking approach to ensure that the skill requirements are met on time.

The economic development of a community has positive impacts on the health of its citizens, and most of the improvement is enabled by the availability of energy.

1.2 HEALTH BENEFITS

Health and energy are interdependent factors that largely impact the progress of rural development, and in rural areas, access to clean energy is crucial to achieve improvements in health (WHO, 1996). Decentralised renewable energy technologies can contribute to improved health along the agri-food chain through the **prevention of malnutrition and food contamination** – thereby enabling access to sufficient safe and nutritious food and supporting food security and safety – and through the **prevention of diseases related to indoor air pollution**.

1.2.1 PREVENTION OF MALNUTRITION AND FOOD CONTAMINATION

- In the **food production** stage, renewables can improve food security by increasing the quantity of food produced, the frequency of yields and the diversity of products. Irrigation can increase yields by up to 300% (Energy4impact, 2016), and access to water can broaden the range of products (cattle, fruits and vegetables), balancing and improving diets and limiting malnutrition. Moreover, renewables can support farmers in making more informed decisions about their crops (and nutritional choices) through access to communication (see section 1.1.2).

- In **the storage, transport and distribution** stages, renewables can enable the proper handling and storage of produce, which impacts food security by extending shelf-lives, reducing food losses and retaining nutrients (see section 1.1.3). In Kenya, solar dryers have helped maintain the flow of green vegetables throughout the year while reducing waste (Practical Action, 2009). Additionally, the availability of reliable renewables-based cooling – such as solar refrigeration systems – can enable the storage and transport of vaccines for cattle and other livestock (see box 2). The "peste de petits ruminants" disease, for example, is a lethal plague for goats and sheep, and causes over USD 2 billion in losses each year, mostly in Africa, Asia and the Middle East (FAO, 2015a). Veterinary vaccination is important for preventing the spread of diseases that can be transmitted to humans, helping to ensure that animal products are safe for consumption.

BOX 2

PROVIDING SOLAR COOLING SERVICES IN LAOS

In 2012, Sunlabob Renewable Energy implemented a successful project to supply around 44 refrigeration systems to increase the availability of vaccine storage in remote locations in five provinces in southern Laos, benefiting more than 11,000 people. The project was managed by the Ministry of Agriculture and Forestry and locally by the Ministry of Health in collaboration with the Asian Development Bank (ADB). Due to the project's success, the ADB partnered with the Ministry of Agriculture and Forestry and Sunlabob to deliver eight solar-powered cooling systems, helping another 4,000 villagers across three provinces. The systems will be used to store livestock vaccines and critical medical equipment, reducing animal losses due to illness and saving the communities money and time (Sunlabob, 2013).

- In **processing**, decentralised renewables can enable activities such as grinding and pressing grains, fruits and vegetables, etc. These processes can contribute to improved nutrition by transforming (sometimes) inedible produce – such as plants and roots – into products high in nutrients. For example, the processing of prosopis trees into flour results in a product very high in protein, carbohydrates, fibre, sugar and other valuable nutrients, making it an excellent source of nutrients for human and animals and for use in cooking (Practical Action, n.d.a.) The processing of products also makes it possible to preserve their nutritional value over a longer period of time, as flour and oil have a longer lifespan compared to the unprocessed raw material.

SEE MORE ON THE BENEFITS OF AGRO-PROCESSING.

- In **food preparation**, the use of renewable energy and efficient cooking technologies – such as solar cookers, biogas and improved cook stoves – to heat food and boil water can help to destroy micro-organisms and parasites, such as staphylococcus and salmonella, that are hazardous to human health. Consumption of polluted water causes 4% of all deaths in rural areas on average, and approximately 1.6 billion cases of diarrhoea are reported worldwide each year, killing nearly 760,000 children under five (WHO, 2013). It is estimated that around 1.4 billion people boil water for treatment, half of them using fuel wood (Save the water, 2016). Food-borne diseases also can be life-threatening and caused 420,000 deaths in 2010 (WHO, 2015).

In addition, the deployment of renewable energy and efficient cooking technologies such as solar cookers, biogas and improved cook stoves in the food preparation process can help to prevent diseases related to air pollution.

1.2.2 PREVENTION OF DISEASES RELATED TO INDOOR AIR POLLUTION

The impacts of off-grid renewables on the prevention of diseases related to indoor air pollution are realised at the **food preparation and cooking** stage. Around 2.9 billion people globally depend on coal and solid biomass fuels to cook daily meals on open fires and leaky stoves. Inefficient cooking and heating practices produce high levels of health-damaging pollutants such as carbon monoxide, which remains trapped indoors due to the lack of ventilation in most dwellings. Indoor air pollution contributes to illnesses such as pneumonia, strokes, heart diseases, chronic obstructive pulmonary disease, asthma, blindness and cancer. Almost 4.3 million people – many of them women and children – die every year from exposure to household air pollution (WHO, n.d.), which has been reported to be as threatening as malaria and HIV/AIDS combined (Lelieveld *et.al*, 2015).

In one analysis, the deployment of clean cooking stoves resulted in a 25% reduction in respiratory infections among children (UNCTAD, 2010). However, the extent to which introducing these technologies impacts health depends on the cooking behaviour of the household, as increased or incorrect usage can undermine reductions in indoor air pollution. As another benefit, if the stove emits less smoke, women and children could move closer to it, and, in the case of outdoor cooking, it could be moved inside the kitchen and also be used to heat the house (IOB, 2013).

The use of decentralised renewables can reduce the risk of respiratory diseases and also reduce carbon dioxide (CO_2) emissions, enabling a cleaner environment.

1.3 ENVIRONMENTAL BENEFITS

Renewable energy technologies offer an environmentally friendly and sustainable solution to energy poverty and, when deployed along the agri-food chain, can contribute both to **reduced deforestation and emissions** and to *improved waste management*. The choice of renewable energy technology determines the extent to which environmental benefits are realised.

1.3.2 REDUCED DEFORESTATION AND EMISSIONS

Traditional solid biomass (fuel wood, charcoal, wood pellets, etc.) constitutes more than 65% of the global share of renewable energy, and in some countries more than 90% of the population relies exclusively on traditional biomass fuels (GIZ and GBP, 2014). In rural areas of the developing world that lack access to modern energy services, solid biomass is used daily for cooking and heating, contributing to deforestation and polluting emissions.

In most of sub-Saharan Africa, fuelwood use by rural households is considered sustainable, as much of the wood comes from dead branches or shrubs in lots and woodlands outside of forests (Hiemstra-van der Horst and Hovorka, 2009; Morton, 2007) and is collected by women and children to fuel small fires (UCS, 2011). However, the overharvesting of fuel wood to supply the charcoal industry, servicing mainly urban dwellers, is contributing to widespread deforestation across Africa[5] (Kissinger *et al*., 2012; Karekezi *et al*., 2012). For example, Kenya's population relies on fuel wood and charcoal for 75% of energy needs, yet the country lacks sustainable forest management practices and a developed forestry sector (UNEP *et al*., 2012). The replacement of charcoal use with renewable and efficient technologies in urban areas would have a significant impact on reducing deforestation.

- At the **food preparation** stage, the use of renewable and efficient cooking technologies can reduce deforestation and emissions related to the

[5] In most countries on other continents, deforestation is driven mainly by commercial wood extraction.

inefficient burning of fuelwood and charcoal. However, the overall environmental benefits depend on the technology used and on the behavioural patterns of the consumer. Improved cook stoves can enable more-efficient combustion, leading to lower levels of fuel consumption and reduced gas emissions, with savings of between 20% and 67% depending on the cooking methods they replace (open-fire cooking or less efficient stoves) (IOB, 2013). However, the expected savings may be offset by changes in cooking behaviour as households consume higher levels of energy as a result of reduced price or effort needed (the rebound effect). As for biogas digesters, their introduction in rural Nepal enabled the saving of almost 250 kg of wood per month per household, resulting in a reduction in household fuelwood consumption of 53%. A household with biogas saves an estimated 3 tonnes of fuel wood per year, resulting in annual saving of almost 4.5 tonnes of carbon emissions (using emission coefficients for non-sustainable firewood of 1.5 tonnes of CO_2-equivalent per tonne) (Katuwal and Bohara, 2009).

The introduction of decentralised renewable energy solutions can reduce pollution and emissions in other stages of the agri-food chain as well, such as by replacing diesel-powered machines for water pumping or food processing.

- In the **food production** stage, water irrigation using renewable energy sources can reduce emissions from the use of diesel-powered pumps. In India, it is estimated that 5 million solar pumps can save 23 billion kilowatt-hours (kWh) of electricity, or 10 billion litres of diesel fuel, resulting in an emissions reduction of nearly 26 million tonnes of CO_2 (IRENA, 2015b). In Bangladesh, the deployment of 50,000 solar irrigation pumps could save the country 450 million litres of diesel and reduce emissions by 1 million tonnes of CO_2 annually (IDCOL, 2015).
- In **the transport and distribution** stages, the use of biofuels can greatly reduce emissions from tractors used in agriculture, although this is beyond the scope of the present study.
- In **processing**, the use of decentralised renewable energy solutions such as solar PV, biogas and micro-hydro to enable the grinding and pressing of grains, fruits and vegetables, and other foods has environmental advantages over diesel-generated electricity. In Sri Lanka, the introduction of biomass digesters to replace diesel for tea drying in nine tea factories saved the burning of 1.2 million litres of diesel and almost 3,000 tonnes of CO_2 annually, along with reducing harmful pollutants such as nitrogen and sulphur dioxide (The CarbonNeutral Company, 2011). The digesters run on tea prunings and other residual materials from agriculture.

In many cases, biogas also has proven to be an effective technology for animal waste management.

1.1.3 IMPROVED WASTE MANAGEMENT

The use of biogas, mostly in the **food preparation and cooking** stages, can be an effective solution for managing organic waste, including food scraps, agricultural waste and animal manure, which can contain pathogens and other bacteria. Left untreated, animal waste contributes to soil and water pollution and also releases methane, a greenhouse gas that is almost 21 times more heat-trapping than CO_2 (Karapidakis *et al.*, 2010).

Biogas digesters running on animal manure provide a cost-effective solution for pig farmers in rural Vietnam, both for energy provision and for the treatment of animal waste. The installation of nine digesters enabled saving almost 2,200 tonnes of CO_2-equivalent per year from electricity generation using diesel, as well as the treatment of 8,500 tonnes of manure annually (SNV and FACT Foundation, 2014), reducing the risk of health hazards.

1.4 WELL-BEING BENEFITS

Access to affordable modern energy services and well-being are closely interconnected, but the impacts are difficult to quantify and separate from the other benefits assessed. There have been several attempts to capture, measure and assess the well-being of societies in order to design national policies that are not limited to economic development but that target sustainable development in a broader form (see box 3).

BOX 3

OTHER MEASURES OF COUNTRY PERFORMANCE

The United Nations developed the Happiness Index in 2011, recognising that GDP does not adequately reflect the happiness and well-being of people and focusing instead on indicators related to well-being and quality of life, among other factors. The United Nations Development Programme also has developed the Human Development Index (HDI), which expands the dimension of income to integrate health and education. These two indicators present evidence that access to energy is correlated with positive development.

In addition, the European Union's Beyond GDP initiative aims to develop indicators that include environmental and social aspects, as well as natural resources. Another measure is the Happy Planet Index, which assesses the extent to which countries deliver long, happy, sustainable lives for the people that live in them.

The Government of Bhutan, for example, has developed Gross National Happiness (GNH) as a richer indicator than economic growth (GDP), as it encompasses well-being in factors such as balanced use of time, harmony with the environment, health, governance, knowledge and wisdom, etc. The 2015 GNH assessment, based on a survey of Bhutanese nationals, showed that people living in urban areas are happier than rural residents, that farmers are less happy than other occupational groups, and that men are happier than women, among other findings (Gross National Happiness, n.d.).The impact of renewable energy deployment on the happiness and well-being of rural populations, in particular farmers and women, needs to be considered in policy making, as it can present an opportunity for their improvement. Cost-competitive and reliable energy services result in economic development and improved health care, but there are additional factors that contribute to the well-being of the community. Not having to carry out physically demanding and time-consuming manual work such as collecting wood, carrying water

WATCH A VIDEO ON THE GROSS HAPPINESS INDEX OF BHUTAN.

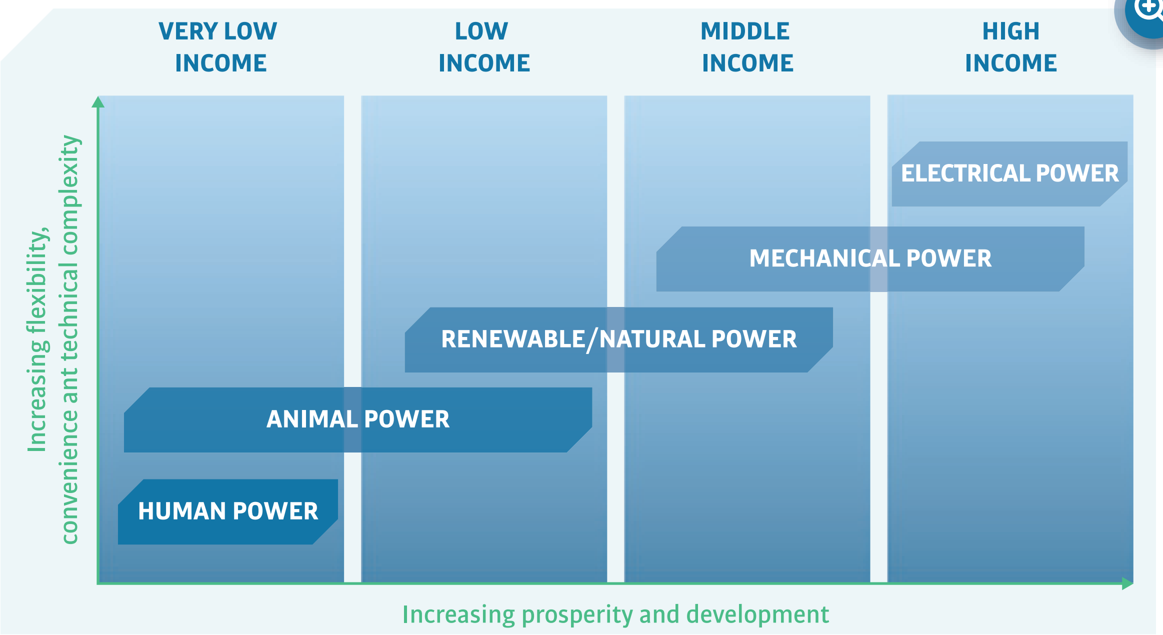
or manually grating coconut, for example, gives more time for education, other productive activities and leisure, which greatly impact the quality of life of people (IRENA, 2016c). Such activities are typically carried out by women and children, and the time savings realised (see section 1.1.1) has an extended effect on education and gender empowerment.

Such considerable time savings, in addition to the reduction of strenuous activities, contributes to the well-being of communities through different dimensions such as **improved quality of life, gender empowerment and improved education**.

1.4.2 IMPROVED QUALITY OF LIFE

Flexible and convenient energy services (natural renewable energy, mechanical energy and electricity) can contribute to the well-being of people. This is why households acquire these more complex energy services as soon as they can afford them. At higher costs, energy sources gain flexibility, convenience and technical complexity. A ranking of the different sources of energy and their impact on prosperity and development is presented in figure 4 (UNDP and Practical Action, 2009). Often, the move of households up the energy ladder and their use of cleaner fuels and technologies demonstrates a higher social status (IOB, 2013). The willingness to pay for these energy services demonstrates their value to rural communities and contribution to their well-being.

FIGURE 4. ENERGY SOURCES



Source: UNDP and Practical Action, 2009

- In **food production**, farmers invest in animals and machinery for land preparation and in powered water pumps to carry water to crops. This improves quality of life through improved yields leading to potentially higher income, and through savings on time that can be spent on more pleasurable activities).
- In **post-harvest, storage, transport and distribution,** the deployment of sophisticated technologies enables food preservation through drying, cooling, pickling, etc. Investing in fossil fuel-based equipment to power dryers and refrigerators improves well-being through reduced malnutrition, the ease of food availability and the ability to enjoy items such as fresh water, ice or ice cream. Investing in renewables to power those activities adds to the well-being of communities through security of supply, reduced need to depend on fuel procurement, and potential savings on fuel spending.
- In **processing,** considerable savings of time and effort can be achieved while carrying out activities such as grinding, pressing, de-husking, grating, etc. Moreover, products such as flour and oil have high nutritional value and can be stored for long periods for food security or sold as commodities for income generation.

- In **retail, preparation and cooking**, improvements in well-being result from more comfortable cooking methods with reduced exposure to indoor air pollution, solutions for waste management, and less time spent on fuelwood collection, along with the mitigation of risk of injuries or accidents during wood collection. Renewables deployment contributes to better health through reduced exposure to more traditional methods of cooking. In the case of biogas, the renewable energy technology also serves as a waste management solution, to rid the village of diseases and unpleasant smells caused by animal manure.

The savings realised on time spent collecting wood and cooking can be invested in education or in productive or leisure activities. A case study on the benefits of biogas deployment in Vietnam showed that 44% of men spent extra time on farm-related activities, 15% on income activities outside of the farm and the rest on leisure. For women, 35% spent the extra time on farm-related activities and only 3% had income-generating activities outside of the farm; 26% spent the extra time on domestic responsibilities such as cleaning the house, 16% on taking care of the children and 19% on leisure (see section 3.2.2). Presenting women with opportunities for productive activities and entertainment contributes to their empowerment.

1.4.3 GENDER EMPOWERMENT

Energy is one of the most essential requirements for sustaining livelihoods and has the potential to support development and poverty alleviation. However, men and women have different energy needs, and energy poverty has a disproportionate effect on women and girls. Moreover, it is estimated that around 70% of the 1.3 billion people living in poverty are women (PCI Global, 2015). Since 2000, gender equality and women's empowerment have been viewed as key drivers in achieving the United Nations' Millennium Development Goals (MDGs) and, more recently, the Sustainable Development Goals (SDGs) (UN, 2014). Access to modern energy services and women's empowerment are interconnected, and the relationship is evident in every stage of the agri-food chain.

- In **food production** and **post-harvest, storage, transport and distribution,** women benefit from reduced time spent on hauling water that can be spent on more productive or pleasurable activities. Moreover, the availability of cooling can offer business opportunities in dairy production (yogurt, mala (similar to sour cream), etc.) that can be undertaken by women (Clancy *et al.*, 2003).

- In **processing,** women benefit the most from reduced time spent on manual work for processing products. Access to processing machinery can encourage women to start businesses in food processing (Clancy *et al.,* 2003).
- In **retail, preparation and cooking**, women benefit the most from reduced time spent collecting fuel wood and cooking, in addition to the mitigated risks of injuries, rape and life-threatening incidents during their search for wood. Moreover, access to clean and easy cooking technologies can encourage women to start businesses in food selling, for example (Clancy *et al.,* 2003).

Women also have a vital role in developing solutions to expand energy access in a cost-effective and sustainable manner. Women generally are the decision makers on energy issues at the household level. Integrating the gender perspective in the design of policies, products and services relevant to energy access is vital for the success of these efforts. The issue of women's empowerment in decision making in energy matters was analysed in IRENA's workstream on jobs. It also was discussed thoroughly during IRENA's Renewable Energy Jobs Conference in Abu Dhabi in January 2014, where participants agreed that the inclusion of gender dimensions in renewable energy strategies would maximise the benefits, both for household consumption and on the micro-enterprise level, where women are primary actors.

WATCH THE SESSION HERE.

The impacts are difficult to quantify, but access to affordable and practical energy services increases the political and economic empowerment of women, encouraging them to take leadership roles and increasing their influence in decision-making processes (Ding *et al*., 2014). Empowering women can lead to additional benefits. As women prioritise education, additional income or savings achieved from reduced spending on fuel is typically invested in children's education.

1.4.4 IMPROVED EDUCATION

Education is the fundamental drive for social change and is a critical foundation to the development of rural areas. This is why the fourth SDG is to ensure that all girls and boys complete quality primary and secondary education with equal access to affordable and quality technical, vocational and tertiary education, including university for all women and men by 2030 (UN, n.d.).

Insufficient time for studying is among the factors inhibiting academic progress in rural areas. The deployment of decentralised renewables in communities that rely on agriculture for their livelihoods can enable better education for community members. This can be done through minimising the time spent on hauling water in the **production** stage, transporting products to nearby villages for processing in the **post-harvest, storage, transport and distribution** stage, manually processing produce in the **processing** stage, and collecting fuel wood in the **retail and cooking** stage.

In addition to freeing up additional hours for income generation, the time savings resulting from renewable energy deployment can be spent on studying, reading or listening to the radio or watching television, which also can be educational (IOB, 2013). In turn, the education of community members can contribute to increasing the productivity of agricultural activities. Renewable energy can enable access to information and can facilitate training of farmers and access to support (Hussain and Byerlee, 1995).

In conclusion, evidence from around the world shows that the adoption of off-grid renewable energy technologies along the agri-food chain offers multiple socio-economic benefits that can impact the livelihoods of the communities where they are deployed, and that contribute to community development in terms of economics, health, environment and well-being. Off-grid technologies can be used to produce heat, electricity and mechanical energy to power activities across all stages of the agri-food chain, offering the potential to overcome many barriers related to energy access.

02 DECENTRALISED RENEWABLES IN THE AGRI-FOOD CHAIN

Granting rural areas access to affordable, reliable and environmentally sustainable energy along the different stages of the agri-food chain can support the development of communities through job creation, poverty reduction, improved health, enhanced access to water and food, better livelihoods and gender equality (IRENA, 2016a).

Decentralised renewable energy solutions play a key role in improving energy access by providing electricity production, heating and cooling, as well as mechanical power in a clean and affordable manner. Applications of off-grid technologies include the use of solar PV for electricity; solar thermal collectors for heating and pasteurisation of dairy products; small hydropower and small wind power for mechanical power and/or electricity; biogas, improved cook stoves and solar cookers for cooking; and biogas with electricity and biomass gasifiers for heating/cooking and electricity (see table 2).

These applications can occur along all stages of the agri-food chain including primary production, post-harvest and storage, processing and retail, preparation and cooking. This chapter discusses the different technologies and applications that can be used; the technical, practical and financial requirements of each; and the benefits they can generate when the information is available.

TABLE 2. APPLICATIONS OF DECENTRALISED RENEWABLE ENERGY SOLUTIONS

TECHNOLOGY	BASIC ELECTRICITY ACCESS FOR GENERAL ACTIVITIES		FOOD PRODUCTION POST-HARVESTING ACTIVITIES INCLUDING AGRO-PROCESSING AND FOOD PRESERVATION FOR STORAGE AND TRANSPORT	POST-HARVESTING ACTIVITIES INCLUDING AGROPROCESSING AND FOOD PRESERVATION FOR STORAGE AND TRANSPORT			FOOD PREPARATION AND WATER PURIFICATION
	LIGHTING AND PHONE CHARGING	LIGHTING AND COMMUNICATIONS (TVs, RADIOS, PHONES, INTERNET)	WATER PUMPING FOR IRRIGATION	DRYING PRODUCE (CROPS, FISH, ETC.)	AGRO-PROCESSING (MILLING, GRINDING, PRESSING, PASTEURISING DAIRIES, ETC.)	REFRIGERATION (COOLING PRODUCE FOR TRANSPORT AND VACCINE STORAGE)	COOKING AND HEATING WATER (HOMES AND COMMERCIAL STOVES)
Pico-scale PV	◆						
Stand-alone solar PV system, including solar home system	◆	◆			◆	◆	
Solar thermal					◆	◆	
Solar cooker							◆
Solar dryer				◆			
Solar/mechanical/wind pump			◆				
Water mill					◆		
Water mill with electrification	◆	◆	◆		◆	◆	
Wind mill					◆		
Wind mill with electrification	◆	◆	◆		◆	◆	◆
Biogas digester							
Biogas digester with electrification/biomass gasifier	◆	◆	◆		◆	◆	◆
Improved cook stove (ICS)							◆

Source: based on IRENA, 2012.

2.1 DECENTRALISED RENEWABLES IN PRIMARY PRODUCTION

Droughts and irregular rainfall patterns have increased globally, contributing to the loss of at least 12 million hectares of arable land every year (UNCCD, 2011). Irrigation is among the measures that can reduce vulnerability to erratic rainfall patterns, substantially improve yields, and also potentially double and triple the quantity of crops grown per year (FAO, 2011b). However, land area with irrigation still represents a marginal share of the total cultivated area, especially in sub-Saharan Africa where only 5% of farmland is irrigated (IWMI, 2010).

Water pumping for crop irrigation and livestock watering requires energy. In areas that lack access to electricity, water pumping systems powered by diesel or petrol engines are used, but they are costly due to fuel transportation and maintenance needs. This is why affordable, renewables-based water pumps, such as solar pumps, are gaining popularity in remote areas, with a major impact on agriculture and especially food production. This section discusses the different renewables-based technologies that can be applied for irrigation using mechanical energy and electricity[6].

[6] Irrigation is not the only activity that can benefit from Renewable Energies solutions in the primary production phase. The use of low enthalpy geothermal heat for heating greenhouses to increase production and heating facilities in livestock farming are being employed lately.

2.1.1 WATER PUMPING USING MECHANICAL ENERGY

The majority of people in rural areas gain access to groundwater either by means of a bucket and rope, or by using manual pumps such as hand pumps, and treadle pumps that require human labour. In addition, wind pumps have been applied for irrigation using mechanical power.

Wind pumps were used widely in ancient Egypt, in Europe in the 13th century as well as in the United States between 1860 and 1900, when the agricultural sector started facing water scarcity (FAO, 1986) and they continue to be widely used today.

Techno-economic characteristics. The two existing types of wind pumps differ according to their technical, operational and economic requirements with regard to material and end-use: affordable wind pumps can be designed and built by farmers as a method of low-cost mechanisation using available materials such as bamboo, ropes and discarded plastic.

However, a wind pump can be more robust with a lifetime of 20 years (around 80,000 operational hours), requiring limited maintenance and no major parts replacements, but at a higher price (UNIDO, n.d.). Some companies have developed for the manufacturing of such pumps, such as the local company Bobs Harries Engineering Ltd. (BHEL) in Kenya, which pioneered the development and manufacturing of Kijito wind pumps and has installed more than 300 wind pumps in Kenya and abroad.

Barriers for scaling up. Despite being well suited for most regions in Africa, Asia and Latin America, the uptake of wind power for water pumping has been generally very slow (Practical Action, 2008). In Africa, the challenges facing the dissemination of wind pumps include community resistance to adoption of the technology and a lack of reliable wind data (Harries, 2002). Moreover, wind pumps typically are used for only a fraction of the year depending on the seasonal crops, and therefore investing in a robust model may not always be economically feasible.

WATCH A VIDEO DEMONSTRATING A WIND PUMP SYSTEM IN AFRICA.

2.1.2 WATER PUMPING USING ELECTRICITY

With increasing water scarcity, off-grid renewable energy technologies can be a reliable method for irrigation in areas that lack access to modern energy. Renewable technologies such as solar, wind and biogas can provide sustainable, secure and cost-competitive electricity for irrigation, and also can serve to power other activities at the same time.

Solar pumps

Solar-powered irrigation has been gaining prominence in the past decade, as one of the measures that can improve yields and reduce vulnerability to erratic rainfall patterns, mostly threatening arid land. The areas that are most affected by changing rainfall patterns normally also have abundant solar resources, making solar pumping an attractive solution.

Drivers for deployment. The adoption of solar pumps has been driven mainly by the drastic drop in the cost of solar PV – around 80% between 2012 and 2015 (IRENA, 2016d). System costs can vary significantly depending on the scale and location of the project and on whether after-sales services are included or not. In India, a system costs around USD 8,100 (JAIN, 2015), and similar figures are emerging from Bangladesh, where a system costs around USD 8,400, with an estimated return payment of five years on account of diesel savings and yield improvements. An even shorter payback time is expected in countries like Morocco, when no battery-backed-up systems are used (FAO, 2016 forthcoming). Another factor driving the wide adoption of solar PV pumps is the technological improvement of the pumping systems, enabling the market to provide suitable pumping solutions tailored to specific requirements and conditions, including the integration of PV pumps in hybrid systems. Box 4 discusses the **techno-economic characteristics** of different types of solar pumps.

Benefits. The deployment of solar pumps can result in ample socio-economic benefits, focused on economic and environment benefits as well as their contribution to well-being and gender empowerment. With regard to the economic impacts, solar solutions increasingly are becoming cost-effective solutions in many developing countries including Bangladesh, Benin, Chile, Egypt, India, Kenya, Zambia and Zimbabwe (IRENA, 2015b). The economic benefits of solar pumping solutions are realised at the national/state level and at the farmer level.

BOX 4

TECHNO-ECONOMIC CHARACTERISTICS OF SOLAR PUMPS

Solar pumping systems are fairly easy to operate, with minimum training requirements. Several configurations can be found in the market, and the selection of the most appropriate one depends on context-specific needs and preferences.

One factor to consider is the possibility for the solar panels to be tilted to maximise direct sunlight. Another factor is the mobility of the panels, as they can be placed in direct sunlight, avoiding shadows and obstacles to maximise pumping output. In addition, transportable systems can be shared among different households and can be stored securely to reduce the risk of theft. However, transport of the system requires manpower and effort, especially over long distances.

The possibility of including batteries is another configuration that can be considered as it permits irrigation at night and in early morning hours, a practice that is encouraged for reducing water consumption. However, adding a battery increases the cost and the maintenance needs of the system. The battery life expectancy is still a weak point in this technology, hence most of the systems available in the market consist of a pump that runs directly off solar panels. Other methods for storage include storing water in a holding tank when the system is running at full capacity for usage when the sun is not shining.

WATCH A VIDEO DEMONSTRATING A SOLAR PUMPING SYSTEM IN SENEGAL.

- At the national/state level, reductions in government spending on subsidies can be achieved. In the Indian state of Rajasthan, the deployment of 4,000 solar pumps has enabled the saving of 2.4 million litres of diesel fuel, and consequently, government subsidies on diesel fuel saved exceeded USD 350,000 annually (estimated at INR 24 million for a subsidy of INR 10 per litre of diesel)[7] (see table 3) (Goyal, 2013).

[7] Average exchange rate of USD 1 = INR 58.85 in 2013, when the study was conducted.

TABLE 3. MEASURABLE INDICATORS FROM THE RAJASTHAN SOLAR PUMP PROGRAMME

ITEM	UNIT	TOTAL
No. of pumps in 2012-2013	no.	4,000
Average solar pump capacity	KWp	3
Equivalent electric power saved (4,000 x 3 kWp)	kWp	12,000
Duration in hours a pump runs/day	hINR	6
No. of units saved per day	kWh	18
No. days a pump run in a year	days	200
No. of electric units saved per pump per year 18 x 200	kWh	3,600
Cost per kWh of electricity	INR	5
Money saved by solar pump per year 3,600 x 5	INR	18,000
Conventional grid distribution capital cost saved (not considered)	INR	-
Diesel cost saved per year (diesel generation twice costly than electric)	INR	36,000
Diesel saved per pump per day	litre	3
Diesel saved per pump per year	litre	600
Diesel saved total per year (4,000 x 600)	million litre	2,4
Diesel subsidy saved by Govt. per year (2,400,000 x INR 10/litre)	INR million	24
Diesel subsidy saved by Govt. in 15 years (INR 2.4 Cr x 15 years)	INR million	360
Area irrigated per pump per crop	ha	3
Area irrigated for total 2 crops a year (4,000 pumps x 2 crops x 3 ha)	ha	24,000
Water required for surface irrigation per ha	cubic mtr	5,000
Water saved per Ha due to drip irrigation (40 per cent of 500)	cubic mtr	2,000
Total water saved 24,000 x 2,000	million cubic mtr	48
Total Addl production value due to irrigation through solar pumps	INR million	2,400
CO_2 emissions per litre of diesel	Kg	2.68
Total CO_2 emissions avoided 24,000 litre x 0.29 Kg	tonnes	6,432

Source: Goyal, 2013

- At the farm level, economic benefits are realised through additional income from increased yields, the potential for cropping multiple times in a year and the production of high-value crops. In cases where diesel pumps are replaced with solar pumps, additional benefits include the reduced spending on fuel such as diesel. In India, for example, the replacement of two diesel-powered water pumps with solar pumps on salt farms resulted in annual savings of USD 1,277, enabling the recovery of the investment in three years (SEWA and NRDC, 2015). In Zimbabwe, household incomes increased by 286% for the very poor, 173% for the poor and 47% for middle-income groups after solar pumps were installed (Oxfam, 2015).

In addition, solar pumps have a lower environmental footprint compared to traditional options such as grid electricity and diesel-powered pumps.

- Globally, the deployment of 5 million solar pumps can save 10 billion litres of diesel, translating into emissions reduction of nearly 26 million tonnes of CO_2 (equivalent to annual emissions from 5.5 million vehicles) (Jain *et al.*, 2013).
- At the national level, the installation of 50,000 solar pumps in Bangladesh can save the country 450 million litres of diesel and reduce emissions by 1 million tonnes of CO_2 per year (IDCOL, 2015). On a state level, in the Indian state of Rajasthan, the decrease in diesel consumption from the deployment of 4,000 solar pumps led to 6,432 tonnes of avoided CO_2 emissions in addition to around 48 million cubic meters of water savings per year, due to the increased efficiency of the system (see table 3).

Solar pumping also contributes to the well-being of communities, especially women, as they typically are responsible for fetching the water needed for food production. In a village in Zimbabwe, for example, prior to the deployment of solar pumps, women had to walk at least 4 kilometres each day to carry buckets of water from the dam site to irrigate their gardens (Oxfam, 2015).

Solar pumping also can support women's empowerment through income generation. In Benin, solar pumps were introduced in three Solar Market Gardens farmed by a co-operative of 35-45 women, producing on average 2 tonnes of produce per month and generating approximately USD 7.50 per farmer per week. In the 2013-14 dry season, 27.7 tonnes of produce was cultivated, valued at USD 40,000. The income helped the women feed, educate and provide medical care to their families (Freling, 2015).

Business model. The successful deployment of solar pumps and the realisation of the benefits that they offer depend on a sound business model that ensures the affordability and reliability of the system or service provided. Innovative models that include financing and capacity-building services have proven effective, such as that adopted in Bangladesh by the Infrastructure Development Company Limited (IDCOL) and its partner organisations (see box 5).

Renewables-based pumping also can be powered using electricity from wind or biogas. The technology should be chosen depending on the geographic conditions and available sources at the site.

BOX 5

IDCOL'S SOLAR IRRIGATION PROGRAMME: MICRO FINANCING AND CAPACITY BUILDING

IDCOL's Solar Irrigation Pilot Project started in 2013 with the aim of installing 50,000 solar pumps by 2017, with financial support in the form of grants and loans from development banks such as the Bangladesh Climate Change Resilience Fund (BCCRF), KfW Development Bank, the US Agency for International Development, the ADB, International Development Association (IDA) and the Japan International Cooperation Agency (JICA). The project helped establish a commercial framework for solar irrigation through a fee-for-service model and an ownership model.

In the fee-for-service model, IDCOL provides financing to so-called sponsors or service providers who procure the solar pumps from a list of suppliers previously approved by IDCOL's Technical Standards Committee. The committee sets the technical compliance standards of equipment, reviews product credentials and approves and certifies eligible equipment to ensure quality of the products. The service provider then sells the water to farmers at affordable irrigation rates. A typical financing structure consists of 15% equity, 50% grant and 35% debt. The loan is for a period of 8 years with 9 months grace period over 29 quarterly instalments with an interest rate of 6% annually. The loan is guaranteed through a bank guarantee or land mortgage.

In the ownership model, IDCOL implements the programme through partner organisations, such as Grameen Shakti, which sell solar pumps on microfinance-based credit and install, distribute and maintain the systems. IDCOL provides wholesale financing to participating organisations for relending, and closely monitors programme administration. A similar financing structure is adopted, consisting of 15% equity or down-payment by the farmer, 50% grant and 35% loan to the partner organisation. The loan is for a period of eight years at an interest rate of 6% annually. The partner organisation then offers a loan to the farmer for five years at a 15% interest rate (IDCOL, 2015).

Wind and biogas pumps

Small wind turbines can be used to power water pumps – along with other appliances – using electricity. Similarly, biogas (or solid biofuels) can be used for this purpose, although it is used more commonly used for heating applications such as cooking. Biogas is ideal for animal farms, as it can serve as a waste management solution for animal manure that can be used as feedstock for the digester (section 3.2). Dual-fuel engines for electricity generation are also used (for both biogas and diesel) to ensure continuous functioning when the production of waste is insufficient (Purohit and Kandpal, 2007).

THIS VIDEO FEATURES PURUSHOTTAMBHAI PATEL, A FARMER IN INDIA WHO CONVERTED HIS DIESEL PUMP TO RUN ON A BIOGASDIESEL MIX, ENABLING HIM TO SAVE USD 400 A YEAR ON FUEL SPENDING. IN ADDITION, HE RUNS AN IRRIGATION SERVICE BUSINESS, SERVING A DOZEN NEIGHBOURING FARMERS AT A FEE OF USD 1 PER HOUR.

Table 4 presents the advantages and disadvantages of different renewables-based pumping technologies.

TABLE 4. COMPARISON OF DIFFERENT RENEWABLES-BASED PUMPING TECHNIQUES

	ADVANTAGES	DISADVANTAGES
Manual pumps	• easy to maintain • local manufacture is possible • low capital cost • no fuel costs	• loss of human productivity • often an inefficient use of boreholes • low flow rates
Wind pumps	• unattended operation • easy to maintain • long life • local manufacture is possible • no fuel costs	• water storage required for periods of low wind speed • high system design and project planning needs • not easy to install
Solar PV pumps	• easy to maintain • easy to install • unattended operation • long life • no fuel costs	• high capital costs • water storage required for cloudy days and after sunset • repairs often require skilled technicians
Biogas pumps	• use of dung, benefiting waste management • local manufacture is possible • no fuel costs • can be dual with diesel	• minimum amount of dung required • no unattended operation
Diesel and gasoline pumps	• quick and easy to install • low capital costs • widely used • can be portable	• fuel supplies erratic and expensive • high maintenance costs • short life • noise and fume pollution

Source: based on Practical Action, 2006

Regardless of the technology used, renewables-based water pumping can enable clean irrigation which can increase income for farmers. However, special attention needs to be given to the risk of excessive water withdrawal. The rapidly decreasing costs of technology, the lower operation costs of renewables-based pumps compared to other energy sources (diesel or grid-based), and the growing number of countries announcing large-scale renewables-based pumping plans, taken together, increase the risk of over-withdrawal. As such, a cross-sector view is needed during the phase of programme design, to implement appropriate regulatory measures such as limiting the size of pumps, promoting water-use efficiency, and allowing grid interconnection and integration with other rural electricity loads (IRENA, 2015b).

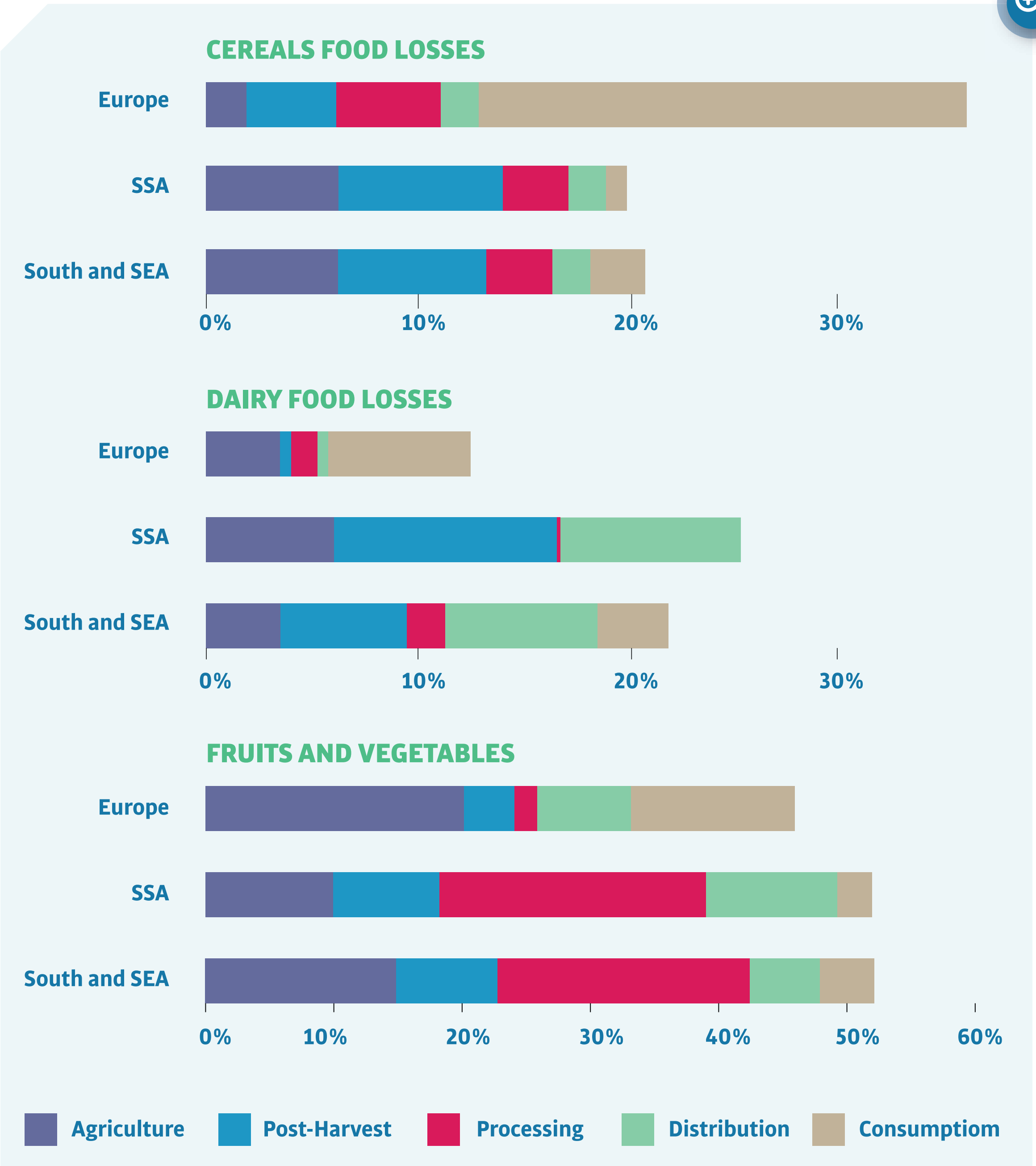
Finally, appropriate methods for post-harvest storage, transport and distribution are essential to sustain value and minimise losses to ensure that the additional crops produced reach the customers in good conditions.

2.2 DECENTRALISED RENEWABLES FOR POST-HARVEST STORAGE, TRANSPORT AND DISTRIBUTION

Almost one-third of the food produced for human consumption – roughly 1.3 billion tonnes – is lost or wasted each year, with a value of USD 1 trillion (FAO, 2012). The per capita food waste in in sub-Saharan Africa and South/South East Asia is estimated at 6-11 kg/year. Although this number is lower than that in Europe and North America (estimated at 95-115 kg/year), it remains considerable in areas with high rates of poverty and malnutrition. In these countries, food losses occur mostly during the early and middle stages of food production and processing.

The lack of proper post-harvest storage, processing and transportation facilities is estimated to cause global losses as high as 45% for fruits and vegetables and roots and tubers, 35% for seafood and fish, 30% for cereals, and 20% for dairy, meat, and oilseeds and pulses. Figure 5 presents the estimated losses of selected foods in sub-Saharan Africa and South/South East Asia. Moreover, almost 50% of fruits and vegetables are lost in sub-Saharan Africa and India, where most of the malnourished people live. In Tanzania, 25% of the milk produced is wasted, and 97% of the meat sold is not properly refrigerated (Fridgehub, 2014).

FIGURE 5. FOOD LOSSES IN DEVELOPING AND INDUSTRIALISED COUNTRIES



Source: FAO, 2012

Given the considerable food insecurity in poor rural areas, minimising food losses where they mostly occur could have a significant impact on livelihoods. This can be done by preserving food through pickling or drying fruits, grains and fish to preserve them longer using heat, or by keeping produce such as fruits, meat and dairy products cooled in cold storage.

2.2.1 FOOD DRYING USING HEAT

Off-grid renewable energy technologies can be used to dry fruit, grains, rice, fish, corn and other agricultural products. Drying food saves for future use a considerable portion of the harvest that otherwise might be lost to mould. The use of a renewables-based dryer is more efficient than the traditional drying method of simply placing the fruit on a shelf under the sun, as the chamber of the dryer protects the fruit from insects, dust and primarily rain, which could damage a large part of the production, especially in tropical areas where rain and humidity are common (AIT, 2006). In addition, a renewables-based dryer makes it possible to dry larger quantities of products in a shorter period of time (Agriculture Solar, n.d.). The most commonly used technology for drying produce is the solar dryer, but other technologies, such as geothermal and biomass, have been considered.

Solar dryers

Solar dryers are practical in rural areas with no access to electricity as they do not require any electric ventilation or back-up heat.

Techno-economic characteristics. Solar energy heats the air and creates an air flow that carries away moisture, which dries the food. Moreover, solar dryers are simple to build using woodworking tools and basic skills (Bhudeva, 2013). Once the items are put in the dryers, the process does not require much attention from the farmers, allowing them to engage in other productive activities. Solar dryers can be built using material available locally, and their construction can employ local workers (AIT, 2006).

Benefits. Benefits associated with the use of solar dryers include the preservation of nutritious products, in addition to economic benefits such as increased income and savings on fossil fuel spending. Solar dryers allow the production of larger quantities and better quality of products that can be sold at a higher price, generating additional income. For example, banana chips produced in Thailand from drying bananas using a solar dryer can be sold for USD 0.36/kg, compared to USD 0.21/kg for chips that are dried over fire or on shelves in the sun, exposed to dust and insects. The increased income from drying 9,600 tonnes of bananas each year in Thailand using solar technology is USD 1.5 million per year (AIT, 2006). Solar dryers also can be used for processing rubber, and the difference in value gained by solar-drying 2.9 million tonnes of rubber over conventional drying in Thailand is between USD 71 million and USD 107 million more in earnings.

Moreover, solar drying can enable savings on fossil fuel and fuel wood spending. In Sri Lanka, for example, 1.38 kg of fuel wood is consumed for drying 1 kg of tea. This figure can be reduced by 15% if locally fabricated gasifiers are used (Jayah *et al.*, 1999). Another example is the introduction of solar dryers for rubber drying in Indonesia, which resulted in the reduction of fuel wood consumption from 1.0-1.5 kg to 0.3 kg of fuel wood per kilogram of rubber (Breymayer *et al.*, 1993). Drying produce also can be done using geothermal energy and biomass.

Drying using biomass and geothermal

Biomass can be used for drying products such as bamboo. Bamboo is a valuable commodity that is used in construction and furniture, but it requires drying to make it suitable for domestic and international markets. African Bamboo, an Ethiopian company, uses a biomass-powered thermal process that combusts the biomass to dry bamboo, as the use of gas provides more heat control than wood. This can benefit more than 2,200 Ethiopian farmers in 30 co-operatives (Powering Agriculture, n.d.). Another option for drying products is the direct use of geothermal energy.

Geothermal energy is increasingly being adopted, especially in the so-called Ring of Fire that reaches from Indonesia, the Philippines and Japan, to Alaska, Central America, Mexico, the Andes and New Zealand. When feasible, geothermal dryers can be used to dry grain crops and beans. The direct use of geothermal heat has been developed in Indonesia for drying cocoa, copra, mushroom and tea (FAO *et al.*, 2015). However, the deployment of this technology faces constraints – including technical and financial barriers – and depends largely on government intervention.

In addition to food drying, refrigeration is a vital method for the preservation of perishable food.

2.2.2 REFRIGERATION USING HEAT AND ELECTRICITY

To reduce losses in the food supply chain, post-harvest storage technologies are needed. Developing refrigeration systems across the entire food supply chain is common in high-GDP countries, but for areas that lack access to electricity, it may prove more challenging (FAO *et al.*, 2015). For instance, approximately 1.5 billion residential refrigerators and freezers are in use globally today, but only about 4% of these units are deployed in sub-Saharan Africa (Wisions of Sustainability, n.d.a), which hosts almost 13% of the world's population. This is due in part to the lack of affordable electricity supply in low-income and off-grid regions. In this case, stand-alone systems based on renewable energy technologies can be used.

It is estimated that increasing access to refrigeration in developing countries can help prevent the spoilage of almost 23% of perishable foods produced (IIR, 2009). In addition, cooling is crucial for the storage of vaccines that are essential in cattle farming. Techniques for storing food include evaporative cooking, thermal cooling using solar energy or biogas, and running a cooling unit powered by off-grid renewables such as solar PV.

Evaporative cooling

In areas with no access to affordable modern technologies, low-cost alternatives such as evaporative cooling can be used to store and preserve food. Evaporative cooling is a basic principle that relies on cooling by evaporation. It is simple and does not require any external power supply (see box 6 for **techno-economic characteristics**). The system can be used for storing food for a longer time, protecting it from humidity and the development of fungi. Moreover, it prevents disease by keeping flies off the food and allows for the conservation of the vitamin and nutrient content of the vegetables (Elkheir, 2004). In India, the project Zero Energy Cool Chamber (ZECC) is training small farmers to build their own low-cost evaporative cooling systems out of bamboo, bricks and sand, to enable them to temporarily store their produce so that they can sell it at the market themselves, at higher prices than they would sell to middlemen (Roy, 2011).

BOX 6

EVAPORATIVE COOLING

Evaporative cooling occurs when air that is not too humid passes over a wet surface. When the water evaporates, it draws energy from its surroundings, which produces the desired cooling effect. The efficiency of an evaporative cooler therefore depends on the humidity of the surrounding air, as dry air can absorb a lot of moisture (providing greater cooling), whereas humid air that is totally saturated with water allows for minimal evaporation.

An evaporative cooler generally consists of a porous material that is fed with water. There are various designs for evaporative coolers, depending on the materials available and the users' requirements. Zeer pot cooling is among them (Practical Action, n.d.b). This "pot-in-pot" system consists of two pots of slightly different sizes. The smaller pot is placed inside the larger pot, and the gap between the two pots is filled with sand, creating an insulating layer around the inner pot. The sand is kept damp by adding water at regular intervals. The system can hold up to 12 kg of vegetables and costs less than USD 2 to produce (Elkheir, 2004).

Benefits. In Darfur, Sudan, the Zeer pot was successful in preserving fruits and vegetables such as tomatoes, carrots, guavas, rocket and okra by extending their shelf-lives by up to two weeks (see table 5), which can lead to an additional 25-30% profit on the income of farmers. The system enabled farmers to sell more of their products due to minimised losses, and to sell them on-demand at favourable market prices rather than being passive price takers (UNDP, 2011).

TABLE 5. EXTENDED LIFE OF VEGETABLES USING ZEER POT COOLING

PRODUCE	SHELF-LIFE OF PRODUCE WITHOUT USING THE ZEER	SHELF-LIFE OF PRODUCING USING THE ZEER
Tomatoes	2 days	20 days
Guavas	2 days	20 days
Rocket	1 day	5 days
Okra	4 days	17 days
Carrots	4 days	20 days

Source: Practical Action, n.d.

Moreover, the production and retail of Zeer pots can create jobs and income, especially for women (*e.g.*, the Women's Association for Earthenware Manufacturing in Darfur). In Nigeria, most farmers remain unemployed during the dry season. The deployment of the Zeer pots created jobs and income for pot makers and distributers, mainly women. However, some products, such as milk, cannot be stored in pots, and other technologies – such as thermal cooling techniques using solar energy or biogas – can be considered.

Solar thermal and biogas cooling

Solar thermal refrigerators can be used for food preservation and for vaccine storage in areas that lack access to electricity and that have a high intensity of solar radiation (see box 7 for **techno-economic characteristics**). Solar thermal cooling systems are still not very affordable, but a pilot project run in Kenya demonstrates the socio-economic benefits that they can achieve (Erickson, 2009).

The ISAAC (intermittent solar ammonia absorption cycle) solar-powered icemaker was pilot tested in Kenya, producing up to 50 kg of ice per sunny day that is capable of chilling up to 100 litres of milk. This can substantially reduce milk losses at the farm level, which can exceed 6% of total production. At 2011 production levels, national annual losses can reach USD 19 million (losses estimated at 60 million kg at USD 0.31/kg) (FAO, 2011c).

BOX 7

SOLAR THERMAL COOLING

Solar thermal systems use solar heat rather than solar electricity to evaporate a refrigerant (commonly a mix of water with ammonia, zeolith or silicagel) and generate the cooling effect (Kima & Infante Ferreirab, 2008). The system mainly consists of a solar collector, a tank for thermal storage, a thermal air conditioning unit and a heat exchanger (Otanicar *et al*., 2012).

The solar energy is harnessed in the thermal collector, increasing the temperature; the refrigerants inside the collector heat up through heat convection, and the hot refrigerants are stored in the thermal storage. The hot refrigerant then runs the thermal AC unit and circulates through the entire system. The heat exchanger transfers the heat between the hot and cold spaces (Ullah *et al*., 2013).

Thermal systems can be suitable for areas with no access to electricity, as they can be made from basic materials and can be designed in a way that enables local production of parts and simple maintenance (Wisions of Sustainability, n.d.b). The installation of the coolers is a straight-forward process that consists of preparing the foundation, positioning and assembling the components, installing the collector, and charging with refrigerant. Local operators can be trained for the installation and maintenance of the icemakers.

Business model. The demonstration project funded by the World Bank consisted of installing three solar icemakers, produced by the Solar Ice Company (SIC) in partnership with the dairy development NGO Heifer Project International.

Benefits. This spurred the establishment of two dairy co-operatives in two rural communities, and the system contributed to food security and helped alleviate poverty through job creation – as it was installed and operated by local technicians – and through additional income generation.

The installation of icemakers induced businesses in milk production for farmers; milk collection, packaging and sale for co-operatives; and the production of yogurt and mala, sold at a higher price than milk. Farmers are paid about USD 0.23 (KES 20[8]) per litre of milk, and co-operatives sell the products at a retail price of USD 0.47 (KES 40) per litre for milk and more for the yogurt and mala. In the first five months of operation, the project generated around USD 19,633 (KES 1,670,806) of revenue, out of which USD 12,150 (KES 1,033,904) was distributed to 184 dairy farmers.

Another example of renewables-based cooling for the preservation of dairy products is biogas-powered systems (see box 8).

[8] USD 1 = 85.1 Kenyan shilling (KES) in 2011, when the study was conducted.

BOX 8

REFRIGERATION USING BIOMASS IN SUB-SAHARAN AFRICA

The lack of proper refrigeration limits the export of dairy products to neighbouring markets in sub-Saharan Africa, since dairy products need to be cooled within four hours after production to fulfil international safety standards. Losses can reach up to 50% of milk production due to the absence or interruption of the cold chain. A biogas-powered refrigerator running on cow manure for feedstock has been developed to help milk supply meet demand. The manure produced by one cow creates enough biogas to refrigerate the milk produced in one day, and enough biogas remains for lighting and cooking purposes (Powering Agriculture, n.d.)

Finally, cooling can be provided using electrical fridges powered by off-grid renewables. In the absence of a mini-grid, fridges can be powered using solar PV.

Electrical cooling

Techno-economic characteristics. Solar technologies can be used to power refrigeration devices. A combination of solar panels and lead batteries is required to provide service overnight and as a back-up during cloudy days, and to avoid power disruptions. Solar refrigerators can be preferred over kerosene or bottled gas-fuelled refrigerators, as they prevent the risk of fuel supply and quality problems, and they offer greater refrigerator reliability and better refrigerator performance (and temperature control). From a cost perspective, they enable savings from spending on procuring and transporting kerosene and from the reduction of food and vaccine losses (Practical Action, 2013).

Although such systems are efficient, there are some drawbacks, such as the need for batteries that increase the price of the installation and maintenance costs, especially in hot climates that cause batteries to deteriorate. The batteries' lifetime is around three to five years, and their replacement adds to the cost of the system. However, a new technology known as "Solar Direct Drive" can store the energy of the sun in frozen tanks instead of in batteries, and can re-use the ice to keep the refrigerator cold during the night and on sunless days. A Solar Direct Drive system is estimated to cost USD 613 compared to around USD 1,015 for a kerosene-fuelled absorption refrigerator (WHO and UNICEF, 2015). PV-powered refrigerators increasingly are being deployed in rural areas that lack access to the grid. Table 6 presents a compilation of pilot projects for the use of solar-powered refrigeration in off-grid settings, including **benefits** and **business models**.

TABLE 6. PILOT PROJECTS FOR THE USE OF SOLAR-POWERED REFRIGERATION IN OFF-GRID SETTINGS

COUNTRY	PROJECT	COST	BUSINESS MODEL AND OWNERSHIP
Nigeria	Cool harvested fruits in solar-powered cold room	USD 88,728	• Local NGO trained on how to build and maintain a solar-powered cold store • Farmers storing products in the cold room pay an amount to the NGO to ensure long-term project financial independence
Senegal	Ice production for off-grid fishing communities with solar PV		• Women's co-operative installs an ice production hall with capacity of 375 kg per 24 hours of ice (3 jobs created per installation earning almost USD 5 per day) • Women trained on business development service and ecological agriculture • Ownership with the co-operatives at sites with high ice demand. Investment and operating costs covered by the sale of ice (at USD 1.66 per 10 kg of ice)
Kenya	PV-powered cold room for the fisheries	USD 55,524	• Technical concept development in consultation with fish farmers, traders, investors and Ministry of Environment • Potential co-investing operators identified and selected. They bring in the fish harvest and treatment infrastructure and staff and provide the land
Tunisia	Solar-powered milk cooling		• Milk cooling solution designed to meet the needs of small and medium-sized dairy farmers to preserve milk during on-farm storage and transportation to collection centres • 10 small-scale milk cooling systems installed, with a capacity of 60 litres per day each, at 6 dairy farms with production volumes ranging from 60 to 180 litres per day • Milk coolers owned by dairy producers and installed on farm. Farmers recoup the investment through increased milk production (reduced waste) and the already existing price premium for cold milk and better quality (the viability of this business and ownership model is still in testing phase)

Source: GIZ, 2016a

Another way to preserve food is to process it into other goods such as flour and oil that retain the nutrients over a long period of time. Renewable energy can be used to power equipment for agro-processing, for example by directly using the mechanical energy of a water or wind mill, or by using the electricity produced by a solar panel.

2.3 DECENTRALISED RENEWABLES FOR FOOD PROCESSING

Renewable energy technologies can supply mechanical or electrical energy that can be used for food processing such as milling grains and pressing vegetables. The term milling refers to the process of size reduction of granular products: milling wheat, for example, means grinding it into flour, whereas rice milling refers to de-husking and polishing, and pulse milling can include separating the husk and splitting the kernel (Rahman, 2007). Pressing vegetables and grains to turn them into oil is another key activity in agricultural production.

Milling and pressing are essential post-harvest activities for most families in rural areas due to the high value of the products as commodities that are traded at local markets and also due to the high nutritional value of grains and edible oils. Having the possibility to grind grains and extract oil can improve the financial security of farmers by facilitating access to higher market prices for their products, and can contribute to their improved health through highly nutritional products (Wisions of Sustainability, n.d.c).

The introduction of motorised mills locally can provide better-quality services, reduce the workload and improve the living standards of rural farmers, particularly women and children. Fuel-driven mills have been deployed in some rural towns, but they require diesel that typically is expensive to procure and transport. Therefore, renewables-based milling machines can

be a viable option for remote communities (GIZ, 2016b), and they can run on mechanical energy such as improved water mills or wind mills, or on electricity such as solar mills or mills running on power from biomass gasifiers or biogas.

2.3.1 AGRO-PROCESSING USING MECHANICAL ENERGY

The deployment of improved water mills or wind mills presents economic benefits related to income generation resulting from increased productivity, improved quality of goods and reduced spending on diesel; and presents health benefits from the preservation of food and nutrients. Moreover, a variation of these technologies, such as the improved water mills with electrification (see section 3.1), can be used to process food during the day, and to produce electricity at night.

Water mills and improved water mills

Water mills can be used for grain milling – such as grinding, hulling, rice polishing and oil pressing – by using the energy produced by the flow of water. Large water wheels transform the kinetic energy of water flow into a rotating movement that rotates a millstone against another, thus grinding the grains. This technology has been used widely in areas lacking access to electricity. There are an estimated 25,000 water mills operating in Nepal, and 200,000 in India (Ashden Awards, n.d.). Recently, improved water mills (IWMs) (see box 9 for **techno-economic characteristics**) have become more prominent, as their utilisation results in considerable economic benefits. A case study on the socio-economic benefits of an improved water mill programme in Nepal has been conducted for this study (see section 3.1).

Benefits. The introduction of IWMs in Nepal has resulted in considerable economic impacts and women's empowerment, among other benefits (see section 3.1.2). The Lal Singh of Dokwala village in the Himalayas, for example, invested USD 810 in an IWM, which gave a return of USD 135 a month and a payback period of about six months as a result of increased grinding capacity and additional services provided. The introduction of the IWM led to an increase in the grinding capacity from around 10-15 kg of grain per hour to about 25–30 kg per hour. The multipurpose IWM that was introduced also enabled electricity generation, therefore providing additional income from selling electricity to households and also promoting new businesses that require electricity (UNDP and Practical Action, 2009).

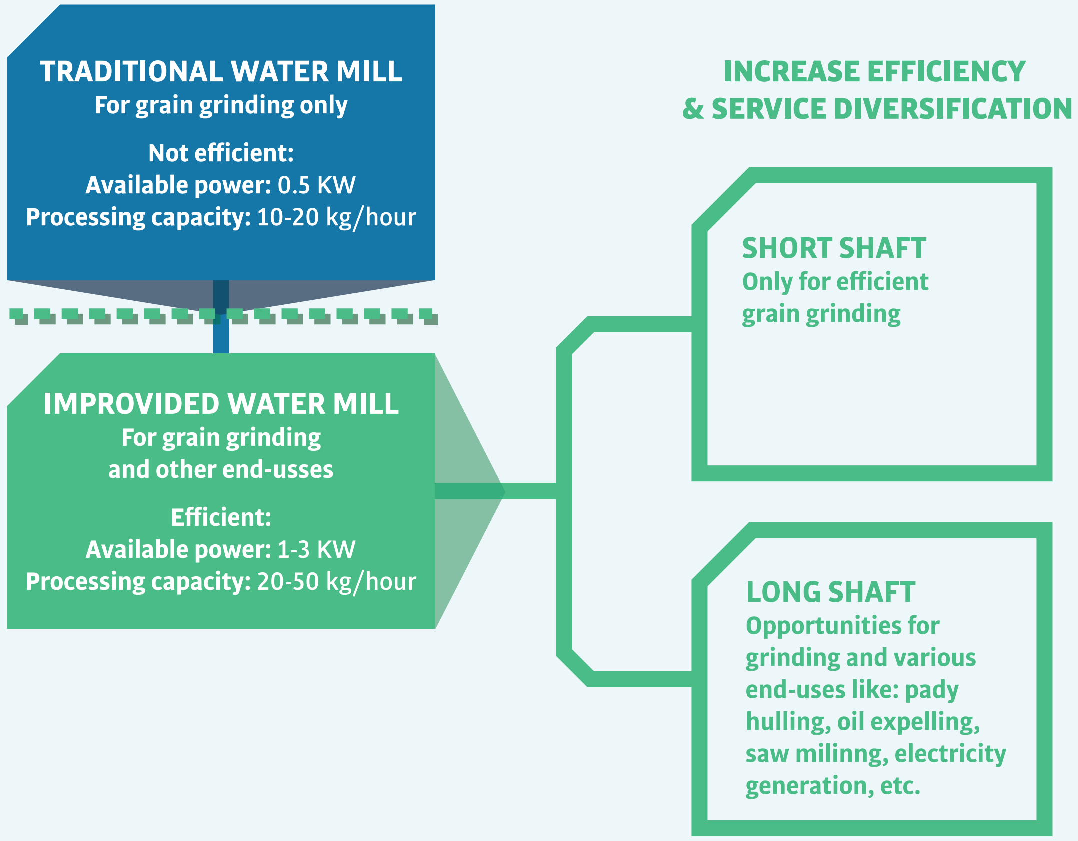
BOX 9

IMPROVED WATER MILLS

The improved water mill (IWM) is a modified version of the traditional water mill with increased efficiency and energy output, improved agro-processing outcomes and also the potential to generate electricity. Improved water mills process cereals at a faster rate (enhanced efficiency by 3 to 5 times) and require minimal maintenance. The replacement of wooden parts – the rotor and shaft – with metallic parts is the main improvement made in the technology (see figure 6) (CRT/N *et al.*, 2014).

Both short-shafted and long-shafted water mills are currently used. The short-shafted mill is solely a grinding mill, whereas the long-shafted IWM provides multiple agro-processing services including grinding, paddy hulling and husking, rice polishing, saw-milling and oil expelling. Moreover, it provides electricity generation for household use

FIGURE 6. TRADITIONAL VERSUS IMPROVED WATER MILL



The economic impact of an improved water mill depends on its model. The short-shafted system provides grinding services only, with estimated annual income averaging almost USD 390 (NPR 39,000[9]), approximately 34% of a family's total annual income. The long-shafted system permits

[9] USD 1 = NPR 98.23 in 2014, but the rate has been rounded up to USD 1 = NPR 100 for simplicity

extra services (electricity generation, saw milling, husking, etc.), enabling income of almost USD 850 (NPR 85,000). This constitutes approximately 74% of a family's total annual income (CRT/N *et al.*, 2014).

Other economic impacts include job creation. The installation of 8,493 IWMs in Nepal has created employment for around 7,572 people. Finally, improved water mills have supported women's empowerment. Among the systems introduced in Nepal, almost 5% are owned by women (CRT/N *et al.*, 2014).

Wind mills

Wind mills are not as popular as water mills as they are more complicated and less reliable. The flow of a river is more predictable and could be controlled to provide the speed or load required by building canals and gates, whereas the wind does not always blow, and when it does, there is no way of controlling the wind velocity and direction. However, not all villages have sufficient water resources or flow, and some rivers even freeze during winter. In these regions, wind mills can be attractive.

Benefits. Initially, wind mills were used for grain grinding and water pumping until other industrial applications emerged such as hulling barley and rice, grinding malt, pressing oil and processing materials (paper production, wood sawing, crushing chalk to make cement, etc.). The use of wind mills increased the efficiency of processing material considerably. For instance, hand sawing was a very labourious task, and windmills greatly reduced the time needed for the process. The amount of time needed to saw 60 beams or trunks only takes 4 to 5 working days using wind milling, compared to 120 days using hand sawing (Low-tech Magazine, 2009). However, it should be noted that such an efficient process for sawing can possibly lead to risks of deforestation. Alternatively, off-grid electricity can be used to power machines.

2.3.2 AGRO-PROCESSING USING ELECTRICITY

Agro-processing machinery can run on power produced by hydro or wind in the presence of a mini-grid, but solar energy or biomass gasifiers or biogas also can be used for more distributed systems when the processing takes part in the fields far from the mini-grid.

Solar mills

Solar mills are suitable for locations with rich solar resources (*e.g.*, tropical areas with high solar radiation and predictable sunshine hours), and, because of their modularity, they can be sized to meet farmers' needs (see box 10 for **techno-economic characteristics**). Moreover, power from solar PV can drive both AC and DC motors to power a mill, and with technological advancement and falling prices of PV technology, solar milling has become increasingly economically viable (GIZ, 2016b). Among the economic benefits of introducing a solar mill is the potential for savings on spending on alternative fuels, in cases where it replaces a diesel-powered mill. For example, 1,200 litres of diesel could be saved per year in Ethiopia through one solar mill. This also results in environmental benefits that can be translated into an estimated reduction of 3.2 tonnes of CO_2 emission per year (Solar Milling, n.d.).

However, solar mills have high start-up costs and generally are not affordable without financial support. The technology also is more prone to breakdowns and requires more training on usage and maintenance than the traditional methods (Wisions of Sustainability, n.d.d). For example, a solar mill was installed in a village in Senegal with power requirement of less than 100 Watts (W). The mill was powered with two 50 W photovoltaic panels and a battery of 85 Amp-hours so that it could process between 15 kilograms and 60 kilograms of grain per day, depending on the solar irradiation (Beshada *et al.*, 2006). However, following installation, the grain mill consumed more electricity than expected, resulting in a disappointing performance of the system. In addition, frequent repairs were required to keep the system running (Wegener, 2011).

BOX 10

SOLAR MILLS

Solar milling works like any electrically driven mill. The solar system for a grain mill usually consists of PV panels, batteries and a charge controller. Some innovative systems do not even require batteries, and the electricity generated by the PV panel is fed directly into the motor drive. This limits the conversion losses, including energy storage losses in batteries, and additional costs related to battery maintenance or replacement, which are a common problem in all conventional solar PV off-grid appliances (No Tech Magazine, 2014).

Biomass gasifiers and biogas-powered mills
Producing gas from biomass provides a reliable, clean source of power for villages and businesses in areas that lack grid electricity, especially for those regions with agricultural or forest waste. Heating organic residues with a limited amount of oxygen produces a gas that can replace fossil fuels for generating electricity or heating.

Benefits. Small-scale systems can assist farmers in agricultural activities by providing electric power for machinery. For instance, Guyana recently opened the first plant with capacity for 600 kg of rice husk, where gas replaces 70% of the diesel consumption needs (FAO *et al.*, 2015). However, attention must be given to the potential enviromental risks of using rice husk gasifiers, as poor maintainance or unproper management can lead to the production of “black water” containing some condensates (ash, tar or char) that may leak into the ground and ultimately into local water sources (Nguyen and Ha-Duong, 2014).

2.4 DECENTRALISED RENEWABLES FOR FOOD RETAIL, PREPARATION AND COOKING

Cooking is one of the main and most traditional forms of water sanitation and of food processing and preparation, yet an estimated 2.9 billion people worldwide in 2012 still lacked access to modern fuels for cooking and heating, relying instead on solid biomass to meet their energy needs (SEforALL, 2015). The use of efficient and clean technologies offers a healthier, less dangerous and more environmentally friendly alternative for meeting energy needs for cooking. In addition, it is more energy- and time-efficient, permitting improved well-being and education (see section 1.4). Efficient and clean technologies include biogas digesters, improved cook stoves and solar cookers.

2.4.1 BIOGAS DIGESTERS

Biogas digesters can be used for cooking and water heating, and they can be installed on a community or household level (see box 11 for **techno-economic characteristics**).

BOX 11

BIOGAS DIGESTERS

Biomass is a gaseous mixture generated during anaerobic digestion processes using organic material (*e.g.*, animal manure or agricultural residues). The feedstock is fed into a digester that can vary in size, starting from 1 cubic metre for a small domestic unit.

The technology is simple, low-cost and low-maintenance, and has been used for decades in areas and communities without connection to the grid. Apart from the availability of feedstock for manure and some water, the requirements of the system are low

Benefits. The deployment of biogas digesters can result in considerable socio-economic benefits, as demonstrated by a pilot project in Vietnam which was later scaled on a national level as a result of its success (see section 3.2). Biogas digesters running on animal manure were considered a solution for pig farmers in rural Vietnam for energy provision and for the simultaneous treatment of animal waste. Nine digesters were installed as a pilot project and were used to produce biogas for cooking, bringing significant environmental benefits (SNV and FACT Foundation, 2014).

Economic impacts include savings on the time spent on gathering fuel wood and cooking, and additional benefits related to using or selling the bio-slurry (preferred over dung as a fertiliser) and selling the biogas produced. The programme resulted in the creation of a market for biogas digesters and in the development of a local industry, creating job opportunities and leading to the development of skills in construction and engineering (a total of 112 trained individuals, including 90 masons and 22 farmers, 10 of whom were women). Other economic benefits resulted from the extension of the farms, as it became easier for farmers to get approval from the government as a result of the reduced environmental issues caused by the manure.

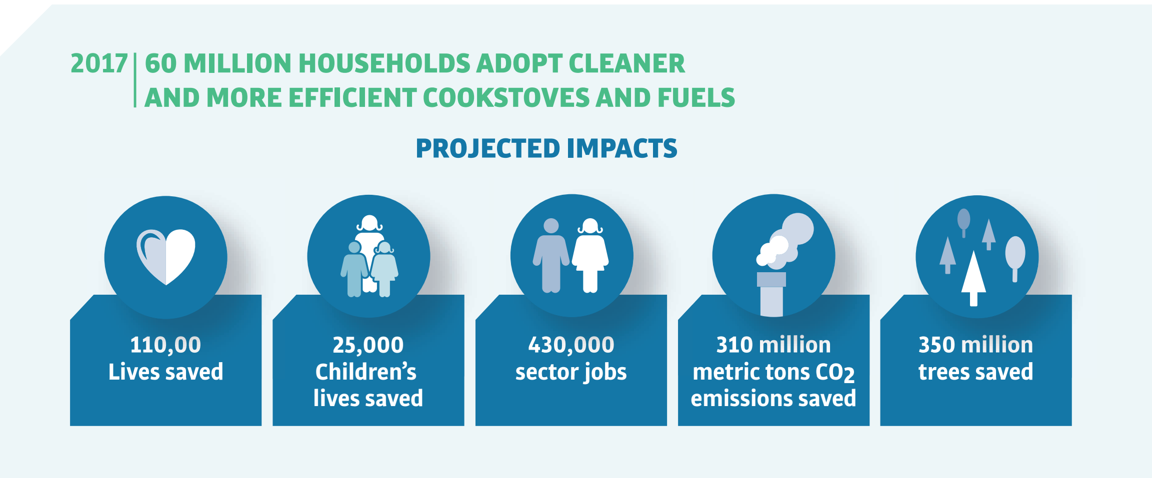
From an environmental standpoint, the digesters can treat 8,500 tonnes of manure and avoid the emission of 2,200 tonnes of CO_2-equivalent per year. In addition, the use of biogas as an alternative to traditional fuelwood and kerosene reduces CO_2. The net savings (manure management, and traditional fuel replacement) of an average size biogas plant has been estimated to 4.6 tonnes of CO_2 -equivalent per year (Bajgain S. *et al.*, 2005).

Moreover, they provided a solution for waste management to control the odour from the manure that was posing a problem in the neighbourhood. Health-wise, the introduction of biogas digesters allowed the treatment of pig manure that otherwise would pose health risks for the residents of the community. Another health benefit is the reduced risk of respiratory infections from burning fuel wood and charcoal indoors. For smaller-scale applications, improved cook stoves and solar cookers can be used.

2.4.2 IMPROVED COOK STOVES

Techno-economic characteristics. There are several types of improved cook stoves (ICSs). Some use clean fuels such as biogas, methane, ethanol, etc., but their affordability in rural areas is still limited (Differ, 2012). The most prevalent type of ICS runs on solid biomass, reducing the need for fuel wood, charcoal, etc. through more efficient combustion. Improved stoves can reduce fuel use by 40-60% relative to open-fire cooking. Such efficient biomass cook stoves are being sold for as little as USD 5-25 per unit (REN21, 2014).

Drivers for deployment. As of 2011, there were more than 160 programmes to promote ICS throughout the developing world (REN21, 2011). The Global Alliance for Clean Cookstoves, for example, was launched in 2010 to promote more than 100 million stoves by 2020. To date, more than 20 million clean cook stoves have been deployed, and it is estimated that by 2017, 60 million households will have adopted cleaner and more efficient cook stoves.



Benefits. The deployment of ICSs in 60 million households could result in saving 110,000 lives, including 25,000 children, around 350 million trees, and 310 tonnes of CO_2 emissions and in creating 430,000 jobs (GACC, n.d.). The estimated number of jobs from ICS varies depending on the type of stove (fuel type, shape, materials used, size, etc.), the delineation of the value chain (liner production, assembling, stocking and selling, cladding and full ICS offering (GVEP, 2012)) and the scale of production (large and small-scale).

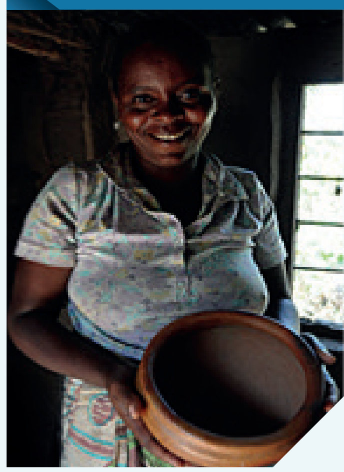
On a large scale, centralised production and distribution channels can reach 100,000 stoves annually. Small-scale local production can be undertaken by trained artisans (see box 12) at lower cost, requiring little or no transportation to reach consumers and offering local employment opportunities. Semi-industrial production of improved biomass stoves also exists, with imported components and local assembly as in Cambodia, the production of 290 000 ICS annually supports the creation of at least 1,100 local jobs. (IRENA, 2012).

BOX 12

IMPROVED COOK STOVES: A BUSINESS OPPORTUNITY

In rural Tanzania, Verediana Salala is a small-scale producer of energy-efficient cook stoves. She produces around 10 cook stoves a day and also uses the local market to sell a load every two weeks. Over one year she has made an average of about USD 300 a month from sales alone. When the opportunity arises, she takes part in trade fairs to market her products further. In this family business, her children help her to transport and sell the stove in the local markets.

SEE PHOTO STORY



In rural Kenya, Mr Muriuki is an entrepreneur involved in providing better-quality cooking technologies. He has developed a new model of improved cook stoves which has enabled additional income. The sales of the new cook stoves have reached up to 1,500 units per quarter, generating revenue of around USD 10,350. Re-investing this income, Mr Muriuki has scaled up his business into a stove manufacturing venture, employing six additional people. In addition, Mr Muriuki trains other improved cook stove producers and manufacturers and offers consultancy services including kiln construction and quality control, which earns him extra.

2.4.3 SOLAR COOKERS

Solar cookers capture the energy of direct sunlight to heat, cook or pasteurise food or drink (see box 13 for **techno-economic characteristics**).

Benefits. Solar cookers do not require any fuels and do not emit air pollutants. A study conducted on the development impact of solar cookers in 2006 in South Africa found that their experimental introduction resulted in several benefits after three years of their purchase, including (Wentzel and Pouris, 2007):

- The time saved from reduced wood collection was estimated at 36% of the normal fuelwood collection time. On average, time savings was reported to be between 18 and 26 hours per month depending on the type of fuel being used, the type of food cooked and how many meals are cooked per month.
- The average monetary savings by households was estimated at between 36% and 40% of monthly expenditure on fuels, depending on the type of fuel that was used.

BOX 13

SOLAR COOKER

There are different types of solar cookers (*e.g.*, parabolic, butterfly, flat-plate collector, solar box and Scheffler), and each one has advantages that can be favoured in certain circumstances.

Box cookers (see photo), for instance, can be built using locally available materials, reducing procurement costs and creating local benefits. They are relatively easy to use as they do not need to be realigned with the position of the sun as frequently as parabolic cookers, but they do not achieve the peak performance values of parabolic cookers. Butterfly cookers have a pot that is easier to handle, with reduced risks of spilling and dirtying the reflector (which reduces its effectiveness), and it can be folded and stored in the house, reducing the risk of theft (GTZ, 2007).

- The overall total average fuel savings over all users and all fuel types) was estimated at 38%.

Barriers for scaling up. Solar cookers can be inconvenient because they almost double the amount of time it takes to boil water relative to traditional stoves and other ICSs (Differ, 2012), and sometimes traditionally preferred meals cannot be prepared by a solar cooker (GTZ, 2007). Another obvious disadvantage is that they can only be used during the day, specifically if it is sunny, and therefore can only complement other cooking methods using fuels or charcoal.

In addition, solar cookers may have limited potential to be used by street vendors for income-generation purposes. In the example of South Africa, they were not suited to the type of foods that the hawkers prepared, as solar cookers cannot reach temperatures high enough to deep-fry food; they were not able to accommodate the high turnover of food to supply customers, as solar cookers can use only one pot at a time; their capacity was found to be small and they can be too slow to supply the dishes in the required time; and they were found to be bulky devices that are not easily transported via public transport (Wentzel and Pouris, 2007).

03 CASE STUDIES

A variety of quantitative and qualitative methods can be used to assess the socio-economic impacts of renewable energy deployment (IRENA and CEM, 2014) as a means to support decision making regarding deployment policies, but they require data that often is not available in the rural context. Moreover, quantitative assessments require assumptions that can involve a certain degree of generalisation and that normally do not capture local context and complexities well. Case studies are therefore used to allow for a closer examination of particular, on-the-ground circumstances as well as non-economic (*i.e.*, social, political and environmental) factors that influence outcomes (IRENA, 2012).

Although case studies may not make it possible to draw broad, generalising conclusions – especially case studies that focus on small communities – they are useful in analysing the potential socio-economic impacts of introducing decentralised renewable energy technologies in such communities. Two case studies are presented for this purpose. The first illustrates the impacts of installing improved water mills for agro-processing and electricity production in communities in rural Nepal. The second shows the benefits of scaling up the biogas programme from a small community to the national level in Vietnam. The biogas systems run on agricultural residues and manure for lighting, cooking and heating purposes.

3.1 IMPROVED WATER MILLS IN NEPAL FOR AGRO-PROCESSING AND RURAL ELECTRIFICATION

3.1.1 INTRODUCTION OF THE IMPROVED WATER MILLS PROJECT

Water mills have a history of providing agro-processing services in Nepal. The key components of traditional water mills (TWM) include wooden turbines and grinding stones produced by local carpenters. The improved water mill (IWM) is a modified version of the traditional water mill with increased efficiency and energy output, improved agro-processing outcomes and potential to generate electricity. The replacement of wooden parts – the rotor and shaft – with metallic parts is the main improvement made in the technology (see section 2.3.1) (CRT/N *et al.*, 2014). Both short-shafted and long-shafted IWMs are currently used. The short-shafted mill is solely a grinding mill, whereas the long-shafted mill provides multiple agro-processing services including grinding, paddy de-hulling and de-husking, rice polishing, saw milling, oil expelling and electricity generation.

A total of 8,493 IWMs plus 25 improved water mills with electrification (IWME) were installed in Nepal between 2003 and 2013, and 21 more IWMEs were under installation in 2016 (AEPC, 2014). An estimated 25,000 or more TWMs remain in existence across the country, 90% of which can be upgraded (CRT/N *et al.*, 2014).

Key players in the IWME Programme in Nepal

The Alternative Energy Promotion Centre (AEPC) is the national executing agency for renewable energy programmes and projects in Nepal, including IWMEs, mini/micro hydro, solar energy, biomass and biogas technologies. The Government of Nepal supports the deployment of these technologies through mechanisms formulated with recommendations from the AEPC. The deployment of IWMs is supported by the National Rural and Renewable Energy Programme (NRREP). Different actors including bilateral organisations, the private sector (companies and entrepreneurs), local governments and community organisations play key roles in implementation at the field level. The electro-mechanical parts (except generators) of IWMEs are produced locally in Nepal through established private industries promoted by the AEPC and the Centre for Rural Technology Nepal (CRT/N) with the support of development partners including SNV Netherlands Development Organisation and GIZ in different project phases. The Rural Energy and Technology Service Centre (RETSC), a subsidiary of CRT/N, plays a capacity-building role with support from development partners. There are 14 IWM component manufactures and 11 IWME installation companies locally.

The Jhirghakhola IWME project

The Jhirghakhola IWME project was selected for this study because of its triple functions (milling, electrification and irrigation) and its remote location in a community almost 160 kilometres from the capital. The project location can be reached by a two-hour drive followed by two hours walking from the nearest road. Jhirghakhola is the source of water for the project. The measured gross head is 9 metres and the designed flow is 85 litres per second, resulting in a generation capacity of 2.7 kilowatts (kW) with an overall efficiency of 40%. The transmission network consists of a 3.55 kilometre low-tension line.

The project was implemented by the CRT/N and participating local communities, with technical and financial support from GIZ-EnDev and SNV. The project was handed over to the users' committee in December 2014 after construction was completed. The committee now owns, maintains and manages the project. As a part of the project, CRT/N also provided capacity building in management for the users' committee.

The total project cost was USD 13,886, which was covered by subsidies (a project subsidy of USD 5,612 in addition to a government subsidy of

USD 1,523) and community contributions (in the form of cash amounting to USD 679 and labour worth USD 6,072 (or equivalent to 2,160 human-days). This cost covered the installation of a water mill for rice de-husking as well as a 2.27 kW capacity power plant, in addition to the transmission.

Socio-economic status of the community

The project provides services (both agro-processing and electrification functions) to 39 households with a combined total of 279 persons[10]. The literacy rate in the community is average: women can read and write because of intensive literacy classes conducted in the village, but almost no one in the village has reached a higher level of education, and there is a high drop-out rate after obtaining a School Leaving Certificate[11] (SLC) due to the lack of access to affordable education. The citizens have formed several community institutions – including users' groups, saving and credit groups, and co-operatives – and are involved in various community development works including irrigation drinking water projects and water mills.

The local economy is based mainly on agriculture. The village also receives remittances (13 individuals from 10 households are working abroad) as well as income from migrants to nearby cities. Only one household owns an occupational business. Because of a lack of market access, economic opportunities are scarce and agriculture remains at a subsistence level. Food security, however, is relatively good: 24 out of 39 households are food-secure from their own production, and the remaining 15 are insecure but for shorter periods that are relatively manageable, *i.e.*, less than three months in a year.

Sources of energy for electricity and agro processing before the IWME project

The IWME was introduced in 2014 to replace diesel mills that were established in 1996. Before 1996, villagers depended on traditional means of rice de-husking and grinding grains – known as *Dhinki* and *Jhanto*, respectively – that are locally fashioned and operated manually.

[10] Comprising 138 men and 141 women. Of the total population, 163 are working-aged, 86 go to school, 16 are infants and 14 are elderly people receiving social security as provisioned for senior citizens.

[11] SLC is the final examination in the secondary school system of Nepal, before joining higher secondary or intermediate level education.

Kerosene was the only source of lighting in the community until the introduction, in 1998, of *Tukimara*[12], a white LED-based lighting system operated by dry-cell batteries. Although this lighting was not as efficient as kerosene, it was preferred because it was safer and easy to handle. However, kerosene remained the main source of lighting until 2000, when a solar system was installed. Nevertheless, solar was not considered a permanent and complete solution to meet the growing demand for energy for lighting, mobile phone charging and running appliances such as television, radio and VCRs. Disadvantages of the solar system included frequent power cuts, insufficient power and high maintenance needs, which drove consumers to find a new solution: installing an IWME plant in the village.

Major functions and services provided by the IWME project

The project serves three functions: agro-processing, electrification and irrigation.

Agro-processing: The plant provides rice de-husking services for more than 180 households (from neighbouring villages) at a tariff of less than USD 0.50 per quintal (almost 100 kg). The rate is almost five times less than that of diesel plants. As a result, an average size household saves around USD 3 per month, a significant figure for rural communities. The mill is normally operated 3-4 hours a day, servicing 4-5 households on average. The users' committee has plans to install a grinding machine as well, which will diversify the services and increase the number of beneficiaries and income sources for the community.

Electrification: The plant provides electricity to 39 households at an affordable tariff of around USD 0.15 per bulb per month. Each household has three to five electric bulbs, which are enough for lighting. This service has resulted in a significant increase in the use of mobile phones, radios, rechargeable torch lights and VCRs. It also provides electricity free of charge to public and private functions and ceremonies such as marriages and festivals, and is used for irrigation as well.

[12] Tukimara is a white LED-based lighting system developed for use in rural Nepal (see http://www.energyhimalaya.com). Tukimara is a combination of two Nepali words (tuki, a kerosene lamp/wicked lamp, and mara, "to kill") so it implies that it kills the kerosene lamp.

Irrigation: The plant provides irrigation services to 0.7 hectares of land, benefiting two households. Through the provision of irrigation, farmers have changed their cropping patterns from maize and millet domination to mostly paddy and vegetables. This has resulted in an increase in income and productivity of nearly three times per unit of land. Two farmers have started selling vegetables from this land, leading to additional income of between USD 20 and USD 30 per season.

Management of the IWME plant
The plant employs one operator who is responsible for both functions: agro-processing and electrification. He is a regular paid worker and also gets fees for services in-kind (milled rice) from each customer as defined by the users' committee (around 1 kg per quintal). He collects tariffs from the customers, as defined by the users' committee, and deposits them in the committee's account. The operator is responsible for minor maintenance works of the system. In the case of major maintenance needs, the committee taps into collected fees. The users' committee meets once a month to make major decisions regarding the system and services.

3.1.2 SOCIO-ECONOMIC BENEFITS OF THE PROJECT

The assessment of the socio-economic impacts is framed around economic, social and environmental dimensions. The economic dimension includes job creation, cost and time savings, and economic opportunities created by the introduction of the IWME. The social dimension includes impacts on health, education, communication, gender roles, safety and welfare, and the environmental dimension includes reduction in pollution and emissions and improvement in the local environment, including household sanitation and hygiene.

The assessment was conducted by collecting primary data and information through focus group discussions with citizens including women, children, youth and elderly people. In addition, interviews were conducted at the household level in the 39 households. Secondary data and information were collected from the literature as well as from relevant documents from sources including the AEPC, CRT/N and SNV. The analysis is focused on the changes in socio-economic and environmental parameters before and after project implementation.

Economic benefits
At the community level, economic impacts of the deployment of the IWME include job creation, income generation and savings on energy spending that occurred before the system was introduced.

Job creation: The Jhirghakhola project provides one regular job for an operator at a salary of USD 225 per year (in cash) plus additional in-kind income as fee-for-services (milled rice) totalling almost 420 kg of rice, worth USD 275 annually at the local market price. The operator also runs a small poultry business supported by the electricity produced. He makes an average of USD 150 in net profit annually from this business. Apart from these two businesses, no other business has been established so far as a direct result of the IWME introduction. Potential future opportunities include a small sawmill and furniture industries. However, villagers recognise that market access is a major impediment for economic growth, despite having the potential and skills needed to operate businesses.

Income generation: The community generates around USD 400 in gross income annually as a tariff from the electricity and agro processing services. This income is spent on the salary for the operator and on maintenance of the plant, with potential savings. In 2015, USD 150 in net annual savings was realised. The savings is used to provide credit to the members of the community at a 12% interest rate. Members of the community can use this credit to initiate or improve their businesses or to cover everyday expenses such as paying children's school or book fees, or accessing health services.

Savings on spending on energy: The introduction of the system has resulted in savings on spending on energy from both agro-processing activities and electricity consumption (see table 7).

TABLE 7. SAVINGS ON SPENDING ON ALTERNATIVE SOURCES

	SAVINGS FROM DIESEL	SAVINGS FROM KEROSENE	SAVINGS FROM SOLAR SYSTEM
Household level	• USD 0.25 compared to USD 1.2 per Muri of rice resulting in savings of USD 798 for 840 Muri of rice per year	• 3-5 litres of kerosene/ month = 48 litres/year on average or USD 43.2 • USD 2.8/month for transport or USD 33.6/ year • Total of USD 76.8/ year per household	• Savings of average annual operation and maintenance cost of USD 33/ year per household
Community level	• Savings of 420 litres diesel per year amounting to USD 378 per year	• Total of USD 2,995 for 39 households	• Savings of average annual operation and maintenance cost of USD 1,287

- Savings on agro-processing is realised at both the customer and community levels from the reduced cost of operating the system. At the customer level, the tariff rate of agro-processing services using IWMs is almost three to five times less than using diesel-generated agro-processing: USD 0.25[13] (NPR 25) per *Muri*[14] of rice compared to USD 1.2 (NPR 120) per *Muri* on average. Based on an annual average volume of 840 *Muri* of rice (equivalent to 50.4 tonnes), the total annual savings from the customer's point of view is equivalent to around USD 798. At the community level, the volume of diesel saved is 420 litres per year, equivalent to around USD 378 per year[15]. These savings could be doubled if grinding services also are provided.
- Savings on electricity is shown by comparing the two available sources of lighting: kerosene and solar. For electricity from the IWME system, each household pays on average USD 0.5 per month for three to five bulbs. This compares to an average consumption of three to five litres of kerosene per month per household, resulting in total savings of 1,872 litres a year, or USD 1,685. In addition, savings are incurred from the distribution of kerosene, estimated at almost USD 2.8 per month per household, adding up to a total cost of USD 1,310. The total savings from the installation of IWME is therefore USD 2,995 per year, compared to the use of kerosene. When compared to solar systems, the calculation must include the system's operation and maintenance needs – such as refilling distilled water every six months and replacing the battery every four years for a system with 20 W capacity (three bulbs). The average annual cost is USD 33 per household, or USD 1,287 for all 39 households.

[13] USD 1 = NPR 101.96 in 2015, but the rate has been rounded down to USD 1 = NPR 100 for simplicity (http://www.xrates.com/average/?from=USD&to=NPR&amount=1&year=2015).

[14] *Muri* is a volumetric unit of measurement of cereal grains, equivalent to 90.91 litres.

[15] Considering the market price for diesel of USD 0.9/litre (NPR 90/litre) at the time the study was conducted.

Tankamaya walks two hours carrying a load of paddy from the IWM, even though the diesel-operated milling plant is closer to her house. Use of the IWM is far cheaper and saves her more than USD 1 per service and about USD 3 a month. Her fellow villagers also do the trip for the same service.

Savings on time spent: The introduction of the IWME system has resulted in savings on time spent on both agro-processing activities and energy provision.

- For agro-processing services, there is no time saving achieved compared to the diesel-run process. Savings are achieved only in the travelling time from the house to the milling machine when applicable, depending on its proximity to the house. There are 13 households that travel for only 30 minutes to 1 hour compared to 2-3 hours to the diesel plant. This has saved almost 108 hours per household per year. The other households actually spend more time travelling since they are closer to the diesel plant. However, compared to the traditional means of agro-processing, women are saving a significant amount of time each day (approximately 2 to 3 hours a day) on grinding and de-husking rice, every other day.
- For electricity services, time is saved from travelling to purchase kerosene, or for the maintenance of the solar system. Although the savings in time spent are not significant, the system has largely contributed to the satisfaction with the service and to the general well-being of the community.

Scaling up this programme can lead to further benefits at the national level. They include jobs created in different segments of the value chain including IWM manufacturers, installers, service providers, IWM owners, finance institutions involved to finance IWMs, etc. (see box 14).

BOX 14

MACROECONOMIC IMPACTS OF IWM AND IWME IN NEPAL

As of 2015, a total of 8,493 IWMs (7,490 short-shafted and 1,003 long-shafted) and 25 IWMEs, with a combined capacity of 62.6 kW, had been installed in Nepal (AEPC, 2015). These IWMs provide diversified agro-processing services to 441,636 households, and IWMEs provide electrification services to 871 households (only 23 IWMEs are included in this calculation; 2 more are already completed and 21 more were being installed as of 2015-16).

Project owners. The average annual income from short-shafted IWMs is estimated to be USD 390 and that from long-shafted IWMS is estimated to be USD 850, which contributes to approximately 34% and 74% of family income, respectively. For the IWME, the estimated average annual income is USD 1,942 (Shrestha *et al*., 2014). On this basis the total income generated at the entrepreneur level by the installed IWMs is USD 3,822,200, which contributes greatly to the welfare of the project owners.

Operation. Each of the IWM or IWME plants is estimated to employ at least one operator, whether an entrepreneur or an employee of the users' community. Thus, at least 8,493 jobs have been created.

Manufacturing and installation. Fourteen companies are registered as qualified IWM manufacturers in the country, and a large number of installers are generating employment at this level. Unfortunately, employment and income data are not available. The costs of the system components (turbines, generator and related parts) for short-shafted, long-shafted and IWME per kW of capacity are almost USD 1,000, USD 1,600 and USD 2,500, respectively (NPR 10,000, NPR 16,000 and NPR 250,000) (Kafle B., 2016). Based on these unit costs, the total gross income generated for the manufacturers is estimated to exceed USD 9 million. An estimated 40% of the total cost of IWMs is spent on engineering work (construction of canal, installation of pipes, etc.) that also contributes to local businesses.

Financing. There are 27 financing service centres that provide investment opportunities for middle-class entrepreneurs and employment opportunity for rural youth. Data on employment and income are not available. In addition, there are several finance and microfinance institutions, including commercial and development banks, involved in financing the IWMs; certain levels of income and employment are generated, but the amount has not been studied yet.

Source: CRT/N *et al*., 2014

Environmental benefits

As mentioned previously, the introduction of the IWME in Jhirghakhola has replaced four diesel plants in the village, resulting in savings of 420 litres of diesel a year. This has contributed to emission reductions of 1.1 tonnes of CO_2 annually (at the rate of 2.61 kg/litre). Similar to the savings on diesel spending, saved annual emissions would more than double if the grinding plant also were installed. Moreover, the replacement of kerosene lamps has resulted in the reduction of 1,872 litres of kerosene a year, contributing to emissions reductions estimated at 5 tonnes of CO_2 annually (at the rate of 2.682 kg/litre). In addition, the use of dry-cell batteries, responsible for water and environment pollution, was reduced greatly due to the switch from *Tukimara* to electricity. The dry-cell batteries were replaced by durable rechargeable ones.

- **Replaced four diesel plants and 420 litres of diesel, equivalent to 1.1 tonnes of CO_2**
- **Potential to replace 1,872 litres of kerosene annually, equivalent to 5 tonnes of CO_2**
- **Replaced dry-cell batteries with durable rechargeable ones**

Health benefits

Most of the community members that were interviewed, especially women (mostly involved in household chores) and children (who study next to polluting kerosene lamps), have seen a reduction in respiratory and eye diseases as a result of the lower exposure to pollutants. In addition, improvement in the quality of light inside the kitchen and stores has improved the cleaning, processing and cooking of food as well as keeping kitchen utensils/appliances clean, positively impacting health. Moreover, women are relieved from walking long distances while carrying heavy loads for agro-processing, which also contributes to health improvement.

Education benefits

Two local students, Chhabimay and Sita Ale, shared their experiences studying with wick kerosene lamps. The difficulties that they faced included frequent interruptions from the lamp turning off (from blowing air or running out of kerosene), dim light that stressed their eyes (resulting in headaches) and difficulties breathing. Students often must stop their studies because of poor and limited lighting. Shovakumari, one of the parents, says that she was compelled to discourage her children from studying at night to save kerosene, but now, with the different type of lighting, she encourages it.

Most of the women participating in the focus group discussions and interviews stated that with the better and longer lighting period, their children have increased their study times at home and have improved their results significantly.

With the extension in lighting time, children's interest in studying increased their study time, as reflected in their habits and actual study hours at home. Parents encourage their children to study more and encourage them to complete their homework.

Similarly, most of the children interviewed expressed that they have increased their study time at home, they are more interested in studying, and their school attendance and achievements have improved significantly (see table 8). Children also gained extra studying time as they are no longer kept busy with drudgery work such as spending two hours transporting rice to the milling machine.

TABLE 8. IMPROVEMENT IN EDUCATION IN NEPAL

Increase in study hours	26 out of 36 children increased their study hours by 2-3 hours each day	10 children expressed that their interest has increased but not much
Homework	23 students used to have unfinished homework, but now they complete their homework each day	13 students said they used to complete their homework anyway
Improvement in results	25 students have improved their results	11 students have the same results as before
School attendance	18 out of 36 students often used to miss classes before, but now they rarely do	13 students said they always attended classes anyway
Stress on eyes	19 students expressed that they have realised significant changes in eye's stress	17 students have not felt any difference

Impacts on well-being

The overall impact on the well-being of the community is difficult to measure and quantify in monetary terms. However, members of the community who were interviewed gave a qualitative description of the improvements resulting from the introduction of the IWME system.

Access to communication and entertainment. After the introduction of the IWME, households are contemplating purchasing a television. The number of mobile phone users has increased greatly in the village, with the increase in charging facilities. Community members use the phones to call meetings, gather people, invite them to events and ceremonies and, more importantly, to enquire on the whereabouts of relatives and friends residing outside the village for reasons including work, study, etc.

Indrakumari a local woman, says: "Communication has made my life very easy and comfortable. Each and every minute I am updated about my husband who is abroad for work." She adds: "There are several wives, mothers and children whose husbands, sons and fathers are outside their homes to earn their livelihoods and are happy just like me." The more frequent use of the radio, which can run now on electricity and not batteries, and the easy source of communication, enable women to learn new skills, obtain

information about health issues, and understand other useful information that applicable to them. Moreover, communication has helped local youth and men broaden their networks, finding jobs and income opportunities abroad and in nearby cities.

Perception of service and community well-being. Neerbahadur, the secretary of the users' committee, is very happy to be the first to have an IWME plant in his village. He remembers in the past having to depend on kerosene and *Tukimara* (operated by dry-cell batteries), which were infrequent and inefficient energy sources. Narayanbahadur Ale, a local resident, says: "Before, we had to sell one chicken for lighting a month, but now one chicken is enough for lighting for three months." Similarly, Ganeshkumari, with a bigger family, says: "I had to spend NPR 500-600[16] (USD 5-6) each month for lighting, but now I pay only NPR 60 (USD 0.6)." Villagers are very happy to pay the tariff for both electricity and agro-processing.

Moreover, the lighting improvements have made it easier for women to conduct their typical business, such as cleaning, cooking, caring for children and undertaking income-generating activities such as handloom, making mats, mending clothes, weaving *Dhaki* and making bamboo materials. Almost all of the women in the villages are engaged in such work along with household chores. In addition, the women are happy to benefit from the positive environmental impacts of the system.

Increased safety. Women interviewed said they feel safer from theft and harassment now because of the availability of lighting at night. Before the system was introduced, there were frequent instances of animal attacks (such as by leopards and jackals), mostly targeting livestock. Cases of minor injury at home due to lack of lighting also were frequent in the past. Ganeshkumari remembers her grandmother falling from a ladder and suffering serious injuries. Such cases have been reduced greatly with lighting. Villagers were using burned firewood as torches at night to access toilets, stores and other places. The introduction of lights that can be recharged with electricity has facilitated their movement at dark. Villagers also said that kerosene lamps were very unsafe, with risks of accidents if handled improperly.

[16] USD 1 = NPR 101.96 in 2015, but the rate has been rounded down to USD 1 = NPR 100 for simplicity.

3.2 BIOGAS IN VIETNAM FOR LIGHTING, COOKING AND HEATING

3.2.1 INTRODUCTION OF THE BIOGAS PROGRAMME

The Biogas Programme for the animal husbandry sector in Vietnam was founded in 2003 with the objective of developing a commercially viable domestic biogas sector that would provide a solution for Vietnam's animal waste mismanagement problem, turning it into a sustainable source of energy for rural farmers.

The biogas unit consists of a mixing tank (to mix the dung with water), an inlet, a digester tank and a compensation tank. Under anaerobic conditions, bacteria decompose the mixture, producing biogas which is collected under the dome and pushes the digested slurry out to the compensation tank. The main technology used is the brick fixed-dome biogas digester (known as the KT model), as it requires relatively little maintenance, can be constructed with materials that are locally available and can be produced by local masons.

Another type is the fibreglass-reinforced plastic biogas digester made of fibreglass and resin (commonly referred to as a composite biogas digester) prefabricated in local workshops. The advantage of composite biogas digesters is the very short installation time and the relatively low skilled labour required for installation. However, the digesters are limited to a volume of around 6 cubic metres, which is only suitable for a small percentage of Vietnamese livestock producers. Also, the costs per unit volume of the fibreglass digesters are considerably higher than for the KT models.

Business model of the biogas programme

The biogas programme was initiated by the Vietnamese Ministry of Agricultural and Rural Development (MARD) in partnership with SNV Netherlands Development Organisation, which acted as a technical advisor, and was implemented by the Department of Livestock Production under the MARD. This institutional framework helped ensure that ownership of the programme stays mainly publicly owned. Between 2003 and 2014, the programme was supported by the Dutch Government. Since 2013, Energising Development (EnDev), has taken over a large share of the funding in combination with funds from the sales of certified emission reductions (carbon credits).

The biogas programme activities comprise seven components: training of biogas masons, training of government technicians, quality control, demand creation, provision of an end-user subsidy, research and development, and development of an exit strategy.

Training of biogas masons. Since the start of the biogas programme, more than 1,700 masons have been trained in construction of the various designs of the brick, dome-shaped, domestic biogas digester. Upon completion of this six-day training, the mason becomes a qualified biogas mason team leader who can gather a team to provide support in building biogas digesters. After successfully completing three high-quality biogas digesters under supervision, the mason team leader receives a mason code which formally allows him to construct domestic biogas digesters under the national biogas programme.

Training of government technicians. The biogas programme has trained more than 1,000 government technicians on biogas technology. Upon completion of the training, the technicians play an important role in communicating the benefits of biogas technology, identifying potential households and checking the requirements for the construction of a domestic biogas digester (space available, sufficient funding, number of animals). Upon completion of the construction of the biogas digester, these technicians provide training to the households in the operation and maintenance of their digesters and the benefits of using the digestate (called bio-slurry in Vietnam) as an organic fertiliser. The responsibilities of the government technicians related to demand creation have been reduced over the last few years, and private sector companies are strengthening their skills in the marketing and sales of digesters. They are taking the lead in creating awareness and raising interest among farmers to purchase a biodigester.

Quality control. The government technicians are responsible for conducting inspection visits to each biogas digester, both while it is under construction and after the construction is completed to ensure that it meets the programme's requirements. The data collected during visits is included in the national biogas digester database to ensure long-term programme success.

Demand creation. In the first years of the programme, a strong focus was placed on the creation of demand for domestic biogas digesters by raising awareness of the benefits of biogas and bio-slurry, mostly by government technicians. The programme also advocates for the benefits of biogas technology via mass media such as TV, radio and the local loudspeaker system.

Provision of an end-user subsidy. The programme has provided a fixed flat rate subsidy of approximately USD 55 (VND 1.2 million)[17] per digester. This subsidy has encouraged early adopters by reducing the total investment cost for the digester. On average, the end-user investment subsidy has been slightly below 10% of the total investment. Recently, however, the project has started to phase out the subsidy in several provinces and is monitoring the results of this phase-out.

Research and development. To continually adapt or improve the biodigester technology deployed and to improve standardisation, performance and construction techniques, a number of research projects[18] were carried out. Projects focused on researching the use of bio-slurry for productive purposes, conducting demonstrations to illustrate the benefits of the use of bio-slurry as fertiliser, and organising innovation contests for end-users, biogas companies and local technicians.

Exit strategy. After 12 years, the biogas programme had developed the foundations for a commercial domestic biogas sector. To ensure the total phase-out of the support provided, all of the components of the biogas programme are designed in a sustainable and cost-effective way. Moreover, the programme was registered as a carbon credit project under the Clean Development Mechanism (CDM). The final step is to ensure that enterprises will continue to make a living from providing biogas technology and associated services by increasing their responsibilities. These now include finding customers, providing end-user training and delivering high-quality

[17] USD 1 = VDN 21 920 on average in 2015, at the time of the study.

[18] http://biogas.org.vn/english/An-pham.aspx.

digesters. If successful, they will receive a results-based incentive of around USD 55 per digester. This prepares enterprises for phasing out support for the programme. Moreover, enterprises will start paying for project services such as end-user training and quality control. The subsidy for end-users also is being phased out in the provinces where the results-based financing system is implemented.

3.2.2 SOCIO-ECONOMIC BENEFITS OF THE PROGRAMME

Since its inception, the programme has facilitated the construction of more than 150,000 domestic biogas digesters, resulting in access to a clean, renewable and reliable energy source while addressing a waste management challenge, reducing Vietnam's carbon emissions by more than 480,000 tonnes of CO_2-equivalent per year. The programme also contributed to creating thousands of jobs and improving living conditions for approximately 750,000 individuals in Vietnam's rural communities.

Economic impacts

At the national level, economic impacts of the deployment of the biogas programme include job creation, income generation and savings on the energy spending that occurred before the system was introduced.

Job creation. The average biogas digester construction team consists of 4 people (Lien, 2013), including the biogas mason team leader, 1.5 skilled masons and 1.5 untrained assistants on average. On average, the skilled masons earn around USD 9 (VND 200,000) per day, while the untrained assistants earn around USD 7 (VND 150,000) per day. The total working days for the whole team was estimated at around 3.7 days implying 14.8 human-days per digester. Expert interviews with the technical staff have found that the actual figure can go up to 30 human-days (6 days for a team of 5 masons) but the conservative estimate of 14.8 human-days per digester will be considered in this analysis. For 150,000 digesters, the total amount of human-days under the programme amounts to 2,212,571 human-days. Based on 220 working days per year, the project thus has resulted on average in around 774 full-time equivalent (FTE) jobs each year for the duration of the 12-year project.

In addition, most of the "biogas enterprises" are informal entities, and only around one-third of them are registered with the provincial authorities (Lien, 2013). Around 35% of the digesters constructed by biogas enterprises are not considered part of the national support programme (EPRO Consulting, 2013). Based on this estimation, the total FTE jobs on an annual basis can be estimated at 1,083 since the start of the project.

Income generation. The jobs created from biogas construction, assuming a full-time basis of 220 working days, are quite attractive. The trained masons would earned an annual income of approximately USD 1,986 and the untrained assistants an annual income of USD 1,490, compared to an average GDP per capita of USD 1,028 in the same year (tradingeconomics, n.d.). Additional income is generated from other productive activities that can be undertaken using biogas.

The biogas digester produces both biogas and bio-slurry. The biogas can be used for cooking (for household consumption and mostly for feeding livestock), lighting and other income-generating activities such as the production of rice wine and tofu, and for egg hatching. The bio-slurry, when applied as a fertiliser, can result in increased yields of crops of better quality that can be sold at higher prices. Unfortunately, no data are available on the actual

resulting increase in income, probably due to the fact that the manure itself was used as a fertiliser before the introduction of biogas.

More potential for income generation can result from undertaking activities during the time saved on daily tasks as a result of biogas deployment. On average, 1.49 hours are saved per day for each household, mainly from cooking (0.69 hour/day), manure collection (0.42 hour/day), and wood and agricultural residue collection (0.23 hour/day) (EPRO Consulting, 2013). A biogas digester therefore results in annual time saving of 543.85 hours, equivalent to 30% of an average full-time job per family[19].

Based on a very conservative estimation of the average income from agricultural activities of USD 0.03 per hour (Giang, 2014), this would result in additional income of USD 16.4 per year. However, it should be noted that the time saved is not always used for income-generating activities, and it differs by gender: 44% of men spent extra time on farm-related activities, 15% on income activities outside of the farm and the rest on leisure. From female respondents, 35% spent extra time on farm-related activities and only 3% had income-generating activities outside of the farm; 26% spent the extra time on domestic responsibilities such as cleaning the house, 16% on taking care of the children and 19% on leisure.

[19] Based on 220 working days per year and working days of eight hours.

Finally, it was noted that domestic biogas digesters generally have a bigger impact on savings than on income generation. Biogas typically replaces fuels that are bought and collected, while the bio-slurry results in savings on chemical fertiliser and in some cases pesticides, as bio-slurry repels termites and pests that are attracted to raw dung. Moreover, bio-slurry has other advantages over using the manure itself as fertiliser, as it is odourless, does not attract flies and can reduce weed growth by up to 50% (Biogas Rumah, n.d.).

Savings on spending on energy and fertilisers. The savings realised from biogas deployment depends mainly on the type of fuel used and on whether the household pays for the fuel in monetary terms, as it can be collected for free (*e.g.*, agricultural residue and fuel wood). If all the fuel that was saved had to be paid for, the annual savings per household was estimated at USD 167 (VND 3,669,763) (EPRO Consulting, 2013). In practice, a household typically saves just around USD 55 (VND 1,204,367). In addition, some households also reduce their electricity consumption due to biogas-powered lights, rice cookers, heating lights, water heaters or electric stoves. The average annual savings per household amounted to 69.62 kWh/year, resulting in an average saving of USD 4.5 (VND 98,721).

With regard to savings on fertiliser, it was found that not all households fully use the bio-slurry: 53.8% did not use it at all, 40.3% used it, and 5.9% partly used it. The use of bio-slurry resulted in savings on average of 13.47 kg of chemical fertiliser per household per year, equivalent to USD 4.8 (VND 106,000). This amount was estimated at nearly USD 22.8 (VND 500,000) per household per year (Thu, 2015). The savings related to the use of organic fertiliser varies greatly depending on the crops that the bio-slurry is used for. A study performed in 2007 showed that if bio-slurry was used on tea plantations the full investment in the biogas digester could be earned back within a year (Von Eije, 2007). The economic impacts do not account for externalities of the saved environmental damages, as biogas presents a solution for the major problem of managing animal waste.

Environmental benefits

Domestic biogas technology results in various environmental benefits, and 64% of biogas users reported a cleaner environment around their households from improved handling of manure, which is the main reason for making the investment. In Vietnam, the predominant feedstock for the biogas digesters is pig manure, which is significantly malodourous. After the introduction of biogas digesters, the stables are regularly cleaned up and the manure is stored in an airtight tank, completely eliminating the smell in most cases, as bio-slurry does not smell. The improved manure storage and management also helps to prevent groundwater infiltration and pollution.

Biogas digesters also reduce the emission of greenhouse gases from the use of fossil fuels such as LPG or from the production of fertilisers. The largest reduction is related to the improved manure management system, as manure causes considerable methane emissions, around 21 times that of CO_2. During the combustion of biogas, the methane is converted into the relatively less harmful CO_2. As such, the biogas digesters constructed under the programme are registered with the Voluntary Gold Standard and result in voluntary emission reduction certificates. Each digester reduced 6.7 tonnes of CO_2-equivalent per year on average, according to the calculations executed as part of the registration procedure with the Gold Standard. Not all digesters are currently registered under this mechanism, but according to this measurement the programme reduces over 1 million tonnes of CO_2-equivalent per year[20]. The income from carbon revenues by now is sufficient to cover around 50% of the programme expenditures on an annual basis.

Health benefits

Biogas often replaces traditional biomass fuels such as agricultural residue, fuel wood or charcoal. Depending on the fuel used, inefficient cooking systems produce different levels of household air pollution by releasing gasses and small soot particles that infiltrate the lungs. The World Health Organization recently included air pollution as one of the causes of cancer. The lack of ventilation in places where cooking takes place usually worsens these effects. The cleaner-burning biogas strongly reduces particulate matter and CO_2 emissions and thereby greatly reduces the risk of various diseases such as pneumonia, stroke, ischemic heart diseases, chronic obstructive pulmonary disease (COPD), asthma, blindness and lung cancer.

[20] This estimate excludes the reduced emissions due to the displacement of chemical fertiliser, as there is not yet an approved methodology.

Impacts on well-being

In traditional Vietnamese households, women and children are mainly responsible for collecting fuel wood and cooking, along with most other household tasks. Therefore, most benefits related to time savings and health improvement directly benefit women and children as end-users. In addition to better health and increased time availability, the overall quality of life for women is improved as the drudgery from carrying heavy loads of fuel wood and cooking in dirty kitchens with harmful smoke is eliminated. The study found that 26% of women spent the extra time on domestic responsibilities such as cleaning the house, 16% on taking care of the children and 19% on leisure.

SNV is currently piloting, with support from the Nordic Development Fund (NDF) and the ADB, an approach to include more women in the biogas supply chain, with the aim of scaling up this approach country-wide where possible.

04 CONCLUSIONS

Energy is a key enabler of social and economic development. In areas where energy access has been slow to reach, the introduction of decentralised renewable energy has provided solutions that support economic activities. In the case of the agri-food sector, renewable energy applications can bring a wide range of benefits, resulting in economic, health and environmental improvements. To maximize them and improve the livelihoods of the 2.9 billion people with no access to clean cooking fuels and the more than one billion people who lack access to electricity, effective policies and regulations must be implemented and appropriate business models adopted, while following an integrated resource management approach.

EFFECTIVE POLICIES AND REGULATIONS ARE NEEDED TO CREATE AN ENABLING ENVIRONMENT FOR RENEWABLES DEPLOYMENT

The feasibility, sustainability and scalability of decentralised renewable energy solutions in the agri-food sector highly depend on appropriate institutional and policy frameworks. Clear and targeted measures can support renewable energy markets by incentivizing local enterprises, stimulating demand, thereby promoting productive uses. Potential policies to support the deployment of decentralised renewable energy solutions in the agri-food chain include:

- Designing development plans that are tailored to local conditions, including consideration of the renewables resource potential, grid extension plans, agricultural activities, and specific cultural needs of the community to support the development of a local market for decentralised renewables.

- Levelling the playing field for renewables solutions by addressing market distortions, such as phasing out subsidies on diesel and kerosene, where possible.
- Putting in place specifications and standards to ensure market differentiation between high- and low-quality products to support a strong market development and ensure users' confidence in the technology.
- Reducing the upfront capital costs for productive uses of renewables through fiscal incentives such as import duty or value-added tax (VAT) exemptions for renewable energy equipment and appliances used for activities in the agri-food chain, such as water pumps for irrigation, milling and grinding machines for agro-processing, and biogas digesters for cooking.
- Improving institutional co-ordination during the formulation of deployment policies among the different entities responsible for agriculture, energy, health, economic development and the environment.
- Facilitating consultations with stakeholders and interactions with community members to encourage co-operation between farmers and service providers and ensure adequate capacity building on the use of decentralised solutions for communities, farmers, financing agencies, the private sector, among others.

POLICIES SHOULD SUPPORT CAPACITY BUILDING AND TRAINING TO MEET SKILLS DEMAND AND TO REDUCE DEPENDENCE ON FOREIGN KNOW-HOW

The application of decentralised renewable energy solutions for productive uses requires that both energy and service providers have relatively advanced technical and business skills to finance, design, install and operate the systems. A shortage of skills could constitute a major barrier to the deployment of renewables and to the achievement of the benefits. Installations undertaken by unskilled workers can result in performance issues and a negative perception of renewable technologies. Maximising the socio-economic benefits of decentralised renewable energy solutions requires forward-looking education and training policies.

- Given that most of the manufacturing equipment in rural areas is imported, the majority of jobs created are in distributing, installing, operating and maintaining systems. Training programmes, therefore, should provide the necessary technology-specific and technical skills, in addition to skills for support services such as marketing and after-sales, price design, quality assurance and micro-financing.
- In the agri-food chain, the necessary skills depend on the activity performed and on the type of produce harvested, and they include skills required for harvesting, processing and selling produce. To retain skilled workers (and avoid migration to urban areas), decision makers can ensure that minimal conditions are met and can offer incentives that encourage the employment and empowerment of women, for example. It is essential to include gender perspectives in both policies and capacity-building initiatives.

Some jobs could be lost as markets transition from conventional energy sources (kerosene, diesel, fuel wood) to renewables-based sources, and from manual to mechanised agricultural processes. Government strategies can support the transition, including from manual unskilled labour towards more skilled and commercially oriented occupations, by facilitating education and training to prepare the workforce for new technologies and productive uses. In this light, estimates are needed on the number of workers at risk of losing livelihoods and support government intervention to address potential dislocation of livelihoods and losses in employment and income.

GOVERNMENT INTERVENTION IS NEEDED TO FACILITATE MARKET ACCESS FOR PRODUCTS AND TO ENABLE INCOME GENERATION

The adoption of decentralised renewable energy solutions in the agri-food sector can result in considerable income generation in the form of increased productivity and new income-generating activities. However, the profitability of such activities depends largely on the demand for the service/product they provide and on the community's willingness to pay for it. A lack of access to markets or to information related to local and regional demand can result in wasted produce, corresponding to a waste in energy, labour, water, and other resources.

To stimulate demand for the new or additional products or services offered, governments can support farmers in identifying the appropriate produce to harvest and determining the right prices, customers, and standards and grades to ensure they find a market outlet.

Finally, it is important to create an enabling environment both in terms of infrastructure development, for example, building roads to transport the produce and business development, for example, help farmers develop the technical and financial capability to procure and operate tools and equipment, identify the most appropriate business model and access micro-financing resources.

BUSINESS MODELS NEED TO BE TAILORED TO SPECIFIC CONDITIONS TO ENSURE THE SUCCESSFUL AND SUSTAINABLE DELIVERY OF PROJECTS

Rural farmers, as well as renewable energy project developers and service providers, often face challenges in accessing finance. Partnerships between international development agencies, governments, financial institutions and the private sector are crucial for supporting the sustainable deployment of solutions through policy, financing and technical innovation. Appropriate business models and institutional approaches, supported by the availability of micro-financing and other funding mechanisms, are necessary.

Tailored delivery models are essential to maximise the benefits of decentralised solutions in the agri-food sector. In the fee-for-service model, for example, customers procure the productive service, such as agro-processing, and not the system itself. The additional income generated by the energy provider can assist in increasing system profitability and energy affordability, while providing impetus for domestic economic growth. In some cases, the ownership model may be preferred, mainly due to the falling cost of renewable energy technologies. Analysing existing practices and conducting pilot projects can help identify the most suitable models corresponding to the funding mechanism available to overcome the financial barriers that impede deployment.

The relatively high capital cost of renewable solutions, despite the recent reduction for some technologies, requires access to end-user financing corresponding to the consumers' income, cash flow and current expenditures on services (in the energy and agri-food sectors), such as micro-financing.

Micro-financing can provide affordable, long-term finance to farmers and service providers, coordinating different financial resources and often using public resources to leverage private sector investment. Micro-financing institutions established at the local level can be involved in training and empowering communities to ensure the profitability and sustainability of the project. Moreover, linking financial support with specific pre-conditions such as the use of drip irrigation for water pumping can help maximise socio-economic benefits, such as mitigating the challenge of the water-energy nexus.

THE NEXUS BETWEEN FOOD, ENERGY AND WATER MUST BE CONSIDERED AT ALL TIMES

With decentralised renewable energy, the cost of the system generally is paid upfront and subsequent usage is at no cost (or minimal), potentially leading to over-exploitation of natural resources. For example, renewables-based pumping can permit excessive withdrawal of water resources and deplete aquifers. It also may increase the surface of land harvested and lead to the over-exploitation and degradation of soil, contributing to climate change and endangering food security.

Avoiding these outcomes will require assessing the impacts of renewables-based pumping on water resources (direct and indirect) to ensure that improvements in the affordability and reliability of energy services do not further aggravate the depletion of aquifers. Such an assessment, along with the broader analysis of the impacts of the deployment of decentralised renewable energy, requires sound data collection. Data need to be collected, analysed and disseminated in a systematic manner following a comprehensive framework.

SOUND DATA COLLECTION AND AWARENESS-RAISING ARE NEEDED TO MAINSTREAM THE SOCIO-ECONOMIC BENEFITS OF DECENTRALIZED RENEWABLES SOLUTIONS

Despite some recent efforts, data on the socio-economic benefits of decentralised renewable energy solutions for consumptive and productive uses are scarce, and major gaps remain in the availability of both quantitative and qualitative assessments on the risks associated with the dependence on fossil fuels and solid biomass. In the agri-food sector, in particular, improved data on the increase in productivity, income and product shelf-life as a result of introducing renewables would strengthen the case for deployment. Only a few studies and programmes gather data on benefits, and rely on heterogeneous methods.

Sound and rigorous information based on harmonised methods is urgently needed to analyse the socio-economic benefits of decentralised renewable energy solutions. This is essential to inform policy choices and monitor policy effectiveness. Robust evidence and data on the impacts of renewables-based water pumping on cost savings, for example, can make the business case for government intervention that facilitates the adoption of solar pumps.

In addition, such information can support raising awareness of the benefits of renewable energy solutions and debunking existing misconceptions about the cost and reliability of renewable technologies, thereby gaining public acceptance. In the agri-food sector, such data contributes greatly to informing farmers, service providers and practitioners on the technical, business and economic potential of decentralised solutions. Such information includes data on the populations at risk, their level of energy access, time spent on chores related to agriculture (e.g., water hauling), manual food processing (e.g., grinding) and fuelwood collection and their exposure to health and environmental risks.

Policy makers can play a key role by supporting institutions specialized in data collection, research and analysis to provide evidence on the impact of renewable energy on rural development while mainstreaming the relevant methods of assessment in projects and activities related to this sector.

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