Modern Energy Services for Modern Agriculture

A Review of Smallholder Farming in Developing Countries

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Poverty-oriented
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A Review of Smallholder Farming in Developing Countries
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Abbreviations

AC	Alternating Current
ATI	Appropriate Technology International
ATTRA	National Sustainable Agriculture Information Service USA
CA	Conservation Agriculture
CBO	Community Based Organisation
CIAT	International Centre for Tropical Agriculture
DAP	Draught Animal Power
DC	Direct Current
DGIS	Directorate-General for International Cooperation Dutch Ministry of Foreign Affairs
EnDev	Energising Development
ESMAP	Joint UNDP/World Bank Energy Sector Management Assistance Programme
ESCO	Energy Service Company
EU	European Union
FAO	Food and Agriculture Organisation of the United Nations
FM	Frequency modulation
GATE	German Appropriate Technology Exchange
GDP	Gross Domestic Product
GEF	Global Environment Facility
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit, Germany
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit, Germany
HDC	Heat Driven Cooler
HERA	Povert-oriented Basic Energy Services
HP	Horsepower
ICT	Information and Communication Technologies
KfW	Kreditanstalt für Wiederaufbau
kW	kilo Watt
kWe	kilo Watt equivalent
kWh	kilo Watt hour
LPG	Liquid Petroleum Gas
MFI	Micro Finance Institution
MFP	Multi Functional Platform
MHPP	Micro Hydropower Program
MJ	Mega Joule
MT	Metric Ton
NCAT	National Centre for Appropriate Technology
NGO	Non Governmental Organisation
OECD	Organisation for Economic Cooperation and Development
PA	Practical Action
PSDA	Private Sector Development for Agriculture
PV	Photovoltaic
R&D	Research and Development
SARD	Sustainable Agriculture and Rural Development
SME	Small and Medium Enterprises
SMS	Short Message Service
SVO	Straight Vegetable Oil
SHS	Solar Home System
SSA	Sub-Saharan Africa
UNDP	United Nations Development Program
UNEP	United Nations Environmental Program
USAID	United States Agency for International Development
VFD	Variable Frequency Drive
W	Watt

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The report aims to highlight the important role played by modern energy services and related technologies in the modern agricultural production process for smallholders in developing countries. It focuses on energy input in agricultural production, processing and commercialisation in order to increase crop production and add value to products, enhance food security, increase income for farmers and rural enterprises and finally boost the development of rural areas.

The information was compiled from various relevant publications, secondary literature, the experience of programmes implemented by colleagues of GIZ and personal communication with colleagues.

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Abstract

Modern agriculture needs modern energy - the two are closely linked. For many developing countries, agriculture is the dominant sector in developing the economy. Increasing productivity and the modernisation of agricultural production systems are the primary drivers of global poverty reduction and energy plays a key role in achieving this. Energy input to modern and sustainable agricultural production and processing systems is a key factor in moving beyond subsistence farming towards food security, added value in rural areas and expansion into new agricultural markets.

There are two main energy requirements for greater agricultural productivity in a market-oriented agriculture, provided either by renewable or conventional energy sources or a combination of both:

1. Energy for transport (fossil fuels or biofuels) is needed for many services within the supply chain, from the production process to transport to markets. Market-oriented agriculture is heavily dependent on vehicles for transport and on favorable infrastructure such as linkages to roads. Access to markets is a major incentive for farmers to increase production in order to increase income.

2. Energy for production, processing and commercialisation is provided in different forms. In many rural areas, supplying electricity by connecting to the national grid is economically or logistically unfeasible. Decentralised power production with renewable energy systems and hybrid systems (combination renewable/fossil) proves more reliable, more environmentally friendly and more cost-effective than fossil fuel systems alone.

In many cases, renewable energy technologies and hybrid systems can provide energy services that neatly support the production process, e.g. by providing irrigation (pumps) or post harvest treatment (cooling) or processing (drying, milling, pressing). The requirements of mechanical energy in the agricultural production process are also of critical importance and include human and animal labour as well as fuels for mechanisation, pumping and other activities, and indirectly the production of fertilisers and agrochemicals.

The report aims to highlight the important role played by modern energy services and related technologies in modern smallholder agriculture throughout the supply chain, from agricultural production, post-harvest and storage to the processing and commercialisation of crops. It also touches on the dual role of agriculture as energy user and producer and suggests management models to minimise risks for farmers by buying energy services on a fee-for-service basis.

1. Introduction

Agriculture is the engine of sustainable development – and energy is a major driver in this process.

Agriculture contributes significantly to economic and social development in the vast majority of developing countries. 45 per cent of the developing world's population lives in households involved in agriculture and most depend on agriculture and the agri-based economy for their livelihoods. In agriculture-based countries, the agricultural sector generates on average 29 per cent of gross domestic product (GDP), employs 65 per cent of the labour force, and is crucial in driving overall growth. The increase in agricultural productivity is the primary driver of global poverty reduction.[1]

In providing for human needs, agriculture has many functions: its primary role is to produce food and other primary goods for human consumption and thereby contribute to food security. Agriculture provides foodstuffs and drinks, produces animal feed and also delivers a wide range of non-food goods and services. For example, plant and crop-based resources are used as raw materials for a wide variety of industrial product, including pharmaceuticals, synthetics, biofuel production, rubber for tyre production, wood and other fibres for paper and furniture production, starches for adhesives and as ingredients in the confectionery industry, vegetable oils are used as food additives and in paints and resins, and of course fibres such as cotton, silk, linen, jute and hemp are used in the clothing industry.

All these production and transformation steps require energy, which is thus considered a key factor in agriculture in achieving sustainable development and poverty reduction. Most donor governments and international organisations have recognised the importance of integrating energy into agricultural policies to promote Sustainable Agriculture and Rural Development (SARD), by making available new and renewable energy sources and improved energy efficiency for rural household and agro-industrial needs in rural development programmes.[2]

Access to clean, reliable and affordable energy services for basic human needs at household level (cooking, heating, lighting, communication), health stations (healthcare), schools (education); productive uses to improve productivity in agriculture (e.g. water pumping for irrigation, fertiliser, mechanised tilling); and commercial cottage industries and agro-enterprises (agricultural-processing), represents the minimum level required to improve livelihoods in the poorest countries and to drive local economic development on a sustainable basis.[3]

The links between energy input and improvements in agricultural productivity are very close and the benefits can be widely spread for rural economic and social development by:

- providing food security on local and national level;
- raising farmer and rural incomes;
- stimulating the local economy: higher incomes for farmers and farm labourers create increased demand for basic non-farm products;
- creating job opportunities;
- avoiding population migration - especially youth - into peri-urban and urban centres by offering job opportunities;

[1] World Bank (2007) and the World Bank Website.
[2] FAO (2000a)
[3] AGECC(2010)

- growing upstream sectors (production facilities such as fertilisers, fuels, farm machinery) and agricultural service sectors (financing institutions, repairing of machinery, etc.);
- growing downstream sectors (agro-processing enterprises) and business development sectors;
- encouraging entrepreneurial activities such as diversification into new products and expansion into new markets.[4]

Access to basic energy services such as lighting and electricity enables farmers to adopt longer and lighter production procedures, allowing them to extend production by cultivating diversified crop species and shortening fallow periods, thus generating more income.

However, the agricultural production cycle is also highly sensitive to fluctuating energy prices caused by raising crude oil prices. Over the last decade, and owing to the food price crisis in 2007-08, fossil fuel prices have also increased, leading to their substitution by renewable energy sources such as biofuels (mainly ethanol and biodiesel). High fuel costs for transportation and farm machinery are of particular importance as they also reflect higher production costs, thus causing higher food prices.

This also applies to fertilizers - whose production accounts for the most energy-intensive stage within the agricultural supply chain - as well as to pesticides and animal feed. Owing to higher prices for agricultural inputs, farmers have often no longer been able to apply fertilisers, which has led to lower productivity, lower income, lower food security and therefore to higher prices for food and more poverty in rural areas.

Even if agriculture is an important user of energy in developing countries, it is not the predominant user. Direct energy use in agriculture accounts for only a relatively small proportion of total final energy demand in national energy accounts (excluding the energy required for food processing and transport by agro-industries). In OECD countries, the figure is around 3-5 per cent, and in developing countries around 4-8 per cent. Nevertheless, a small amount of additional energy, even where insignificant at the level of national energy balances, can make an important contribution to a local rural economy, as agriculture itself contributes significantly to economic and social development (FAO 2000a).

This report provides an overview of the agricultural production cycle of crops following the mapping design of the GIZ Value Links methodology.[5] Through mapping, the value chain system is visualised by drawing the sequence of productive processes, which here applies to primary production (land preparation, cultivation, irrigation, harvest), post-harvest and storage, transformation (processing) and commercialisation. The agricultural applications, energy requirements at each step, energy sources utilised and types of technology applied will all be outlined.

Agricultural sectors such as farm forestry, animal husbandry, fishery and aquaculture—where energy input is also important but only at certain stages—are not considered in the report.

[4] Diao et al (2008)
[5] GTZ ValueLinks Manual (2008a)

2. Modern agriculture's need for modern energy services

Modern agriculture needs modern energy services. A major component of market-oriented modern agriculture is access to markets, which requires energy for transport as well as access to affordable physical infrastructure. As commodities produced in rural areas must be transported rapidly and efficiently from farmgate to processing facilities, and on to local markets or wholesalers (transportation and bulk storage), improvements in road networks and transportation are of vital importance. A significant increase in farmer income can be achieved if favorable infrastructure connects them to markets, thus significantly reducing transportation costs. In many parts of sub-Saharan Africa, and in the more remote rural areas in Southeast Asia and Latin America, poor rural roads fail to connect smallholders efficiently to local markets or agribusiness processors. Roads that are impassable in the wet season, for example, force farmers to sell their produce in the dry season at low prices. This in turn leads to higher prices for consumers in the wet season from which smallholders cannot benefit. The quality of roads also plays a role in the transportation of produce by bulk or refrigeration. Poorly constructed or maintained roads prohibit use by larger vehicles, therefore constraining market access.[6]

Transport costs often represent the bulk of marketing costs, depending on fuel prices and access to roads, often reflected in a considerable percentage mark-up within the product price calculation. Fossil fuel-powered or biofuel-powered transport cars or pick-up trucks offer the most frequently used modes of transportation.

Fossil fuels are by far the dominant source of primary energy in the world, with oil, coal and gas together supplying more than 80 per cent of the total. Renewable energy sources represent around 13 per cent of total primary energy supply, with biomass (including agricultural and forest products and organic wastes and residues) dominating the renewable sector at 10 per cent.[7] Biofuels are energy carriers that store the energy derived from biomass. Despite rapid growth in their use over the past decade in certain countries, biofuels accounted for only 3 per cent of global road-transport fuel demand in 2009.[8] A comprehensive study has compared the energy consumption of different transport methods in Europe.[9] Small highway vehicles, particularly cars used for hauling small amounts of produce, are much less energy-efficient than large trucks. Rail transportation is estimated to be about three times more energy-efficient on average than trucking and marine transport is the most efficient transport mode.

Agro-processing also extends markets and has significant implications for poverty reduction, food security and economic development. A recently published ESMAP paper argues that the most efficient way to deliver effective and lasting impact when designing a rural electrification scheme is to ensure that such programmes have a direct impact on livelihoods and revenue generation, in addition to the more conventional impact on standards of living.

Increasing revenue generation can be accomplished by improving the productivity of existing production processes and creating new lines of activity to generate employment and local demand.[10] A World Bank paper defines productive uses of energy as activities "that involve the utilisation of energy—both electric, and non-electric— in the forms of heat, or mechanical energy for activities that enhance income and welfare. These activities typically occur in the sectors of agriculture".[11]

[6] FAO (2008)
[7] IEA (2007)
[8] IEA (2010)
[9] Van Essen et al (2003)
[10] ESMAP (2008)
[11] Kapadia (2004)

The need for and impact of modern energy services on improving agricultural productivity is demonstrated by the example of utilising micro-hydropower as a renewable energy source for productive use in rural Indonesia. Under the GIZ/DGIS EnDev micro-hydropower program (MHPP) the energy service was expanded from domestic use only to include productive use, which significantly improved rural livelihoods and income generation. A diversified energy service enabled the community to use electricity also for productive processes such as grain threshing and rice hulling. The operations were carried out under community management and led to an increase of income within a short time. The workload of women was also significantly reduced.[12]

Following the impact chain the graph below should be read from the bottom upwards.

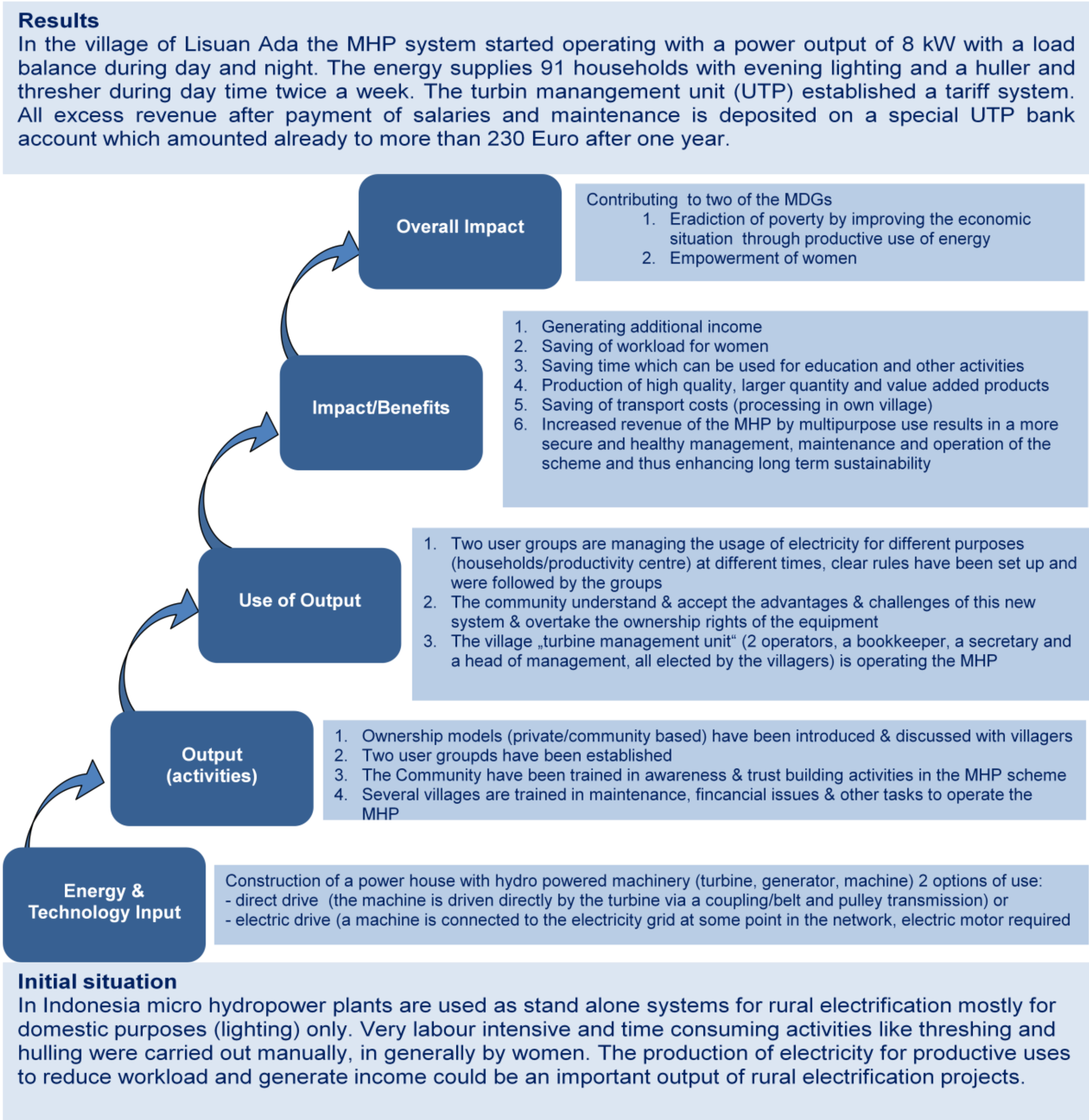

Figure 1: Impact Chain GIZ/DGIS EnDev Micro-Hydropower Program

[12] GTZ/Entec (2008b)

In many developing countries, agricultural production, processing and commercialisation are still based to a large extent on human and animal energy as there is often insufficient mechanical, electrical and thermal energy available. Three different levels of intervention for energy input can thus be considered:

1. Basic human work for tilling, harvesting and processing, together with rain-fed irrigation;
2. Use of animal work to provide various energy inputs. (Neither level involves direct energy input from an external fuel source, although indirect energy input is needed for the production of food for human consumption, animal feed and cultivation inputs like fertilisers, herbicides, pesticides and insecticides);
3. The application of renewable energy technologies (e.g. wind pumps, solar dryers, water wheels, biomass conversion technologies), fossil fuel based technologies (e.g. diesel engines and generators) or hybrid systems (a combination of both) for motive and stationary power applications and for processing agricultural products.

2.1 Access to electricity, mechanical power and thermal energy

Modern energy services include different types of energy: electricity from the grid, decentralised renewables, conventional technologies and mechanical and thermal energy. They also include fuels such as natural gas, liquid petroleum gas (LPG), diesel and biofuels (bioethanol and biodiesel) as well as improved biomass cooking stoves.

The scale and nature of the access gap and the locations involved mean that electrical and non-electrical power (mechanical and thermal energy) will need to be provided through both centralised and decentralised energy technologies and systems.

2.1.1 Electrical energy

1. Connection to the national grid: If the grid is available and sufficiently reliable, it is usually the first choice for power supply. The remoteness of some areas combined with low population density often make grid-based electrification an economically unviable option.
2. An alternative to the costly extension of the public electric grid is the installation of local mini-grids with one or more small power generation units supplying electricity to several households, villages or communities.
3. In decentralised off-grid or stand-alone systems the electricity generated is used by a single user or household, e.g. a solar household system (SHS) or household biogas plants. Except for lighting, space heating and cooking with biogas, stand-alone systems are not relevant for the agricultural production process.

Decentralised systems are more attractive for isolated applications than grid solutions since they can be deployed more rapidly and do not require costly extension capacities. Moreover, there is often significant local business-building and job creation potential in these solutions. Their levelised costs relative to grid-based solutions depend on a variety of factors, in particular the capital cost of the generation technology (in part related to capacity of supply required) and distance from the existing grid. Renewable energy technologies, including small hydro, solar, wind and various types of bioenergy, are ideally suited to mini-grid and off-grid applications, especially in remote and dispersed rural areas. The key challenges related to both include significant initial capital investments, the capabilities required to install and maintain these systems, and defining and implementing appropriate pricing systems. Mini-grid systems have added operating complexity and costs, including load balancing. However, in many cases the value of aggregating supply at community level so that it is available for productive use during non-peak hours for household use will outweigh the costs.

In light of rising fossil fuel prices, electricity generated from renewable energy sources can also be considered economically competitive, especially where the price of diesel as an alternative is already high and its price becomes even higher owing to transport to remote areas. The main benefits of renewables—and the reasons for government support—are that they reduce CO_2 emissions (where used instead of fossil fuels) and reduce dependence on imported fuels, notably oil and gas.

2.1.2 Mechanical energy

The use of mechanical power in agricultural production and processing is crucial. Mechanical power is defined as 'the effective outcome of transforming different forms of energy sources (e.g. wind, hydro, fossil fuels) to kinetic energy (to cause motion)', creating electrical and non-electrical power. Non-electrical power includes sources such as human power (e.g. treadle pumps, rope pumps, etc.), animal power (e.g. oxen, donkeys), renewable/natural power (e.g. wind pumps, hydro turbines, biogas engines) or fossil energy (e.g. gas/diesel engines/pumps etc.) without intermediate conversion to electricity. These can be roughly ranked in terms of their technical complexity, cost and flexibility, although the suitability and fit of a given energy source to a mechanical power application is strongly dependent on context.[13]

2.1.3 Thermal energy

Thermal energy inputs for smallholder agricultural applications are provided by solar and biomass systems, e.g. solar heat for drying (tea, coffee, fruits, vegetables) or combustion of biomass to produce process heat (e.g. food processing).

2.2 Choosing the right energy source for smallholder applications

Different technologies are often flexible in terms of the type of energy source that may power them. The World Bank's Energy Sector Management Assistance Program (ESMAP) published a comprehensive economic comparison of 22 power-generating technologies based on costs in 2005. It aimed to characterise the technical and economic viability of electricity generation technologies (both renewable and conventional) to serve rural, peri-urban and urban populations in developing countries. The work provides a capital cost comparison and an electricity cost comparison for renewable energy and conventional energy technologies.[14] Since that time, equipment costs as well as fuel costs have risen sharply. The results should therefore be seen as merely indicative. The World Bank ESMAP unit is currently updating these data and the report is expected to be available in May 2011.[15]

In terms of energy requirements for greater agricultural productivity, it should be emphasised that agriculture plays a dual role as an energy demand and supply sector in the form of bioenergy (biomass). Biomass is energy stored in organic material (e.g. wood, agricultural residues, animal by-products, fuel crops, agro-industrial by-products) and offers a significant potential source of renewable energy supply in the form of heat and electricity. In order to generate heat or electricity, biomass can be combusted, gasified, biologically digested, fermented, or converted to liquid fuels.

Woodfuel, charcoal, agricultural residues and small-scale biogas production are traditionally used for household purposes. Large-scale biomass utilisation from agricultural crops and residues, agro-industrial processes and its by-products offer huge potential for decentralised heat and electricity supply and the production of biofuels. In light of rising crude oil prices and

[13] UNDP and Practical Action (2009)
[14] Worldbank (2008)
[15] According personal communication with Mrs Jane Ebinger jebinger@worldbank.org

the search for renewable fuel solutions, the worldwide hype on biofuels for transport has lost ground to a more realistic valuation of its use.[16],[17],[18].

Local use of straight vegetable oils (SVO) in rural areas thus offers an interesting alternative, which can also be converted to biodiesel for transport and diesel engines or generate electricity for stationary use, to drive machinery or as an electricity generator. Including oil seeds in farming systems gives smallholders the opportunity to participate in this emerging market. Rape seed oil is relatively easy and reliable to use in diesel engines and other oils like palm oil, sunflower, soybean, coconut, Jatropha and cotton oil have also been used to fuel motors. In many cases the oil is only a by-product that is rarely extracted. Some engines are specially designed to operate on vegetable oils. The German Elsbett company provides vegetable oil engines and provides sets for the conversion of tractor or truck engines to be fuelled by SVOs. Small (<20 kW) Lister-type diesel engines produced in England or India and commonly used worldwide are also appropriate for SVOs as fuel.

Many companies offer small generator sets especially for SVO use. A study assessing the potential and drawbacks of SVOs for decentralised fuel and electricity generation in rural areas came to the conclusion that, from a technology point of view, they provide a very viable option for decentralised small-scale application if the energetic use of all plant parts including the woody parts is integrated. The use of SVOs also depends on the flexibility of engines to use both diesel and SVO and the availability of standardised oils. However, to build up a complete local electricity supply system based on SVO would be much more complicated and costly. The upstream part especially, with logistics for collection, transport, processing, storage of the oil fruits or fuel, would prove very challenging.[19]

Another type of biomass conversion is biogas technology: the generation of combustible gas from anaerobic biomass digestion—a technology which is already well-known and applied worldwide. Biogas-producing farm households in developing countries use it mostly for lighting, cooking and space heating. For smallholders it represents an opportunity to adopt a recycling energy economy: biomass (energy output) is converted (anaerobic fermentation) into a modern energy carrier (biogas), which is then used for different household purposes (energy input), whereas the residues from biogas production provide fertiliser as an important farm input. In industrialised countries, the main purpose of biogas plants is power generation and conversion of biogas to electricity has become a standard technology. A study, assessing the biogas sector in developing countries, concluded that bigger biogas plants are generally more appropriate, even for relatively small power applications in the range of 10-100 kW. The electricity generation component of a biogas power plant does not require much more know-how and maintenance than a normal generator set for fossil fuels. However, little experience has been acquired so far concerning the use of biogas power plants to cover the basic energy needs of the rural population. Most biogas power plants are connected to agro-industrial facilities and provide electricity only to very few immediate neighbours. However, calculations show that biogas could play a role in supplying isolated grids, where it represents a least cost option. By contrast, the establishment of appropriate feed-in tariffs stimulates the construction of efficient plants and their continuous and efficient operation. As long as national framework conditions are unfavorable, electricity generation from biogas will remain limited to a few pilot applications.[20]

The biomass conversion technology of gasification is basically the conversion of solid fuels such as wood and agricultural residues into a combustible gas mixture. In order to produce electricity, the generator gas is used as a fuel in an electric generator set with a combustion

[16] IEA RETD and IEA Bioenergy (2010)
[17] CE Delft (2010)
[18] FAO (2008)
[19] GTZ/ HERA (2010c)
[20] GTZ/ HERA (2010b)

motor. The study came to the conclusion that the technology is not yet ready to be applied for communal purposes or for providing electricity to households and small businesses in remote areas. [21]

Table 1: Overview of Renewable Energy Technologies

Energy source	Conversion to	Most applied technologies and applications	Remarks
Solar energy	Heat, Mechanical energy, Electricity	- Photovoltaic (PV) driven pumps for irrigation, - crops, fruits, spices drying, ice making and cold storage (through absorption or heat driven refrigeration).	PV systems are limited to agricultural activities that require little power input only. FAO provides an inventory of PV applications (Annex 1).[22]
Wind energy	Mechanical energy, Electricity	- direct use: grinder, mills, mechanical water pumps - electrical water pumps	Option for energy intensive processing activities
Microhydro energy (water)	Mechanical energy, Electricity	- direct use: mill, grinder, - electrical motor for processing.[23]	Option for energy intensive processing activities
Biomass energy	- Heat - Electricity - Liquid biofuels - Biogas	- dryer (fruits, herbs,spices) - fermenter (tea) - combustion motor or electric motor (fuels like ethanol and biodiesel for transportation) - anaerobic digester: biogas for lighting, cooking and heating and industrial biogas for decentralised electricity.	- Biomass is organic material used to generate electricity, to produce heat or biofuels for transportation. - Bioenergy is derived from wood, agricultural crops, residues, animal by-products, agroindustrial by-products.
Hybrid power systems	Combine fossil fuel-fired generators with wind or solar electrical power	- Wind/PV Hybrid - Wind/Diesel Hybrids Used in the food processing sector (grinding of corn, wheat and millet, and milling of grain-hulling paddy).	- Together, they provide a more reliable and cost-effective power system than is possible with either wind, solar or diesel alone. - An emerging technology.

2.3 Approaches to sustainable energy services for rural electrification

Many public programmes and private sector-led markets attempt to provide sustainable electricity services for rural populations. Some rely on equipment donated through bilateral development assistance programmes, while others include sustainable mechanisms for servicing installations or commercial viability. Only a few employ public or private “fee-for-service” electricity providers.

The sustainability of energy services can be defined in terms of technical, environmental, economic and social issues. Reliable access to technologies and their spare parts and repair services, reliable access to fuels (supply, distance, prices, quality) or adequate grid electricity, cost-effectiveness, and management capacity have to be addressed to secure technical sustainability. Meeting the technology needs of farmers and other actors in the value chain in a cost-effective manner is particularly important, so that the capacities and costs of energy-consuming technologies can be adapted to the capacities and resources of agricultural production. The benefits of efficient producer-technology also include minimisation of debt and debt-related expenses, shortened amortisation periods, reduction of waste from excess capacity, and, most fundamentally, the maximisation of the profitability and viability of enterprises. Improved energy efficiency in mechanical handling equipment and in drying and separating operations is also important. Potential energy savings can also

[21] GTZ/ HERA (2010a)
[22] FAO (2000b)
[23] Weingart and Giovannucci (1997)

be made through changes in the design and use of farm machinery and technologies and improvements in farming systems such as conservation agriculture (CA). Renewable energy technologies can reduce environmental impact and help achieve a greater degree of self-sufficiency in developing countries by reducing the need for imports of fossil fuels and promoting the development of locally sourced energy supplies through renewable energies.[24]

Sustainability of energy services also depends on customers' financial, management and business-related capacities. The farmer as businessman needs to possess management skills such as personnel management, detailed financial planning or handling of sophisticated technology. The same applies to agricultural cooperatives, whose personnel generally consists of their farmer members. If a cooperative aspires to produce on any scale, access distant and sophisticated markets, at the highest prices, and spread its production throughout the year, it cannot rely solely on the farming expertise of its membership. However, energy services can generally be managed by operators if they have the right training and required skills and expertise to not only use but also maintain the technology.

The employment of public or private "fee-for-service" electricity providers is considered to be conducive to sustainability. Market-oriented business models, such as *energy service companies* (ESCO), are gaining in importance in support of groups of farmers, villages, communities and rural enterprises in the provision of modern decentralised energy services. ESCOs are private operators who typically own the energy production and supply equipment, and charge for energy services on a fee-for-service basis. The business risk in terms of energy supply is fully overtaken by the ESCO.This frees farmers, entrepreneurs, and businesses to focus on farm management and income generation and relieves them of both the financial and technical risks associated with the energy production equipment. The use of such services generates income for users, who can in turn also pay for the service. However, even if it constitutes an emerging market, the ESCO model for stand-alone systems has to date been implemented in very limited ways, especially in Africa. ESCOs generally require financing, but the financial returns for the ESCO may take up to 10 years to materialise, whereas most developing country banks will not provide financing with an equivalent term. ESCO financing therefore must currently come from either government or multilateral sources. Another financing complication is that the ESCO run the risk of customers abusing or stealing equipment. However, customers often prefer individual solutions at household level, given their experience of joint use, in which handling and maintenance of the energy service can prove difficult to sustain and require a range of skills provided by ESCOs. The core issue for both, either individual households or agricultural cooperatives, remains the availability of maintenance skills acquired through training or from specific service providers. However, improving the ESCO model could be a way forward if energy programmes include socio-economic studies in their planning.

Another fee-for-service model is *leasing,* or *hire-puchase*, whereby the private leasing company retains ownership of the energy production and supply systems until the customer has completed payment over the lease period. Experience with the leasing company approach has met with success in countries such as in China (Gansu Solar Electric Light Fund), Laos (Sunlabob) and the Dominican Republic (Enersol).

In the *concession model* a concession for fee-for-service operations is signed between the private service provider and the government. The concession approach is relatively recent in rural development practice and very few examples of implementation are yet available. A case study from six developing countries suggests that the regulatory, institutional, and financing challenges of concessions are significant and that it remains difficult to identify the

[24] USAID (2009)

most appropriate types of concession for different contexts. [25]

In the traditional *dealer model* a dealer purchases systems and sells them directly to the customer, who owns the system and is responsible for it. The business risk is fully taken over by the customer, e.g the farmer.

For all types of electricity services, past experience has shown that no single institutional model reliably provides better success rates than others. However, the following matrix summarises the main characteristics of business models for stand-alone renewable energy system delivery and indicates important risk minimisation opportunities for farmers, which is crucial in choosing an energy service.[26]

Table 2: Energy Service Provider, Overview of Business Models

Model	Ownership	Financing	Product flow	Service flow	Risk for the customer
Dealer model 1: Cash sales	All components owned by customer	Not applicable	Individual purchase of system, installation by dealer or consumer	Provided by dealer on a fee-for-service basis through service contracts	100 per cent own risk
Dealer model 2: Credit sales	All components owned by customer, system could be used as collateral	Credit provided by commercial banks, micro finance institutions (MFI) or vendor	Individual purchase of system, installation by dealer	Provided by dealer as part of after sales agreement or on fee-for-service basis through service contracts	50 per cent customer, 50 per cent financing institution
Fee-for-service 1: Leasing	Main system owned by leasing company, other components usually owned by customer	Provided by leasing company through leasing agreement	Installation by leasing company or supplier under contract to company	Provided by leasing company or private vendor under contract to company.	No risk for the customer
Fee-for-service 2: ESCO	System owned by ESCO	Provided by ESCO through service agreement	Installation by ESCO	Provided by ESCO as part of service agreement	No risk for the customer
Concession	All components owned by concessionaire	Provided by ESCO through service agreement	Installed by concessionaire or by supplier under contract	Provided by concessionaire as part of service agreement	No risk for the customer

[25] Worldbank (2000)
[26] Worldbank (2006)

The experience of multifunctional platforms as a business model is analysed below and the difficulties of installing a sustainable system are clearly indicated:

Table 3: Lessons Learned from Multifunctional Platforms (MFP)

One business model comprising a technical and organisational solution to increase access to energy is the multifunctional platform (MFP), supported by donors in five West African countries since 1994. The MFP consists of a small diesel engine mounted on a chassis, to which a variety of food-processing equipment is attached, including grinding mills, vegetable or nut oil presses and dehuskers, as well as other equipment such as battery chargers, welders and carpentry equipment; according to business demand. It can also generate electricity for lighting and pumping water.[27]

Besides the technical element, the concept comprises three important organisational elements strongly linked to the donor agenda: (1) the MFP should be owned, operated and maintained by community-based organisations (CBOs); (2) members of the CBOs should exclusively be women; and (3) the engine should preferably be driven by biofuel produced by women.

A critical analysis of this concept as a promising model at policy level came to the conclusion that its integration seems to have had limited or even adverse effects on the outcome of the program. The paper provides indications that, in terms of achieving low-cost energy services in rural areas, single-purpose implements and private ownership by both men and women might be a better option than the multipurpose implement owned and operated by women's groups. This analysis again stresses the argument for building development aid on existing structures instead of inventing new complicated all-embracing concepts and approaches.[28]

UNEP has supported the preparation of a Toolkit for Energy Entrepreneurs which covers the topics that must be addressed in a business plan for any clean energy business. Each step in the process is designed, whether you are interested in selling electricity generated from hydropower to a national utility or manufacturing energy-efficient cooking stoves.[29]

According the international NGO Practical Action (PA) three main activities should be promoted to achieve sustainable delivery of energy to the poor: (1) the creation of local and national capacities; (2) mobilisation of local capital; and (3) energy literacy.[30]

[27] UNDP and Practical Action (2009)
[28] Nygaard (2010)
[29] UNEP/ AREED (2005)
[30] Practical Action (2009)

3. Energy input in the agricultural production chain

As modern agriculture requires energy input at all stages of production, processing and commercialisation, modern energy services need to be deployed.

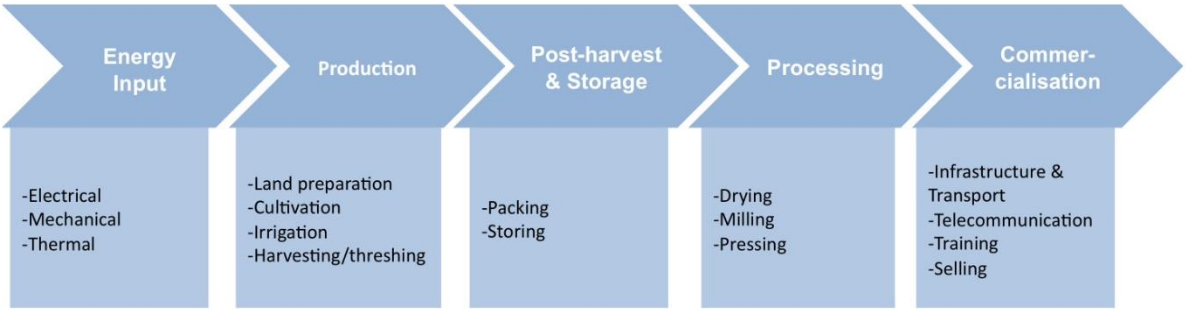

Figure 2: Overview Value Chain Agricultural Production

The agricultural production chain involves the following steps:

- Production
- Postharvest and storage
- Processing
- Commercialisation

The following chapters provide an overview of energy requirements for each of these steps and for the selection of suitable efficient technical options to meet those energy needs.

3.1 Production

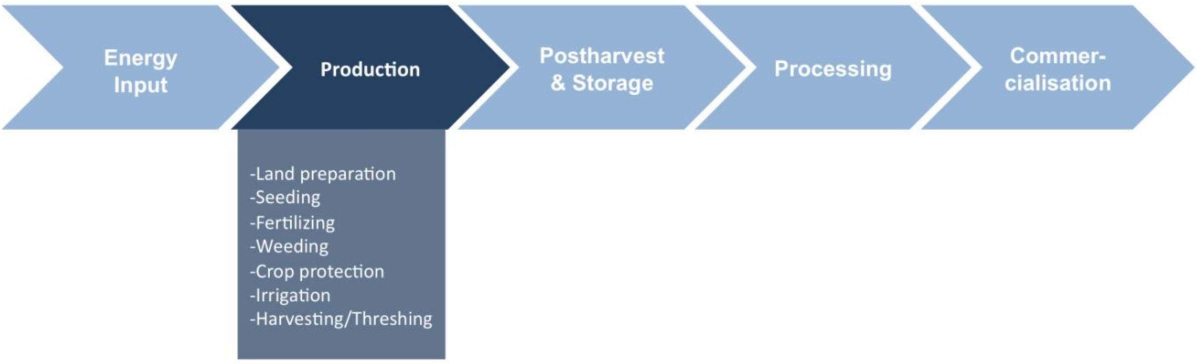

Figure 3: Value Chain Agricultural Production: Production in detail

3.1.1 .Land preparation, cultivation, harvesting and threshing

The power necessary for agricultural production is provided by human labour, draught animals or engine-driven machinery. Mechanisation is a key input in any farming system applying tools, implements and machinery to improve the productivity of farm labour and land. Based on the power source, the technological levels of mechanisation have been broadly classified as hand-tool technology, draught animal technology and mechanical power technology.[31]

The bulk of direct energy inputs in smallholder production is provided by human and draught animal power (DAP). Agriculture in developing countries relies heavily on the physical capability of farmers, with often limited output, depending on the physical energy available. A

[31] FAO (2006)

fit person consumes around 250-300 W in terms of energy, depending on climate and with a rest of 10-30 minutes/hour. The efficiency of energy conversion is only 25 per cent, with a maximum power output of 75 W. Operations involving human skill include activities such as planting, weeding, spraying and harvesting and using hand tools. Most horticultural commodities are harvested manually, including those grown in highly industrialised nations. Energy requirements during harvesting include mechanical energy for digging up root and tuber crops. For example, a simple, labour-saving cassava harvesting tool was introduced to Thai farmers by the International Centre for Tropical Agriculture (CIAT) reducing person-days from 15-40 (depending on the type of soil and the yield) to 5-10 days only. The tool costs 2.50 USD, is produced by local manufacturers and can be used collectively by farmers.[32] Harvesting early in the morning when air temperatures are cooler also helps to reduce energy requirements and cooling costs.

Activities such as ploughing, soil preparation, water lifting, pulling inputs and threshing require fewer skills but greater energy input and are hence mostly powered by draught animals such as buffalos, horses, donkeys, camels or oxen. Power output ranges from 200 W for a donkey for 4 hours daily work to over 500 W for a buffalo (FAO 2000a). Draught animal power can alleviate human drudgery and is generally considered to be an affordable and sustainable source of power for smallholders, also given its great potential for diversification and expansion e.g. for transport and non-farm work. Efforts to expand the use of draught animal power should include work on animal efficiency, which can be improved through modernisation of equipment, better breeding and animal husbandry, feeding and veterinary care.

In sub-Saharan Africa (SSA), human effort contributes about 65 per cent of the power required for land preparation and subsequent weeding, the principal demand peaks in the farming cycle. An example comparison shows that a typical farm family relying solely on human power can cultivate only 1.5 hectares per year. This rises to 4 hectares if animal power is available and to over 8 hectares if tractor power can be accessed (FAO 2006).

Transition to increased mechanisation of agricultural operations occurs using diesel or gasoline-powered tractors and harvesters. Fuel powered two-wheel tractors are often used for agricultural production, with different attachements for tillage, bed planting, row planting, harvesting and threshing. In Bangladesh, power tillers (12-15 hp) are used for about 70 per cent of farm work because of their versatility (UNDP/PA 2009). The fuel requirements for digging up root and tuber crops, e.g. of a potato digger are 0.57 gallons of diesel fuel per ton of product (1.96 litres/MT) (USAID 2009). Energy use depends mostly on the speed at which activities are carried out. As tillage operations within arable farming systems often have the highest energy requirements and lead to soil degradation, the reduction of mechanical tillage is promoted by the approach of conservation agriculture (CA).

In general, a four-wheel tractor will not be economically feasible for a smallholder with a typical land holding of up to 5 hectares. Government-run tractor hire schemes in SSA countries have not been able to increase farm productivity. On the other hand, the concept of a rental market for privately owned and operated tractors has potential that may increase in the future (FAO 2006).

[32],Appropriate Technology (2010)

Besides direct energy demand in agriculture there are also indirect energy inputs in the form of sequestered energy in fertilisers, herbicides, pesticides, and insecticides, all of which require energy in their production, distribution and transport processes. Fertilisers form the largest of these energy inputs to agriculture, whilst pesticides are the most energy-intensive agricultural input (on a per kg basis of chemical) (FAO, 2000).

Need for these inputs however can be reduced by the use of farm-own organic manure or by agro-industry based bio-fertiliser production, e.g. generated from biogas plants (at household or industrial level). The promotion of locally produced organic fertiliser also has the advantage of avoiding the negative environmental impact of mineral fertilisers and benefits from the shorter distances required for distribution, thus reducing energy requirements and fuel costs.

Past experience in Asia indicates that the key factors driving mechanisation and consequently power for agricultural development are guaranteed markets and farm prices for key crops, favorable government policies and availability of credit. The example of India shows that favorable government policy and farmer demand have led to increased availability of appropriate and locally manufactured farm machinery and ultimately to India becoming the world's largest tractor manufacturer.[33]

A very comprehensive comparison of *Energy Use in Conventional and Organic Cropping Systems* has been carried out by the National Sustainable Agriculture Information Service (ATTRA) of the US National Centre for Appropriate Technology (NCAT). The report shows, in a review of existing studies, that there are many complexities involved in comparing energy consumption in conventional and organic cropping systems. Certain research indicates that organic agriculture is more energy-efficient than conventional agriculture, but not in all cases. In some cases, organic agriculture may be more energy-intensive, depending on the specific farming operation, the crop produced and the post-production handling. It is important to assess the energy-intensiveness of food systems in a holistic manner that incorporates energy consumption for the entire life cycle of the food product.[34]

3.1.2 Irrigation

Access to water is a major determinant of land productivity and active water management through irrigation offers an important opportunity to stabilise yields. Irrigation is therefore of the utmost significance in the agricultural production process and this chapter is consequently accorded great importance. Irrigated land productivity is more than double that of rainfed land. In sub-Saharan Africa, only 4 per cent of the area in production is under irrigation, compared with 39 per cent in South Asia and 29 per cent in East Asia (World Bank 2007). With growing water scarcity and costs of large-scale irrigation schemes rising, there is a need to enhance productivity by improving existing schemes, expanding small-scale schemes and developing water harvesting.

"Irrigation" refers to the distribution of water for growing crops, including the use of water storage and pumping, where appropriate. The energy demand for irrigation purposes is the energy required to lift water by pumping from surface sources, such as ponds, streams, or canals; or from below-ground sources using open wells or boreholes. This water is typically pumped to surface canals, reservoirs, or elevated tanks. The energy demand for water lifting is calculated by multiplying the head (the vertical distance from the water source to the field

[33] FAO (2009a)
[34] Hill (2009)

in metres) by the volume of water to be raised in cubic metres (m^3). Pumping energy needs are typically expressed in units of m^4.
Decisions about energy and irrigation should be made on the basis of three key sequential steps: [35]

- **a.** *Choosing the right irrigation technology:* understanding the irrigation system needs for a given context,
- **b.** *Choosing the right pump technology:* understanding the various pumping technologies available
- **c.** *Choosing the right energy source:* assessing which power sources are possible, desirable, and locally available to provide the necessary energy for that system.

a. *Choosing the right irrigation technology*

The question of which irrigation water distribution system is most suitable will depend on several factors including the crop(s) cultivated, climate, location, scale/area of agricultural production, quantity of water required over time, system cost, access to capital, local agricultural workers' technical capacity, local availability of equipment, maintenance and repair services and availability of spare parts. Irrigation systems differ in their peak and average water requirements, the need for water storage (e.g. tanks, cisterns), and the ultimate need for pumping and energy. Where small producers (<two hectares) are targeted, the more expensive irrigation technologies may only be accessible through membership of cooperatives and farmers' associations, who have sufficient ability to raise capital, as well as having the management capacity for technology adoption, operation, maintenance, and replacement. The reliability of the selected irrigation system and the ability of its maintenance is of primary importance for farmers.

Table 4: Commonly Used Irrigation Technologies

Irrigation system	Technology	Advantage	Disadvantages
Manual irrigation	Using buckets or watering cans	Low infrastructure and technical equipment requirements	High labour inputs
Surface irrigation	Water moves over and crosses the land by gravity flow; water level can be controlled by simple soil dams; water in ditches can be pumped or lifted by human or animal power to the level of the field.	Low cost and simple technology	Inefficient use of water, potentially high evaporative losses, can lead to increased soil salinity
Sprinkler/ overhead irrigation	Piping water to one or more central locations within the field and distributing it by high-pressure sprinklers or guns. Numerous system types exist, including centre pivot, rotating, traveling/water-wheel, lateral move/side roll/wheel line.	Potential labour savings and more efficient use of water than in surface irrigation.	These systems can be expensive and require technical capacity to operate and maintain.
Drip irrigation/ Micro irrigation	Delivers water directly at or near the root zone of plants, drop by drop.	Highly water-efficient method of irrigation, since evaporation and runoff are minimised (also reduces chemical input if required); any pumps can be used; saves labour; lower water pressure and energy use are required compared to other automated systems.	Difficult to regulate the pressure in sloped sites; system maintenance can be higher than other irrigation systems (if water has to be filtered to remove particles that may close the tubes); the system can be fairly costly to install, esp. higher end automated technologies (although some very low cost models exist which require much more labour).

[35] Most of the information in this chapter is cited from the excellent USAID publication "Empowering Agriculture-Energy options for horticulture", prepared by Winrock International, March 2009.

In general, the scale of production, costs of the technology and organisational capacity of the farmers will drive decisions about which irrigation approach to use. The size, cost, and capacity of suitable technologies increase along with the scale of production.The following table provides some guidance for the selection of irrigation technologies based on key criteria such as production scale, energy source, and budget.

Table 5: Comparative Analysis of Irrigation Methods (Source: Winrock International, Empowering Agriculture, USAID 2009)

Irrigation Method	Irrigated Area	Water Requirements	Energy Requirements	Capital Cost	Operating Cost
Manual	<0.5 ha	Low to High	Low (manual only)	Low	Low to Medium***
Surface / Gravity fed	Unlimited	High	Low (manual only)**	Medium	Low
Sprinkler	Unlimited	Medium	High	High	High
Drip / Micro-irrigation	Unlimited	Low	Medium	High	Medium

* The amount of water used in a manual system will depend on the technology used for distribution.

** In some systems, pumping may be required at certain points in the system.

*** Operating costs will depend on local labour costs and the type of manual irrigation technology used.

b. *Choosing the right pump technology*

There are a wide variety of pump technologies available for irrigation, but not all are appropriate for every type of irrigation system. Pumps differ in their pumping approach, size and capacity, the type of water source they are suitable for (groundwater or surface water), the scale/area of irrigation possible, their cost and technical complexity.

Pumps can be classified into three categories: hydraulic, manual or motorised, as described in Annex 2. The various water pump categories and data regarding their technical specifications and costs are described in Annex 3.

Table 6 offers guidance regarding the most appropriate type of water pump, given the area to be irrigated, combined with the water table depth.

Table 6: Appropriate Irrigation Water Pumps for Different Irrigation Areas (Source: Winrock International, Empowering Agriculture, USAID 2009)

<table>
<tr><th>Irrigated Area</th><th>Water Table < 8 m</th><th>Water Table > 8 m</th></tr>
<tr><td>< 2 ha</td><td>Manual Pump:
Hand pump
Treadle pump (~ 1 pump/0.5 ha)

Motorised Pump
3 – 5 hp mechanical pump
< 5 hp electric pump</td><td rowspan="3">Motorised Pump:
3 – 5 hp mechanical pump (submersile only)
< 5 hp electric pump (submersible only)</td></tr>
<tr><td>2 - 4 ha</td><td rowspan="2">Motorised Pump
> 5 hp mechanical pump
> 5 hp electric pump</td></tr>
<tr><td>> 4 ha</td></tr>
</table>

c. *Choosing the Right Energy Source*

Different pump technologies are often flexible regarding the type of energy source powering them. There follows an overview of the different energy sources available for motorised pumping, and the definition and characteristics of each.

- *Grid electricity*

Where grid connection is available an electric pump can be powered directly. However, the cost, availability, reliability, and quality of local electricity supplies determine the use of this energy source.

- *Fuels for combustion engines*

Motorised pumps can be powered by fossil fuels (diesel, gasoline), either through generators that create electricity,[36] or by transmitting power to the pump through a drive belt and vertical rotating shaft. In addition, some submersible pumps (i.e. progressing cavity pumps) operate by direct displacement, like piston pumps. The pumps tend to be more expensive but nevertheless more efficient than centrifugal pumps. The use of biofuels (plantoil, biogas) is still limited. A few experiments are underway, e.g. in India with biofuels made from local oilseeds (UNDP/PA 2009), in the GIZ PSDA program in Kenya with biogas (GTZ/HERA 2010b) and in Nepal, where Winrock International is supporting community-grown jatropha oil for irrigation pumps.[37]

- *Solar energy (photovoltaic)*

Solar pumps are electric pumps powered by electricity produced from photovoltaic (PV) panels. A solar-powered DC submersible pump reaching a depth of 50 m can pump 2.7 m^3/hr and installing this type of pump costs from USD 2,700 to USD 10,000. The systems in use are generally highly reliable and therefore have very low failure rates (less than 1.5 per cent of operation time). Daily operation does not require specially-trained personnel and maintenance efforts and costs are low; the comparatively high investment costs can therefore be recouped. Regular cleaning of PV modules and maintenance by competent personnel as well as reliable availability of spare parts are basic requirements for efficient and sustainable system operation. Furthermore, awareness campaigns for users as well as an appropriate maintenance concept with private sector participation are essential for success. Experience from PV pumping projects has shown that there is a general danger of theft and vandalism of PV modules. The economics of PV pumping systems for irrigation are dependent on numerous factors. In general, PV pumps for irrigation can only be operated cost-efficiently under the following conditions:

- In order to reduce the energy requirements of PVP irrigation systems, water-conserving and energy-saving micro-irrigation techniques have to be applied;
- The plot size for PVP irrigation must be below 4 hectares;
- High rates of system utilisation are necessary to achieve economic viability of PVP irrigation systems;
- PVP systems are therefore limited to irrigating permanent crops and continuous crop rotation in arid climates;
- High value-added cash crops like fruits, vegetables and spices should be given preference to ensure returns on high initial investments;
- Low-interest loans should be available for the same reason;
- PVP irrigation systems require careful planning of the crop schedule and demand a certain level of user skills.[38]

[36] Note that all electric pumps, regardless of energy source, can be controlled by automated signals, such as float or pressure switches, allowing them to pump at any time of day or night. This effectively raises their daily capacity to over 200 m^3, whereas non-electric motorised pumps controlled by human operators are limited by the number of hours worked.
[37] Energia (2009)
[38] IEA (2006)

GIZ has experience of PVP irrigation in projects in Chile (smallholder farmers), Ethiopia (tree nursery Forestry Dep.) and Bangladesh (irrigation of paddy fields). Experience in Bangladesh has shown that PV panels can have significant spatial requirements depending on the energy needed. This leads to disadvantages for farmers (personal communication with Dr Christoph Messinger). KfW (German Development Bank) has supported the installation and dissemination of PVP pumps for irrigation in several countries in sub-Saharan Africa (Eritrea, Guinea, Mali, Namibia, Burkina Faso).[39] At experimental level there are already technical solutions available for the application of PVP in stand-alone systems to irrigate an area of 30-40 hectares by using variable frequency drives (VFD) for any AC-motor.[40]

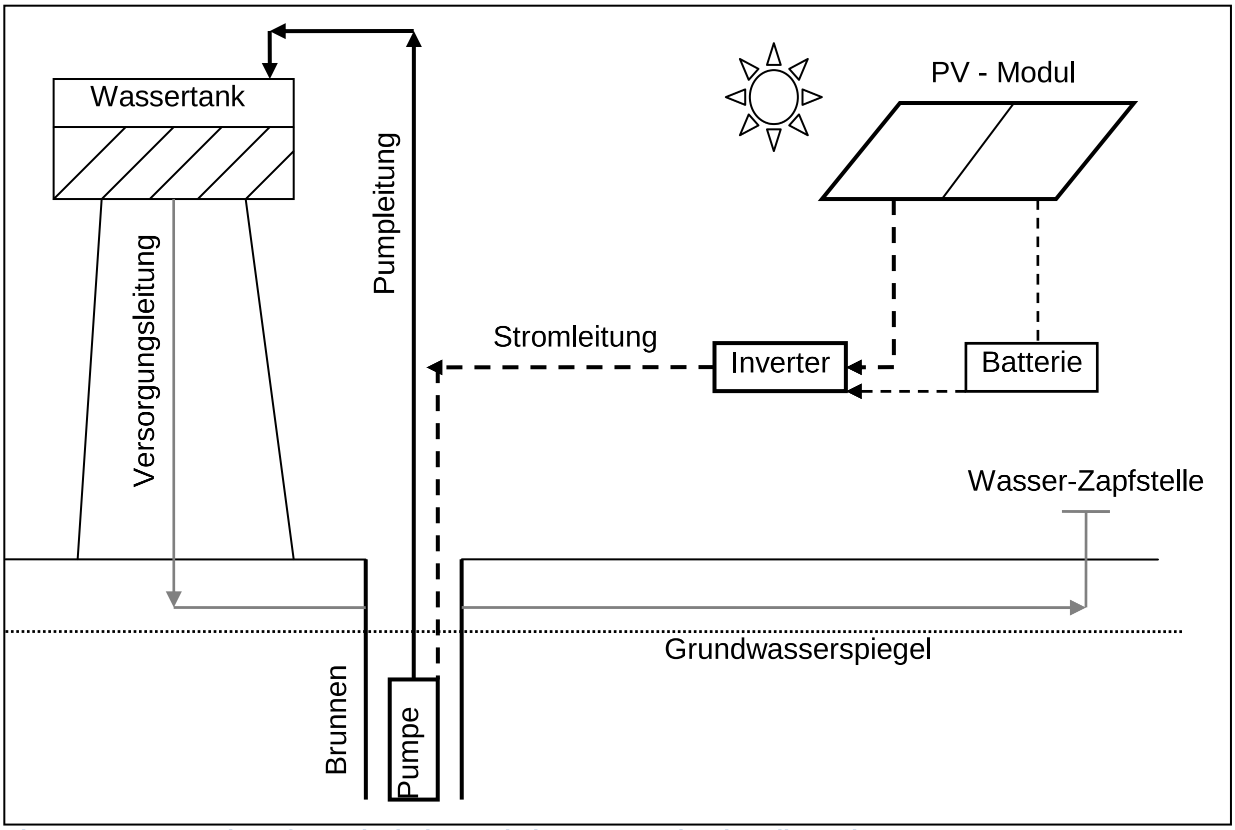

Figure 4: Construction of a Typical Photovoltaic Pump Station (Credit: GIZ)

- *Wind energy*

Wind can be used to power both mechanical and electric pumps.
Mechanical wind-powered pumps use reciprocal non-motorised submersible pumps and require wind speeds of 2.5 m/s minimum up to 4 m/s optimum. Capacity is much lower than for motorised centrifugal pumps, in the range of 1 m^3/hr at depths of 20 metres or more. Mechanical wind pumps require the availability of local maintenance and repair facilities to be able to respond quickly to mechanical failures. Adequate wind speeds must be present at the location of the wells. One advantage is that they can pump day or night as long as there is sufficient wind, and can be used independently of electricity or fuel supplies. A disadvantage is that they must be located directly above the well, a location that may not be optimal in terms of local wind resources. Wind pumps are appropriate in windy areas without other sources of power, and only for small irrigable areas.

Wind electric turbines convert the kinetic energy of the wind into rotational mechanical energy that drives a generator to produce electricity, e.g. for pumping water for irrigation. Windmills are positioned for optimal wind conditions, providing greater site flexibility and in

[39] GTZ (2000)
[40] Personal communication Mr. Neureiter (2010)

addition facilitating electricity production for other uses. Water-pumping applications generally make use of wind turbines with rated output between 1 kWe and 10 kWe. A wide variety of small wind electric turbines is commercially available, with rated outputs ranging from a few tens of watts to 100 kilowatts, and is used worldwide to provide electricity in locations where alternatives are unavailable or are too expensive or difficult to provide.

- *Hybrid systems*

Small-scale hybrid power systems, also a mature technology, are used worldwide. By combining different energy sources (solar-diesel, wind-diesel) hybrids can provide widespread and highly reliable electrical supply. These small hybrid systems are easy to install—no special tools or concrete are required.

The availability and reliability of local power sources, local technical capacity and affordability of an energy source to power the pump selected for irrigation are of great importance for the production of agricultural and horticultural crops. In general, if one of the three main factors of an irrigation system (irrigation technology/pump technology/energy source) is not reliable it might lead to a failure of crops, bringing economic disaster for farmers.

Table 7: Integrated Water Management

The irrigation chapter cannot be complete without stressing the point that water management goes far beyond the mere provision of appropriate technologies. Important factors for successful integrated water management also include, amongst others, strategies for watershed management and its local adaptation, securing access to land and water, advisory and skills training for water user groups with regard to the management of irrigation systems and appropriate production technologies, as well as all activities involved in leveraging the harvested produce such as storage, processing and marketing. For the successful introduction of irrigation in smallholder farming systems, the external support of government and its services for a market-oriented production system is necessary to enable the farmers to acquire the necessary financial means to maintain the irrigation system. Advice from the government sectors on reforms of the frame conditions for a sustainable water management is also a precondition. The development of integrated systems and strategies adapted to the geophysical, climatic and socio-economic conditions supports sustainable, efficient, and effective water use. In this context irrigation in particular can contribute to greater productivity, thus improving smallholder incomes and rural livelihoods.

Dr Elisabeth van den Akker, Senior Advisor for water and agriculture, GTZ Department of Agriculture, Fishery and Food.

3.2 Post-harvest and storage

In developing countries, about 30 per cent of food consumed is perishable. Losses occur at each step of the value chain from harvest, storage, transportation and markets to consumption. Cereal losses are estimated at around 10-30 per cent while losses of more perishable products such as tuber crops, fruits and vegetables can be much higher, up to a total harvest loss.[41] Adequate treatments along the chain, and cold and dry storage facilities can help to reduce food losses, increase food safety and add value to agricultural food products.[42]

[41] www.phlosses.net
[42] FAO (2009a)

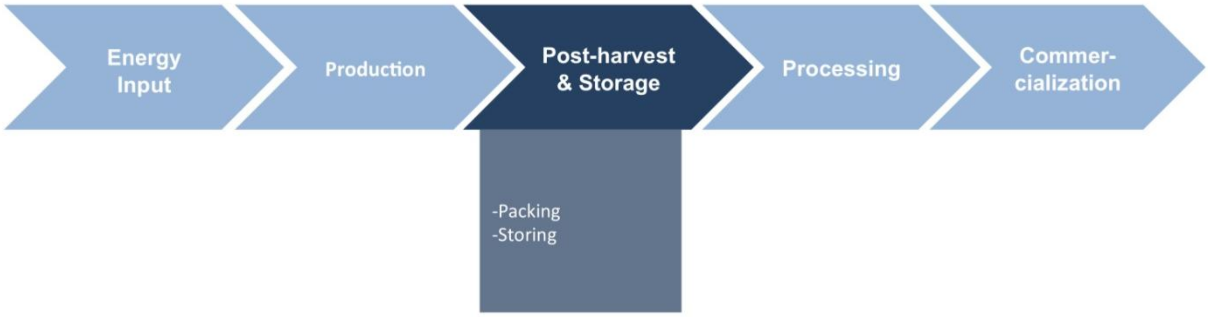

Figure 5: Value Chain Agricultural Production: Post-harvest & Storage in detail

3.2.1 Packing

The best precondition for storage is a proper harvest and post-harvest handling. Sorting, grading, and packing produce into storage containers after harvest to prevent losses is important, especially for easily perishable crops such as tuber crops, vegetables and fruits. Reducing the number of times produce is handled between harvest and consumption will reduce mechanical damage and subsequent losses. Packing houses for crops are often simple structures that provide shade and comfortable working conditions for farm workers conducting manual post-harvest operations. Manual handling is recommended for horticultural high-value produce.

3.2.2 Storage

A certain percentage of the farm produce has to be stored before selling at the market, because production is seasonal while demand, particularly for vegetables and fruits, continues year-round. Storage facilities secure agricultural commodities kept for rapid emergency aid and buffer stocks to stabilise domestic prices. Besides storage at central hubs and transportation centres, more localised storage is often necessary.

- *Dry storage*

To achieve increased production, traditional village stores need to be improved within the means of smallholders to achieve a certain transition to larger and more modern storage systems.[43] This requires the management of dry storage facilities, mainly for post-harvest and storage of grain (maize, sorghum, millet, wheat and rice), pulses (beans, peas), roots and tuber crops, and oilseeds, whereas fruits and vegetables require cold storage facilities. For grain, pulses and oil seeds, mechanical damage mostly occurs during harvesting, transport and processing, while insects, mould and rodents damage produce during storage. For such staple foods, energy input or expensive technology is generally. Good storage practice is the key to maintaining quality and value throughout the storage season. A precondition is that crops are in good condition prior to storage, which means well cleaned and carefully winnowed to remove live adult insects. Straw, chaff, weed seeds, stones and dirt must also be removed, as they hold water and their removal will allow grain to dry faster. The grain should be well dried to an appropriate level of moisture content. Good drying is essential because damp grain will become mouldy and spoil. Solar dryers can be used—sun drying will also help get rid of adult insects in the grain. However, as sun drying will not kill all immature stages, such as larvae living inside grains, it is sometimes necessary to treat the grain with insecticide, thus killing the immature stages once they mature and emerge from the grain as adults. Maize is often shelled by hand. This produces better quality grain but is a very slow process. Quicker and effective shelling can be achieved using a variety of mechanical operated machines. The grain must be sufficiently dry both for these and for safe storage. A good store will keep the grain dry and cool and provide protection against rodents and birds. Practising good store hygiene—keeping everything as clean as is practically possible—helps maintain the condition of the crop and the store throughout the storage

[43] FAO (2009b)

season. As pests can attack the store at any time, it is important to inspect the store and crop regularly. There are many appropriate technologies and traditional methods for preventing post-harvest losses, varying from location to location. Dry storage facilities range from small-scale, on-farm storage to medium and large-scale facilities of several hundred of tons or more.

- *Cold storage*

Cold storage in tropical and subtropical climates can generate high energy demand. In general, the initial cooling, processing and cold storage of fresh fruit and vegetables is among the most energy-intensive activities of the food industry. However, for fresh fruits and vegetables, cooling is also one of the most important steps in the post-harvest handling chain to reduce respiration rates, extend shelf life and protect quality. Deterioration of fruits and vegetables during storage depends largely on temperature, so the temperature must be lowered to an appropriate level, to avoid damage and increase the length of storage time. Controlled temperature storage is a critical factor for most perishable agricultural products and a consistent cold chain is necessary to maintain the quality of many high-value agricultural products. Cooling also offers farmers the opportunity to increase income by extending the period for selling and marketing the products when better prices can be achieved. In developing countries, refrigeration in rural areas must often be operated without reliable electricity supply and the provision of a cold chain or store rooms for cooling bigger quantities of produce is often impossible. Three technologies are available for cooling smaller quantities of produce:

1) Passive/evaporative coolers: where temperatures between 10-25^{o} C are needed, no energy input is required.
2) Absorption refrigerators (heat driven coolers (HDC), requiring temperatures below 10^{o} C; heat as an energy source is used to drive the cooling system (e.g. solar, kerosene-fueled flame).
3) Refrigerators, which are electrically driven, use mechanical compression technology. Refrigeration is dependent on a reliable and continous supply of electricity which can be generated from different sources: from the grid, diesel powered compressor, mechanical power generated from a water turbine, by solar energy converted by solar cells into electricity stored in batteries or by solar energy and evaporation.[44]

Commercial PV-powered refrigerators were introduced in developing countries to cut down the use of kerosene or gas-powered absorption refrigerators, which are the most common alternatives but also those with the most negative impact on the environment. First introduced for medical refrigeration they now also constitute an alternative method of storing small quantities of agricultural products for sale. The newest type of solar refrigerator is solar powered but requires neither solar panels nor a battery as it functions on the principle of evaporation. Solar photovoltaic power for refrigerators has great potential for lower running costs, greater reliability and a longer working life than kerosene refrigerators or diesel generators. A life-cycle cost analysis has shown that the costs are approximately the same for solar and kerosene refrigerators, but because they are more reliable and environmentally friendly, solar refrigerators are the preferred option.[45]

[44] Practical Action (2010a)
[45] Practical Action (2010b)

Table 8: Energy Sources for Different Produce-Cooling Technologies (Source: Winrock International, Empowering Agriculture, USAID 2009)

Categories	Commodities/Technologies	Energy Sources
Low tech (<5 kWh/day)	Field packing of leafy, stem, or fruit vegetables, root, tuber and bulb crops, fruits and berries	Electric grid; Solar power with battery back-up
Basic tech (5 to 25kWh/day)	Packinghouse operations and pre-cooling for tropical and subtropical fruits and vegetables; Evaporative cool storage. (Temperature range 15°C to 20°C)	Solar water heater, Electric grid; Generator (diesel or gas); Hybrid PV/ Generator systems with battery back-up
Intermediate tech (25 to 100 kWh/day)	Cooling and cold storage for temperate fruits and vegetables. (Temperature range 0°C to 7°C)	Electric grid; Generator (diesel or gas)
Modern tech (> 100 kWh/day)	Automated packinghouse operations, pre-cooling and cold storage for any kind of fruits and vegetables. (Temperature range down to 0°C)	Electric grid; diesel back-up generators

3.3 Processing

Agro-processing operations have significant implications for poverty reduction, food security and economic development. Agro-processing transforms products originating from agriculture into both food and non-food commodities, ranging from simple preservation (e.g. sun drying) to the production of goods by modern, capital and energy-intensive methods (e.g. food industry, textiles, paper). Processing is carried out at different levels: household processing for home consumption and/or local markets; small and medium enterprises (SMEs) which serve local, national and cross-border markets; smallholder agriculture delivering commodities for large-scale processing units (like palm oil, cassava, rubber and sugar cane in Thailand) and capital intensive industrial agro-processing. Processing allows agricultural products to be conveniently stored, preserved, transported and presented in forms demanded by consumers. This greatly extends the markets in which they can be sold, and permits sales at higher prices and in larger quantities (FAO 2009b).

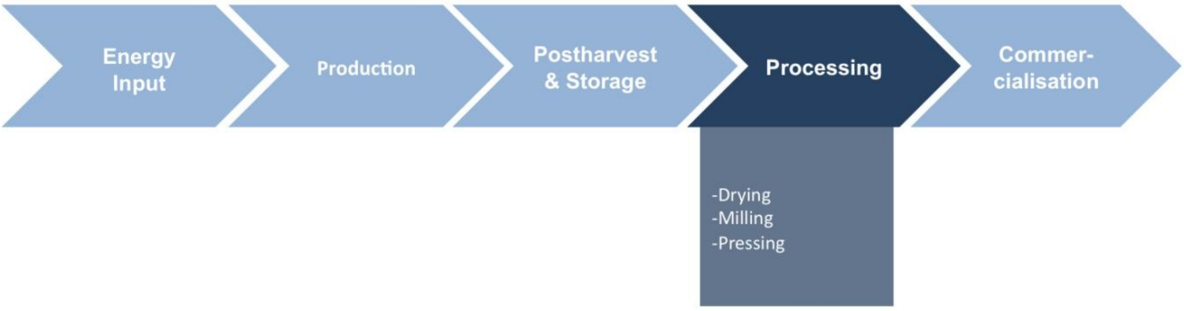

Figure 6: Value Chain Agricultural Production: Processing in Detail

Successful processing enterprises can create reliable commercial markets for farmers, generate foreign exchange, provide employment, contribute to food security by preserving food, and represent a stable and profitable source of income for processors and for the farmers who provide raw materials. Processing at farm or—better still—at cooperative level helps farmers to increase their income and save time and resources as the energy service is available in the village. Upstream industries are engaged in the initial processing of products, such as rice and flour milling, oil pressing and fish canning. Downstream industries undertake further manufacturing operations on intermediate products made from agricultural materials such as bread and noodles. Major opportunities for diversification are possible through the processing and use of residues and by-products such as molasses, rice husks and press cake, which are generated in processing operations further upstream in the value chain. The creation of employment through agro-processing also serves to reduce migration of unskilled young people from rural areas into cities. In addition, it should be stressed that, in many countries, women are strongly involved in small-scale agro-processing and related commercialisation activities.

Food transformation activities are generally less energy-intensive and release less CO_2 and metal residues than most other industrial activities per product unit. Most food processing activities at farm and SME level utilise energy derived from mechanical power, with many alternatives for technologies powered by humans, animals, water or stationary engines.[46]

3.3.1 Drying of Produce

To add value to fresh fruits and vegetables, they must be dried before packaging and marketing. Drying of fresh produce, which contains up to 95 per cent water, to a safe moisture content of 7-8 per cent requires the application of low heat and ventilation for best results. Processing fruits and vegetables on a small-scale level is therefore less mechanised than other agro-processing activities. It is important that the used equipment is constructed of stainless steel because acids in fruits corrode mild steel. Peeling, cutting, or slicing produce into uniformly sized pieces is usually required for successful drying. This is typically done by hand. Machines are available for larger quantities and can speed up the peeling, cutting, or slicing of produce. For drying commodities (e.g. tea, coffee, copra or abaca) in larger quantities, heat assisted drying is used, with many different types of dryer available.

- *Direct and indirect solar drying*

Laying produce out in the sun to dry naturally is common in sunny climates and is a very inexpensive drying method. It is still the predominant method for producing raisins worldwide. However, traditional sun drying methods often yield low quality as the produce is not protected against rain and dust and other contaminations.

Indirect solar drying requires a covered dryer that protects produce from direct sunlight while capturing more heat from the sun. With natural air flow inside, an indirect dryer reduces heat and pest damage while speeding up drying.

- *Heat-assisted drying*

In rainy weather regions or humid locations, heat-assisted dryers create warm air flow inside the dryer to speed up drying. Heat sources may be electric, propane, wood, or any other locally available fuel. Appropriate drying temperatures can easily be achieved with low-powered, relatively inexpensive technologies. The majority of energy used in heated air dryers is actually used to heat the air. Electricity for moving air is only a small fraction of the air heating costs, which depend on the initial and final moisture contents of the product. If energy conservation measures such as air recirculation are incorporated into the operation, fuel use can drop significantly.[47]

- *Solar Drying*

Solar drying facilities combine traditional and industrial methods, meaning low investment

[46] FAO (2009)
[47] USAID(2009)

costs and high product quality. The “Hohenheim”-type solar tunnel dryer combines simple construction, use of renewable energy and easy handling. The model is equipped with a photovoltaic (PV) driving fan with a power requirement of 20-40 W. The thermal energy gained from solar radiation is up to 60 kWh/day (equivalent to 15 kg of firewood). A cooperative development between the Institute for Agricultural Engineering in the Tropics and Subtropics of Hohenheim University and INNOTECH Engineering Ltd., solar tunnel dryers are in commercial operation in more than 60 countries all over the world.[48]

Table 9: Case Study Dryer Phillipines

A high-capacity flatbed dryer adapted in Vietnam using rice hull for fuel was modified for Philippine conditions. The modified design named PRUAF is now operational in 113 units in different regions of the Philippines. Private entrepreneurs, local government units and co-operatives financed the construction of the dryers with technical assistance from the Philippine Rice Research Institute. The dryer has lower running costs than existing dryers owing to the use of rice hull as fuel, low labour requirements and costs, low repair/maintenance costs and higher drying capacity than similarly priced dryers. The dryers have been successfully used for maize, soybean, coffee and banana chips. It is estimated that drying coffee and maize yields an internal rate of return of 20 per cent.[49]

Table 10: Energy Requirements for Drying Agricultural Products (Source: Winrock International, Empowering Agriculture, USAID 2009)

Drying Technology	Typical Capacity	Energy Use (kWh, litres or BTU)/MT
Direct solar drying	0.5 MT	0
Indirect solar drying	1.0 MT	0
Heat-assisted drying (small scale)	< 2 MT /day	6 kWh and 2,300 MJ
Heat-assisted drying (intermediate scale)	2 to 5 MT/day	6 kWh and 2,300 MJ
Heat-assisted drying (large scale)	>5 MT/day	6 kWh and 2,300 MJ (57.8 L diesel)

3.3.2 Cereal milling

To prepare the cereals for further processing, the chaff has to be separated from grain, either manually with a winnowing tray or mechanically by a powered shaker or grinder. Mechanical power is also available for dehusking rice or shelling maize as an alternative to manual work with rice hullers or huskers and maize shellers. The same applies to other cereals and crops for which special machinery has been or is being developed. Bran as a by-product of dehulling cereals is a source of income if sold as poultry feed and other animal feed.

Milling transforms grain into flour for food preparation. The main crops that are milled are maize, rice, sorghum, teff and millet, using hammer or plate mills. A hammer mill crushes aggregate material into smaller pieces with hammers (beaters) made from hardened alloy steel which are rectangular for efficient grinding. Hammer mills are also used to pulverise by-products of coconuts (copra), palm kernels & other oil seeds (press cake). Wheat is milled with roller mills but these are too expensive for small-scale operations.[50]

Most operations utilise energy derived from mechanical power, with many alternatives for technologies powered by human, animal, water or a stationary engine. Mechanised milling operations are far more efficient and far less labour intensive than manual methods, using wind/micro-hydro and hybrid power systems (wind/hydro/diesel) for energy intensive

[48] Fa. Innotech
[49] FAO (2006a)
[50] FAO (2005)

processing activities. Mills can be powered directly by transforming energy from sources such as wind or water or by electricity generated from a combination of fossil fuel-fired generators with wind or hydro power. Hybrid systems are an emerging technology as they provide a more reliable and cost-effective power supply and offer the opportunity for diverse applications.

Table 11 compares manual corn grinding and mechanised corn grinding with a Jatropha oil-fueled engine. The renewable fuel source was generated from smallholder farming. However, some harvesting operations still require manual labour to maximise product ripeness and quality.

Table 11: Energy and Power Requirements for Milling 100kg of Corn (Source: Winrock International, Empowering Agriculture, USAID 2009)

Power and Time Requirements	Manual Corn Milling	Mechanised Corn Milling (Jatropha oil)
Power required/kg of corn/hour	50 watts	50 watts
Power of one person	50 watts for several hours (healthy adult) 100 watts for 5-8 hours (trained athlete)	
Power of 10 hp motorised mill		5.000 watts
Jatropha oil consumed	none	2 liters
Time Requirements		
Time to pick 8 kg jatropha seed	None	8 hours
Time to press jatropha seed (hand press)	None	2 hours
Miscellaneous labour (jatropha seed drying, etc.)	None	4 hours
Total time (labour)	**50 hours**	**14 hours**

3.3.1 Edible oil extraction

Edible oil is a high-value product for generating income. The main crops for oil extraction are nuts, e.g. groundnut, shea nut, coconut, palm kernel, oil seeds (e.g. sesame, sun flower, mustard seed) and oil palm fruit. By-products of oil seeds include press cake with high protein and nutrient contents for animal feed, whereas the by-products of coconut and groundnuts are for human consumption. Both generate additional income for farmers. The by-products of agro-industrial oil mills are used in biogas digesters for electricity generation or generation of process heat or steam.

There are many hand-operated technologies for pressing oil (spindle press), hydraulic presses or engine driven oil presses. There is huge demand for mechanical power alternatives to reduce drudgery for humans. Researchers and development specialists working with Appropriate Technology International (ATI) have developed a method to introduce small-scale oil expelling enterprises to rural areas in Africa. A typical set-up consists of a ram press for extracting the oil, a filtration device, tools for maintenance, and perhaps most importantly, training, support and information on the proper use of the oil and cake (the residue of the seeds after the oil has been squeezed out), and the socioeconomic and nutritional benefits of an oilseed processing enterprise. The ram press, driven manually by a long handle, consists of a small piston that presses a measured load of oilseeds into a metal cage. The basic design was developed in Tanzania in 1985 by Carl Bielenberg of ATI. The original and improved versions are now widely used there, as well as elsewhere in Africa.[51]

[51] Oil press ATI

The dry process of extracting oil cannot be executed only by mechanical or hydraulic presses, but also by continuously operating screw presses, known as oil expellers. Expellers are usually driven by petrol or diesel engines or electric motors but can also be run on animal or water power.
A small motorised expeller, named KOMET, is being manufactured by IBG Montforts + Reiners, Moenchengladbach, Federal Republic of Germany. Large sized material, such as copra or palmkernels, must be crushed into pieces of about 5 mm diametre. The standard power source is a 3 kW electric motor with stepless variable gearbox. Alternatively the unit can be driven by a diesel engine (11 kW at 3000 rpm), equipped with a dynamo and clutch (GATE 1989).

In general, in Asia, Latin America and Africa there are large numbers of processing equipment and machinery manufacturers. However, investment in research and development (R&D) is required to upgrade traditional small-scale technologies. In sub-Saharan Africa for example, the use of rudimentary technologies for processing millet, sorghum and other local cereals has led to increased dependence of the growing urban population on imported wheat and rice. Critical factors for sucessful processing activities are also access to raw materials, inputs such as packaging materials, machinery and spare parts and qualified human resources (FAO 2009a).

3.4 Commercialisation

Figure 7: Value Chain Agricultural Production: Commercialisation in detail

Markets play an important role in rural development, income generation, food security, developing rural-market linkages and gender issues. Agricultural commercialisation covers the services involved in getting agricultural produce from farm to consumer. This involves numerous interconnected activities, such as planning production, growing and harvesting, grading, packing, transport, storage, agro- and food processing, distribution, and sale. Such activities cannot take place without the exchange of information and are often heavily dependent on the availability of suitable finance.

Commercialisation systems are dynamic, competitive and involve continuous change and improvement. Prosperous businesses have lower costs, are more efficient, and can deliver higher quality products than less successful ones. Commercialisation must be customer-oriented and profitable for the farmer, transporter, trader, processor, etc. This requires those involved in commercialisation chains to understand buyer requirements, both in terms of product and business conditions. Improvement of commercialisation systems also needs a strong private sector, backed up by appropriate policy and legislative frameworks and effective government support services. Amongst the many interventions needed for improving commercialisation systems the most important support services are those considered here, in which energy input plays a major role.

Energy input is necessary within the market infrastructure for storage and processing, in terms of fuels for transport, supply of market information, training of farmers in marketing at all levels and lighting for physical market places.

3.4.1 Market infrastructure and transport

Continued provision of safe and nutritious food at affordable prices will require increased food production, effective rural-to-urban market linkages and efficient support services. Storage facilities to minimise post-harvest losses and reduce health risks can solve logistical, food safety and marketing problems. Agro-processing extends markets to meet increased food demands. The energy input in storage and processing facilities has been described above. Investment in rural power supply facilities is a requirement for infrastructure improvement in general, not only for marketing. Rural infrastructure design must enable smallholders to access local markets easily and reduce input costs such as transport and distribution. Manual technologies for transportation consist largely of animal-powered vehicles, carts, or wagons. Fossil fuel-powered or biofuel-powered engines for transport cars or pick-up trucks offer the most frequently used mode of transportation.

3.4.2 Information and telecommunication technologies (ICT)

Market information is crucial to enable farmers and traders to make informed decisions about what to grow, when to harvest, to which markets produce should be sent and whether or not to store it. Modern information and communication technologies (ICT) open up possibilities for market information services to improve information delivery through SMS on cell phones and the rapid growth of FM (frequency modulation, a broadcast technology) radio stations offer more localised information services. Mobile phones also reduce communication and information costs significantly by reducing travel distances. In India a study found that the expansion of mobile phone coverage led to a significant reduction in consumer prices (4 per cent) while at the same time fishermen’s profits increased by 8 per cent (GTZ 2010). In the long run, the internet may become an effective way of delivering information to farmers. PV-powered cell phones, PV-powered satellite phone kiosks (as in the case of Bangladesh-Grameen Shakti operations) have a typical power peak of 0.2-0.3 kW and include a 50 Wp system with 2 lights and a socket to charge cellular phone batteries.

3.4.3 Training facilities

Training facilities for farmers, traders and others in the various chains increase understanding of the social, technical, economic and environmental factors that affect the safety, quality and value of agricultural production and marketing. Providing buildings with power, including renewable energies such as solar lighting or energy-efficient construction materials, will help them to function as a model for modern energy services. For example, farm lighting (including security and safety of scattered buildings) with PV/ battery system) requires a power supply in the range of 50-500 watts. Computer equipment for training requires 8-300 Wp systems in addition to powering lights, fax, TV, etc. Internet servers for e-commerce are mostly integrated in a multifunctional solar facility (1 kW).

3.4.4 Selling

Efficient marketing infrastructure such as assembly markets, retail markets and wholesale markets is essential for cost-effective marketing. Terminal wholesale markets are located in major metropolitan areas, where produce is finally channelled to consumers through trade between wholesalers and retailers, caterers, etc. The characteristics of wholesale markets have changed considerably as retailing changes in response to urban growth, the increasing role of supermarkets and increased consumer spending capacity. These changes require responses in terms of how traditional wholesale markets are organised and managed. Despite the growth of supermarkets, there remains considerable scope to improve agricultural marketing in developing countries by constructing new retail markets. Rural assembly markets are located in production areas and serve primarily as places where farmers can meet with traders to sell their products. These markets may be occasional (perhaps weekly) or permanent, often taking place at night or in the early morning when lighting is needed. If there is no connection to the public grid, use of solar lanterns can be an alternative. PV rechargeable fluorescent lanterns range between 10 and 20 watts per lantern.

4. Conclusions

Access to modern and reliable energy services offers smallholders the opportunity to increase their productivity and enter new markets by a variety of applications in the commercial service sector and facilitates the provision of basic social services. These changes can support the shift from traditional and unsustainable farming practices towards more modern farming practices, offering opportunities to increase incomes and improve livelihoods.

Large numbers of people in developing countries will still remain unconnected to the public grid in the next decade due to high extension costs in rural areas. Rural off-grid electrification can provide an alternative solution at lower cost, particularly as costs of off-grid technologies decline. For off-grid applications, renewable energy technologies can reduce environmental impact and provide lower-cost alternatives to conventional energy technologies. However, the use of renewable energy technologies for increasing agricultural productivity is still limited by the energy requirements of the application. The use of solar energy by PV systems is limited to activities requiring little energy input (pumps for irrigation, solar dryer, small refrigerators), while wind and micro-hydropower are options for energy intensive processing activities. Biomass energy offers a wide variety of energy supply opportunities for agricultural use ranging from small-scale level for rural households to large-scale level for biofuels, heat and steam generation for industrial processes and decentralised electricity generation. Hybrid systems, combining conventional and renewable energy sources, are currently the most reliable and efficient energy supply systems for rural areas.

1. The successful application of modern energy services is determined by the following factors:
   - The availability of service, maintainance, spare parts and information dissemination of the energy provider, the suitability of the energy technology or system for the market in terms of reliability, affordability and profitability, (no experience with farmers);
   - Building up technologies based on existing structures, e.g. improving the efficiency of water pumps instead of installing new technology;
   - Ensuring farmer participation at all stages, from planning to the implementation process of a technology system, including the provision of training.
2. Improvements in modern electricity supply require fair competition and sustainable commitment. As electricity supply is a long-term business, the full lifetime costs of the systems must be considered (comparison between diesel and renewables), in addition to favorable financing (e.g. subsidising tariffs and not investments, special conditions from local banks) and the establishment of partnerships between foreign investors and public and private sector organisations in the partner country.
3. The bundling of rural services with other existing services (e.g. water, communications, financial services, consumer electronics sales and service) by the service provider can achieve synergies and reduce high transaction costs.
4. The use of agricultural commodities as feedstocks for biofuels and production can only be renewable when done sustainably and if biofuel production helps to improve food security. Large-scale production of biofuels implies large land requirements for feedstock production. Liquid biofuels can therefore be expected to displace fossil fuels for transport only to a very limited extent.
5. The integration of smallholders into booming commodity markets (increasing demand for agricultural products for biofuels) by linking them with new agricultural and organisational production systems (contract farming, outgrower schemes, partnership farming, farmer associations, nucleus plantations with outgrowers) offers them the chance to modernise their farming systems. Here energy input for and output from agriculture must be focused on future self-sustaining energy systems.

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Annex

Annex 1: Use and impact of PV applications for agriculture (FAO 2000b)

Agricultural activities stimulated with PV (% of all respondents)

Irrigation	23 %
Refrigeration of crops/meat/fish/dairy/other	2 %
Lighting (poultry, livestock)	9 %
Water pumping for fish farming	5 %
Water pumping for cattle drinking	19 %
Pest control	2 %
Electric fencing for grazing management	14 %
Light for fish processing	2 %
Light for fishing	5 %

source: FAO survey

Impact of PV systems on agriculture (% of all respondents)

Higher productivity (higher yield)	28 %
Lower losses (death rate) or faster production	16 %
Better natural resource management	19 %
More land to be cropped	7 %
Multiple crops per year	12 %
New, more marketable product	12 %
More animals can be raised	16 %
Better quality products (higher prices/more sales)	19 %
Access to more profitable markets (e.g. through conservation of product for transport)	0 %
Others, Safer fishing	2 %
Namely: Cost savings through production instead of purchase of forage (micro-irrigation)	2 %

Source: FAO survey

Although the survey responses do not go into sufficient detail for in-depth cost-benefit analyses and are too few to serve as a representative sample, it is possible with the help of literature to make general comparisons concerning the economic competitiveness of the various applications.

Annex 2: Overview of different types of pumps for irrigation

1. Hydraulic pumps

Hydraulic ram pumps use the power of flowing water to lift a small fraction of the water to a vertical height of up to 200m. The water flowing into the ram pump is diverted and the energy produced from the whole flow is directed to only a small fraction of the flow, enabling this fraction to reach up higher than the original source of the water, enabling new heights to be reached. No external conventional energy supply, such as fossil fuel or electricity is required, making this technology suitable for upland villages which often lack access to water and energy sources.

AIDFI (Alternative Indigenous Development Foundation) from the Philippines has over 10 years of experience in ram pump technology and is also serving countries such as Cambodia, Ecuador, Afghanistan, Nepal and Mongolia GIZ has included ram pumps in a program in Tadjikistan (personal communication with Elmar Dimpl).

2. Manual pumps

A range of hand and foot-operated pumps is available for small-scale irrigation. Most of these operate entirely or partially on suction. Two-cylinder manual and treadle suction pumps can reach depths of 7 to 8 metres for irrigation. Their output is approximately 7.5 m^3 per hour for two-person foot pumps at depths of up to 5 m, with output decreasing to 4 m^3/h at depths of 7 m. A hand operated two-cylinder irrigation pump can provide 4 to 5 m^3/h over the same range of depths, but its physical demands limit its effective daily output. Low-lift treadle pumps with large diametre cylinders, used for surface water sources (vegetable gardening along river banks) or very shallow wells of 2-3 metres, have higher capacities, in the range of 10-15 m^3/hr. Foot-operated treadle pumps have higher outputs than manual versions because they use the weight of the operator’s body as a counterbalance. For this reason, they can be operated for longer periods than hand pumps, consequently with higher daily outputs, and are often a more appropriate solution for the irrigation demands of crops.
The social enterprise KickStart operates in Kenya, Tanzania and Mali, offering two models of pedal pumps for small-scale irrigation for an area of 1 to 2 acres.

3. Motorised pumps

a. Shallow water pumps

The most common motor pump used in small-scale agriculture is the centrifugal surface-mounted pump with a head limit of 6 metres. This mechanical engine-powered pump, usually 3.5 to 5 HP and gasoline powered, has an output in the range of 20-50 m^3/hr. Operating costs vary according to the type of fuel/energy used. Diesel engine pumps, by contrast, are usually at least 10 HP, and therefore of greater capacity than typical gasoline engines used to power irrigation pumps. Larger, more expensive mechanical centrifugal pumps also exist, with greater output capacity. Differing widely in terms of quality, a 5 HP pump manufactured in India or China has an output of approximately 40 m^3/hr. Fuel consumption varies depending on motor size, output, and pumping head.

b. Deep water pumps

Pumping from greater depths requires submersible pumps, which are installed below the water level in wells to push water upward by means of pressure. Submersible pumps must always be used for depths beyond 10 metres and for larger-scale irrigation operations (greater than 4 hectares). A 3 HP submersible pump can reach a depth of almost 40 metres and pump at capacities of approximately 9 m^3/hr. Motorised submersible pumps may be tailored to meet the needs of farms of almost any size. Installation may require far higher total costs, depending on the need for well drilling and installation, pipes, extension of electric wires or installation of off-grid generation equipment where applicable, construction of reservoirs (tanks), and others.

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Annex 3

Table 1 Energy and Power Requirements for Water Pumping to Irrigate 1 ha of Land

Power and Time Requirements	Treadle Pump	Diesel Centrifugal Pump (Jatropha oil)
Power to raise 2.5 m3/hour from 6m depth	100 watts	100 watts
Power of person	50 watts for several hours (healthy adult) 100 watts for 5 – 8 hours (trained athlete)	
Power of 5 hp diesel pump		2,500 watts
Jatropha oil consumed	none	1 liter
Time Requirements		
Time to lift 100 m3	20 hours	1.6 hours
Time to harvest Jatropha seed	none	4 hours
Time to dry Jatropha seed, etc.	none	2 hours
Time to press Jatropha seed	none	1 hour
Total time (labor)	**20 hours**	**8.6 hours**

Many mechanised agricultural and horticultural operations are far more efficient and less labour intensive than manual methods. Table 21 compares water pumping for irrigation by human power with a Jatropha oil-fueled engine. For stationary engines, the use of pure vegetable oil may be an attractive option. Few such engines are designed to operate on vegetable oils.

Table 2 compares technical and cost aspects of various water pumps

Pumping Technology	Purchase Price	Energy Use	Maximum Head (m)	Output at 7m (m3)**	Pumping Cost per m3
Treadle pump	$100	$0.25/h labour	7	4	$0.06
Manual 2-cylinder suction pump	$120	$0.25/h labour	7	4	$0.08
Manual rope & washer	$200	$0.38/h labour	20	12	$0.32
Diesel suction pump	$700	0.4 L/h	8	40	$0.02
Gasoline centrifugal pump	$400	0.4 L/h	6	19	$0.04
Submersible electric pump*	$2,800	2.24 kw	70	9	$0.14
Submersible diesel pump*	$2,800	1 L/h	70	9	$0.14
Solar pump*	$2,736	0	70	1.6	$0.06
Wind electric pump*	$4,000	0	240	1	$0.19

*includes pump but excludes pipes
**assumes a 7 m well possesses the recharge rates sufficient to supply the outputs indicated

Table 3 provides information regarding the relative cost of each of the major pump types discussed.

Capital Budget for Pumping	Available Options
Under $100	Manual and treadle pumps
$200-$600	Mechanical suction pumps – 3-5 hp; manual or treadle pumps
$600-$2000	Mechanical suction pumps – >5 hp; distribution pipe networks
>$2000	Submersible electric or mechanical pumps for deep borehole wells

NOTE: Cost figures for borehole wells, distribution systems, irrigation technologies, etc. cannot be provided here because they can vary by a factor of two to ten, depending on well depth and aquifer material, extent of the distribution system, local pricing of services and supplies, and other parameters specific to individual operations and locations. Consequently, the price ranges given here are for the pumps only.

Source of all three tables: USAID (2009)-Empowering Agriculture, Energy Options for Agriculture (Winrock International).

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