POWERING AGRICULTURE
Sustainable Energy for Food

MASSIVE OPEN ONLINE COURSE
COURSE READER
CHAPTER A
INTRODUCTION TO THE ENERGY-AGRICULTURE NEXUS

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INTRODUCTION

The United Nations projects a world population of 9.7 billion by 2050. As a result, the world will have to feed 2.5 billion more people than today. The United Nations Food and Agriculture Organization estimates that by 2050 current food production needs to rise by 70 percent to satisfy the expanding demand (FAO, 2011). Given the planetary boundaries, especially limited energy and water resources, meeting this target is one of the century’s biggest challenges. At the same time, increased demand for processed food, meat, dairy, and fish adds further pressure to the food supply system, and growing impacts of climate change pose a further constraint (Godfray et al., 2010). The question to be answered is: ‘How can we feed more people, in a better way, with improved access to modern energy, yet without consuming more water and soil, or generating more greenhouse gas emissions?’ (Altenburg, 2014).

UNIT A1
THE ENERGY-AGRICULTURE CHALLENGE

1.1 The Water-Energy-Food Nexus

The above question highlights the rapidly growing demand in a world with limited resources, which cannot be replenished but rather are diminishing every day. Specifically, the interdependency of water, energy and food is of concern. Food production requires water and energy throughout the agri-food sector. Energy production requires water and a substantial amount of biomass which needs to be produced using soils, water and nutrients. About 30 percent of global energy usage can be traced back to the food sector (FAO, 2011). This includes supply industry, agricultural production, processing, transport, merchandising and consumption. Agricultural primary production alone accounts for 20 percent, along with food processing (including transport), amounting to 40 percent. The agricultural and food sector thus contributes significantly to global energy consumption along the agricultural value chains. Agriculture is currently the number one consumer of water
resources, accounting for 70 percent of all freshwater use. Water is required for food production, processing, transport and preparation. Energy production processes use another 15 percent of global freshwater withdrawals (FAO, 2011). Energy, on the other hand, is a basic requirement for the withdrawal / pumping, distribution and treatment of water. The interdependency between the sectors has become more and more evident, as the international debate progresses since the Bonn 2011 nexus conference (FAO, 2014). The Water-Energy-Food Nexus (WEF) also displays a high degree of complexity and is a topic too vast to be covered in the course of this MOOC. To reduce complexity and create space for learning and interaction the following sessions will concentrate on the two dimensional nexus of energy and food in agricultural value chains.

1.2 Population Growth and Food Production

Why energy and agriculture? In the 1960s, the ‘green revolution’ offset the looming food disaster. Its success was based on improved plant breeding, intensification due to irrigation, increasing usage of inorganic fertilizer and energy inputs along the food chain. From farm mechanization, chemical fertilizers and pesticides to processing, cooling and packaging, fossil fuels made a significant contribution to this success. Such resources will not be available at cheap prices forever – all the more reason to start looking for alternatives. As the human population continues to grow, so does the demand for food. Figure 1 shows: agricultural production will need to increase by 60 percent relative to 2005 to meet food demand in 2050 (Alexandratos and Bruinsma, 2012).

CLOSE-UP

The World’s Soil Resources

“A group of leading soil scientists, including the University of Delaware’s Donald L. Sparks, has summarized the precarious state of the world’s soil resources and the possible ramifications for human security. […]"

As the population of the planet grows toward a projected 11 billion people by 2100, the key to producing enough food will be to find better ways to manage the agricultural lands we already have, Sparks says, rather than expanding into new areas. However, this will mean overcoming some rather daunting challenges.

According to Sparks and his colleagues, soil erosion greatly exceeds the rate of soil production in many agricultural areas. For example, in the central United States, long considered to be the “bread basket” of the nation, soil is currently eroding at a rate at least 10 times greater than the natural background rate of soil production. The loss of soil to erosion also involves the loss of key nutrients for plant growth, leading to the need for commercial fertilizers. However, the current rate of fertilizer production is unsustainable, according to Sparks. […]”(Chajes, 2015)
To meet global food demand by 2050, agricultural production must **INCREASE BY 60%**

However, a simple repetition of the green revolution to meet the increasing demand is highly unlikely. Fossil fuels are being increasingly exploited. We now know that this is happening at the cost of increasing greenhouse gases in the atmosphere. In addition, the continuing dependency on fossil fuels in the agri-food sector creates a high risk of fluctuating prices, potentially making food unaffordable for the economically weak – at least temporarily. The supply of fertile arable land is finite and therefore increased demand for food also puts pressure on the planet’s limited resource base. For example, irrigated land produces double or triple the outcome compared to rain-fed systems and accounts for 40 percent of the global cereal supply. The answer could just be to call for more irrigated land, but it may not be as simple as that. To identify effective changes, stakeholders will have to look at different aspects and segments along the agri-food value chains. For instance, approximately 40 percent of the global land area is classified as agricultural land with only very limited opportunities for expansion (FAO, 2011). The FAO estimates that globally every year 25,000 million tonnes of topsoil are washed away by water erosion. Not only is the area available for food production limited but its suitability for production is being continuously eroded. There is an urgent need for solutions. Cultivation methods that make efficient use of resources are a major step forward.

**Figure 1** Food Demand Today versus 2050: Food demand does not fully translate into demand for agricultural production due to losses during transport, storage and processing until consumption (CGIAR, based on Alexandratos & Bruinsma 2012).

CLOSE-UP

**The Future of Food and Farming**

“Substantial changes will be required throughout the different elements of the food system and beyond if food security is to be provided for a predicted nine billion people. Action has to occur on all of the following four fronts simultaneously:

- More food must be produced sustainably through the spread and implementation of existing knowledge, technology and best practice, and by investment in new science and innovation and the social infrastructure that enables food producers to benefit from all of these.
- Demand for the most resource-intensive types of food must be contained.
- Waste in all areas of the food system must be minimized.
- The political and economic governance of the food system must be improved to increase food system productivity and sustainability.”

(Foresight, 2011)
1.3 Agricultural Production and Value Chains

One conclusion to draw from the above analysis is that the agri-food sector must become more efficient to feed more people. This can be achieved either through energy efficiency measures or through the application of renewable energy. In any case, changes need to include the entire agricultural value chain as shown in Figure 2. This includes: the input provider, the farmers, the processors, the packagers, the distributors and retailers.

Efficiency gains can be made in agricultural processing by decreasing energy input and use, as well as by reducing food losses before, during and after processing. In sub-Saharan Africa alone, 20 percent of harvests are lost, which comes at an annual cost of US $4bn (FAO, 2011). Losses often occur due to non-existent, inadequate and/or interrupted energy inputs during storage or transportation and in markets.

**Figure 2** Agricultural value chains (Sims et al., 2015).

Figure 3 shows the losses in agricultural value chains by comparing value chain segments between developing countries and developed countries. The majority of food loss in developed countries occurs in consumption and retail, whereas in developing countries food losses mainly occur at the pre-harvest/harvest, processing and retail
stages. These are the processes with opportunities for improvement.

However, reducing waste is not only a matter of energy: reducing waste is first and foremost about behaviour. By joining forces, civil society, private sector and government in high-GDP countries can reduce waste in the retail and consumption sector.

Figure 3 Food Losses Along Agricultural Value Chains (FAO 2014).
UNIT A1 RECAP

• The world’s human population will reach 9 billion by 2050 – demand for food will grow.

• Rapidly growing demand for resources in a resource limited world defined by planetary boundaries.

• The agri-food sector has to become more efficient to meet the growing demand.

• Around 30 percent of global energy usage can be traced back to the agri-food sector, including supply industry, agricultural production, processing, transport, merchandising and consumption.
UNIT A2
CLIMATE CHANGE

The relationship between agriculture and climate change is twofold – agriculture is a contributor to greenhouse gases and is a sector affected by the impacts of climate change.

2.1 Climate Change and Primary Agricultural Production

Meeting the increasing demand for food is further challenged by the impacts of climate change. Impacts can include extreme events such as drought and floods and changing rain and temperature patterns. Collectively, this has a great impact on the agro-business sector. Food security is influenced by decreases in production in certain areas and incomes are at risks due to volatile food prices.

Agriculture remains the main income source for rural populations (2.5 billion). Already extreme weather events and diseases are reported to negatively affect agricultural production. As a result of climate change impacts, significant crop decrease in maize production of up to 30 percent by 2030 is expected in Africa and up to 10 percent for staple crops in Asia (FAO, 2013).

These changes call for adaptation measures such as new technologies and the cultivation of new crops. Studies predict the shortage of water and food for billions of people due to climate change.

2.2 Adaptation to Climate Change

In view of growing food demand, successful adaptation to climate change must do more than just maintain the status quo. It requires the increase of production under inferior conditions. Therefore, adaptation strategies need to be broadly supported by institutions.
and policies and resulting legislation need to be modified. Targeted investments will be required and capacity development will be needed to achieve integrated action across diverse sectors. The complexity of the challenge has been highlighted in the report on the International Assessment of Agricultural Knowledge, Science and Technology for Development, published in 2009 (UNEP). The report also stresses the central role of the small-scale farming sector in meeting the challenges outlined above. Successful adaptation will require action on all scales: from subsistence farmers to the national frameworks and international agreements (UNEP, 2009).

Broadly speaking, climate change adaptation will require the farmer/smallholder to

i) shift to more robust crops or more stress-tolerant varieties,

ii) modify land use, e.g. trees in farmland,

iii) integrate soil cultivation and conservation,

iv) increase irrigated land, taking account of sustainable water management,

v) integrate water harvesting technologies.

Whereas adapting our agricultural production systems to better deal with the effects of climate change is a central need, agriculture also contributes to climate change, as shown in Figure 4.

CLOSE-UP

The Carbon Footprint

"The carbon footprint is a measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product."

(Wiedmann and Minx, 2007)
Figure 4 shows, agricultural, food and other land use (AFOLU) represent 24 percent of total GHG emissions. Methane release in this context should not be overlooked. The flooding of rice fields, which creates anaerobic conditions, is a major contributor. Studies show that one third of all agricultural methane emissions derive from rice production (FAO, 2011). Alongside adaptation, mitigation is therefore another area of concern for agricultural value chains and will be addressed later in this chapter (read also the CLOSE-UP: Adaptation and Mitigation).

### 2.3 Climate Neutral Productivity Growth
As this chapter pointed out at the beginning: agriculture must produce more while faced with the impacts of a changing climate. More production growth needs to be achieved without further increasing the GHG load already in the atmosphere. From 2001 to 2011, carbon dioxide emissions from crop and livestock production increased from 4.7 billion tonnes to over 5.3 billion tonnes. This is equivalent to an increase of 14 percent (Tubiello et al., 2014). The use of fossil fuels and fossil-based energy needs to be reduced dramatically. Possible solutions include the introduction of renewables, optimization of processes and lowering of energy intensity. Land use needs to change so that it no longer releases GHG into the atmosphere but eventually builds up carbon stocks in soils and biomass. The same applies to agriculture, especially with regard to beef cattle farming and paddy rice production, which are now considered to be major methane emitters.

The potential for optimization in the supply of food is very much linked to the supply of energy. Abundant energy resources such as wind, solar, hydro and biomass energy are available. These technologies make on-site generation of electricity and thermal energy possible. The implementation is feasible on all scales, from subsistence farming to large-scale agriculture. Some technologies...
have improved significantly, both technically and economically: one example is the significant decrease in solar power plant prices.

Lowering energy intensity builds on behavioural changes, the development and implementation of low-carbon practices, and investment in improved technologies with a particular focus on energy efficiency. In the last three decades, the deployment of energy efficient practices has led to more efficient energy usage in high-GDP countries. The goal should be to globally enable the production of more food per unit of land with less energy inputs, calling for higher efficiency of energy use in agriculture. Besides reducing GHG emissions, this has the potential to make food production more resilient and less dependent on a fossil fuel-based energy supply.

An example of energy saving potential can be found in the highly energy-intensive processing of tea in Kenya. Drying, grading and packaging consume immense amounts of energy. Together, these activities account for up to 30 percent of total production costs. Replacing lighting with low energy alternatives, upgrading fans, better fuel wood management and the use of alternative fuels can lead to significant improvements – which can result in 34 percent energy savings in fuel wood and 2 percent in electricity (Ethical Tea Partnership).
UNIT A2 RECAP

- Extreme weather events due to climate change impact agricultural production.
- Adaptation measures need to be implemented, such as new technologies and cultivation of new crops.
- Introduction of renewables, optimization of processes and lowering of energy intensity can design productivity growth in a carbon-neutral way.
- Agricultural processing can mitigate climate change by increasing energy efficiency and by applying renewable energy technologies.
UNIT A3
ENERGY INPUT IN AGRICULTURAL VALUE CHAINS

This unit focuses on agricultural value chains, discusses their indirect and direct energy inputs and explores the energy usage from production to processing, post-harvest and storage. Last but certainly not least, the financing side of alternative energy.

Figure 5 Energy Inputs in Agricultural Value Chains (Best, 2014).

3.1 Energy Input in Agricultural Production

Potential for climate change mitigation and hence for decreased GHG emissions lies in every single step of the agricultural value chain with its diverse direct and indirect energy inputs. Figure 5 further displays the energy inputs. Energy is used at every stage: from production over processing, post-harvest and storage to distribution and retail.
Direct and indirect energy inputs are equally necessary in agricultural value chains but they occur at different steps. Farms and processing plants apply direct energy at the operational level. It comprises, for instance, product supply and transport energy, with fuel or biofuel being used to bring the produce to the market. Additional energy consumed for production, processing and commercialization of products is categorized as direct energy input, as is energy for irrigation, land preparation and harvesting.

When correctly used, direct energy in irrigation systems has the potential to reduce water and energy consumption at the same time and further increase yield. If conventional energy sources are substituted by wind-powered or solar PV irrigation systems, irrigation can become sustainable. Nevertheless, sustainable irrigation also uses resources. With low-cost easily accessible energy in particular, there is a risk of over-exploitation (see CLOSE-UP of the Rebound Effect for more information).

Indirect energy is applied through the use of machinery, pesticides and fertilizers. A closer look at fertilizers, especially nitrogen fertilizers, clearly reveals the amount of energy input. Nitrogen fertilizer accounts for an energy input of 19.4 kWh per unit (Sims et al., 2015). Nonetheless, energy-intensive fertilizers have the potential to save indirect energy through advanced engineering and computer-aided technologies. Improving accuracy and timing of applications, with biosensors for soil fertility monitoring and trace gas detection, can significantly reduce fertilizer usage and thus decrease energy inputs.

3.2 Energy Input in the Downstream Sector
The downstream sector in agricultural value chains includes processing, post-harvest, storage, cooling, distribution and retail. These activities can easily consume large amounts of energy, so energy efficiency measures and renewables are very important.
Tobacco production in Zimbabwe is an example: the (heat) curing process accounts to over 50 percent of the total on-farm energy demand (Sims et al., 2015). The use of solar power can replace natural gas or liquefied petroleum gas in this heating process. There are several measures to preserve food. Cooling is one alternative to maintain food quality; however, its carbon footprint is by no means negligible. For some products, the total carbon footprint can amount to 10 percent and that’s only taking their refrigerated storage into account. If electricity inputs, the manufacturing of cooling equipment and lost refrigerants are considered, it is clear that GHG emissions from the refrigeration process are skyrocketing (Sims et al., 2015).

Energy consumption does not stop with the on-farm food operations and measures to preserve product quality. The processing and packaging part of the agricultural food chains is also a main contributor to overall energy utilization. A retail food product, for instance, needs around 14 kWh/kg to 28 kWh/kg for processing and packaging (Sims, 2008). Food processing plants in the USA are one example of this immense consumption of energy. The wet-milling of corn accounts for up to 15 percent of total energy used by the food industry. When not applying the best technologies, food processing plants are producing with an energy intensity up to 50 percent higher than necessary. By utilizing thermal and mechanical vapour compression, the milling of wet corn could save up to 15 to 20 percent in its energy-intensive dewatering, drying and evaporation process (Sims et al., 2015).

Small-scale food processing plants in developing countries often use outdated technologies and, as a result, consume more energy than necessary. The possibilities for improvement are abundant especially in regard to energy efficiency measures. Good maintenance of older processing plants can lead to energy savings of 10 to 20 percent without investing in new capital. By improving
combustion efficiency, reusing the heat from exhaust gases and applying high-efficiency motors, energy savings of up to 20 to 30 percent are achievable. With higher capital investment, even higher energy saving can be achieved (Sims et al., 2015).

Transport is another consumer of energy in agricultural value chains. For instance, when transporting for fresh fruit by air or by road to markets several hundred kilometers away, transport can account for up to 50 to 70 percent of the total carbon footprint. However, only around 1 percent of food products are transported by air, so that typically, the energy input for transport is a relatively small share of total energy inputs into an agricultural value chain (Sime et al., 2015). While transport is a relevant topic for the Energy-Agriculture Nexus, this course does not further elaborate on this topic but focuses on the value chain steps of primary production, storage and handling, and value added processing (Figure 2).

### 3.3 Financing of Alternative Energy Solutions

Agricultural value chains contain many opportunities for energy efficiency measures and renewables. Investment in these sectors can yield significant savings in energy and reduce GHG emissions. Of course, alternative energy solutions come at a cost. Whether they are applicable is very much dependent on the individual situation and financial background. For instance, lack of access to the energy grid changes the opportunity costs dramatically and thus influences the decision-making process. Cost-benefit analysis and feasibility analysis are valuable to spark a decision. Chapter 6 will cover these analytical tools in detail.

Not to be underestimated is the institutional background: Do financial arrangements exist? Does a functioning credit market enable loans, for instance? Is alternative access to conventional energy planned or in existence? Chapter 5 will provide information

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**CLOSE-UP**

**Solar-Powered Refrigeration for Dairy Farms in Kenya**

Due to limited electrification in rural areas, 85 percent of Kenya’s 800,000+ dairy farms do not have access to refrigerated storage and transportation. This deficiency in the distribution chain results in less than half of the milk produced actually reaching dairy processors. Of the milk that is processed, up to 30 percent of it may spoil without appropriate cold-storage options. Consequently, many dairy farmers and processors unnecessarily may lose significant earning potential from their operations.

Recognizing the need for affordable cold-chain technologies, SunDanzer has developed a small-scale portable cooling system tailored for use in the Kenyan dairy market. The system comprises a photo-voltaic refrigerator (PVR) that uses solar energy to cool a chest refrigerator. This uses phase-change materials (substances which are capable of storing and releasing large amounts of energy) as energy storage. SunDanzer also developed milk can blankets to retain the cold temperature as farmers transport the milk to the collection.

This clean energy solution aims to increase dairy farm productivity and income by significantly decreasing milk spoilage. Effective cold-chain storage lowers bacteria count and improves milk quality for consumers. These improvements can play a major role in the livelihoods of approximately one million smallholder dairy farming families in Kenya. (PAEGC, 2016)
on policies and regulation for the Energy-Agriculture Nexus.

Additionally, external costs play a major role in relation to alternative energy solutions. “External costs” means that all costs are included – and that also means the costs to the environment when environment-unfriendly measures are used. Once again, this changes the incentives and can favour alternative measures.

UNIT A3 RECAP

• Direct and indirect energy inputs are needed in agricultural value chains.
• Processing, post-harvest, storage and cooling are energy-intense steps of many agricultural value chains.
• Reduction of energy consumption in processing plants presents high potential for increasing energy efficiency.
• Options for financing alternative energy solutions is very much dependent on the individual context, such as the insitutional setting.
CHAPTER A
SUMMARY & CHAPTER WRAP-UP

- Population growth
- Limited resources
- Increasing demand for food

These are the tremendous challenges this century faces. The following questions address these challenges:

1. How can we produce more food while using less energy?
2. How can agriculture become energy-smart?
3. How can energy technologies provide efficient and sustainable power for agricultural processes?

With an outline of the current situation, an introduction to climate change and its implications for agriculture, and an insight into energy usage in agricultural value chains, this chapter provides a basis for further discussion of the energy-agriculture nexus in the ongoing course and introduces solutions focusing on energy efficiency measures and the use of renewable energies.

From Week 2 to Week 4, the MOOC will provide knowledge on the technological side of the Energy-Agriculture Nexus, including an overview of renewable energy resources and technologies. Further, solar and bioenergy are introduced with a focus on potential technological solutions for agricultural value chains. Energy efficiency will be the final unit of the technological chapter.

From Week 5 to Week 7, the MOOC will continue to explore economic aspects on the macro- and micro-level and will take a closer look at business options and investment planning for clean energy solutions for agricultural value chains. Further, it is recommended to watch the video with Katie Kennedy Freeman from the World Bank on approaches to support investment in clean energy solutions in developing and emerging countries.
RECOMMENDED READING

REFERENCES


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INTRODUCTION

Chapter B1 provides an introduction to the technical part of the MOOC "Powering Agriculture - Sustainable Energy for Food". Weeks 2 to 4 cover renewable energy technologies and energy efficiency in agricultural value chains. Chapter B1 provides an overview on renewable energy (RE) resources and a selection of technologies to harness these resources. In the beginning of the chapter, the linkage between REs and agricultural value chains will be discussed, followed by a general description on the origin of renewable energy resources. Chapter B1 focuses on major RE technologies currently used around the world. However, Solar power – one of the most versatile technologies – will have a unit for itself, including a design guide for solar powered irrigation systems. Nonetheless, the other technologies are briefly explored – Bioenergy will be presented in detail in the next week of this MOOC. Chapter B1 closes with some final remarks, followed by a case study for this week.

FOSSIL AND RENEWABLE ENERGY RESOURCES

Energy is available in many different forms. One group of energy resources is stored in oil, coal and natural gas, is depleting and non-renewable – called fossil fuels. Another group of energy resources is derived from every day’s solar radiation and either directly or indirectly converted to useful forms. Those renewable energy resources have many advantages over fossil fuels: They are available almost everywhere on Earth; they do not deplete and are free of charge (only the technology used for energy conversion generates costs). Converted into different useful forms of final energy (e.g. mechanical, electrical or useful heat) renewable energies play an important role for many different economic sectors, including the agricultural and food sector. Particularly in remote rural areas in developing and emerging economies, where agriculture often is an important income generating sector and grid access is not given, renewables can provide access to modern energy for farmers and agribusiness, and even displace existing fossil fuels with more sustainable energy systems.
UNIT B1.1 RENEWABLE ENERGY AND AGRICULTURAL VALUE CHAINS

Globally, the demand for food increases due to population growth and the transformation towards higher protein diets in emerging middle classes in many countries. To meet the global food demand and to increase the productivity of the agricultural food systems, energy inputs play a critical role, both on the farm and beyond the farm.

Currently, global food supply and consumption already accounts for around one third of total annual end-use of energy and for around one fifth of total annual global greenhouse gas (GHG) emissions, as energy inputs are required at almost all steps along the agricultural value chain (Sims, et al., 2015). Nowadays, most of these energy inputs are based on fossil fuels such as oil, coal or natural gas. Especially water pumping for drinking, irrigation and food processing consumes large amounts of fossil fuels. Furthermore, heat and cooling required for agricultural processes, as well as fertilizers and machinery contribute to high-energy use in the sector.

As GHG emissions are considered to be the driving force behind global warming, reducing them is of major importance. By reducing their GHG emissions, most farmers or businesses in developed or developing countries may only gain few, if any, direct benefits – but the numerous co-benefits of a technology shift towards renewable energy makes the topic attractive and worth rethinking the current energy use. This might help not only to reduce emissions but also to benefit from potential cost savings, improving health, local employment opportunities, improved independency and many other benefits (Sims, et al., 2015).

Chapter A has already provided an introduction to the Energy-Agriculture Nexus and its challenges. By presenting renewable energy resources and technologies, this Chapter B marks the start...
of a technical perspective on the Nexus, providing concrete approaches for clean energy solutions for agricultural value chains.

To identify opportunities for using renewable energy in agricultural processes, it is useful to analyze the whole value chain of a product or service. Chapter A1 already introduced the (agricultural) value chain concept. Figure 1 shows a common agricultural value chain with eight different steps. Each of the steps needs an energy input of some sort; for example electricity or fuels for pumping, transportation or milling. The value chain analysis method provides a simple approach to not only identify energy inputs, but to also identify opportunities for using waste products or waste energy for another step along the value chain. To clarify this approach, let us take a look at the milk production value chain.

Figure 1: Agricultural value chains (Sims, et al., 2015)

Figure 2: Steps along a milk value chain and energy inputs; adopted from (Sims, et al., 2015)
Example: Milk Value Chain

Milk production is resource intensive in terms of energy inputs and water consumption all along the value chain. Value chains differ based on the country, as well as based on the farmer. Depending on the land conditions, the way to feed, milk and further process, including energy input, vary. There are particularly large differences in energy use in the post-harvest stages of milk production.

However, the example (Figure 2) shows that energy input appears in different forms. The first energy input is required during land preparation for grazing; there is a need for fertilizer and irrigation. During the feeding process, fuels are used to power machinery for land preparation for feed production, transportation and processing of feed, etc. Especially on farms with larger quantities of livestock, milking is often mechanized and therefore it needs electricity and sometimes heat as an input energy. Similar requirements can be observed during cooling, transportation and processing of milk. Thus, many forms of energy are used to produce the packaged end product: milk (for other final dairy products such as cheese, milk powder etc. activities within the processing and packaging stages of the value chain can significantly change and influence energy demand. The same applies to differences in the extent to which the value chain is developed in a country or region).

Many of these energy inputs are fossil fuel based (especially in the production of animal feed, diesel for tractors, natural gas for the production of fertilizers), emitting greenhouse gases. Alternative energy sources for milk production, which are solely based on renewables, are shown in Table 1.
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<td>sprinkler controls.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Irrigation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Milk harvesting</td>
<td>Variable speed drive motors on vacuum and milk pumps.</td>
<td>Biogas from anaerobic digestion of manure for heat and electricity.</td>
<td>Biogas option depends on scale and cost of labor to maintain and operate the plant.</td>
</tr>
<tr>
<td>Milk cooling</td>
<td>Pre-cooling of milk and heat exchanger for hot water.</td>
<td></td>
<td>Standard practice to pre-cool milk before storing in refrigerated milk tank ready for collection. On small scale, milk kept cool in churns by spraying with cold water.</td>
</tr>
<tr>
<td><strong>PROCESSING</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermal treatment</td>
<td>Pasteurization, thermization, and homogenization.</td>
<td>Concentrating solar power (CSP) or bioenergy for heat generation.</td>
<td>Wide range of standard energy efficiency options for motors, fans etc.</td>
</tr>
<tr>
<td></td>
<td>Real time monitoring of heat energy use. Recovering steam for heating. Recovering waste</td>
<td>Evaporative coolers using solar PV panels.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>heat from milk chillers.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drying and cooling</td>
<td>Improved technology designs of dryers.</td>
<td>PV-powered refrigerators (solar chillers). Bioenergy heat such as from wood pellets.</td>
<td>Drying for milk powder production requires high temperatures and a reliable heat supply.</td>
</tr>
<tr>
<td>Water usage</td>
<td>Water used in cleaning-in-place (CIP).</td>
<td>Wastewater produced from dairy processing can be recycled to produce biogas for heat,</td>
<td>Raw biogas is corrosive so can be scrubbed of H₂S for use in engines.</td>
</tr>
<tr>
<td></td>
<td>Water recycling and reuse. Using on-demand hot water systems rather than storage tanks.</td>
<td>electricity or transport fuels.</td>
<td></td>
</tr>
<tr>
<td><strong>TRANSPORT</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diesel fuel use</td>
<td>Implementing sustainability measures (such as EURO standard vehicles). Route optimization.</td>
<td>Liquid biofuel or biogas powered vehicles. Electric heavy duty vehicles beginning to reach the market.</td>
<td>Good truck operators use less fuel. Driver training courses exist.</td>
</tr>
</tbody>
</table>
As indicated in Table 1 there are many possibilities to add value to agricultural products by using renewable energy. In some cases, renewable energy technologies provide basic energy access (e.g. for irrigation water pumping) or replace existing diesel generators and thereby contribute to avoiding fuel transport and costs. In other cases, the renewable energy source is an integral part of the whole production, particularly when waste from production can directly be used as an energy source. An integrated energy source will eventually reduce waste, costs and increases the sustainability of a product or process.

→ IN WEEK 4 WE WILL EXAMINE:

WHAT SUSTAINABILITY MEANS AND HOW TO ASSESS IT.

To optimize the design of a sustainable process within an agricultural value chain, it is essential to assess the situation holistically: starting from exploring the region and location that the process will be based in, and finishing by optimizing individual process parameters. Some project planners even adjust processing temperatures or similar central parameters to meet the needs of the available energy source in an optimal way. Therefore, the first step towards a holistic integration of clean energy solutions for agriculture is about understanding the origins of energy resources. Additionally, it is important to understand the agricultural production details and the implications for energy requirements.
Renewable Energy Resources

On our planet Earth, there are three sources for renewable energy: solar radiation, heat from the Earth’s core (geothermal energy) and gravitational force resulting from planetary movements (tidal power). Energy resulting from solar radiation accounts for about 99.9% of all energy available on Earth. Energy from the sun can be felt on our skin on a sunny day, and is evident in our surroundings. For example, it appears in the form of wind, i.e. air movement that is the result of the temperature differences across different locations on Earth. Also, solar radiation is responsible for plant growth (photosynthesis); and thus for Bioenergy resources. The evaporation of water and the melting of snow / ice is also a result of the sun’s energy, thus hydropower can be attributed to solar energy. With the help of suitable technologies, each of these resources can be converted into useful energy – some examples include: electricity, heating, cooling and powering machinery.

Theoretically, energy from the sun is abundant and the annual solar energy that the Earth receives is much higher than the world’s annual energy demand. It is even higher than the total known fossil fuel reserves, as illustrated in Figure 3. Despite this fact, due to technological limitations and economic reasons, our global energy supply today is dominated by fossil fuels. However, renewable energy technologies are being developed and implemented in a faster pace than ever before.

Even if the renewable energy resources are distributed throughout the world, location plays a huge factor when deciding which resource should be applied and in what level of intensity. Solar and wind energy resources are intermittent in nature – this indicates
that not all resources are suitable for each location, purpose or application. Site-specific analysis is hence crucial. In case of solar energy, equatorial regions are more suitable than far Northern and Southern regions. Figure 4 shows the average solar radiation for different regions of the Earth.

Generally speaking, each location has some sort of renewable energy potential. Sometimes this potential is directly visible and at other times different resources have to be combined. However, there is almost always a way to tap nature’s vast energy supply. To find out about the potential around your area, look for renewable energy projects nearby or talk to your national institutions to access studies on different potentials.

B1.1 RECAP

• Use of renewable energy in rural remote areas of many developing countries could help farmers to increase agricultural productivity as well as to earn more money by value addition to their produces (e.g. controlled drying of fruits and vegetables, cheese production from milk, off-seasonal production of fruits and vegetables with irrigation, etc.)

• The potential for using REs in the agricultural value chain is plentiful and often has many advantages compared to conventional technologies like diesel generators.

• A high level of integration of RE into an agricultural process can lead to high efficiencies, low environmental impact and low production costs.

• There is always some sort of RE resource available in any location, it is just important to choose the adequate source or a good combination of sources.
UNIT B1.2  INTRODUCTION TO ENERGY RESOURCES AND TECHNOLOGIES

This unit will give a short overview of different technologies suitable to harness renewable energy resources and will introduce practical examples for agricultural uses. Wind energy, Bioenergy, solar-thermal, solar photovoltaics (PV) as well as hydropower will be explained in this unit.

<table>
<thead>
<tr>
<th>ENERGY SOURCE</th>
<th>CONVERSION TO</th>
<th>MOST APPLIED TECHNOLOGIES AND APPLICATIONS</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar Energy</td>
<td>- Heat</td>
<td>- Photovoltaic (PV) driven pumps for irrigation</td>
<td>- PV systems are limited to agricultural activities that require little power input only.</td>
</tr>
<tr>
<td></td>
<td>- Mechanical Energy</td>
<td>- Crops, drying of fruits / spices, ice making and cold storage (through absorption or heat driven refrigeration)</td>
<td>- FAO provides an inventory of PV applications</td>
</tr>
<tr>
<td></td>
<td>- Electricity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wind Energy</td>
<td>- Mechanical Energy</td>
<td>- Direct use: grinder, mills, mechanical water pumps</td>
<td>Option for energy intensive processing activities</td>
</tr>
<tr>
<td></td>
<td>- Electricity</td>
<td>- Electrical water pumps</td>
<td></td>
</tr>
<tr>
<td>Micro Hydro Energy</td>
<td>- Mechanical Energy</td>
<td>- Direct use: mill, grinder</td>
<td>Option for energy intensive processing activities</td>
</tr>
<tr>
<td></td>
<td>- Electricity</td>
<td>- Electrical motor for processing</td>
<td></td>
</tr>
<tr>
<td>Biomass Energy</td>
<td>- Heat</td>
<td>- Dryer (fruits, herbs, spices)</td>
<td>- 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, agro-industrial by-products.</td>
</tr>
<tr>
<td></td>
<td>- Electricity</td>
<td>- Fermenter (tea)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Liquid Biofuels</td>
<td>- Combustion motor or electric motor (fuels like ethanol and biodiesel for transportation)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Biogas</td>
<td>- Anaerobic digester: biogas for lighting, cooking and heating and industrial biogas for decentralized electricity</td>
<td></td>
</tr>
<tr>
<td>Hybrid Power Systems</td>
<td>Combine fossil fuel-fired generators with wind or solar electrical power</td>
<td>- Wind/PV Hybrid</td>
<td>- Together, they provide a more reliable and cost-effective power system than is possible with either wind, solar or diesel alone.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Wind/Diesel Hybrid(s)</td>
<td>- An emerging technology.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Used in the food-processing sector (grinding of corn, wheat and millet, and milling of grain-hulling paddy)</td>
<td></td>
</tr>
</tbody>
</table>
Hydropower

Worldwide, hydropower is the most widely used renewable energy resource due to its significant advantages over other renewable resources: high energy density, low cost and reliability in particular. Hydropower plants are available from very small sizes of only few Kilowatts (kW) to multi-Gigawatts (GW). Small hydropower plants, generally in kW range, are used for rural electrification in many countries and have high potential to be integrated into the agriculture value chain in those locations.

Hydropower, especially small-scale hydropower (up to 1 MW), works according to a simple principle: water from streams or rivers runs through a turbine, the turbine rotates and turns tools (pumps, mills etc.) or a generator which can produce electricity. To achieve a reliable production of energy, it is important to have good knowledge about the local water resources and to design the system accordingly.

Figure 5 illustrates a typical small-scale hydropower system. Its main components are: the weir where water is raised and diverted from the main river; the forebay where it is collected and usually gutted and the penstock pipe which leads the water into the power house. Inside the power house the turbine and, usually a generator, is located.

\[ P = \rho \cdot q \cdot g \cdot h \cdot \eta \]

- \( P \) = power [W]
- \( q \) = water flow rate [m³/s]
- \( h \) = head (falling height) [m]
- \( \rho \) = density of water (1000[kg/m³])
- \( g \) = 9.81 [m/s²]
- \( \eta \) = efficiency of the systems, usually between 50% and 75% for micro/small hydro
FOR A CLOSER LOOK: CONSIDER THE MICRO HYDRO POWER SCOUT GUIDE PROVIDED BY GIZ

The theoretical power output of such a hydropower system can be estimated by multiplying the water flow of the river by the height difference from intake to the turbine, the system efficiency as well as some constants (see Box). An annual or daily energy yield can be estimated by further multiplying the power output by the number of hours the system is running during this period.

An alternative solution is an in-stream turbine. However, this type has not yet been commercially used in a wider scale. Smart hydro is an example.

SYSTEM EXAMPLE: SMART HYDROPOWER (IN-STREAM TURBINE)

The Smart Hydropower turbine was developed to produce a maximum amount of electrical power with the kinetic energy of flowing waters. Because it is powered by kinetic energy and not with potential energy it is known as a so-called “zero-head” or “in-stream” turbine. As such, no dams and/or height differences are necessary for the operation of this device; the course of a river remains in its natural state and no high investments in infrastructure are required. Because the amount of kinetic energy (velocity) varies from river to river, the capacity of an in-stream turbine ranges: from a minimum of a few watts to a maximum of 5 kW.
Wind Energy

Humankind has been using wind energy since ancient times – for sailing, water pumping and grinding. Using modern technology, i.e. a wind turbine, is now used also for electricity production in many parts of the world. Its global application has been increasing almost exponentially over the past years.

Wind, the result of global and local temperature differences, represents another source of renewable energy. The governing principle of wind energy is the transformation of wind flows into rotational movements. This is indeed the same principle as for hydropower systems. The power output of a wind energy system is generally estimated by multiplying the available wind speed by the swept area of the rotor (See MORE TO LEARN). Similar to hydropower, the rotational force can be used either directly (irrigation pumps etc.) or to drive a generator and produce electricity. Of course, wind does not blow as constantly as a river flows. Therefore, estimating annual energy yield slightly differs. Let us have a look at one example:

**POWER EQUATION**

\[
P = 0.5 \rho A v^3 C_p \eta
\]

- \(P\) = power [W]
- \(A\) = swept area of blades \([m^2]\)
- \(v\) = wind speed at hub height \([m/s]\)
- \(\rho\) = density of air \((1.29[kg/m^3])\)
- \(C_p\) = power coefficient (Betz’s coefficient) \((59\%)\)
- \(\eta\) = system efficiency

**MORE TO LEARN**

- Link: Wind Energy Introduction
- Link: Animated Wind Pump
- Link: Energy Yield Calculation
To calculate the energy yield of a wind turbine, we multiply the generated power by the duration the turbine is running. As a wind turbine produces different power outputs at different wind speeds, the mentioned multiplication is a little more complex. We therefore look in detail at the wind conditions in a specific location. Such data can be obtained from wind/weather measurement stations, or from wind atlas if available for the site of interest. Figure 8 shows which wind speeds were predominant at the location. This graph is called the frequency distribution. One can see that a wind speed of about 5 m/s occurs more than 1000 hours a year, while stronger wind speeds are less frequent throughout the year.

The second input for calculating the annual energy yield of a wind turbine is the power curve of the wind turbine we want to use. The power (Figure 9) curve is specific for every turbine model and normally provided by the manufacturer. It says at which power output the turbine generates which wind speed. Now we have to multiply the hours and the corresponding power output for every wind class (1 m/s; 2 m/s; 3 m/s...). The result can be observed in Figure 10. Note that most of the annual energy is produced with a wind speed of 10 m/s even though wind speed occurs at 5 m/s most often. (To understand its cause, take a look at the POWER EQUATION above.)

To get the annual energy production (AEP) of the turbine, we sum up the energy yield \( E_i \) from every wind speed \( f_i \times P_i \). These calculations can be done with software support (e.g. Excel) or manually:

\[
AEP = \sum E_i = \sum f_i \times P_i = [(372 \times 0 kW) + (702 \times 0 kW) + (941h \times 4 kW) + (1077h \times 10 kW) + (1107h \times 22 kW) + \cdots] = 578355 \text{kWh}
\]
SYSTEM EXAMPLE: WIND PUMP FOR IRRIGATION

Wind pumps are one of the first applications for using nature’s power to improve agricultural processes. Already in the 9th century, they were used to irrigate fields or to drain the land. Nowadays the technology is mostly used where a grid connection is too far away and wind conditions are steady enough to provide a reliable pumping solution. The design of a wind pump always depends on the application. Firstly, a distinction between mechanical and electrical wind pumps has to be made. Electrical wind pumps normally have the disadvantage of a lower efficiency, but pumps can be placed away from the location of the wind turbine. To choose the right wind turbine considerations about the desired pumping technology and extraction depth have to be made upfront. Centrifugal pumps generally work better with faster rotating wind turbines while piston and diaphragm pumps work better with slow rotating turbines.

In off-grid areas, where there is sufficient wind (>5 m/s) and ground water supply, wind pumps often offer a cost-effective method for domestic and community water supply, small-scale irrigation and livestock water use. To select a suitable wind pump, the following information is needed: mean wind speed, total pumping head, daily water requirement, well draw down, water quality and storage requirements (GTZ, 2007).

»» FOR FURTHER CALCULATIONS: WATER PUMPING WINDMILLS
Bioenergy

Bioenergy resources are generally all energy resources derived from biological origin. They can be in solid, liquid or gaseous form. They are basically biological material derived from living or recently living organisms, contrary to coal or gas which were created over a long timescale (millions of years). Bio-fuels are generally defined as liquid fuels derived from biomass. Examples include ethanol produced from sugar cane, bio-diesel produced from rapeseed or Jatropha, etc.

Often, biomass is further processed to increase the energy density, which simplifies transportation and use of the fuel. Biofuels can be used in many ways e.g. for heating, cooking, processing, cooling or as a direct petrol replacement. Therefore, the field of Bioenergy has many aspects and can be as simple as burning wood in a stove or very sophisticated as biogas plants for power production. What they all have in common, however, is that energy is released which was once delivered by the sun and stored by photosynthesis processes in plants.

Bioenergy technologies are especially useful when waste products of the agricultural production can be used to power production processes itself. Most common in the agriculture and energy interface is the generation of electricity from agricultural residues, such as from crops (e.g. straw and husk), from animal husbandry (e.g. manures and slurries) and from other organic material from excess production or insufficient market (e.g. fruit processing residues, grass silage). The idea is to have as little waste as possible and therefore a high utilization of resources. Circular economy concepts like cradle-to- cradle often involve Bioenergy as a core technology. An overview of different ways to convert biomass into Biofuels/Bioenergy can be seen in Figure 12 and details on this topic will be presented in Chapter B2.
SYSTEM EXAMPLE:

BIOGAS-POWERED EVAPORATIVE COOLING

The University of Georgia Research Foundation (UGARF) has developed a refrigeration unit powered on biogas that is generated from cow manure. The unit regenerates zeolite plates, which retain their capacity to capture water vapor from the evaporative milk chilling process. Partnered with Smallholder Fortunes, UGARF is refining the design of the refrigeration unit, and testing it with farmers in Uganda. The refrigeration device increases agricultural value and productivity by decreasing milk spoilage.

★ EXPLORE MORE: HERE.

MORE TO LEARN

Link: Lecture on Bioenergy Video Series
Link: Circular Economy Video
Solar Thermal

Solar thermal technologies harness solar energy for thermal energy use (heat or cooling). The technologies comprise flat plate collectors for low temperature applications. Examples are solar water heaters, solar air heaters for space heating or drying, etc. For high temperature application (e.g. power production), the concentrating collectors are used. In this case, incident solar radiation on a larger surface area is concentrated to a receiver having smaller surface area using reflecting mirrors. Compared to simple flat plate collector use, these concentrating power plants are more complex. Solar cooking has also been practiced in many countries, though still in pilot scale. Most common agricultural practice of solar thermal energy use is solar drying.

Figure 15: Solar thermal collector for water heating (Source: Cachogaray/Wikimedia)

MORE TO LEARN

Link: Solar Collectors
Link: Solar Water Heater Overview by Brian Norton
SYSTEM EXAMPLE:

SUNCHILL™ AGRICULTURAL PRODUCT REFRIGERATION

SunChill™ is a novel, off-grid refrigeration solution enabling increased agricultural productivity by: (i) removing field heat from crops immediately following harvest (ii) providing continued product cooling at local markets and/or central processing facilities. This clean energy solution transforms 50°C solar thermal energy into 10°C refrigeration using solid refrigerants and local, non-precision components. These characteristics enable production of a low cost, low-maintenance technology that reduces spoilage and benefits the livelihoods of smallholder farmers.

››› EXPLORE MORE: HERE.

Solar Photovoltaics (PV)

Solar PV is one of the most popular renewable energy technologies. Its large-scale application has been so far in developed countries, mainly for electricity generation and supply to the grid. In developing countries, solar PV has been used in off-grid application, mainly for rural electrification. Off-grid systems work independent, with the help of battery storage systems. The use of PV could be expanded beyond lighting, to different agro-processing activities in many countries, e.g. powering of small loads used in agro-enterprises. Solar PV is a technology that uses solar cells for energy production by converting sunlight directly into electricity. Solar cells are made of semi-conductor materials to convert sunlight directly into electricity. When sunlight is absorbed by these materials, it causes electrons to flow through the conductors generating electric current.

›››TAKE A LOOK AT THE CLOSE-UP:

2MIN VIDEO TO UNDERSTAND THE PROCESS!
Solar cells produce direct current (DC) electricity. There are two broad categories of solar cells - crystalline and thin film. The key components of a photovoltaic power system are solar cells interconnected to form a photovoltaic module (the commercial product), the mounting structure for the modules or array (several modules mounted and interconnected together to produce a desired voltage and current (power capacity), the inverter (essential for grid-connected systems and required for many off-grid systems), the storage battery and the charge controller (for off-grid systems only).

Performance of PV modules depends on the amount of solar irradiation received on the module surface, which varies with location and season. For this reason, systems normally need to be carefully designed for specific sites.

Let us have a look below at an example on how to calculate a required PV system size to supply a demand (load).

**EQUATION 2: REQUIRED PEAK POWER OF PV MODULE**

\[ P_{\text{peak}} = \frac{E_{\text{demand,month}}}{Q} \cdot \frac{I_{\text{STC}}}{G_{\text{total,month}}} \]

- \( P_{\text{peak}} \) = Peak power of the PV array under Standard Test Conditions [W]
- \( E_{\text{demand,month}} \) = Monthly energy demand of the system [Wh]
- \( I_{\text{STC}} \) = Irradiance at Standard Test Conditions (1 kW/m²) [kW/m²]
- \( G_{\text{total,month}} \) = Monthly total solar radiation on module plane [kWh/m²]
- \( Q \) = System quality factor (between 40 and 70% for off grid projects) [%]

We will now estimate the peak power for a system that is capable of powering a 30W (Watt) light bulb for 3 hours every day for one month during winter in Germany. Therefore, we estimate the required energy demand by multiplying 30W times 31 days times 3 hours which equals 2790Wh in one month. This is the Energy we are demanding from the PV system \( (E_{\text{demand,month}}) \). We presume a quality factor \( (Q) \) for the used system of 50%. The quality factor depends on the overall performance of the PV system and its system...
configuration (higher for grid connected systems and less for off grid ones). The total solar radiation in a month is specific for each location on the globe. For Berlin, it is around 25kWh/m² in December. You can find these monthly values for your location by using the NASA database (Link: NASA).

By using Equation 2, we can now calculate the PV size needed to supply our light for December:

**EQUATION 3: REQUIRED PEAK POWER FOR THE CASE SCENARIO**

\[
P_{\text{peak}} = \frac{2790 \text{ Wh}}{0.5} \cdot \frac{1 \text{ kW}}{25 \text{ kWh/m}^2} = 223.2 \text{ W}
\]

We chose the month of December, as it is the worst combination of demand and available radiation according to German weather conditions: higher demand and less radiation, resulting in an enormous system size. However, with this big size, we will now be able to supply the demand of additional months, easily.

During night and also on cloudy days, there is no electricity generation from a PV system – a battery should always be included in such system. In our example we will take three autonomy days and calculate the storage battery size (Bc) needed.

**EQUATION 4: ESTIMATION OF BATTERY CAPACITY**

\[
Bc (\text{Wh}) = \frac{E_{\text{demand, day}} (\text{Wh})}{\text{Battery depth of discharge (\%)} \cdot \frac{\text{Autonomy days (day)}}{\text{Overall battery system efficiency (\%)}}} \]

\[
Bc = \frac{90 \text{ Wh}}{80\%} \cdot \frac{3}{80\%} = 422 \text{ Wh}
\]

If we choose a 12V battery, we would need about 35 Ah battery size.

In grid-connected areas, we would not need any battery backup storage as a result of a grid power supply always being available.
B1.2 RECAP

- There are different renewable energy resources available on Earth. However, their quantity and type vary from place to place.

- The technologies used to harness renewable energy resources and convert them into useful energy forms are called renewable energy technologies.

- Hydropower is the most widely used renewable energy resource today. Many micro hydro power plants used in rural areas of developing countries could power different agro-processing machinery besides providing light.

- Wind energy is traditionally used in the agricultural sector for processes such as grains grinding and water pumping. Modern wind turbines could be used in grid-connected as well as in off-grid locations for power generation. The use of wind power for powering agro-enterprise is so far limited, only the mechanical energy from wind-mills is still used for water pumping.

- Bioenergy has a direct linkage to agriculture, because agricultural activities/processes need energy and energy generating technologies could use the agricultural waste products as resources. This circular economy concept is gaining importance in recent years for the efficient use of resources.

- Solar energy can have two applications, solar thermal and solar PV. Different thermal processes in agro industries could benefit of solar thermal, including solar cooling. Solar PV electricity can be used in versatile ways.

- The type of energy source preferred always depends on the resources available on site.

- Choosing a specific technology should always be based on the idea of optimal utilization of resources as well as cost minimization.
UNIT B1.3
SOLAR ENERGY IN AGRICULTURE

In the previous section, we discussed the use of solar energy in general under two broad applications – thermal use and electricity. In the following section, we will discuss each common application of thermal (solar drying of fresh fruits and vegetables) and solar PV (PV powered irrigation) in agricultural value chains.

Solar Powered Irrigation

Around the world, agriculture is predominantly situated in rural areas. Particularly in rural areas in developing and emerging countries, a good energy infrastructure often does not exist. However, it is often not possible or desired to base the production on rain-fed agriculture only. Therefore, groundwater needs to be pumped to the surface to irrigate the land. Where grid based electricity is not available, diesel gas or petrol driven pumps are the most widespread technology used nowadays. The prevailing disadvantage – besides their environmental impact – is the constant need for rather expensive fuel and a high level of maintenance. The use of solar powered irrigation systems (SPIS) on the other hand can provide a predictable and reliable energy source in most areas of the world and is basically maintenance free after installation, due to its capsuled design. The drawback of rather high initial costs can be compensated by a suitable business model (see Chapter C3 in Week 7).

Figure 19: Schematic diagram of a solar powered irrigation system (Hahn, et al., 2016)

MORE TO LEARN

Promoting, Financing and Advising on SPIS – Manual and Tools for Development Practitioners, GIZ (PDF)
(Hahn, Sass, & Fröhlich, 2016)
Components of a SPIS

Even though the configuration of a SPIS always depends on the local circumstances and available resources, there are some components which all systems have in common. As indicated in Figure 19, a SPIS consists of one or more PV panels, connected to a controller unit (responsible for adjusting the output frequency according to the irradiation levels) which in turn runs the electric pump in the well or basin. Depending on the availability of solar radiation and water, the water will either be used directly for irrigation or pumped into a storage tank to use it when needed. In some cases a filter system is recommended to prevent the tubes from clogging and is installed directly after the pump.

Design of a SPIS

Before considering to design a SPIS, solid knowledge about the used farming system, the crop’s water demand and the general availability of water is needed. These factors strongly influence the decision of which type of SPIS is suitable. In this MOOC, we focus on the energy technology i.e. solar PV as an energy source, as a new component to an existing irrigation system. However, we want to stress the importance of adequate water management to achieve a truly sustainable result that is considering water, energy and agricultural aspects.

Step 1: Collecting Data

Daily Crop Water Requirement $V_{\text{day}}$ [m$^3$/day]

This should be known by the farmer but can be analyzed or optimized by using comprehensive procedures (see: cropwat)

Total Pumping Head [m]

This is the height difference between the water level in the well/basin along with the highest point of the system (e.g. storage tank or sprinkler outlet), plus pressure losses due to friction in the pipes.

(Link: See pumping head calculator)

Mean Daily Global Solar Radiation $G_{\text{total, day}}$ [kWh/m$^2$/day].

This can be measured on site or obtained from the NASA website (Link: NASA)
Step 2: Select system type

Depending on the available water resource (well or surface water) and the site-specific conditions, different technical SPIS configurations are possible. Configurations differ in the following main aspects:

- Type of water source (well or surface water)
- Motor pump installation (submersible or surface)
- Use of water tanks (irrigation by gravity)
- Direct irrigation (without water storage)
- Grid connected / off-grid

Nevertheless, the size of the PV generator is mainly determined by the water and pressure requirements of the irrigation scheme. Therefore, water-saving irrigation technologies such as drip irrigation – working at comparably low operating pressures – are the preferred option in connection with PV pumping systems. The following table will give you a short overview of the main system types and their characteristics.

Table 3: SPIS types and characteristics (Hahn, et al., 2016)
Step 3: Estimate PV System Size

To estimate the system size, a simplified equation will be used:

**EQUATION 5: PV SYSTEM SIZE FOR IRRIGATION** (Hahn, et al., 2016)

\[ P_{\text{Peak}} = 8.0 \times \frac{H_T \times V_{\text{day}}}{G_{\text{total,day}}} \]

- \(V_{\text{day}} = \) Daily crop water requirement (m\(^3\)/day)
- \(H_T = \) Total pumping head (m)
- \(G_{\text{total,day}} = \) Mean daily global solar radiation for the design month (kWh/m\(^2\).day)
- \(P_{\text{peak}} = \) Solar panel power (W\(_p\))

As indicated in Equation 5, the collected data from Step 1 will be used to calculate the power of the required photovoltaic system. Based on the estimated power requirement, a suitable size and amount of solar PV panels can be calculated.

Important to consider when choosing the right system size is the actual water demand. The water demand is not constant over the course of a year thus it is important to size the system appropriately. This means, the system can either be sized to meet the peak demand (during the driest months of the year) or be designed to meet the average water demand throughout the year. A peak demand sized system is therefore oversized during large parts of the year while a smaller system might be undersized during peak demands but less expensive.

**Below you will find some additional links for SPIS sizing:**

- **Meteorological Data Sources:** [Link]
- **Crop Water Requirement: CROPWAT:** [Link]
- **System Example:** [Link]
- **Manufacturers Channel:** [Link]
- **Case Study:** [Link]
Solar Drying

Post-harvest loss of agricultural commodities is of significant concern in many developing and emerging countries. On the one hand, lack of awareness about the high amount of losses, and on the other hand lack of proper knowledge on benefits of using simple post-harvest and conservation technologies. A significant amount of agricultural production is wasted in many countries. Introduction of appropriate post-harvest technology could help in saving the wasted food. It also helps to add value on the quality of products that result in a high market price.

The most common approach to preserve freshly harvested cereals, fruits and vegetables is to dry and store them. Open sun drying has been practiced since ancient times – with this said, it is not free of problems such as the high dependency on weather conditions, slow drying rates, the risk to contamination, etc. Using mechanical dryers could avoid these problems; however, they are energy intensive. Next to mechanical solutions, simple solar powered drying can reduce the moisture content of vegetables and fruits to store them for longer periods. Especially in countries where industrial technologies for preservation are not available or not applicable – such a simple solution bares high potential (Gewali & Bhandari, 2005).

There are different types of solar dryers, such as direct drying (solar box dryer), indirect drying (solar cabinet dryer), mixed mode drying (solar tunnel dryer) or hybrid drying (hybrid solar/biomass cabinet dryer). Small-scale solar box and cabinet dryers are based on natural air convection, while solar tunnel dryer is based on forced convection (air circulation fan necessary).
Solar Box Dryer

This dryer is simply a box with a glass cover at the top, inclined at an angle to allow maximum solar radiation into the box. Inner walls of the box are made of aluminum sheet with black coating to absorb the solar radiation entering through the transparent glazing. A rectangular opening is made at the lower part of the front wall for air inlet. A chimney made of galvanized iron sheets, attached at the top of the box permits the moist air exit. The products to be dried are spread on three trays made of stainless steel wire mesh, which are placed inside the box. Each tray is provided with a drawer for ease of loading and unloading. Slower drying rates and discoloration of products are the major problems experienced with the box dryer. This dryer is recommended for domestic use due to its small drying capacity.

Solar Cabinet Dryer

The design of a solar cabinet dryer is somewhat complex compared to the box type dryer and is also relatively more expensive to fabricate. This dryer consists of two parts: a collector to heat the incoming ambient air using solar radiation and a drying chamber in which commodities to be dried are spread on a number of trays on different layers. The solar collector consists of a corrugated aluminum sheet as absorber. The box of the collector is made of galvanized iron (GI) sheet. For insulation purpose, glass wool is inserted in between two covers of the box. The outer cover of the drying chamber is also made of GI sheet and that of inner cover is made of aluminum sheet. Between these two covers glass wool is inserted for insulation. This chamber is partitioned into separate chambers; each chamber provided has a door and different drying trays made of stainless steel wire mesh. Warm, moist air from inside the drying chamber is driven out through the chimney placed at the top of the drying chamber. Due to its indirect mode of heating, it is very useful for drying of herbal products, which are sensitive to direct sunlight. These dryers are recommended for community use and small-scale income generating industries.
Solar Tunnel Dryer

The solar tunnel dryer consists of several solar collectors and dryer boxes arranged in the form of a tunnel. The product is loaded on trays kept inside the dryer boxes. A small blower at the air inlet end of the drying tunnel is used for forced air circulation through the collector and drying chambers. The commodities to be dried are placed in a thin layer on the drying trays. Heat is generated by absorption of solar energy on the absorber of the collector as well as on the commodity itself. Air enters the tunnel at one end, and is heated while passing through the solar collector. The hot air is forced through the products placed on the trays inside the tunnel. Forcing the air ensures secure removal of moisture even under unfavorable weather conditions, and hence spoilage of products due to enzyme reaction or growth of harmful microorganisms is almost excluded. These dryers are recommended for large scale drying for commercial operation.

Figure 25: Solar tunnel dryer (Photo: R. Bhandari, 2004)
Solar-Biomass Hybrid Cabinet Dryer

Biomass resource has been taken as the supplementary fuel in the design of the hybrid solar biomass drying system. In this dryer, a biomass stove has been installed at one side of the drying chamber of the basic solar cabinet dryer, adjacent to the collector system. The stove is made of steel sheets. The hot flue gas from the stove is passed through the heat exchanger that is installed at the bottom of the drying chamber. The heat exchanger transfers its heat to the ambient air coming through the solar collector into the drying chamber. After having passed through the heat exchanger, flue gas exits through the outlet, installed at another side of the drying chamber.

During operation, hot air enters into the drying chamber and then passes through the products to be dried. Warm, moist air from the drying chamber exits through the chimney placed at the top of the drying chamber. This type of dryer is recommended for the drying of fish and meat products.

B1.3 RECAP

- Solar energy has significant potential to be integrated into agricultural value chains, from very small to large-scale applications.

- Solar PV systems, already used in almost all countries worldwide – ranging from large-scale power generation to small-scale solar home systems for lighting, could play a vital role in water pumping taking advantage of cheaper (water) storage systems.

- On the one hand, PV pumping could replace fossil fuel or grid electricity based water pumping, on the other one it opens up a new door for farmers to increase agricultural productivity with irrigation.

- Even if the technology is very simple and can be manufactured locally, solar dryers are important for preservation and value addition of fruits and vegetable products.
SUMMARY & CHAPTER WRAP-UP

The global energy demand has been continuously increasing for decades, with higher growth rates in developing countries in recent years. This trend is expected to continue with the economic and population growth in many developing and emerging countries. Out of this energy demand, about one third of the energy is consumed as a result of food production, supply, and consumption. Today, the majority of this energy comes from fossil fuels. Fossil fuels have finite reserves and cause environmental problems, most notably they contribute to climate change. Renewable energy resources could mitigate these problems of resource scarcity and emissions. RE resources are regenerative and distributed almost everywhere on the Earth. Especially in developing countries, where subsistence agriculture is a lifeline for many, access to clean energy solutions for agricultural processes could have multifold benefits. It could not only help displacing fossil fuels, but also opening up new opportunities for farmers to increase their productivity and add value on the produce. And interestingly, the waste products from agricultural activities could be used to produce energy (heat or electricity) and thus closing the circular economy.

In this Chapter B1, you were provided with an overview on these resources and technologies as well as some practical examples of their implementation in agricultural value chains. In the upcoming Chapter B2 you will learn about Bioenergy, a very important energy source within the Energy-Agriculture Nexus, including in-depth knowledge about Bioenergy resources and technologies, and the use of Bioenergy in agricultural value chains.
RECOMMENDED READING:

**Unit B1.1**

Utz, V., 2011. Modern Energy Services for Modern Agriculture A Review of Smallholder Farming in Developing Countries, GIZ HERA Poverty-oriented Basic Energy Services

Sims, R., Flammini, A., Puri, M. & Bracco, S., 2015. Opportunities For Agri-Food Chains to become Energy-Smart, s.l.: FAO and USAID

GIZ 2014, Productive Use of Thermal Energy, An Overview of Technology Options and Approaches for Promotion

**Unit B1.2**

GTZ, Isat., Biogas Digest, Volume I + II Biogas Basics and Biogas - Application and Product Development

GTZ 2009, Micro Hydro Power Scout Guide

Dan New 2004, Intro to Hydro Power

**Unit B1.3**

Infogate, GTZ 2001, Solar Drying Technology for Food Preservation

Gewali et. al, 2005, Solar Drying Technology Packages Developed at Recast


USDA 2010, Design of Small Photovoltaic (PV) Solar-Powered Water Pump Systems
REFERENCES


Sims, R., Flammini, A., Puri, M. & Bracco, S., 2015. Opportunities For Agri-Food Chains to become Energy-Smart, s.l.: FAO and USAID.


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Introduction to Chapter B2: Bioenergy Overview

Unit B2.1 Brief Overview on Bioenergy Resource and Technologies

Unit B2.2 Introduction to Biogas

Unit B2.3 Use of Biogas Technologies in the Agricultural Value Chain

Unit B2.4 Biogas Utilization Options

Summary & Chapter Wrap-Up

Recommended Reading

References
PART B OVERVIEW

Unit B1.1: Renewable Energy and Agricultural Value Chains

Unit B1.2: Introduction to Energy Resources and Technologies

Unit B1.3: Solar Energy in Agriculture

Unit B2.1: Overview on Bioenergy Resources and Technologies

Unit B2.2: Introduction to Biogas

Unit B2.3: Use of Biogas Technologies in Agricultural Value Chains

Unit B2.4: Biogas Utilization Options

Unit B3.1: Introduction to Energy Efficiency

Unit B3.2: Energy Auditing

Unit B3.3: Energy Efficiency in Agricultural Value Chains

Unit B3.4: Environmental Life Cycle Assessment and Sustainability
INTRODUCTION

Chapter B.2 will provide you with a technical overview on bioenergy resources and technologies, biogas fundamentals, and the many uses of biogas in the agriculture sector. This reader will introduce the process by which methane is generated, the technologies that can be used to generate methane and factors to consider when choosing a technology, and the different ways biogas can be used as an energy source.

BIOENERGY RESOURCES:

The Food and Agriculture Organization (FAO) defines bioenergy as all energy derived from biofuels, which are fuels derived from biomass (that is, matter of biological origin). These biofuels can be subdivided into three types, solid, liquid, and gas and by origin, forest, agriculture, and municipal waste (Cushion, et al., 2010).

UNIT B2.1 OVERVIEW ON BIOENERGY RESOURCES AND TECHNOLOGIES

In the past decade bioenergy has seen an uptick in interest from the international community. While instability in oil regions has been one factor in the shift towards renewable energy resources, other factors such as demand for self-supply energy commodities, increase in energy security, stimulate rural development, reduce the impact of energy use on climate change, and provide a clean more environmentally friendly energy source have played a large role in the promotion of bioenergy resource development (Cushion, et al., 2010).

The basic bioenergy process involves the translation of organic material into an end product, including biogas, which can then be used to produce energy. Figure 1 provides a general schematic of the biomass to bioenergy conversion process.

MORE TO LEARN

Link Bioenergy Development: Issues and Impacts for Poverty and Natural Resource Management
Bioenergy Resources

Organic material comes from a variety of resources, including municipal, industrial, and agricultural activities. The main feedstocks used today to produce bioenergy are:

**Food Waste**
Food waste can come from a variety of sources, including grocery stores, restaurants, cafeterias, and homes. Some types of food waste packaging can also be digested, such as paper food packaging, cardboard boxes, paper towels, napkins, and wax paper (American Biogas Council, n.d.).

**Farm Manures and Slurries**
Manure produced through agricultural operations like on dairy farms or hog farms provides an excellent feedstock for anaerobic digestion. The digestate that is produced is also of a higher caliber fertilizer than that of undigested manure.

**Agro-industrial Wastewaters**
Many agro-industries generate wastewaters with high levels of organic matter that generate biogas due to their typical wastewater treatment and disposal practices. These agro-industries include palm oil mills, sugar processing and refining, ethanol production, and food processing facilities.

**Crop Residues**
Crop residues can come from either crops grown for traditional purposes like corn for food or tobacco for cigarettes, or they can come from crops that are grown specifically for the production of energy. These crops include sugar cane, sugar beets, grassy crops like switch grass, starchy crops like wheat, maize or potatoes, and woody crops in the tree family that are traditionally used for combustion purposes (Biomass Energy Centre, 2011).

Regarding access to resources, basic data should show that a sufficient amount of organic waste is constantly available and of adequate quality. Securing a guaranteed and regular feedstock supply for biogas plants should not be taken for granted. In practice, this means that all elements of the waste management value chain must contribute to the smooth functioning of the entire system – i.e. the collection, transport, handling and storage of the biowaste feedstock.
»» **FIGURE 2** PROVIDES EXAMPLES OF SEVERAL DIFFERENT FEEDSTOCKS AND THEIR ASSOCIATED BIOGAS PRODUCTION POTENTIAL.

**Bioenergy Technologies**

Choosing the appropriate technology for converting organic matter into bioenergy is key to optimizing energy production. The technologies available today for bioenergy conversion can be broken up into three general categories: direct combustion and thermochemical processes; biochemical processes; and, other processes.

Direct Combustion: Direct combustion is the most common form of bioenergy and is typically employed at fossil-fuel fired
power plants. The process involves the combustion of solid biomass feedstock, most often some type of woody waste, in the presence of excess oxygen in boiler in order to produce steam which is then converted to electricity. The heat produced from the combustion process can also be used in direct thermal applications such as to heat a building (Sass Byrnett, et al., 2009).

**Thermochemical and Biochemical Conversion**

Typically cellulosic materials that are not viable for the treatments described above due to their difficult nature to break down can be made into ethanol. Materials such as grass, wood waste, and crop residue are all good feedstocks for both thermochemical and biochemical conversion. Thermochemical conversion uses heat and chemicals to break down the cellulose in the feedstock to make syngas. Biochemical conversion can use a variety of high temperature, high pressure acid, enzymes, or other treatment techniques to break down the lignin and hemicellulose that surround the cellulose. Hydrolysis using enzymes and acids then breaks down the cellulose into sugar which in turn is fermented to produce ethanol (Sass Byrnett, et al., 2009).

**Thermochemical processes**

*Pyrolysis:* Pyrolysis uses high temperatures and pressure in the absence of oxygen to decompose organic matter, which can result in gas, pyrolysis oil (bio-oil), or charcoal (bio-char). Bio-oil is the most common product as it has the most end-uses such as for thermal energy that can be used to heat buildings or water, or for power generation. The temperature of the reaction determines the end-product (Sass Byrnett, et al., 2009).

*Gasification:* Gasification converts solid fuel to gas through either a chemical or heat process. Solid biomass like woody waste is heated to a high temperature (above 700 degrees Celsius) with limited oxygen. This in turn converts the feedstock into a flammable synthesis gas known as “syngas”. Syngas is then either combusted to produce steam in a boiler for electricity or heat for thermal applications (Sass Byrnett, et al., 2009).
Biochemical Processes

Anaerobic Digestion: Anaerobic digestion involves the decomposition of organic or biological waste by microorganisms in the absence of oxygen. This process produces a gas composed largely of methane and carbon dioxide (CO2). The methane can be used to produce electricity or heat in much the same manner as with the above described methods (Sass Byrnett, et al., 2009).

Fermentation: Starchy plants are often used in the biochemical fermentation process to convert sugars into alcohol. This is the most common process used to produce ethanol from corn and sugarcane (Sass Byrnett, et al., 2009).

Other processes

Transesterification: Transesterification is a process that converts oils or fats into biodiesel. The process involves the removal of water and contaminants from the feedstock, the mixing with alcohol (typically methanol), and a catalyst (such as sodium hydroxide). Fatty acid methyl esters and glycerin are produced as byproducts of the process. The glycerin can be used in pharmaceuticals and cosmetics, while the esters are considered biodiesel and can be used as vehicle fuel or for other fuel purposes (Sass Byrnett, et al., 2009).

B2.1 RECAP

- The basic bioenergy process is the translation of organic material into a final product that is used to produce energy.
- The main feedstock to produce bioenergy include: food waste, farm manures and slurries, agro-industrial wastewaters, and crop residues.
- Bioenergy technologies can be divided into 3 types:
  - Thermochemical processes – pyrolysis and gasification
  - Biochemical processes – anaerobic digestion and fermentation
  - Other processes - transesterification
UNIT B2.2

INTRODUCTION TO BIOGAS

Biogas is a gas that is produced during the anaerobic degradation of organic materials. It is primarily composed of methane (60%-70%) and carbon dioxide (30%-40%). Biogas also has trace amounts of other components such as water vapor, hydrogen sulfide and ammonia.

Because of its composition, biogas is a greenhouse gas that is detrimental to the environment and an important factor in climate change. Another byproduct that is produced, called “digestate” also provides a rich fertilizer that can be used in agricultural and gardening practices.

The World Bioenergy Association estimates that if fully utilized, biogas could cover close to 6% of the global primary energy supply – equal to one quarter of the current consumption of natural gas. Currently 30 million tons of methane emissions are produced worldwide each year from agricultural operations, if this waste were treated through anaerobic digestion, it is estimated about half of these 30 million tons of methane emissions could be avoided. However, biogas deployment at the global level has been slow on the uptake due to several factors:

- Lack of information about the possibilities of biogas;
- Lack of a trained labor force;
- High capital costs for commercial scale plants;
- Natural gas is a cheaper alternative; and
- Government policies and programs do not adequately facilitate/support biogas programs.
Global data on current installed capacity of biogas plants does not exist, but the World Bioenergy Association estimates that 40 billion m³ biomethane equivalent – equal to 1080-1440 PJ of energy - is produced annually. India and China are global leaders in the biogas field with an estimated 4.5 million biogas plants in India and over 40 million biogas plants in China. While these plants range in size and technology from a few m³ to large commercial scale plants, the majority are small household systems that are used to produce gas for cooking, heating water, and lighting (World Bioenergy Association, 2013).

The high organic content of municipal solid waste in low- and middle-income countries (up to 60%) causes numerous problems in the handling and disposal of the waste. Banning the dumping or landfilling of organic waste is therefore of great benefit: it reduces the generation of landfill gas, relieves the pressure on scarce landfill capacities and mitigates all of the conflicts, costs and social burdens involved.

By reintroducing recyclables into value chains, the use of a biogas technology that uses waste as feedstock promotes a circular economy. The advantages are twofold: (1) energy is recovered and (2) the nutrient cycle is closed.

**BENEFITS AND CO-BENEFITS OF ANAEROBIC DIGESTION INCLUDE**

- Energy recovery
- Nutrient cycle is closed
- Health
- Climate change mitigation & pollution reduction

**CLOSE UP**

The Nutrient Cycle

If derived exclusively from clean, source-separated waste streams, the spent and sanitized digestates left over from the process are subsequently further processed into organic fertilizers and soil amendments that can, at least in part, replace mineral fertilizers. In this way the nutrients are recirculated, which contributes to closing the cycle between food-consuming urban spaces and food-producing rural areas.

When anaerobic digestion projects focus on waste, they are more likely to be sustainable and far less likely to threaten food supplies.
METHANE

Methane is combustible gas with the scientific formula CH4. It has a heating value of 34.4 MJ/m3 and a greenhouse gas global warming potential of 25 times that of carbon dioxide when emitted from human activities. Methane is also formed in many natural processes such as in wetlands, natural gas seeps, and intermittently from saturated soils. It is part of the natural carbon cycle. When methane is oxidized to the atmosphere it forms carbon dioxide (CO2) and water (H2O).

The methane formation process is comprised of three steps:

STEP 1 ACIDOGENESIS:
Hydrolysis of insoluble and complex soluble compounds to form organic acids and alcohols.

STEP 2 ACETOGENESIS:
Reduction of organic acids and alcohols formed in Step 1 to acetate, hydrogen, and carbon dioxide.

STEP 3 METHANOGENESIS:
Further reduction of the products produced in Step 2 to methane and carbon dioxide.

This process is part of the global carbon cycle, which involves the fixation of carbon as CO2 by photosynthesis and the subsequent release as the organic matter synthesized decomposes anaerobically. The microorganisms responsible for Steps 1 & 2 reproduce more rapidly than the methane forming bacteria. If the population of methane forming bacteria is not adequate to reduce the organic acids and alcohols as they are produced, accumulation will occur.

Although the organic acids are sources of energy and carbon at low concentrations, they become toxic at higher concentrations. Thus, the absence in balance between the fermentation and methane forming bacterial populations can cause methane formation to be inhibited.
Carbon Dioxide

Carbon dioxide is a primary greenhouse gas with the chemical formula CO2. Carbon dioxide is produced and absorbed by many organisms naturally such as plants, animals, and microorganisms. This CO2 is part of a natural environmental balance. However, when human activities also produce CO2 as a byproduct this balance is upset and new ways must be derived to treat CO2 in order to mitigate the effects of climate change caused by the release of primary greenhouse gases into the atmosphere (United States Environmental Protection Agency, 2015).

Figure 3 The Carbon Cycle | Source: https://www.windows2universe.org/earth/climate/images/carboncycle_jpg_image.html

B2.2 Recap

- Biogas is primarily composed of methane (60%-70%) and carbon dioxide (30%-40%).
- Biogas is underutilized at the global level, and there is a lot of potential to increase biogas use and replace traditional fossil fuels.
- Some of the main challenges to biogas implementation are: lack of information, lack of government policies, lack of trained labor force, high cost, and cheaper alternative fuel sources.
- The methane formation process is 3 steps: acidogenesis, acetogenesis, and methanogenesis.
- When CO2 is formed naturally it is part of the carbon cycle and mitigates itself, but when released from human activity it is a harmful greenhouse gas that contributes to climate change.
UNIT B2.3 USE OF BIOGAS TECHNOLOGIES IN AGRICULTURAL VALUE CHAINS

Anaerobic digestion can be carried out using a wide range of technologies. In order to determine the best fit technology, there are many factors to consider:

- Size: large, medium, small, micro
- Cost: capital investment required
- Level of technology
- Operation and Maintenance requirements
- Terrain: space available, geotechnical studies, etc.
- Waste characteristics: total solids concentration
- Climate: temperature, rainfall

Anaerobic digestion systems range in cost depending on the complexity of the technology and the size of the system. As a rule of thumb, the investment cost is approximately US$5,600 for 5 kW installed capacity (World Bioenergy Association, 2013) for small scale systems, and up to $3,500 to $4,500 per kW for larger and more sophisticated systems. In terms of operation size, for the simplest covered anaerobic lagoon technology for 150 animals, investment cost can be as low as US$25,000 and as high as US$1.3 million for a 5,000 animal operation. More complex technologies like plug flow digesters range from US$200,000 for 100 animals to US$1.8 million for 7,000 animals (Balsam, 2006). While investment costs for anaerobic digestion systems are often much higher than simply disposing of waste in landfills, costs are often offset by the sale of electricity to the local grid, the replacement of electricity on-farm with energy generated from biogas, and the sale of digestate as compost. In addition, there are many grant programs and funding schemes available (especially in developing countries) to ease the upfront cost of installing a biogas system.

CLOSE UP

Takamoto Pay-as-you-go Biogas

The company Takamoto has introduced an innovative Pay-as-you-go financing scheme for small scale biogas systems used for cooking in Kenya. Traditionally, a family-sized biogas system in Kenya would cost US$1,000-US$1,500, but with the Pay-as-you-go scheme, installation is as low as US$100. Once the systems are installed, farmers feed the systems with animal waste (typically from the family cows), and when they are ready to use the biogas, they simply add credit via their mobile phones and the system switches on! These systems are advantageous because most farmers can afford them without taking out loans and paying high installation fees, and Takamoto maintains the system for life.

Source: www.takamotobiogas.com
Aerobic Digestion Technologies

Aerobic digestion technologies can be divided into two categories based on size: (1) large and medium scale; and (2) small scale. They can also be operated as either a batch process or a continuous process. Batch anaerobic digestion systems are the most common and cheapest form of digestion. In these systems, the feedstock is introduced to the digester, the digester is sealed until the anaerobic digestion is complete. Most of the small scale technologies described below are batch systems. In a continuous system, feedstock is introduced in a continuous flow or added in stages and removed in the same manner – this means there is a constant flow of biogas being produced. Most of the large and medium scale technologies described below are operated as continuous systems.
Large and Medium Scale Technologies

Complete mix digester:
These digesters are made from a constant volume, flow-through, controlled temperature, silo-like tank where the feedstock is heated and mixed. Waste is mixed using gas recirculation, mechanical propellers, or liquid circulation. It can handle feedstock up to ~15% solids and therefore is suited to operations that produce a fairly liquid feedstock such as washing out manure. This type of digester is more expensive than others and is one of the least common (Balsam, 2006).

Covered anaerobic lagoon:
The covered anaerobic lagoon is one of the simplest and cheapest technologies available for large scale operations that contain 3% or less solids – coarse solids must be separated out or they will form a crust on the surface of the lagoon inhibiting biogas production. It consists of a liquid pool or “lagoon” that is topped by a pontoon or floating cover. Seal plates extend down the sides of the pontoon into the liquid to prevent exposure of accumulated gas to the atmosphere. These digesters are ideal for warmer regions where atmospheric heat helps maintain the digester temperature without having to input extra energy (Balsam, 2006).
Plug-flow digester
A plug-flow digester is an unmixed tank where waste is pumped horizontally into one end of the digester in turn pushing the older material out through the opposite end. Biogas formed in the tank bubbles to the top where it is collected. No heat is used in this type of digester, and the cover can either be a fixed rigid top, a flexible inflatable top, or a floating cover (Balsam, 2006).

Upflow anaerobic sludge blanket (UASB):
In a UASB system, wastewater enters the reactor from the bottom and flows upward into suspended sludge blanket filters. The sludge blanket acts as a filter to remove unwanted solids and also contains microorganisms that facilitate the anaerobic digestion process. The motion of the biogas that is being produced acts as a mixer, making a mechanical mixer unnecessary (Tilley, et al., 2014).

Small Scale Technologies

Fixed dome digester:
In a fixed dome digester the top is the gas holder and the bottom contains the waste slurry. As gas is produced, the slurry is displaced into a compensation tank and gas pressure increases with the volume of gas stored and the height difference between the slurry level in the digester and the slurry level in the compensation tank. Because fixed dome digesters have no moving parts they are fairly inexpensive and they are well-suited to colder areas because they are constructed partially underground (The GEF Small Grants Programme (SGP), n.d.).

Floating drum digesters:
Floating drum digesters are comprised of an underground digester and a moving gas holder on top. The gas holder can either float on the slurry or on a water jacket. Depending on the amount of gas stored in the gas drum, it moves up and down with the gas fluctuation. Plants that use a water jacket are slightly more efficient as they are less likely to get stuck in the scum layer (The GEF Small Grants Programme (SGP), n.d.).
Bag Digesters:
Bag digesters are made from a durable flexible plastic and sit largely above ground in order to utilize sunlight as a heating source. As the bags heat up, methane gas is formed and the bag inflates as the gas moves to the surface. Gas can then be piped out of the bag for utilization. These systems are very inexpensive and easily transportable, however due to the material they have a shorter lifespan than most digesters that are made from more durable materials like concrete and steel (International Fund for Agricultural Development (IFAD), 2012).

Figure 10 Bag Digesters | Source: http://www.fao.org/docrep/t0541e/T0541E09.htm

»» THE TABLE BELOW HIGHLIGHTS THE ADVANTAGES AND DISADVANTAGES OF THE ABOVE-DESCRIBED ANAEROBIC DIGESTION TECHNOLOGIES
When considering an anaerobic digestion system, the main design considerations are: size; cost, technology complexity; operations and maintenance; terrain; waste characteristics; and, climate.

Biogas systems are expensive, as a rule of thumb, the investment cost ranges from $1,600 to $4,500 per kW installed capacity for small and large systems, respectively.

Large and medium scale anaerobic digestion technologies include: complete mix digesters; covered anaerobic lagoons; plug flow digesters; and, UASB.

Small scale anaerobic digestion technologies include: fixed-dome digesters; floating-drum digesters; and, bag digesters.
UNIT B2.4 BIOGAS UTILIZATION OPTIONS

Once biogas is produced from the anaerobic digestion process, it can be utilized in various ways as an energy source. It can be used in a process known as cogeneration to produce electricity and heat, it can be used as a cooking fuel, to power lights, and to drive vehicles. All of the above mentioned uses replace traditional fuel sources therefore making them a more sustainable, renewable energy source.

Cogeneration

Cogeneration, also commonly referred to as combined heat and power (CHP) or “cogen”, is the production of electricity from biogas and the use of the waste heat from the generation process. The process uses the biogas to fuel a turbine which in turn drives a generator to produce electricity. Typically engines used to generate electricity through cogeneration have an efficiency of up to 40%.

Waste heat from the turbines, which is normally around 75% of the fuel energy input into the engine can be reused to provide hot water or heat. In the anaerobic digestion process it is common practice to recover engine heat for heating the digester and providing water and space heat for the farm. By using both the waste heat and the primary fuel to produce electricity, cogen systems are able to reach about 80% efficiency resulting in lower GHG emissions as fossil fuel use is reduced.

Depending on the size of the operation, there are a variety of turbines that can be used in the cogen process. For industrial processes, gas turbines (500 kW-250 MW) and steam turbines (50 kW-250 MW) are the most efficient, while for smaller operations, reciprocating engines (up to 5 MW) and micro turbines (30 kW-300 kW) are better suited (Center for Climate and Energy Solutions, 2011).
Lighting and Cooking
Biogas can be used as a direct energy source for cook stoves. This is a very popular method of use in developing countries where people often still have to spend hours each day collecting firewood for cooking. Small anaerobic digesters that run on animal waste and crop residue from family farms like bag digesters and floating dome digesters can provide a reliable source of biogas that can feed directly into a cook stove, therefore eliminating the need to use firewood in cooking. Cook stoves that burn biogas also provide a much cleaner gas which improves indoor air quality for families that previously relied on firewood or other less pure sources of gas like diesel (United States Environmental Protection Agency, 2008).
This type biogas source can also be hooked directly into a gas lantern and provide a steady source of lighting.

Vehicle Fuel
Biogas is becoming increasingly popular as a vehicle fuel in the form of compressed natural gas (CNG). However, in order to produce CNG the biogas must be “cleaned” or upgraded in order to remove impurities and make it a suitable fuel. Biogas upgrading involves the removal of water, carbon dioxide, hydrogen sulfide, and other trace elements. The resulting upgraded biogas has a higher content of methane than raw biogas, which makes it comparable to conventional natural gas and thus a suitable energy source for vehicles that have been retrofitted to run off of CNG (U.S. Department of Energy, 2015).

B2.4 RECAP
• Biogas has many different end uses such as cogeneration to produce electricity and heat, cooking fuel, to power lights, and to drive vehicles
• Cogeneration is the production of electricity from biogas and the use of the waste heat from the generation process
• Biogas can be used in simple cook stoves and for lighting to replace traditional fuel sources like kerosene and wood.
• Biogas can be converted to vehicle fuel as CNG

Link SNV: Improved Cookstoves

CLOSE UP
Biogas-Powered Evaporative Cooling for the Dairy Industry
Powering Agriculture Energy Grand Challenge Innovator University of Georgia Research Foundation (UGARF) has developed a device to chill milk and keep it cool using cow manure to produce biogas. This solution is particularly important in low-income countries where milk often spoils before it can be transported to market. Not only do these systems provide a practical solution to farmers to ensure their product lasts longer and stays cool while being transported, but the systems can also be used to provide gas to households to power lights and cook stoves, replacing “dirty” fuel sources like kerosene, wood, and charcoal with clean burning biogas.
Source: www.poweringag.org

Figure 12 Biogas Cookstove | Source: https://greenheatug.wordpress.com/2012/08/28/biogas-at-kps-2/
SUMMARY & CHAPTER WRAP-UP

Bioenergy resources are abundant yet underutilized throughout the world. With the wide range of available feedstocks such as farm manure, food waste, crop residues, and wastewater and many different treatment methods ranging from traditional combustion processes to fermentation and anaerobic digestion processes, there are many opportunities across many sectors to implement bioenergy projects.

In the developing world, 70% of people that live in poverty rely on agriculture for their livelihood. This provides ample opportunities for the implementation of family-sized biogas operations that would greatly improve the quality of life for the world’s poor living in rural areas by replacing traditional fuel sources that can be expensive (kerosene or charcoal) or time consuming and unreliable (wood gathering) with a consistent clean burning fuel source like biogas.

By increasing the amount of biogas produced in utilized around the world, inevitably the release of harmful greenhouse gases to the atmosphere would be reduced, in turn contributing to global efforts to mitigate climate change. It would also contribute to the reduction of reliance on natural gas and other traditional fuel sources that are not renewable, with a much cleaner, renewable fuel.
RECOMMENDED READING

Unit B2.1


Unit B2.2
EPA 2010, Methane and Nitrous Oxide Emissions from Natural Sources, Environmental Protection Agency.


Unit B2.3


International Fund for Agricultural Development (IFAD), 2012. Flexi Biogas Systems: inexpensive, renewable energy for developing countries, IFAD.

Unit B2.4
REFERENCES


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PART B OVERVIEW

Unit B1.1: Renewable Energy and Agricultural Value Chains

Unit B1.2: Introduction to Energy Resources and Technologies

Unit B1.3: Solar Energy in Agriculture

Unit B2.1: Overview on Bioenergy Resources and Technologies

Unit B2.2: Introduction to Biogas

Unit B2.3: Use of Biogas Technologies in Agricultural Value Chains

Unit B2.4: Biogas Utilization Options

Unit B3.1: Introduction to Energy Efficiency

Unit B3.2: Energy Auditing

Unit B3.3: Energy Efficiency in Agricultural Value Chains

Unit B3.4: Environmental Life Cycle Assessment and Sustainability
INTRODUCTION

Chapter B3 will provide you with a general understanding of the term efficiency and the concept of energy efficiency. Furthermore, this chapter will briefly present energy auditing (EA) – a tool to identify energy efficiency measures and to assess investment related energy efficiency measures. Thereby, also typical energy technologies and energy processes that occur in many agricultural value chains are addressed.

In section B3.3 two projects are illustrated as examples to demonstrate where energy efficiency measures can be applied. To round up this chapter, we will discuss the concept of life cycle assessments and sustainability briefly. In the following “EE” is used as abbreviation for energy efficiency.

UNIT B3.1 ENERGY EFFICIENCY

Efficiency

The term efficiency is used in many different fields, for example in engineering, economy, medicine as well as in sociology. However, quite often the word is used ambiguously. Therefore, we start by having a look at the meaning of this term.

Generally, efficiency is defined as the ratio of the desired output (useful effect) to the required input (used resources) of any system (Pérez-Lombard, et al., 2012). Efficiency can easily be expressed as:

\[
\text{Efficiency} = \frac{\text{Output}}{\text{Input}} = \frac{\text{Service Output}}{\text{Used Resource}}
\]

The equation highlights that efficiency always involves both used resource and provided services. Therefore, efficiency can be improved if the same service is provided using fewer resources, or if a better service is achieved with the same resource consumption as before. These two scenarios are often referred to as minimization and maximization strategy, respectively.
Let us look at a simple example: One person pushes a rock on a flat surface over a distance of five metres. Here the used resource is the energy of the person while the service or output is pushing the rock five meters. Now let’s add that the person uses something to reduce friction between the surface and the rock. The person can either go with the maximization strategy and push the rock further with the same energy used as before or the person can push the rock over the same distance (five meters) and use less energy – this would then be called a minimization strategy. Mathematically, both ways have the same efficiency improvement. However, one way aims to reduce the input resource while the other way wants to extract as much as possible out of the resource. As you can conclude, increasing efficiency does not necessarily mean to save resources – as you have already learned in week 1 (remember the “rebound effect” in Reader 1). In our small example the resource described is the muscle energy of a person. In other systems, the used resource can be natural resources, money, labour, material or even time.

As in many cases the goal is to make processes better, we strive to increase efficiency.

**Energy Efficiency**

Now that we know about the general concept of efficiency, let us turn our focus to energy systems. Assessing their efficiency is classically achieved by looking at energy conversion efficiency (\( \eta \)), (Greek letter Eta).

\[
\eta = \frac{\text{Useful Energy Output}}{\text{Energy Input}}
\]

Equation 2 Energy Conversion Efficiency

A diagram on energy flows and energy losses serves to better illustrate EE, considering the energy losses occurring in all energy converting processes.

**Recommended reading:**
Steven Sorrell: The Rebound Effect: an assessment of the evidence for economy-wide energy savings from improved energy efficiency; [Link](#)

**NOTE**
Remember the ‘Rebound Effect’ from Week 1

**WHAT’S ENERGY EFFICIENCY?**

“Energy efficiency is a way of managing and restraining the growth in energy consumption. Something is more energy efficient if it delivers more services for the same energy input, or the same services for less energy input.” (International Energy Agency)
The most common example of calculating EE is a conventional power plant where heat is converted into electricity by using a turbine and a generator. In such thermal power plants, energy input would refer to the heat we feed into the process and electricity we get as a useful output. Both elements are energy flows and can be quantified by using thermodynamic calculations which result in an absolute value for efficiency.

Unfortunately, such a straightforward procedure is not always applicable. Let’s have another look at the example from the video of this week again:

As we said, modern light bulbs with LED technology are able to provide a light with brightness or more accurately, with visible light of 1000 lumen with electricity input of 20 Watt. On the other hand, the old incandescent light bulb technology needs five times more electricity input to provide the same brightness of visible light. Using Equation 1, we can actually see the difference in numbers:

For 1000 lumen Brightness…

<table>
<thead>
<tr>
<th>Incandescent Bulb</th>
<th>LED Bulb</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 Watt</td>
<td>20 Watt</td>
</tr>
</tbody>
</table>

Figure 3 LED technology

\[
\text{LED bulb} = \frac{\text{Output}}{\text{Input}} = \frac{\text{Brightness}}{\text{Power}} = \frac{1000 \text{ lumen}}{20 \text{ Watt}} = 50 \frac{\text{lm}}{\text{W}}
\]

\[
\text{Incandescent light bulb} = \frac{\text{Output}}{\text{Input}} = \frac{\text{Brightness}}{\text{Power}} = \frac{1000 \text{ lumen}}{100 \text{ Watt}} = 10 \frac{\text{lm}}{\text{W}}
\]

As you can see, the LED uses the input resource in a more efficient way. However, we have to be aware that this comparison is only acceptable when the output or service is really the same in both technologies. In the case of a light bulb, some people might say that brightness is the only important factor, but others might argue, the LED provides a different light colour and therefore a different or less valuable service than the incandescent bulb. “Therefore, it is worth distinguishing between quality and quantity of output service. Evaluating the quality of services is generally difficult, especially when multiple services are provided by the system subject to analysis (Pérez-Lombard, et al., 2012)”. As a result, we mostly focus on evaluating the quantity of output service, which can be measured more easily.

In addition, it is important to closely look at the denominator of the efficiency equation (the energy input). When comparing different
technologies with another, not only the end use appliances (like a light bulb) might be changed but also the form of energy input. For example, changing a system in which power and heat are conventionally generated in separate generation cycles while waste heat remains unused to a a) more efficient system with heat reuse and heat recovery or b) even to a combined heat & power supply (co-generation facilities) system. See the info boxes for more detailed examples.

Now the energy production itself should be incorporated into the evaluation of efficiency.

»» EXCURSE

TO CONVENTIONAL ELECTRICITY GRIDS AND THEIR RELATION TO ENERGY EFFICIENCY

Figure 1: Decommissioned open pit mine next to a town in Germany (Source: Andreas Hannusch, Wikimedia)

Nowadays in most countries worldwide, electricity is supplied to the end-user through a distribution grid, which is fed by the centralized power plants. Commonly these power plants are powered by fossil resources like coal, gas or oil and in some cases the plants are nuclear power plants. According to the International Energy Agency, coal fired power plants account for about 40% of global power generation.

In order to understand how energy efficiency plays a role in power generation let us discuss the power generation from coal.

CLOSE UP

Heat Recovery & Co-generation

a) A system of heat reuse and heat recovery:
This could e.g. mean waste heat from power generation process in power plants or from industrial production processes or others is used for other nearby cooling/ heating demands such as dairy production, greenhouses or other agri-food related facilities.

b) A combined heat & power supply/ co-generation facilities:
Due to the simultaneous generation of heat & power on-site and in a decentralized way, co-generation plants reach aggregate efficiencies up to 80-95% compared to efficiencies of separate generation processes of around 50%. To cover heat, power and even cooling demands in one combined and efficient generation, also a ‘tri-generation’ system can be applied in agri-food production processes.
Many processes are involved from mining coal to the electricity at the power socket in your home. The major steps include: (1) the mining process, (2) transport to the coal power plant, (3) burning and energy conversion process, (4) transmission of electricity, and (5) electricity use at home.

Electricity generation starts with acquiring the energy resource. In this case, coal is mined either from open mining (e.g. Figure 3) or deep underground mining. Mining normally involves operations like cutting, drilling or blasting the surrounded rock or soil while insuring proper drainage, ventilation and lighting. The coal will then be cleaned and transported to the coal power plant.

In the processes involved in mining and transportation energy losses occur. Approximately, an equivalent of 15% of the energy content of coal is lost before it enters the power plant where the coal is burnt to generate high temperature and high pressure steam. During this process another 25% of the initial energy content is lost. Further losses occur during turbine operation and other processes within the power plant. When the electricity is finally fed into the main grid, only about 20-30% of the initial energy content could be used (please note that the average efficiency of a coal power plant is often referred as between 30 and 35%, however this value does not include the energy needed for mining and transport to the power plant gate). Further losses occur during transmission and distribution of the generated power to the consumer, in particular if power system networks lack proper technology (see the example in the box). The final amount of energy arriving at the end user is thus just a fraction of the energy stored in coal. If all losses would be incorporated into the energy efficiency analysis, it would result in a low value. Improving the EE of supply system should therefore be of high priority of any nation.

**IN CONCLUSION,** when assessing energy efficiency one has to make sure that the services provided and the input resources used by the system are comparable and measurable. Additionally, defining the system boundaries plays a huge role as the above coal power generation example shows.
Energy Efficiency – Global Dimension and Co-Benefits

The International Energy Agency (IEA) considers energy efficiency as „the world’s first fuel“. On global level more than half of the worldwide consumed primary energy is lost in production processes, by transport and general energy consumption. The resulting global high energy efficiency has hardly been captured. Facing this situation, energy efficiency has also gained high attention on the international political agenda: e.g. energy efficiency is incorporated in the new global agenda of „Sustainable Development Goals“ (SDGs), and as 2/3 of global Greenhouse Gas Emissions (GHG) derive from energy consumption (of power, fossil fuels etc.), energy efficiency is also a key for climate protection and will play a major role in international processes for realizing global climate goals (after COP 21 in Paris). Besides high climate relevance, energy efficiency increase also addresses various so-called co-benefits (or multiple benefits): security of energy supply, import improvements, increased productivity & economic growth, modernization of facilities and more.

Overview on common energy efficiency measures & technologies for agricultural value chains: As the agri-food sector heavily dependents on fossil fuel inputs (for production, transport, processing, and distribution – remember Reader 1), and as this energy demand will even increase due to growing global food demand, opportunities for real energy savings are numerous along many agri-food chains – by increasing energy efficiency and using energy more wisely to avoid wasting it.

The following table gives a short overview of typical energy demand occurring in many agricultural value chains (due to applied energy intensive processes and technologies), and of common technologies and measures for increasing energy efficiency well as other co-benefits.
<table>
<thead>
<tr>
<th>WHICH ENERGY (SERVICE) DEMAND?</th>
<th>WHICH AGRI-FOOD PROCESSES/ VALUE CHAINS?</th>
<th>WHICH COMMON ENERGY EFFICIENCY TECHNOLOGIES/ MEASURES?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat supply</td>
<td>- greenhouse farming</td>
<td>- CHP (Combined Heat and Power) / co-generation</td>
</tr>
<tr>
<td></td>
<td>- food processing (dairy production, drying fruits &amp; vegetables, canned food etc.)</td>
<td>- Waste heat recovery (e.g. by heat exchangers that use 'waste' heat for pre-heating other processes)</td>
</tr>
<tr>
<td></td>
<td>- CHP (Combined Heat and Power) / co-generation</td>
<td>- waste heat from (nearby) power plants</td>
</tr>
<tr>
<td></td>
<td>- Insulation of networks/ pipeline, building facilities</td>
<td>- Insulation of networks/ pipeline, building facilities</td>
</tr>
<tr>
<td></td>
<td>- Where possible/ feasible using renewable sources for heating demands (e.g. solar thermal, geothermal, also by heat pumps, bioenergy heat plants etc.)</td>
<td>- Minimizing heat load at the end of the processing phase of the cold chain</td>
</tr>
<tr>
<td></td>
<td>- Etc.</td>
<td>- Efficient and 'climate friendly' refrigeration systems (also with new/ renewable technologies are available, such as solar absorption chillers)</td>
</tr>
<tr>
<td></td>
<td>- Etc.</td>
<td>- Efficient greenhouse ventilation systems</td>
</tr>
<tr>
<td>Cooling &amp; air conditioning / cold storage / cooling chains</td>
<td>- In all agri-food sectors where food quality needs to be maintained after harvesting, while processing and for transporting food/ agri products =&gt; dairy/ milk production, rice production, vegetable production, beverage industry, drinking water treatment and processing etc.</td>
<td>- CHP/ tri-generation</td>
</tr>
<tr>
<td></td>
<td>- CHP/ tri-generation</td>
<td>- Insulation of networks/ pipeline, building facilities</td>
</tr>
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</tr>
<tr>
<td></td>
<td>- Efficient greenhouse ventilation systems</td>
<td>- Efficient greenhouse ventilation systems</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>- In many agri-food sectors/ processes</td>
<td>- Reducing heavy energy inputs in fertilizer manufactur-ing, but also by more accurate application methods.</td>
</tr>
<tr>
<td>Water supply/ pumping</td>
<td>- Greenhouse farming</td>
<td>- for irrigation: using gravity supply where possible;</td>
</tr>
<tr>
<td></td>
<td>- Irrigation for all agri-chains</td>
<td>- using efficient water pump designs (correctly matched to suit the tasks</td>
</tr>
<tr>
<td></td>
<td>- Beverage industry &amp; drinking water treatment</td>
<td>- applying efficient designs of electric motors for pumps</td>
</tr>
<tr>
<td></td>
<td>- food processing in general</td>
<td>- sizing pumping systems to actual water requirements</td>
</tr>
<tr>
<td></td>
<td>- maintaining all equipment regularly;</td>
<td>- maintaining all equipment regularly;</td>
</tr>
<tr>
<td></td>
<td>- drip irrigation in row crops;</td>
<td>- drip irrigation in row crops;</td>
</tr>
<tr>
<td></td>
<td>- varying irrigation rates by using automatic regulation control systems</td>
<td>- varying irrigation rates by using automatic regulation control systems</td>
</tr>
<tr>
<td></td>
<td>- alternative fuels/ energy sources for driving pumps (e.g. solar and wind-powered pumps)</td>
<td>- alternative fuels/ energy sources for driving pumps (e.g. solar and wind-powered pumps)</td>
</tr>
<tr>
<td>Machinery (also tractors etc.)</td>
<td>- many agri-food processes (growing, harvesting, processing)</td>
<td>- correct gear and throttle selection</td>
</tr>
<tr>
<td></td>
<td>- for irrigation: using gravity supply where possible;</td>
<td>- efficient automation (efficient electric drives &amp; motors, as well as automate monitoring &amp; control systems) for production and processing</td>
</tr>
<tr>
<td></td>
<td>- using efficient water pump designs (correctly matched to suit the tasks</td>
<td>- Etc.</td>
</tr>
<tr>
<td></td>
<td>- applying efficient designs of electric motors for pumps</td>
<td>- Etc.</td>
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</tr>
<tr>
<td></td>
<td>- Etc.</td>
<td>- Etc.</td>
</tr>
<tr>
<td>Transport and distribution of food</td>
<td>- Transport of food commodities (such as milk powder, rice in bulk, fruits and vegetables etc.), partly under controlled atmosphere or refrigeration,</td>
<td>- See as under cooling/ air conditioning</td>
</tr>
<tr>
<td></td>
<td>- Etc.</td>
<td>- Etc.</td>
</tr>
</tbody>
</table>

Table 1: Measures for increasing energy efficiency in agricultural value chains
B3.1 RECAP

- Generally, efficiency is defined as the ratio of the desired output (useful effect) to the required input (used resources) of any system.

- Efficiency measures can be targeted at both used resources and provided services. Energy efficiency is a way of managing and restraining the growth in energy consumption. However, a process can become more efficient even though the input resources are not decreased.

- Assessing energy efficiency is only possible when the systems to be compared are examined within the same system boundaries.
UNIT B3.2 ENERGY AUDITING

A TOOL FOR IDENTIFYING ENERGY EFFICIENCY POTENTIAL & MEASURES

Within the agricultural value chain many processes need energy, mainly for electricity, heat and cooling demands. The energy however is not always delivered in a useful form and therefore an energy conversion often has to take place. For example, in lift irrigation a diesel engine converts chemical energy of diesel into mechanical energy for powering the shaft of a pump. This pump then converts shaft power into potential energy of water by lifting the water to a higher elevation. Within all steps of conversion energy losses occur. The whole process can turn out to be inefficient. If one changes the system or process to be more efficient, it not only saves energy by reducing the amount of diesel, but also saves money, as less fuel has to be bought and transported to the irrigation field. A win-win situation.

An important tool or method for finding such potentials for energy efficiency measures and for assessing their financial viability is an energy audit, which can be carried out at different levels. A simple level just includes a brief site inspection as well as assessing the broad energy input and output of a system – this identifies low cost energy saving opportunities. Medium level audits include an in-depth analysis of energy costs, energy usage and system characteristics along with on-site energy demand measurements to identify energy efficiency measures which are more capital intensive and need to be aligned with the financial budget plan of the site. The most sophisticated level, which is referred to as an investment grade audit, includes an additional continuous monitoring of system data and process characteristics.

Energy audits on such comprehensive levels can also form an important basis or first step for introducing and establishing energy management systems (EMS) in enterprises/other institutions. They enable efficient management of energy demand and consumption in production or processing entities – also in agricultural value chains (International Standard for EMS: ISO 50001).
THE MAIN GOALS OF ENERGY AUDITS ARE:

- Understanding how energy is used within the system or process, and where it is wasted
- Finding alternative measures to reduce energy losses and improve the overall performance
- Performing a cost-benefit analysis for highlighting which energy efficiency measures are best to implement

THE AUDIT ITSELF CAN BE DIVIDED INTO FOUR DIFFERENT PHASES:

1. Review of Energy Use
2. Site Assessment
3. Energy and Cost Analysis
4. Audit Report

1. Review of Energy Use

In this phase of the auditing process the energy use of the system, e.g. a small diary milk factory, is assessed by reviewing the energy bills or the past fuel consumption patterns in the past. Also, a system diagram is sketched showing the energy flows within the system along with a list of used equipment and their energy demand. The more detailed the energy usage data is the better will be the actual analysis. At this point, monthly data is most common; however, daily or even hourly data would be more accurate. With the collected data the auditor is able to calculate the total energy demand for specific scenarios (seasonal variation/ production intensity) and is able to set each system component into comparison. Then, it is possible to determine a “per square meter” energy use or “an energy use per produced product unit”, to benchmark the system against other similar buildings or processes. With these preliminary analyses, experienced auditors can estimate how much potential the system or building bears for efficiency improvements.

2. Site Assessment

During the site assessment, the mentioned system components are examined and their performance data is collected. This
step can include, for example, the operation characteristics of a fan used for drying or the lighting used throughout the building. Such a process can vary largely in terms of effort.

3. Data Analysis

The data analysis step is the most complex part of an energy audit and involves technical and cost analysis. Methodologies for analyzing the collected data vary widely and are subject to the system or process to be assessed. The technical analysis can incorporate a simple spreadsheet energy balance where all input and output parameters are determined or can be achieved by designated software packages. The same methods apply for the cost analysis, where current energy costs, costs for implementation of energy efficiency measures as well as potential savings over time are considered. The results of both analyses lead in a further step to a hierarchy of the most promising changes to the system in both financial and technical aspects. Guiding indicators are amongst others the payback period, life cycle costs as well as internal rate of return of the energy efficiency measures. You can find more information about such financial analysis in weeks six and seven of this course. Further aspects to be considered are operation and maintenance of planned implementation, reliability and their ease of installation.

4. Audit Report

The last phase of the auditing process is creating a comprehensive report. Including all recommended energy efficiency measures and how different combinations of lead to cost and energy savings.

B3.2 RECAP

- Energy auditing is the analysis of process or system in regard to their energy usage and energy losses.

- By reviewing load patterns, executing site visits and measuring process energy demands, suitable energy efficiency measures can be discovered.

- Energy audit results are useful for economic and environmental betterment of the analyzed processes, thus it is a very important tool in energy sector.
UNIT B3.3 ENERGY EFFICIENCY IN AGRICULTURAL VALUE CHAINS: A CASE STUDY

Let us now examine an example from the agricultural value chain to see how system changes can lead to a better performance and reduce energy use. The following case study section is based on the report: “Subsector Analysis: Harnessing the renewable energy potential in the Kenyan flower industry” (Ogallo, 2015).

In Kenya, the flower production sector is one of the largest contributors to national GDP within the agricultural sector. Flower production is comprised of large, medium and small scale producers. Many farms have already incorporated high level technology, like drip irrigation, automatic greenhouse ventilation systems, pre cooling, cold storage facilities and artificial lighting to increase day length. Furthermore, renewable energy technologies like rooftop PV installations, solar thermal for heating as well as biogas plants that use waste products are commonly installed. However, energy audits at a number of facilities identified major potential to improve energy efficiency.

Due to energy requirements for water pumping, lighting, refrigeration heating and sanitary processes, greenhouse farming is considered to be an energy intensive industry. About 10 to 20% of total operating costs result from energy costs.

Energy Demand Assessment

Energy audits revealed that the thermal energy demand appears when hot water is used to warm seedling beds for better cultivation. The thermal demand is usually covered by hot water boilers powered by diesel or kerosene.

Electrical energy demand is generated by multiple activities as indicated in Figure 4. The largest share in our example case, results from water pumping for irrigation. In total a typical small scale farm, has a monthly energy demand of about 11.5 MWh. The electricity demand is distributed over the day with demand peaks during midday (due to irrigation schedules) and a base demand which stays relatively constant over the rest of the day as indicated in Figure 5.
Recommendations for Energy Efficiency Measures

Based on the energy audit, several measures were recommended. Amongst others, the use of high efficient motors and pumps, LED lighting, better cold curtains, variable speed drives and instituting an energy management system was suggested. Let us have a closer look at two recommendations, which can be incorporated in other industries and systems as well.

1. Replacing existing irrigation pumps with better sized pumps
   Irrigation pumping was found to be only 10% efficient. By recommending the appropriate pumping system to deliver the same amount of water with appropriate pressure head at the furthest places and avoiding throttling of pumps, a pumping efficiency of 65% is achievable. This results in significant energy savings with a payback time of less than one month.

2. Incorporating a heat recovery system
   Floating drum digesters are comprised of an underground digester and a moving gas holder on top. The gas holder can either float on the slurry or on a water jacket. Depending on the amount of gas stored in the gas drum, it moves up and down with the gas fluctuation. Plants that use a water jacket are slightly more efficient as they are less likely to get stuck in the scum layer (The GEF Small Grants Programme (SGP), n.d.).

These two examples can just give a hint, how energy efficiency solutions can be incorporated into a production set up. More examples can be found in the recommended reading material as well as on the website energypedia.

SUMMARY

- Energy audits are particularly significant, when farms or companies with similar processes are compared.

- Reusing energy within a system, e.g. heat recovery systems, often leads to major improvements in efficiency.
UNIT B3.4 ENVIRONMENTAL LIFE CYCLE ASSESSMENT AND SUSTAINABILITY

Transforming a project to become more energy efficient is already a big achievement. However, as we have seen on the first example of this reader, energy efficiency goes beyond the farm gate. As energy is used throughout the whole value chain of a product, it is important to assess not only the process within the farm but also think about the resources and materials required for production and its impacts on the environment. Everyone producing or consuming a product should ask oneself, whether the product is sustainably produced. But what does sustainability mean and how can we achieve it?

WHAT IS SUSTAINABILITY/ SUSTAINABLE DEVELOPMENT?

The most common definition of sustainable development was established by the World Commission on Environment and Development of the United Nations in 1987. It states:

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

In more practical terms, we use the idea that overall sustainability has three pillars: Environment, Economy and Society. If one of the three pillars is not considered adequately, the whole system’s sustainability is affected. Environmental sustainability is the ability of the environment to support a defined level of environmental quality and natural resource extraction rates indefinitely. Social sustainability is the ability of a social system, such as a country, family, or organization, to function at a defined level of social well-being indefinitely. War, poverty, inequality, injustice, and low education rates, etc. are symptoms that a system is socially less sustainable. The last pillar is economic sustainability which is the ability of an economy to support a defined level of production indefinitely.
To determine if we are working in a sustainable manner, different tools may be used. One scientific tool is called life cycle sustainability assessment (LCSA). It is a tool to systematically analyze impacts of products, processes or services along the entire life cycle. Formerly LCAs were mainly applied to quantify environmental impacts. Nowadays, there are approaches to quantify even the economic and the social impacts. These rather new approaches are called life cycle costing and social life cycle assessment.

The United Nation Environment Programme (UNEP) defines LCSA as the evaluation of all environmental, social and economic negative impacts and benefits in decision-making processes to produce in a sustainable manner throughout the life cycle. Performing such an assessment for a product gives the chance to not only structure all information about a product in coherent way, but will show parts within a value chain in order to avoid or reduce negative impacts on the environment. In general, the LCAs are used to support decision making. On one hand it supports consumers choosing the more sustainable product and on the other hand supports producers to better plan their production. The (environmental) life cycle assessment (LCA) measures negative impacts on nature, the life cycle costing addresses the economic sustainability and the social life cycle assessment assesses the impact on societies.

The Environmental LCA

Nowadays, the Environmental LCA is the most commonly performed assessment tool. ISO (International Standardization Organization) has developed two standards: ISO 14040 describes the framework for LCA and ISO 14044 describes the procedure to carry out the LCA. ISO consists of four phases to perform the LCA:

1. **Goal and Scope Definition**
   The first phase of a LCA specifies the objective(s) and the framework of the assessment. This includes, for instance, definition of the system boundaries, of the system's functional unit, and of requirements in terms of data quality.

2. **Life Cycle Inventory (LCI)**
   The LCI step includes data collection for all required input and output materials (resources, emissions), as well as energy flows. All material and energy flows are recorded and compiled in the inventory.
3. **Life Cycle Impact Assessment (LCIA)**
   The LCIA refers to the calculation of potential environmental impacts, human health impacts and effects on resource availability. Impacts are calculated based on the inventory results and specific characterization models for each substance in the inventory.

4. **Interpretation**
   The calculated LCI and LCIA results are interpreted with respect to the goal of the LCA study and recommendations for decision-making are given.

**Life Cycle Costing**

Life cycle costing (LCC) is the oldest of the three life cycle techniques. Developed originally from a strict cost accounting perspective, in recent years LCC has gained its importance.

LCC is essentially an aggregation of all costs that are directly related to a product or services over its entire life cycle – from resource extraction over the supply chain to use and disposal. It also takes into account external relevant costs and benefits anticipated. The four phases are similar to environmental LCA are:

1. Definition of Goal,
2. Scope and Functional Unit;
3. Inventory Costs,
4. Aggregate Costs (by categories and interpretation of results)

**Social Life Cycle Assessment**

A social life cycle assessment (SLCA) is described as ‘a social impact (and potential impact) assessment technique that aims to assess the social and socio-economic aspects of products and their potential positive and negative impacts along their life cycle.

Different than the environmental LCA, the SLCA focuses on the people involved with producing and consuming a product. It assesses not only working hours per product produced, but also assess if the impact of a products life cycle influences human rights, working conditions, health and safety, and socio-economic repercussions.

**MORE TO LEARN**

Link: [Guideline for Social Life Cycle Assessment](#)
Compared to environmental LCA and LCC, SLCA is generally more difficult to execute in a standardized way. Due to the fact that social impacts are often subjective and far reaching, finding a quantitative measure is difficult. However, a well performed SLCA can reveal major shortcomings and negative impacts LCA and LCC cannot capture.
SUMMARY & CHAPTER WRAP-UP

• Energy efficiency has the potential to reduce the usage of resources, energy costs and environmental impacts often with simple methods or small changes.

• In some cases, energy efficiency is achieved by increasing the output while maintaining the input resource. However, note that a small change in used input resources (e.g., electrify) can result in much larger resource conservations as the effect multiplies at the beginning of the value chain (e.g., amount of coal not to be excavated).

• Energy audit helps to systematically find energy losses and potentials for energy savings and can therefore lead to quick return of the costs for the analysis.

• Not only the processes located on the farm or in the factory need to be sustainable but also the whole product chain, from resource to disposal or recycling.

• Assessing the life cycle of a product informs about its environmental, economic and social impacts and provides the bases for fact based decision making.
RECOMMENDED READING

Unit B3.1
Fereidoon P. Sioshansi 2013: Energy Efficiency: Towards the End of Demand Growth

Rebound-Effect:

Energy Efficiency – Global Dimension:

Energy Auditing:
GIZ provides a comprehensive info pool on role & tasks of energy auditors and energy managers on energypedia: http://energyefficiency.energypedia.info/wiki/Energiemanager_und_Energieauditoren_als_Instrument_zur_Erh%C3%B6hung_der_Energieeffizienz

Unit B3.2

Unit B3.3
REFERENCES


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PART C OVERVIEW

Chapter C1: Policies and Regulations for the Energy-Agriculture Nexus

Unit C1.1: Policies and Politics of Renewable Energy

Unit C1.2: Circular Economy and Scarcity of Resources

Unit C1.3: Regulation of Energy Use

Unit C1.4: Economic and Social Impacts of the Energy Production and Use

Unit C1.5: Markets for Projects at the Interface of Agriculture and Energy

Unit C1.6: Financing for Renewable Energy and Energy Efficiency Solutions in the Agricultural Sector

Chapter C2: Energy and Agriculture on the Micro Level

Unit C2.1: Scale of Agri-Food Enterprises

Unit C2.2: Techno-Economic Analysis of Energy Projects in Agricultural Value Chains

Chapter C3: Business Models for Projects in the Energy-Agriculture Nexus

Unit C3.1: Introduction to Business Models

Unit C3.2: Energy Projects in the Agricultural Sector
INTRODUCTION

Chapter C1 constitutes the first of the MOOC chapters on the economics of the Energy-Agriculture Nexus. Focusing on regulations and policies the chapter starts by presenting relevant policy tools and regulations. In the following the concept of circular economy is introduced as a mode of economic organization to minimize resource use and promote adoption of cleaner technologies in agricultural value chains. Chapter C also touches upon regulation of energy use and transitions to cleaner, renewable energies, as well as upon socio-economic impacts of energy production and use. The chapter closes with a unit on markets and financing needs and opportunities for projects at the interface of energy and agriculture.

Global demands for both food and energy are increasing rapidly due to population growth and rising incomes (see also Chapter 1). On the other hand, however, land degradation, climatic changes, and decreasing growth rates in agricultural productivity are limiting the expansion of food production (von Braun, 2007). Moreover, mitigating global warming and climate change requires reducing carbon emissions from using fossil fuels and from agricultural production, primarily through a transition to cleaner renewable energy sources, and resource conserving and more efficient agricultural practices (Edenhofer et al. 2011, Branca et al. 2011).

In this context, the Energy-Agriculture Nexus is a key platform for sustainable development. Access to clean, reliable and affordable energy for all is not only a crucial Sustainable Development Goal (SDG) (UN Assembly General 2015), but is also an important entry point for achieving several other SDGs, such as eradicating poverty and hunger, mitigating climate change, achieving gender equality and promoting healthy lives. Today, however, over 1.2 billion people still lack access to electricity and 2.7 billion people rely on traditional fuels, namely, firewood, crop residues and animal dung for cooking (IEA 2015). This often leads to women’s drudgery, lower school performance among children, health hazards from indoor air pollution, deforestation, soil erosion, loss of biodiversity and negative impacts on ecology and food security (Rehfues et al. 2005, Rasul 2014, Mirzabaev et al. 2015). To illustrate, women and children in the rural areas of many developing countries are spending an increasing share of their time for collecting firewood, instead of spending this time on other income-generating activities, or in the case of children, for studying. The indoor smoke from the use of traditional fuels is...
estimated to claim up to 4 million lives annually through lung diseases and cancer, again mostly among women – since they are responsible for cooking in most households (Lim and Seow 2012, video).

Therefore, there is a need for a massive deployment of renewable clean energy sources in rural areas and agricultural value chains. Energy is directly used in agricultural production such as for irrigation, crop cultivation in greenhouses, ground water pumping, mechanized agriculture, postharvest processing and transportation (Stout 2012). In fact, the energy footprint of global food production value chains is substantial, accounting for about 30% of total global energy use (FAO 2011), with significant impacts on ecosystems (Khan and Hanjra 2009). At the same time, crops and agricultural residues are also used for energy production. Energy and food production activities often compete for scarce land, water, labor and capital resources that may, consequently, lead to fuel-food tradeoffs. Fortunately, the nexus between energy and agriculture is not only that of tradeoffs, there are also AMPLE OPPORTUNITIES FOR SYNERGIES. For example, if smallholder farming households have access to cleaner energies for cooking, they could use animal dung for fertilizing fields, rather than as fuel, and obtain higher crop yields. Another example is if farmers have access to clean cooling technologies for their produce (e.g. milk, fruits), using BIOMASS or SOLAR PANELS, post-harvest losses could be decreased, improving product quality and farmer incomes. Exploiting such opportunities in the Energy-Agriculture Nexus can, thus, allow for raising agricultural productivity, incomes, and hence, enhance food security. Moreover, the use of renewable and clean energy sources will help in decarbonizing the global energy mix, including in agriculture, thus, contributing to climate change mitigation. Last but not least, better access to energy can also stimulate the expansion of PRODUCTIVE USES of energy for rural development (Cabral et al. 2005, GIZ 2013, video), through expanding agricultural and non-farm income generating activities by helping to create new small and medium-sized businesses along the agricultural value chains and also through re-location of manufacturing industries into rural areas with more favorable access to land and labor resources, thus energizing a broad rural development (video).

Given these opportunities, there is a growing commitment at the global and national levels to increasing the share of renewable energies in the overall energy use, as exemplified by MISSION INNOVATION and BREAKTHROUGH ENERGY COALITION initiatives during the recent Conference of Parties of the UN Framework Convention on Climate
Change in Paris. However, in addition to such initiatives, enabling institutional, regulatory and policy frameworks are also needed to facilitate renewable energy innovations and their wide-spread adoption, as well as for optimizing the energy-agriculture nexus, through minimizing potential tradeoffs and promoting synergies. The next section elaborates on such regulatory and policy issues.

C1 RECAP

- The Energy-Agriculture Nexus can serve as a key platform for sustainable development.

- A wider deployment of renewable energies in agricultural value chains and rural areas will help in improving agricultural productivity, improving food security, eradicating poverty and hunger and promoting healthy lives, especially benefitting women and children.

- Renewable energies in rural areas serve not only for consumptive uses, but also for creating new business opportunities.

- To capitalize on these opportunities, enabling regulations and policies are needed.
UNIT C1.1 POLICIES AND POLITICS OF RENEWABLE ENERGY

Renewable energy sources, as we have seen above, have a considerable potential for improving the sustainability and incomes along the agricultural value chains. However, this potential is not always utilized due to a lack of sufficient political will to challenge fossil-fuel based technologies (Anthoff and Hahn 2010, Lehmann et al. 2012, Sims et al. 2015). Political economy plays a key role in the development of the renewable energy sector. Enabling policies and regulations are often essential for promoting renewable energy technologies, especially during their early stages, when they lack large commercial scales (Sims et al. 2015). For example, the success of bioenergy in a major producing country such as Brazil is linked to the policies promoting biofuel production (video). However, there are many politically sensitive issues in energy policies and regulation regarding, for example, ensuring food security, the premise of job creation, reducing the dependence on fossil fuels, climate change mitigation, preserving the ecological integrity and concerns over large scale land acquisitions in developing countries, and many more. To illustrate, one of the most controversial topics in the Energy-Agriculture Nexus is the role of food crops for producing biofuels. The increase in food prices due to competition between food and biofuels for agricultural crops has significant impacts (von Braun et al. 2008, Ewing and Msangi 2009). The poor are affected especially negatively because they spend a larger share of their income on food (von Braun et al. 2008). For example, Bryngelsson and Lindgren (2013) indicate that a large-scale introduction of biofuels may substantially increase maize prices.

Biofuel expansion could also increase the number of malnourished children by 9.6 million in Africa (Rosegrant et al. 2008). In contrast, emerging technologies, such as ethanol based on cellulosic matter, allow biofuel generation from non-food biomass, but their commercial viability needs to be achieved (IEA 2013, Slade et al. 2009), through supportive regulatory and policy frameworks. This section focuses on such policies and regulations used to support the development and deployment of renewable energy technologies.

In this regard, we can distinguish two ways through which regulations could be viewed (Minogue 2013). The legalistic approach to regulations considers them to consist of laws, rules and decrees by all levels of government, and by non-governmental bodies which are vested with
regulatory power (Minogue 2013). The major objectives of regulation, then, ideally, target achieving efficiency in energy provision, fair pricing, equality of access and environmental sustainability. On the other hand, the economics-based definition advances that the role of regulation is to create conditions for efficient functioning of markets (Minogue 2013). Efficient markets, however, may not necessarily satisfy social equity considerations or take into account environmental concerns as many ecosystem services do not have market prices, hence, are not incorporated into markets. Both approaches have their strengths and weaknesses. There are often risks associated with government failures while trying to solve complex resource allocation problems in renewable energy, which calls for the use of markets and setting clear incentives and standards (Purkus et al. 2012, video). At the same time, government action is needed to overcome market failures. Accordingly, implementing the innovative renewable energy policies requires a proactive government action, societal support and involvement of local governments and communities (Beltramello et al. 2013).

As a result, the renewable energy sector involves a host of policy tools and regulations (Peters and Thielmann 2008, Wesseler et al. 2010, White et al. 2013, Sims et al. 2015), such as:

**Renewable Energy Mandates**: legal requirements to produce a certain share of energy from renewable sources. For example, presently, several countries impose renewable energy mandates on electricity generation on utilities. Similarly, another example, Mexico City mandated all new and renovated swimming pools, as well as large commercial buildings to cover 30% of their energy needs for water heating from solar energy (Cabre et al. 2015). Renewable energy mandates are being applied by an increasing number of countries. According to REN21 (2015), 98 countries and sub-national units had renewable energy mandates by the end of 2014, which represents a nine-fold increase compared to 2004 (REN21, 2015).

**Renewable Energy Targets**: policy commitments to generate a determined share of total energy using renewable sources. For example, Germany targets to generate 35% of its electricity from renewable energy sources by 2020, reaching 80% by 2050 (Droste-Franke 2012). Successful implementation of these targets requires the establishment of effective systems of monitoring and reinforcement (GIZ 2012).

**Feed-in-tariffs**: a policy tool designed to promote renewable energy
generation by guaranteeing the purchase of the generated renewable energy with a long-term contract and at cost-based purchase prices. Under this scheme, electricity generated using solar panels or other types of RE based electricity can receive higher prices than, for example, from the fossil fuel-based electricity generator. Feed-in-tariffs often have digressive element, when guaranteed prices gradually decline over time in order to stimulate cost-reducing innovations in renewable energies sector (video). Feed-in-tariffs can also be applied to photovoltaic irrigation schemes, whereby farmers could sell the excess of the electricity generated to the central grid. Feed-in-tariffs are one of the most widely applied tools for promoting renewable energies. In 2014, they were applied by 108 countries and sub-national jurisdictions (REN21, 2015).

**Net Metering and Flexible Grid Access**: a mechanism that enables small-scale renewable energy producers, for example, households with rooftop solar energy generation, to sell the amount of electricity beyond their own needs to the central grid.

**Transfers and Subsidies**: direct or indirect monetary support to producers or other actors involved in renewable energy production. For example, China provides subsidies for solar energy technologies benefitting poor communities.

**Fiscal Incentives**: reduction of taxes by various mechanisms, such as tax credits, deductions and exemptions, in order to stimulate renewable energy. For instance, under Brazil’s Social Fuel Seal initiative, biodiesel producers are given tax credits (BEFSCI 2012).

**Grants**: non-repayable monetary allocations for specific projects. They are often used to promote renewable energy production, foster research and development and encourage deployment of renewable technologies, for example, the US program of Sustainable Agriculture Research and Education (SARE) program.

**Soft loans**: credits with below market interests charges. This instrument is used by several governments and international donor organizations to promote renewable energies. For example, the International Renewable Energy Agency (IRENA) and the Abu Dhabi Fund for Development (ADFD) have
recently announced USD 46 million worth of soft loans for renewable energy projects in several developing countries.

There are different classifications of these tools into separate categories (Sims et al. 2015: page 83, Azuela and Barroso 2012: page 37). Here for convenience, we can separate them into regulation-based: renewable energy mandates and targets, feed-in-tariffs, net metering and flexible grid access; and incentive-based: tax reductions, grants, subsidies and transfers, and soft loans. In addition to these policy instruments that directly support renewable energy generation, governments can also seek to make renewable energy more competitive indirectly by instituting carbon taxes and cap-and-trade mechanisms, stricter environmental standards (Azuela and Barroso 2012), thereby discouraging the energy generation from carbon-emitting fossil fuels, and making renewable energy generation more competitive.

Finally, besides such national policies and regulations, there are also numerous national and international initiatives for promoting renewable energies\(^1\), which generate new knowledge and provide technical advice, represent the interests of renewable energy producers in political and other fora, mobilize funds for the deployment of renewable energy technologies and carry out other functions supportive to renewable energies.

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<th>POLICY TOOLS</th>
<th>STRENGTHS</th>
<th>WEAKNESSES</th>
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<tr>
<td>Renewable Energy Mandates and Targets</td>
<td>• Market-friendly • Promotes especially more mature technologies</td>
<td>• Requires high administrative and monitoring capacity • Less efficient in case of weak enforcement and low penalties</td>
</tr>
<tr>
<td>Feed-in-tariffs</td>
<td>• to promote different renewable energy technologies, including those which are less competitive due to early stage in their development • Provides legal security when well applied • Predictable revenue streams</td>
<td>• Can be very costly • Appropriate design may require continued adjustments through complex administrative procedures</td>
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\(^1\) To name a few, the United Nations declared 2014-2024 as the Decade of Sustainable Energy for All. The International Renewable Energy Agency (IRENA) is an intergovernmental organization to promote adoption and sustainable use of renewable energy globally. The World Wind Energy Association (WWEA) as an NGO representing the wind power sector worldwide. Renewable Energy Policy Network for the 21st Century (REN21) acts as a global renewable energy multi-stakeholder policy network that provides international leadership for the rapid transition to renewable energy.
### Table 1: Comparison of Various Policy Tools for Promoting Renewable Energies

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<th>POLICY TOOLS</th>
<th>STRENGTHS</th>
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| Net Metering and Flexible Grid Access | • Generally less costly  
• Technically easy                                  | • Not applicable for large scales                                                                                                           |
| Transfers and Subsidies             | • Allows for targeted development of renewable energy technologies         | • Once entrenched, could be very difficult to remove even when there is no longer need for them                                                |
| Fiscal Incentives                   | • Provides incentives especially for new renewable energy projects, by reducing investment costs | • Can be a burden to public budget  
• Lower certainty due to changing political context                                                                                           |
| Grants                              | • Allows for targeted investments to specific renewable energy applications, especially when they are not sufficiently attractive to private markets  
• Particularly applicable for research and development into renewable energy innovations  
• Facilitates renewable energy deployment especially in riskier environments | • Long-term sustainability after grant is over may often be problematic Payback and rate of return may be uncertain |
| Soft Loans                          | • Many agri-/food chains and their sites for processing agro-products or food/beverages | • Often cover capital investment costs only                                                                                                  |

When it comes to the choice of any particular tool in a specific country, there are no fit-all approaches. The choice whether or not to use any of these tools depends on the context of each country (Azuela and Barroso 2012). Moreover, each stage of the development of renewable energies in each country may require different tools, so customized sequencing of these policy tools may be required (ibid.). Each of these policy tools has its strengths and weaknesses (Table 1), which can shape their choice in a specific country context.

Among the policy instruments listed above, transfers and subsidies, fiscal incentives, grants, and soft loans are presently more widely applied to promoting the renewable energies in the agricultural sector in numerous countries. For example, China is a prime example of a country strongly promoting biogas production through various national plans and initiatives, such as the National Rural Biogas Construction Plan (2006-2010), Development Plan for the Agricultural Bioenergy Industry (2007-2015) which involve
various subsidies and fiscal incentives (Qui 2016). The United States provides producer grants for farmers wishing to establish solar energy production in their farms (Xiarchos and Vick 2011). Ethiopia instituted the Rural Electrification Fund to promote off-grid renewable energy adoptions in rural areas, and since 2010, also provides exemptions of import duties to renewable energy equipment. In many developing countries, international donor grants serve as important sources for promoting renewable energies in the rural areas and agricultural value chains (GIZ 2012).

### CI.1 RECAP

- Renewable energy regulations and policies are often outcomes of complex political and social bargaining.

- Policy tools promoting renewable energies are numerous and varied, and include such options as renewable energy mandates and targets, feed-in-tariffs, net metering and flexible grid access, transfers and subsidies, fiscal incentives, grants and soft loans.

- The choice of any policy instrument depends on the context of each country, as each of these tools has its own advantages and disadvantages.
UNIT C1.2 CIRCULAR ECONOMY AND SCARCITY OF RESOURCES

Circular economy is a mode of economic organization which seeks to minimize resource use and promote adoption of cleaner technologies (Andersen 2007). It is opposed to the traditional so-called linear economy concept built around the “make-use-dispose” model.

Under linear economy, many negative externalities of resource extraction, production, consumption and disposing are not included in their prices. Externalities are the costs or benefits that affect the third parties who did not choose to incur these costs or benefits. The concept of externalities is a crucial one in environmental economics, and in environmental sustainability, in general (Video). The true social cost – which includes all the externalities - of the linear economy is very high, making it unsustainable. For example, in agriculture, unsustainable use of soils and land resources could lead to their degradation and erosion. By human life times, fertile soils are non-renewable resource as it takes hundreds of years to form one centimeter of fertile topsoil. As a result, landusers themselves are affected negatively, but not only. Degraded soils provide not only less food and feed, but also significantly less of other ecosystem services, such as carbon sequestration, water purification, nutrient cycling, and many others. This loss of ecosystem services affects negatively not only direct landusers but the whole society. Eroded soils could be flushed to rivers, increasing their siltation, and filling up downstream reservoirs and reducing their hydro-energy production. The producers of hydro-energy may have little to do with land degradation upstream, but are still affected negatively. Externalities can be both negative and positive. Land degradation, as we have seen above, poses a lot of negative externalities.

On the other hand, deployment of renewable energy technologies, such as, for instance, solar panels for decentralized off-grid electricity, could create positive externalities by enabling rural households not only to use it for lighting, heating, cooking, but also by providing the whole society with positive externalities of better environment and health (less deforestation, less indoor air pollution, operating fridges for vaccines), public safety (street lighting), better education (children able to study after dark), and many more. Biogas production from livestock manure in agriculture could provide households with cleaner energy for domestic and productive uses. At the same time, by substituting fuelwood, this may also reduce deforestation,
creating positive environmental externalities for the whole society. One of the underlying principles of circular economy is to mitigate negative externalities and maximize positive ones (Figure 1).

**Linear economy**

- Significant externalities both within the continuum and after disposal
- Not sustainable due to limits to resources

**Circular economy**

- Minimize negative externalities
- Create conditions for re-use in different forms
- Minimize new extraction of non-renewable natural resources

Circular economy calls for minimizing the new resource extraction and instead maximizing the re-use and recycling of already extracted resources. In this mode of economic organization, there is no waste, as so-called “waste” from one production process or consumption, becomes an input to another production process. Circular economy requires that all energy to be produced from renewable or otherwise sustainable sources.

Major conceptual directions in the circular economic thinking are given below.

**Cradle-to-Cradle Approach:** opposes to the so-called cradle-to-grave approach when natural resources are extracted, used, and then disposed of. Cradle-to-cradle approach seeks to maximize the re-use of each natural resource as much as possible (Braungart et al. 2007), even though the achievement of zero waste objective remains for now elusive (Chapter 4).
**Biomimicry**: seeks to organize the production processes in ways that emulate nature. For example, studying the structure of leaves for creating more efficient solar panels is an example of biomimicry (Benyus 1997).

**Industrial Ecology**: a model of industrial organization which seeks to achieve closed loop production processes when wastes become inputs for new processes.

**Blue Economy**: cascading use of resources through value chains, when the waste of one production, becomes the input to the other.

As we can see, the differences between the specific schools of thought within circular economy concept are small, as all of them emphasize minimizing resources use and waste, and call for no-waste production systems. In this regard, water-energy-food security nexus thinking partially overlaps with circular economy concept as it also seeks to minimize the negative externalities between the energy, water and food sectors, and promote synergies between them.

Agricultural production presents ample opportunities for a rapid transition to circular economy. Such approaches as conservation agriculture, integrated pest management, organic farming, use of solar energy for irrigation water pumping, integrated crop-livestock management, and re-use of organic waste for producing compost can help in reducing the environmental impact of agricultural production and food systems, in general. Deployment of renewable energy sources to replace fossil-fuel energies in the post-harvest management (e.g. solar energy for the refrigeration of dairy products), transportation (biofuels) and along other components of food value chains can provide with promising opportunities for their de-carbonization.

### C1.2 Recap

- Circular economy is a mode of economic organization which seeks to minimize resource use and promote adoption of cleaner technologies.

- Circular economy includes such approaches as cradle-to-cradle, biomimicry, industrial ecology and blue economy.

- Agricultural value chains offer significant opportunities for applying circular economy approaches.
UNIT C1.3 REGULATION OF ENERGY USE

Major objectives of regulation of energy use are increasing energy use efficiency and promotion of the transition to cleaner energy sources. The policies promoting energy efficiency are highly diverse and numerous. The regulations targeted at increasing the energy efficiency of the residential sector represent a major section of these measures. The policy tools used include eco-labels which certify environmental-friendliness of various consumer and industrial products, elaboration of more energy-efficient building codes, various incentives for retrofitting existing buildings for higher energy efficiency, including in farm buildings by heat insulation, more efficient lighting, heating, cooling and ventilation systems, public campaigns at promoting positive behavioral change for reducing the waste of energy. There are vast opportunities for improving energy efficiency of agriculture as well, considering that agricultural value chains are major consumers of energy. For example, even beyond more energy efficient farm buildings, there is a significant scope for reducing the energy consumption in crop production by conservation agricultural measures such as zero tillage, which reduce the amount of fuel consumed, and precision agriculture, which helps in applying the exact amounts of fertilizers needed by each patch of cropped land. Furthermore, there are opportunities for agriculture-energy synergies in the livestock production sector related to biogas production, as also indicated earlier, with the remaining slurry to be used as fertilizer for crop production (VIDEO).

Macro-economic and sectoral policies promoting the transition to cleaner energies include regulations limiting polluting sources of energy such as coal, setting limits to carbon emissions, instituting CAP AND TRADE, MECHANISMS, imposing environmental taxes. On the other hand, the transition to cleaner energies is not only a global or national level process. The stakes from using cleaner energies are not less, but arguably, they are even more vital at the household and community level. Household transition to cleaner and more efficient energy sources can follow two approaches: energy ladder or energy stacking. The energy ladder, as the name implies, conceptualizes energy choice as a linear step by step transition process: with increase in income, energy users abandon less efficient and cheap traditional biomass and shift to intermediate energy sources (charcoal and coal); and then to modern, safer and more efficient energy sources, such as electricity (Hosier and Dowd 1987). In contrast, the energy stacking states that there is no unique and monotonic energy transition process, but energy consumers use multiple energy sources and their choice is dictated by multitude of socio-
economic and cultural preferences (Guta 2014, Heltberg 2004).

Recently, the “energy leapfrogging” has gained increasing policy attention. It refers to a process of energy transition that involves a bypass of the conventional energy and a leap directly to the more efficient, safe and environmentally friendly energy technologies (Murphy 2001). Accordingly, developing countries have the opportunity to borrow the advanced energy technologies from industrialized countries to make a “leapfrog” from less sophisticated energy technologies to modern, cleaner energy alternatives without the need to go through the more pollutant energy sources such as coal and oil (Marcotullio and Schulz 2007). In practical terms, however, a rapid and fast energy transition from traditional biomass and coal to electricity may be difficult to take place (Zhang 2014, Guta 2014). The most successful “leapfrogging” has taken place recently in the mobile phone technology as the millions of people in developing countries have bypassed the landline technology and skipped directly to the use of mobile phones. Energy technology leapfrogging, however, appears to be much more challenging (Murphy 2001). Energy leapfrogging needs a simultaneous “institutional leapfrogging” (Han et al. 2008). Energy leapfrogging is often limited by lack of technological capabilities (Murphy 2001, Gallagher 2006). Therefore, in developing countries energy transition has been constrained by interplay of various socio-economic factors, risk-averse behavior, and lack of institutional and technical capabilities (Guta 2014, Mirzabaev et al. 2014, Murphy 2001).

Thus, energy transition may often be an ‘incremental’ or ‘gradual process’ that requires technical capacity development, awareness raising and improvements in purchasing power (Murphy 2001).

Transition to renewable energies in agriculture and their varied applications in agricultural value chains can provide with substantial benefits, as indicated in the introductory section. Presently, many rural communities in developing countries do not have access to centralized grids. In this context, decentralized off-grid or community-based mini-grid access to electricity using renewable sources could help in improving rural welfare and increasing the productivity of agricultural production. There are already promising uses of solar energy at various stages of agricultural value chains (Chapter 2), including for irrigation, water pumping, water desalination, drying crops and forages, for heating greenhouses, for refrigeration in post-harvest management of produce and for other post-harvest value additions.

Case: Germany

Germany serves as an example for a gradual policy-driven energy transition – Energiewende – initiated in 2010 (Stegen and Seel 2013). One of the targets is to increase the share of renewables in the energy production to 80% by 2050 (BMU 2012). In order to trigger investments in renewable energies, above the market minimum prices are mandated for renewable energy sources. The minimum prices (per kWh) differ by source of energy. In the context of the globally inter-linked energy markets the long term cost-effectiveness to compete internationally needs to be achieved and will be a key factor for the long-term success of the project. The experiences made so far with the energy transition provide lessons for policies that target the expansion of renewable energies. For instance, charging final consumers for the higher energy prices, as done in Germany, is likely to be unfeasible in countries with lower per capita income. Furthermore, the extension of the country-wide energy grid in Germany is not only cost-intensive, but also faces opposition by dwellers living close to the new energy lines. This emphasizes the scope for decentralized energy grids where energy can be produced on a much smaller scale. Net economic growth and positive employment effects of the energy transition, even in the short-term, should encourage the take-up of policies that foster investments in biomass (Blazejczak et al. 2011, video).
C1.4 Recap

- Regulation of energy use pursues two objectives: increasing energy use efficiency and transition to cleaner energy technologies.

- Energy use efficiency measures include eco-labels, energy-efficient building codes, various incentives for retro-fitting existing buildings for higher energy efficiency, public campaigns for reducing energy waste.

- Energy transition can follow energy ladder, energy stacking or energy leapfrogging approaches.

- Rapid transitions to cleaner renewable energies may require a similar rapid progress in the institutional frameworks governing energy production and use.

Unit C1.5 Economic and Social Impacts of Energy Production and Use

Access to energy is a key component of sustainable development (BMZ 2014). Energy is a crucial input to all economic activities. There is a high correlation between energy use and economic growth, even though there are many countries now which have successfully started decoupling economic growth from energy use through higher energy use efficiency (Stern and Cleveland 2004). Lack of access to modern energy technologies, especially electricity, is limiting the expansion of income-generating activities along the agricultural value chains in many developing countries. Access to clean, reliable and affordable energy, especially in the rural areas of the developing countries would help reduce poverty, enhance food security, lead to healthier lives, and promote gender equity (Mirzabaev et al 2014).

Presently, more than 1.2 billion people still lack access to electricity and 2.7 billion people rely on traditional fuels, namely, firewood, crop residues and animal dung, for their energy needs (IEA 2015). Modern renewable energy development can reduce poverty (Kartha and Leach 2001), for example, by creating employment opportunities (IRENA 2015, 2016, Jacob et al. 2015). However, this job creation potential of the renewable energy sector is currently underutilized.
The modern renewable energy sector employed only about 7.7 million people worldwide in 2015, with high concentrations in a few countries, such as Brazil, China, Germany, India and USA (IRENA 2015). Even this figure is expected to be male-dominated, as employment rate among women in the sector is low (ibid.). On the other hand, employment effect of renewable energies should not be viewed only within the renewable energy sector itself, but also across the agricultural and manufacturing value chains where they are used. Access to renewable energy sources in agriculture could create new opportunities for higher value agricultural businesses in rural communities, as demonstrated by the projects under the Powering Agriculture Initiative. Such innovative uses of renewable energies would allow for increasing the incomes of rural households, stimulate entrepreneurial dynamics through micro- to small-sized rural business creation. Furthermore, renewable energy projects could also allow for increasing agricultural productivity (biogas projects making manure available for fertilizing fields, PV lighting extending daily hours for field work, renewable energy-based mechanization technologies by improving agricultural labor productivity).

Besides these economic dimensions, the deployment of renewable energies has considerable social and gender effects. The use of traditional biomass for domestic cooking through inefficient cooking stoves without proper ventilation can have detrimental consequences on human health through indoor air pollution. Lung diseases, arising from indoor air pollution due to incomplete combustion of biomass while cooking or heating, account by some estimates for up to 4 million premature deaths annually worldwide, affecting mostly women (Lim and Seow 2012, Rehfuess et al. 2006). Improved access to clean bioenergy sources, such as using biogas for cooking, adopting more efficient cooking stoves, could, thus, have substantial health benefits, which, in turn, positively affect labor productivity and incomes (Duflo et al 2008, video). For example, better access to clean energy could facilitate boiling of water before consuming, thus, lowering the risks of waterborne diseases (Rehfuess et al. 2006). Improvements in health through reduced indoor air pollution may also allow for reducing medical expenses for poor households, improve school and work attendance (Duflo et al. 2008).

Access to electricity also facilitates a broad rural development. Many poor communities do not have access to centralized grids, and are especially likely to benefit from local small-scale renewable energy projects, such as local mini-hydro, solar and wind energy for
mini-grids (Gerber 2008, Chakrabarty et al. 2013). The access to electricity through decentralized mini-grids could facilitate a wider fuel switching to modern renewable energies (Heltberg 2004). In Assam, India, access to electricity was found to increase literacy rates from 63.3% to 74.4% (Kanagawa and Nakata 2007); similarly, in Brazil, rural electrification was found to reduce poverty by 8% and the Gini coefficient of inequality from 0.39 to 0.22 (Pereira et al. 2008).

C1.5 RECAP

• Access to clean, reliable and affordable energy, especially in the rural areas of the developing countries would help reduce poverty, enhance food security, lead to healthier lives, and promote gender equity.

• Generating employment, allowing for agricultural and rural businesses with higher value added, raising agricultural productivity are the major channels through which deployment of renewable energies in rural areas, will achieve these objectives.

• Deployment of modern renewable energies is also likely to have significant gender-dividends, in terms of improving women’s health and expanding their employment opportunities in income generating activities.
UNIT C1.6 MARKETS FOR PROJECTS AT THE INTERFACE OF AGRICULTURE AND ENERGY

The Energy-Agriculture Nexus provides substantial business development opportunities along the agricultural value chains. **Value chains** are modes of organization of economic activities that “are required to bring a product or service from conception, through the different phases of production (involving a combination of physical transformation and the input of various producer services), delivery to final consumers, and final disposal after use” (Kaplinsky and Morris 2001). For example, dairy value chain may start with livestock farming, whose product – milk, would then serve as input to milk processors, who produce a variety of dairy products (cheese, yoghurts, etc.), which then go to retailers, and from them to consumers. However, Virchow et al. (2014) argue that this conventional view of value chain is no longer sufficient. Due to existence of synergistic links among numerous related value chains in agriculture, they need to be viewed as comprehensive value webs. Any changes in one of the chains will have repercussions all across the value web. Hence, the policy actions need to seek to minimize the inefficiencies in the entire value web (ibid.). For example, if we take maize value web, maize produced in the farm could be fed to various different value chains, it can be used either in food production, or feed production, or in fuel production. Each of these represent distinct value chains, however, any price changes in any of these would affect all the rest of the value web.

Modern renewable energy solutions could help increase productivity, efficiency and incomes along the entire agricultural value chains, by providing opportunities for increasing the added value generation. There are numerous promising uses of renewable energies for increasing the value added along the various stages of agricultural value chains. At the production level, crop and livestock production are already being used for the production of energy (biofuels, biogas, cf. Chapter 3), and this is likely to grow further due to various policy incentives and technological innovations. Solar energy is being used for **irrigation water pumping**, water desalination, for heating greenhouses. At postharvest stage, there are opportunities for using renewable energies for drying crops and forages, for refrigeration of produce and for reducing food losses (REEEP 2015). There are also opportunities for wider use of **biomass for combined heat and electricity generation**, for **thermal processing of wood products**, **gasification of rice husk**.
Private businesses are expected to play an important role in all stages of this process if rapid growth in demand for clean energy technologies offers new profit opportunities (Beltramello et al. 2013). Economic viability of renewable energy applications in agriculture depends on availability of effective demand which can pay for the delivered goods and services, cost competitiveness of renewable energy with fossil fuels, enabling regulations indicated earlier, such as government subsidies, and access to other sources of capital and know-how, such as private investments or credits, or development grants, loans and technical assistance. To give an example, studies have indicated that in off-grid rural communities in developing countries, the conventional diesel electricity generation can be less cost effective compared to renewable sources (Alfaro and Miller 2014). Alfaro and Miller (2014) find that in Liberia, although small diesel units have lowest capital costs, small hydropower, small biomass projects and solar panels generate electricity at lower prices. The comparison of long-run per unit breakeven cost of electricity and households’ willingness to pay showed that households can afford biomass and small hydropower, but not electricity generation from diesel and solar panels (ibid). In such contexts, extended payment schedules, low interest rates and taxes can improve household electricity affordability (Lahimer et al. 2013).

C1.6 RECAP

- Renewable energies provide opportunities for increasing incomes by developing higher valued added agricultural value chains in rural areas.

- Various agricultural value chains often form complex inter-linkages in the form of value webs.

- Renewable energy technologies are applicable in all the stages of agricultural value chains from production, through processing and post-harvest management till commercialization.

- Economic viability of renewable energy applications in agriculture depends on various factors such as availability of effective demand, cost competitiveness with fossil fuels, enabling regulations and access to finance.
UNIT C1.7 FINANCING FOR RENEWABLE ENERGY AND ENERGY EFFICIENCY SOLUTIONS IN THE AGRICULTURAL SECTOR

To reiterate, today, over 1.2 billion people still lack access to electricity and 2.7 billion people are without clean cooking technologies (IEA 2015). In many developing countries around the world agriculture is still very much dependent on muscle energy, with very limited mechanization (Best 2014). Evidently, the financing needs to overcome these challenges are substantial. According to the estimates of the International Energy Agency (2011) 49 billion USD of investments will be needed annually to achieve universal access to modern energy services by 2030 (45 billion for universal electricity access and an additional 4.4 billion USD for clean cooking). Fischedick et al. (2010) estimate that annual global financing needs for renewable energies between 2021-2030 are about 750 billion USD if CO₂ concentration in the atmosphere to be kept below 450 ppm (parts per million). For doubling the global rate of energy efficiency, an additional 30-35 billion USD are needed in low-income countries, and 140-170 billion USD in medium-income countries (AGECC 2010).

Achieving these financing objectives presents substantial challenges. Given the scarce public resources in developing countries in addition to competing demands from other sectors (for example, education, social security or health care), the government budget may not be able to finance the energy infrastructure at necessary levels (Terrapon-Pfaff et al. 2014). Financial constraints and lack of credit beyond upfront installation cost, for costs of operation and management of the projects over time, are the key barriers of long-term sustainability of many renewable energy projects. On the other hand, small scale renewable energy projects, like those we have seen in the agricultural sector, are often discriminated against by capital markets – which prefer to work with large actors to limit operational costs and for better risk management, making the role of government and development partners indispensable.

There are numerous financial and organizational tools for funding renewable energy projects in rural areas and agricultural value chains, including soft loans, also indicated earlier, loan guarantees, and technical assistance funds, subsidies, venture capital and

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2 Corresponds to a 50% chance of keeping global warming under 2°C.
private equity, renewable energy service companies (RESCOs), and microfinance. Microfinance and RESCOs are one of the most often used approaches for financing small-scale renewable energies, especially for solar panels. RESCOs are innovative organizational forms where instead of selling the renewable energy technology, RESCOs sell its services for a monthly fee. RESCOs are especially applicable to small rural solar energy technologies, for example PV solar home systems (Liming 2009). These various sources of funding for renewable energies could be combined in innovative combinations through public-private-community partnerships (ibid.). Such funding tools as venture capital and private equity, or issuing of corporate bonds are usually more applicable for large scale renewable energy generation, with their use in funding small-scale agricultural value chains being minimal. Initiatives at improving energy use efficiency in agricultural value chains are often funded through public or international sources. For example, the Clean Development Mechanism (CDM) can be a source of funding for using agricultural by-products as an energy source (Larson et al 2011), however, the extent of funding going to agricultural energy use efficiency projects from the CDM remains relatively limited.

Summarizing, successful deployment of clean energy businesses in the agricultural sector would require a good understanding of the functioning of the related value chains and the broader value web - sound business and financial planning to ensure the economic viability of the business, its access to funding, technologies, inputs; a good knowledge of the demand characteristics for the outputs of the business, and, of course, importantly, this also involves a careful study of relevant regulations and policies.

C1.7 RECAP

- The financing needs for providing universal access to modern energies in developing countries are substantial and often exceed local funding capacities.

- There are several financing tools for funding renewable energies in the agricultural sector, such as microfinance, soft loans and loan guarantees, subsidies and grants, venture capital and private equity, and their various combinations through public-private-community partnerships.

- Government and international donors often need to play indispensable roles in promoting renewable energies in agricultural value chains as the private sources of funding tend to avoid these investment areas due to high administrative and monitoring costs.
DEFINITIONS AND KEY CONCEPTS

CIRCULAR ECONOMY is a mode of economic organization that seeks to minimize resource use and promote adoption of cleaner technologies.

DECENTRALIZED ENERGY SOLUTION (DES): a small scale and local transformation of renewable resources (wind, solar radiation, biomass, small hydropower) into electricity or thermal energy used in different activities by communities or households in different rural settings around the world.

ENERGY TRANSITION: a theoretical concept used to describe the relationship between economic growth (income) and energy utilization pattern.

EXTERNALITIES are the costs or benefits that affect the third parties who did not choose to incur these costs or benefits.

FEED-IN-TARIFFS: a policy tool designed to promote renewable energy generation by guaranteeing the purchase of the generated renewable energy with a long-term contract and at cost-based purchase prices. Feed-in-tariffs often have digressive element, when guaranteed prices gradually decline over time in order to stimulate cost-reducing innovations in renewable energies sector.

NET METERING AND FLEXIBLE GRID ACCESS: a mechanism that enables small-scale renewable energy producers, for example, households with rooftop solar energy generation, to sell the amount of electricity beyond their own needs to the central grid.

REGULATIONS: laws, rules and decrees by all levels of government, and by non-governmental bodies which are vested with regulatory power.

RESCOs: renewable energy service companies, are innovative organizational forms where instead of selling the renewable energy technology, RESCOs sell its services for a monthly fee. RESCOs are especially applicable to small rural solar energy technologies.

TRANSFERS AND SUBSIDIES: direct or indirect monetary support to producers or other actors involved in renewable energy production.
RECOMMENDED READING

Click on the hyper-links provided throughout this reader for further information & data and see below our recommended reading list!


**Jacob K, Quitzow R and Bar H (2015).** Green Jobs: Impacts of a Green Economy on Employment. GIZ, Eschborn-Bonn, Germany


REFERENCES


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CHAPTER C2
ENERGY AND AGRICULTURE
ON MICRO LEVEL

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PART C OVERVIEW

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Unit C1.3: Regulation of Energy Use

Unit C1.4: Economic and Social Impacts of the Energy Production and Use

Unit C1.5: Markets for Projects at the Interface of Agriculture and Energy

Unit C1.6: Financing for Renewable Energy and Energy Efficiency Solutions in the Agricultural Sector

Chapter C2: Energy and Agriculture on the Micro Level

Unit C2.1: Scale of Agri-Food Enterprises

Unit C2.2: Techno-Economic Analysis of Energy Projects in Agricultural Value Chains

Chapter C3: Business Models for Projects in the Energy-Agriculture Nexus

Unit C3.1: Introduction to Business Models

Unit C3.2: Energy Projects in the Agricultural Sector
INTRODUCTION

Chapter C2 describes how to analyze the costs and benefits of investing in agri-food energy technologies, highlighting the related economic aspects. Adopting an agricultural value-chain approach illustrates different investment opportunities. Investments include interventions to provide modern energy for the reduction of post-harvest losses, efficiency gains in the manufacture and management of agricultural inputs and in the introduction of renewables to displace costly and environmentally unsustainable fossil fuels. Section C2.1 introduces the different scales of agricultural enterprises, which show differences in management and potential to adopt renewable energy and energy efficiency interventions; and vary in terms of capital availability. Section C2.2 presents investment planning for renewable or energy efficient technologies in agricultural and food enterprises, providing guidelines on how to perform a cost-benefit analysis of an energy investment and identifies decision support tools that can be easily adopted by farmers and food processors.

UNIT C2 ENERGY AND AGRICULTURE ON MICRO LEVEL

Traditionally agricultural production has been depended on external energy inputs, such as manual labor, animal power and combustion of biomass to provide heat. Energy inputs are also needed for storage, processing, transport and distribution of food products. These forms of energy inputs have largely been displaced by fossil fuels, as agriculture has become more industrialized and farm production and food processing have become more intensive. Hence provision of the modern energy services is essential throughout the agri-food chain, and its associated industries have become largely dependent on fossil fuel inputs for activities such as heating, cooling, transportation, water pumping, lighting, animal comfort, mechanical power, etc. (FAO and USAID, 2015).

More so, energy is needed by agriculture indirectly for the manufacturing of agriculture inputs such as machinery, chemical fertilizers, pesticides, buildings, etc. This energy is usually accounted to other sectors (e.g. industry) but is in reality embedded in inputs needed for agricultural activities. Considering all these inputs, it was estimated that around 1/3 of total end-use energy consumed globally is for the agri-food chain (FAO, 2011).
Sustainable energy interventions in an agri-food enterprise include the introduction of renewable energy technologies or of energy efficiency measures. Energy efficiency gains in food production can be seen as an improvement in energy intensity (i.e. obtaining the same output or service by using less energy). A more energy efficient food chain would thus obtain the same result by using less energy or by reducing energy losses.

Renewable energy technology may be very relevant for rural communities still without access to modern energy services or where conventional energy is particularly expensive, for example due to poor road infrastructure and the fact that the national electricity grid is not reliable. In such remote locations, small-scale hydro, wind, and solar power systems can replace fossil fuel generators in producing electricity for the production, storage, handling and processing of food products.

Investment addressing the food-energy nexus can target different stages of the food value-chain, therefore it is appropriate to adopt a value-chain approach (Figure 1). Each step of the value-chain presents in fact different challenges to ensure the relevant energy services are provided efficiently, cost effectively and minimizing the reliance on the fossil fuel market.

This lecture refers to investments in renewable energy and energy efficiency options that can take place from the agricultural production stage to the food processing activities, leaving aside intervention in the transport and logistic sectors, in the marketing and distribution phase, and in food preparation and consumption.
Applying a value-chain approach, it becomes evident how the value of food products tend to increase as more processing occurs and more inputs (energy, water, packaging materials) are consumed. Considering milk as an example (Figure 2) producing, pasteurising and bottling fresh milk requires around one tenth of the total energy input into cheese making. The energy input decreases the water content of the final product, from around 0.6 calories per gram of fresh milk, to the 5 to 8 times higher calorie content per gram of cheese. Similarly, the energy used for milling paddy rice (to remove bran and husks) or for the post-harvest treatment of vegetables increases their value. The energy interventions considered span from solar-power irrigation systems to cooling and cold storage facilities, and from the use of residues (e.g. rice husks) for energy production to geothermal energy for processing (drying, cooling, boiling, etc.) (FAO/USAID, 2015).
C2 RECAP

- Sustainable energy interventions in an agri-food enterprise include the introduction of renewable energy technologies or of energy efficiency measures, which can result in improvement in energy intensity.

- Each step of the value chain presents different challenges to ensure that the relevant energy services are provided efficiently, cost effectively and minimizing the reliance on the fossil fuel market.

- Applying a value chain approach, it becomes evident how the value of food products tend to increase as more processing occurs and more inputs (energy, water, packaging materials) are consumed.

- The energy interventions considered span from solar-power irrigation systems to cooling and cold storage facilities, and from the use of residues for energy production to geothermal energy for food processing.
UNIT C2.1 SCALE OF AGRI-FOOD ENTERPRISE

The spectrum of agricultural enterprises is complex and diverse. These enterprises range from basic subsistence smallholder farmers growing food for their own consumption to large commercial, corporate farms supplying huge supermarket chains across the world. These systems vary according to their dependence on energy inputs and different energy sources, so they show differences in management and incorporation of renewables.

For instance, human and animal power are commonly used in small-scale operations, but are being increasingly substituted with fossil fuels in other systems. Obviously, the adoption of fossil fuels depends on their availability and prices, so it will be favored in regions where these are relatively inexpensive. At the same time, renewable energy technologies are increasingly substituting fossil fuels in several medium and large-scale agricultural production and processing activities.

Defining rigidly clear boundaries between ‘small’ farm and ‘large’ farm enterprises is not possible, but in this lecture we try to identify some features that can be used to classify agro-food enterprises. Table 1 illustrates the relationship between the different farm size and energy carriers and intensity. Obviously, there are exceptions to this categorization. For example, small enterprise tea plantations employ many pickers or small family fishing boats have relatively high fossil fuel dependence.

In order to represent the various levels and intensities of energy inputs, agri-food enterprises can be divided between industrial large-scale farming systems using modern technologies, small business and family farms using simple technologies, and small-scale subsistence farming equipped with traditional technologies (Table 1). These differences in scale impact on the ability to manage and incorporate renewable or energy efficient technologies and are therefore considered throughout the techno-economic analysis of agro value-chains/projects.

Subsistence Level:
This is the smallest system, in which households are engaged in

NOTE
ENERGY INTENSITY
In this context energy intensity is defined as the amount of energy used in food production per unit of food produced (MJ per ton of food produced).
basic forms of small-scale agricultural activities and produce food solely for their own consumption. Subsistence producers use very low energy inputs, usually deriving from human and animal power. These energy inputs are difficult to measure and not included in world energy statistics (FAO, 2011). Priority for subsistence farmers are gaining access to energy and securing an adequate livelihood. Lack of financial resources limits their ability to meet these priorities and to invest in sustainable energy solutions. Still, coordinated networks of subsistence farmers can benefit from renewable energy systems such as small-scale hydro, wind and solar powered systems.

**Small Family Units:**
Small family units are usually engaged in a variety of activities, including cultivating small gardens or rice fields, tending orchards, raising livestock and maintaining dairy herds (FAO, 2011). In most countries, small-scale farmers provide fresh food to local markets and/or to processing plants. Depending on the degree of modernization, different renewable energy technologies and energy efficiency options exist for these small enterprises, except for those that depend solely on human and animal power. For instance, small farms may utilize solar heat for crop drying, on-farm produced biogas for cooking and electricity generated from a solar photovoltaic (PV) system (FAO, 2011).

**Small Businesses:**
The differences between Small Businesses and Small Family Units are that small businesses can be family-managed but are usually privately-owned, they usually operate at a slightly larger scale and employ several staff. Having a larger capital availability, these businesses have opportunities to reduce their fossil fuel dependence by investing in on-farm renewable energy, which could also provide additional benefits for the surrounding local community.

**Large Corporate Businesses:**
‘Corporate’, ‘industrialized’, ‘market-based’, ‘commercial’ and ‘multi-national’ are terms used to describe modern, large-scale, food systems that produce food, fish, feed or fibre (FAO, 2011). Large-scale systems are usually dependent on high direct and indirect external energy inputs throughout the supply chain and have access to finance for capital investment for renewable energy technologies and energy efficient equipment. Therefore, they have large potential to substitute fossil fuels with renewable energy sources and energy efficient options for production or processing activities, such as solar/wind irrigation.
Energy and agriculture on micro level

Energy may be used on-farm or sold off-farm for additional revenue (FAO, 2011).

<table>
<thead>
<tr>
<th>SCALE OF PRODUCER</th>
<th>OVERALL INPUT INTENSITY</th>
<th>HUMAN LABOR UNITS</th>
<th>ANIMAL POWER USE</th>
<th>FOSSIL FUEL DEPENDENCE</th>
<th>CAPITAL AVAILABILITY</th>
<th>MAJOR FOOD MARKETS</th>
<th>ENERGY INTENSITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subsistence level</td>
<td>Low</td>
<td>1-2</td>
<td>Common</td>
<td>Zero/ low</td>
<td>Micro-finance</td>
<td>Own consumption</td>
<td>Low</td>
</tr>
<tr>
<td>Small family unit</td>
<td>Low/ medium</td>
<td>2-3</td>
<td>Possible</td>
<td>Low/ medium</td>
<td>Limited</td>
<td>Local fresh/ own use</td>
<td>Low / high</td>
</tr>
<tr>
<td></td>
<td>Medium/ high</td>
<td>2-3</td>
<td>Rarely</td>
<td>Medium/ high</td>
<td>Limited</td>
<td>Local fresh/ regional own use</td>
<td>Low / high</td>
</tr>
<tr>
<td>Small business</td>
<td>Low/ medium</td>
<td>3-10</td>
<td>Rarely</td>
<td>Medium/ high</td>
<td>Medium</td>
<td>Local/ regional/ export</td>
<td>Low / high</td>
</tr>
<tr>
<td></td>
<td>Medium/ high</td>
<td>3-10</td>
<td>Never</td>
<td>High</td>
<td>Medium</td>
<td>Local/ regional/ export</td>
<td>Low / high</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>10-50</td>
<td>Never</td>
<td>High</td>
<td>Good</td>
<td>Regional process/ export</td>
<td>Low / high</td>
</tr>
<tr>
<td>Large corporate business</td>
<td>Medium/ high</td>
<td>3-10</td>
<td>Never</td>
<td>High</td>
<td>Medium</td>
<td>Local/ regional/ export</td>
<td>Low / high</td>
</tr>
</tbody>
</table>

Table 1: Typologies of typical “small” and “large” scale farms and fisheries based on qualitative assessments of unit scale, levels of production intensity, labor demand, direct and indirect fossil fuel dependence, investment capital availability, food markets supplied, and energy intensity. (Source: FAO, 2011)
C2.1 RECAP

- The spectrum of agricultural enterprises is complex and diverse, ranging from basic subsistence smallholder farmers to large commercial farms.

- In order to represent the various levels and intensities of energy inputs, agri-food enterprises can be divided between industrial large-scale farming systems using modern technologies, small businesses and family farms using simple technologies, and small-scale subsistence farming systems equipped with traditional technologies.

- The differences in scale impact the ability to manage and incorporate renewable or energy efficient technologies and are therefore considered throughout the techno-economic analysis of agro value chains/projects.

UNIT C2.2 TECHNO-ECONOMIC ANALYSIS OF ENERGY PROJECTS IN THE AGRICULTURAL VALUE CHAINS

Micro-level: Investment planning

This section presents steps to plan investment in renewable energy technologies and energy efficiency in agricultural and food enterprises. It highlights opportunities for sustainable energy interventions along agri-food chains and analyses their feasibility and financial and economic cost-benefits related to the investment. Lastly, this section presents existing tools that can be used to assess the financial and economic viability and environmental impact of such interventions.
When planning an investment, the operator or project manager should first perform a feasibility analysis (and sometimes a pre-feasibility analysis)\(^1\). This is an analysis of the ability to complete a project successfully, taking into account legal, economic, technological, scheduling and other factors. A feasibility study allows investigating the possible negative and positive outcomes of a project before investing too much time and money.

A first important step is to contextualize the investment into an economic, institutional, social and technical framework. In fact, constraints and challenges to the use of sustainable energy in the agricultural and food industries, particular in developing countries, can stem from these areas. For instance, Figure 3 summarizes the main constraints on biomass supply and barriers to sustainable bioenergy supply chain mobilization. A clear identification of financial, economic, institutional, social and technical opportunities and risks is required as a first screening for the goodness of the investment.

Figure 3 Constraints and barriers to sustainable bioenergy supply chain mobilization. Source: IEA Bioenergy, 2015.

\(^1\) In principle, both pre-feasibility study and feasibility are similar. The differences are in the level of accuracy and the depth of analysis. Pre-feasibility study offers the fastest method to select the best business scenario. Feasibility offers deeper analysis of the selected scenario and whether or not the project should be continued.
Some of these barriers would be considered in detail in the economic analysis, but first an identification of constraints to the investment is necessary also during the preliminary feasibility study. In fact, the identification of significant barriers or constraints could make an investment in a specific technology unfeasible in a particular environment, even though it would seem financially attractive. In case of investment in renewable technologies, examples of constraint are: lack of access to finance, high cost of capital, market failures, network failures, insufficient legal and institutional framework, lack of skilled personnel, social, cultural and behavioral factors, geographic constraints and sustainability concerns.

The adoption of the technology/practice by an entrepreneur or farmer goes through different steps:

- Awareness by an entrepreneur/farmer who learns about the technology/practice

- Evaluation by an entrepreneur/farmer to assess the technology in terms of costs and benefits

- Adoption by an entrepreneur/farmer who decides to adopt it in full, but modify or adapt it to suit the local situation and special needs

The adoption of the technological option depends also on the risk perceived by the farmer/entrepreneur, therefore stakeholder involvement is relevant. Weak connectivity between actors, social biases and traditions may represent constraints to the adoption of sustainable energy technologies.

Renewable energy and energy efficiency interventions can be at difference stages of the agri-food value chain, from production to commercialisation (Figure 4).

The methodology to perform a techno-economic analysis of the investment is the same regardless of the technology and the value-chain stage. The analysis performed in this lecture covers investments from production to processing, but does not consider the commercialisation stage.

MORE TO LEARN

**Link:** An overview of the energy technologies that can be introduced along the relevant ‘hot points’ in the production chain of selected food products is provided by FAO/USAID, 2015. Opportunities for Agri-Food Chains to become Energy-Smart.
While deciding whether to invest in renewable energy technologies and energy efficiency, an agricultural and food enterprise would compare this option with the energy source or technology currently used (e.g. fossil fuels). Analysis from many demonstration and commercial renewable energy plants show that costs of projects are very site-specific (Figure 5). Levelized costs of many renewable energy technologies are becoming more and more competitive with current average costs of fossil-fuel powered electricity, heat and transport fuels they displace. Moreover, costs for renewable energy technologies are declining as the size of their markets is increasing. For example, in remote rural regions with no electricity grid access, autonomous renewable energy systems avoid expensive grid connection costs and are already competitive.

CLOSE UP

Levelized Cost of Energy (LCOE)

The levelized cost of energy (LCOE) represents the cost of an energy generating system over its lifetime. Levelized cost of electricity is often cited as a convenient summary measure of the overall competitiveness of different generating technologies. It is calculated as the per-unit price at which energy must be generated from a specific source over its lifetime to break even (recover all costs, including financing and an assumed return on investment). LCOE usually includes all private costs that accrue upstream in the value-chain, but does not include the downstream cost of delivery to the final customer, the cost of integration, or external environmental or other costs. Subsidies and tax credits are also not included.
In order to assess quantitatively the attractiveness of an investment in sustainable energy options a Financial and Economic Analysis (FEA) needs to be performed. In the following paragraph we describe the necessary steps to perform a financial analysis and an economic analysis. Additionally, we introduce some tools that can help small businesses in performing a financial analysis.

The main goal of financial analysis (FA) is to examine the financial returns to project stakeholders (i.e. beneficiaries, institutions and governments, etc.) in order to demonstrate that all actors have enough incentive to participate. A financial analysis provides the foundation for an economic analysis (EA), which is carried out to ascertain a project’s desirability in terms of its net contribution to the economic and social welfare of the country (or sub-national entities) as a whole\(^2\). In the area of development studies, the terms "financial" and "economic" are commonly defined as follows:

- A financial analysis is undertaken from the perspective of individual agents, or categories of agent (farmers, retail traders,


Figure 5: The costs of electricity, heat and liquid biofuels produced from renewable energy sources can be higher than when produced from conventional fossil fuels, but under specific circumstances, some renewable technologies are already competitive (shown where they overlap with the vertical range bars of conventional wholesale electricity, heat and gasoline/diesel costs). Source: Based on IPCC, 2011, where specific technologies, as indicated by the lines on the bars, are detailed.
primary assemblers); it includes the analysis of production-utilisation accounts, the profitability of investments, etc.

• An economic analysis is undertaken from the perspective of the overall economic system (national economy, sector or chain) or large groups of heterogeneous agents; it includes the analysis of taxes, subsidies, etc.

The financial and economic analysis (FEA) of investment projects is a usual requirement of most governments and International Financing Institutions (IFIs) in order to ensure the financial and economic viability of an investment.

In the context of the project’s logical framework, the financial and economic analysis starts with investigation of the proposed project’s main objectives and targets. Then the relevant project benefits and costs are identified and monetized to perform a quantitative analysis.

The financial and economic analysis basically consists of two main steps:

1. **Financial Cost-Benefit Analysis:**
   an assessment of the project’s financial profitability and sustainability in order to determine whether the farmers or other stakeholders have sufficient incentive to participate in the project

2. **Economic Cost-Benefit Analysis:**
   an assessment of the project’s economic viability from the point of view of the national (or sub-national) economy. This step should also examine its expected impact on the government budget to ensure its fiscal sustainability. Furthermore, the economic analysis of investments in renewable energy usually includes an assessment of a project’s impact on social and environmental aspects

In the paragraph below, we will explore these two steps more in detail.

In agricultural and food enterprises, renewable energy technologies are usually adopted as substitutes to traditional energy sources—usually fossil fuels—therefore the financial and economic analysis of the investment requires a comparison with this benchmark.

Project FEA is concerned with the incremental costs and benefits of a project, and therefore it requires a comparison between the potential situations “with” and “without” the project.
1. The first step is the identification and description of both the benchmark scenario (which normally consists in fossil fuel-powered and/or inefficient technologies) and the post-energy intervention scenario (where the technology is adopted). For instance, an irrigation system can be powered by a diesel pump (benchmark scenario) or by a solar photovoltaic (PV) powered pump (post-energy intervention scenario). The financial analysis of an investment in the PV pump would require the comparison between the two scenarios.

2. The second step is the identification of the investment’s outcomes, including the capital and operating costs and the monetized benefits. Because costs and benefits do not occur at the same time – with costs generally preceding and exceeding benefits during the first years of the project – the comparison requires discounting techniques.

3. The third step is the determination of the project’s incremental net flows (financial and/or economic), which results from comparing costs and benefits of the project with the benchmark scenario. With these elements, it is possible to calculate the corresponding project profitability indicators.

Financial Cost-Benefit Analysis
The standard and comprehensive approach for performing a Financial and Economic Analysis is a Cost-Benefit Analysis (CBA). A CBA consists in monetizing all major benefits and all costs generated by the investment and presenting their streams over the lifetime of the technology, expressed usually in number of years (cash flow). Costs and benefits can then be directly compared between different scenarios, as well as with reasonable alternatives to the proposed project.

Generally speaking, a project is considered ‘viable’ if the sum of expected incremental benefits is larger than the sum of all costs accrued in project implementation. This can be assessed through profitability indicators. In general, CBA provides four main indicators, the Net Present Value (NPV), the Internal Rate of Return (IRR), the benefit/cost (B/C) ratio and the payback time. These indicators assess attractiveness of investment by comparing the present value of money to the value of money in the future, taking the time value of money (discount rate) and returns on investment into account. Therefore, these indicators are important decision-making tools for
investors, national governments, as well as for donors and IFIs.

**Net Present Value (NPV):**
The NPV indicator is determined by calculating the costs (negative cash flows) and benefits (positive cash flows) for each period of an investment and by discounting their value over a periodic rate of return. The NPV is defined as the sum of the results when the initial costs of the investment are deducted from the discounted value of the net benefits (revenues minus cost, \( R_t \)).

\[
NPV = \sum_{t=0}^{N} \frac{R_t}{(1+i)^t} + R_0
\]

Where
- \( R_t \) is the sum of all the discounted future cash flows
- \( R_0 \) is the (negative) cash flow at time zero, representing the initial investment
- \( t \) is the time of the cash flow, depending on the project lifetime
- \( i \) is the discount rate or rate of return.

Therefore, the NPV of a project depend on its net benefits, the project lifetime and the discount rate. Whenever the NPV is positive (NPV > 0), the project is considered worthwhile or profitable. Comparing the NPV of several possible investments allows for identifying the alternative that yields the highest result – for cases in which the alternatives are mutually exclusive. Among mutually exclusive projects, the one with the highest NPV should be chosen.

**Internal Rate of Return:**
The IRR indicator is defined as the discount rate at which the NPV equals zero. This rate means that the present value of the positive cash flow for the project would equal the present value of its costs. If IRR exceeds cost of capital, project is worthwhile, i.e. it is profitable to undertake.

For a project to be profitable, the IRR has to be greater than the interest rate that could be earned in alternative investments or than the opportunity costs of capital (\( r \)). Therefore, when IRR > \( r \) the project is considered viable.
NPV and IRR are calculated on the same project cash flows of incremental net benefits. However, when we want to choose between two alternative projects with differences in the scale of investment, IRR should not be used. In fact, NPV is preferable when the investors set their goals in absolute terms, since it ensures that the operator reaches an optimal scale of investment in absolute term, while IRR expresses the return in percentage. For example a project with an IRR of 500% on USD 1 is less attractive than a project with an IRR of 20% on USD 100, although the former has a higher IRR. Moreover, the calculation of IRR is not possible when the flow of net incremental benefits does not have a negative element.

The Benefit/Cost Ratio (B/C) indicator is the ratio of the present value of benefits to the present value of costs over the project lifetime. The B/C ratio provides some advantages when a ranking of alternative investment projects is needed under budget constraints. If B/C ≥ 1 the project is accepted; if B/C < 1 the project is not profitable.

Payback Time (PBT): The (PBT) measures the time required for the net cash inflows to equal the original capital outlay. It is the number of years required for the discounted sum of annual savings to equal the discounted investment costs, or in other words the time span after which the investment will start to pay back. It does not give indication of the magnitude of the investment, and, differently from the other indicators, it expresses the profitability of the investment in time. Between two alternative projects, the stakeholder would choose the one with the shortest payback period. From the perspective of a private stakeholder (financial analysis) participating in the investment with risk capital, the wealth created by a project is defined as the financial NPV (FNPV). In Financial Analysis, all costs and benefits should be valued at market prices. Only cash inflows and outflows are considered (depreciation, reserves and other accounting items not corresponding to actual flows are excluded).

Investment projects are risky by nature, and risks should be assessed during all steps of the project cycle. Once the flows of costs and benefits and related indicators are calculated, the “robustness” of these indicators to percentage changes in one or more inputs and/or outputs can be tested using the “sensitivity analysis”. Simple methods are available for modelling risk, requiring minimum expertise in statistics and probabilities, together with

CLOSE UP
Steps in Financial Cost-Benefit Analysis:

1. Identify benefits and costs for both investment and benchmark scenarios for their lifetime.
2. Compare the discounted flows of benefits and costs and calculate the differences between the obtained results and the benchmark scenario in order to determine the net incremental benefits of the proposed interventions.
3. Calculate the project financial profitability indicators of each scenario (i.e. financial NPV, financial IRR, B/C ratio, payback time), applying these investment criteria to make an investment decision (positive or negative).
user-friendly computer programmes. Risk and sensitivity analysis are beyond the scope of this lecture, but worth mentioning. In practical terms, quantitative risk analysis complements classical FEA by providing a more detailed understanding of the project dynamics and uncertainties. The insights gained by quantitative risk analysis may be useful for project design and evaluation.

**Economic Analysis**

The basic principles for carrying out financial and economic analysis are the same and both are required for project screening and selection. However, the Financial Analysis deals with the cost and benefit flows from the point of view of the individual, farmer or food processor in our case, while the economic analysis deals with the costs and benefits to society. The Economic Analysis takes a broader view of costs and benefits, and the methods of analysis differ in important aspects. An enterprise is interested in financial profitability and the sustainability of that profit, while society is concerned with wider objectives, such as social and environmental issues, and net benefits to society as a whole.

The main differences between financial and economic analysis are that the economic analysis:

- attempts to quantify "externalities", i.e. negative or positive effects on specific groups in society without the project entity incurring a corresponding monetary cost or enjoying a monetary benefit. This includes both environmental and social impacts resulting from the energy intervention

- removes transfer payments, i.e. subsidies and taxes; and

- makes use of "shadow prices” that might differ from the “market prices”, which reflect the effective opportunity costs for the economy, thus achieving a proper valuation of Economic Costs and Benefits from the perspective of the economy as a whole.

An economic analysis takes into account energy subsidies and taxes, the impacts of the renewable energy project on land, labor and human rights, local people livelihood, environment, GHG emission, etc. (FAO, 2015). These and other externalities and co-benefits are context specific and can be inserted in the analysis in order to modify the structure of economic costs and benefits of the project. These include for example economic incentives to renewables or fossil fuels, or costs.

to mitigate climate change or to ensure the more efficient use of water and land, costs accrued in the treatment of water, measures to contain negative environmental impact, etc. which are of course part of the picture, although not present in the financial investor business plan.

A tool that can be used to introduce in the analysis basic social and environmental externalities of a technical intervention is the FAO Nexus Assessment (FAO, 2014). This assessment consists in an easily applicable methodology to quickly evaluate possible interventions against overarching development goals such as food security, and the sustainability of energy and water supply, use and management in a specific context. A simplified version of this tool, the Water-Energy-Food (WEF) Nexus Rapid Appraisal (LINK), can be used for a desk assessment of the impacts of an intervention on water, energy, food, labour and costs in a specific country context.

The procedures to quantify and monetize these and other environmental and social factors are not always straightforward and are beyond the scope of this lecture, and deriving “shadow” and economic prices net of transfer payments are therefore not easy tasks, but lead to calculate economic performance indicators adopting a social discount rate: economic NPV (ENPV), IRR, B/C ratio and payback time.

Cost-Benefit Analysis Tools

to Assess Energy Interventions in the Agri-food Chain

Cost-Benefit Analysis can be unfriendly to a non-professional audience. Several online tools are available to support small and medium businesses in performing cost-benefit evaluation of their investment in an energy-food context. A non-exhaustive list with some examples is provided below:

WinDASI - a software for Cost-Benefit Analysis (CBA)
of investment projects:

FAO provides this tool to carry out cost-benefit calculations of investment projects. After cost and benefit data are inserted in the database, WinDASI guides the user how to calculate: a) flows of physical quantities of outputs, inputs and investment items; b) flows of current, discounted and cumulative costs, benefits, and net benefits; c) flows of incremental (With-Without project) current, discounted and cumulative net benefits; and e) project indicators such as the Net Present Value (NPV), the Internal Rate of Return (IRR), the Benefit/Cost Ratio (B/C) and Sensitivity

MORE TO LEARN


[LINK]: FAO Water-Energy-Food (WEF) Nexus Rapid Appraisal.

CLOSE UP

Steps in Economic Cost-benefit Analysis:

1. Convert all market prices into economic/shadow prices that better reflect the social opportunity cost of the good.
2. Remove transfer payments (taxes and subsidies) and quantify externalities (positive and negative).
3. Compare costs and benefits of the project with the benchmark scenario to obtain the project’s incremental net flows.
5. Perform sensitivity analysis in order to deal with the main risks and uncertainties that could affect the proposed project.
Analysis. Calculations can be carried out at different levels of aggregation, for the different components of an investment project (i.e. plans, zones and projects). In addition, WinDASI allows for calculation and comparisons of different projects alternative scenarios (with–project versus without-project). The WinDASI program is downloadable from the FAO EASYPol website:\[\text{HERE}\]

VCA Tool - a software for Value-Chain Analysis to assess socio-economic and environmental policy impacts: developed by FAO, this tool allows different scenarios to be built and to analyse the socio-economic impact of various policies such as the adoption of new low-carbon energy efficient technologies or support for renewable energy. The information about how inputs and outputs would change before and after the intervention is exogenous and can come from other sources. Among other things, the tool allows for: commodity chain analysis; impact analysis using shadow prices; financial analysis; impact analysis using market prices; scenarios comparison; cost-benefit analysis; competitiveness and profitability indicators. The software is available at: \[\text{HERE}\]

Power Irrigation Tool: this FAO tool evaluates economic, environmental and social aspects of different energy sources for irrigation in order to help operators to assess the economic viability of different power supply options and water pumping technologies. The tool assesses the economics associated with different energy sources for irrigation including the cost, price, and payback time. It can be accessed: \[\text{HERE}\]

RuralInvest - A Participatory Approach to Identifying and Preparing Small/Medium Scale Agricultural and Rural Investments: developed by the FAO Investment Centre, it provides support to local communities, private entrepreneurs or producers’ associations to conceive and implement their own investment projects through a range of materials and training courses including technical manuals, custom developed software, user guides and instructor’s materials. More information: \[\text{HERE}\]

RETScreen: the tool performs cost and financial analysis considering for instance: base case system energy cost (e.g. retail price of heating oil); financing (e.g. debt ratio and length, interest rate); taxes; environmental characteristics of energy displaced (e.g. oil, natural gas, grid electricity); environmental credits and/or subsidies (e.g. GHG credits, deployment incentives); indicator such as payback period, ROI, NPV, energy production costs. It has been developed by CanmetENERGY and can be downloaded \[\text{HERE}\]
The journey from financial to economic analysis is not always smooth and the investigator has to make a decision on political, economic, social and environmental factors to be included in the analysis according to the focus of the analysis. For investment in renewable technology, a list of relevant energy policies adopted by each country is provided by the IEA/IRENA Joint Policies and Measures database. This dataset summarizes economic instruments, policy support and regulatory instruments, research, development and deployment (RD&D) strategy and voluntary approaches targeting renewable technologies. Hence, it can be useful to identify transfer payments (taxes and subsidies) and to convert market prices into economic/shadow prices.

Another useful tool that can be adopted to include in the analysis social and environmental factors is the already mentioned FAO Nexus Assessment, which assesses the performance of some energy interventions in terms of water, energy, food, labour and costs in a specific context (FAO, 2014).

MORE TO LEARN

**LINK**: FAO/USAID, 2015. Opportunities for Agri-Food Chains to become Energy-Smart. Available [HERE](#).

MORE TO LEARN

**LINK**: IEA/IRENA Joint Policies and Measures database. Available [HERE](#).
C2.2. RECAP

• Before performing financial and economic cost-benefit analysis, the investment must be contextualized into an economic, institutional, social and technical framework to identify relevant barriers and constraints.

• The first step is the identification and description of both the benchmark scenario and the investment scenario.

• The second step is the identification of the investment’s outcomes, including the capital and operating costs and the monetized benefits.

• The third step is the determination of the project’s incremental net flows, which results from comparing costs and benefits of the project with costs and benefits of the benchmark scenario. With these elements, it is possible to calculate the financial project profitability indicators.

• The next steps are converting market prices into economic/shadow prices; removing transfer payments (e.g. taxes and subsidies) and quantifying positive and negative externalities to calculate the economic flows.

• Perform Sensitivity Analysis in order to deal with the main risks and uncertainties that could affect the proposed project (optional).

SUMMARY & CHAPTER WRAP-UP

This week’s reader has provided a general overview on how to perform a micro assessment of investments in renewable energy. More details on this topic can be found in the recommended literatures and in the references.
RECOMMENDED READING

FAO, 2016. INVESTMENT LEARNING PLATFORM (ILP): FINANCIAL AND ECONOMIC ANALYSIS. ONLINE RESOURCE.

IFAD, 2015. IFAD’S INTERNAL GUIDELINES ECONOMIC AND FINANCIAL ANALYSIS OF RURAL INVESTMENT PROJECTS. BASIC CONCEPTS AND RATIONALE. THE INTERNATIONAL FUND FOR AGRICULTURAL DEVELOPMENT (IFAD).
REFERENCES


FAO/USAID, 2015. Opportunities for Agri-food chains to become energy-smart. FAO and USAID.


IRENA. Costs: Renewable energy costs, technologies and markets


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PART C OVERVIEW

Chapter C1: Policies and Regulations for the Energy-Agriculture Nexus

Unit C1.1: Policies and Politics of Renewable Energy

Unit C1.2: Circular Economy and Scarcity of Resources

Unit C1.3: Regulation of Energy Use

Unit C1.4: Economic and Social Impacts of the Energy Production and Use

Unit C1.5: Markets for Projects at the Interface of Agriculture and Energy

Unit C1.6: Financing for Renewable Energy and Energy Efficiency Solutions in the Agricultural Sector

Chapter C2: Energy and Agriculture on the Micro Level

Unit C2.1: Scale of Agri-Food Enterprises

Unit C2.2: Techno-Economic Analysis of Energy Projects in Agricultural Value Chains

Chapter C3: Business Models for Projects in the Energy-Agriculture Nexus

Unit C3.1: Introduction to Business Models

Unit C3.2: Energy Projects in the Agricultural Sector
INTRODUCTION

In the first technical chapters of the MOOC (B1 to B3) you have learned about different renewable energy technologies that you could use for your agricultural activities. In the previous economic chapters C1 and C2 you have been presented macro and micro economic aspects relevant to clean energy projects for agricultural value chains.

Building on the previous chapters this week C3 aims to provide you with basic knowledge on business models and common methods for business decision making (capital budgeting) – with a focus on hands-on aspects. Business models thereby do not necessarily refer to a complete new business but also apply to changes within an existing business e.g. introducing energy efficiency measures in a food processing company.

The second part of this chapter discusses detailed examples of financial analysis of grid connected and off-grid clean energy projects in the agricultural sector. You will find that these case studies bring together much of the content of the previous chapters and hopefully will help you in implementing your own clean energy solutions for agricultural activities.

UNIT C3.1 BUSINESS MODELS

Introduction to Business Models

Although the business model is a fundamental part of an economic activity, the term is understood and defined in many different ways. To put it simple, a business model describes the core strategy of an organization for how to generate money and by this determines how the company produces, distributes prices and promotes its products.

Usually all starts with an idea about how to earn money. Ideas might expand further on how to improve livelihood. The crucial point is about offering a product or a service that does not yet exist in the market, but that has a high potential to create value for people who will be willing to pay for the product or service. This idea should be commercially viable and sustainable.

It should be noted that also established businesses develop new business models; for instance, optimizing a core process affects the business model. An example is improved energy access e.g. for a diary collection center that is now able to cool the milk and thereby increase the added-value. For developing a new business or a start-up into a long-term successful business, it requires a well-defined business.
model. One helpful tool for this is the Business Model Canvas template which describes nine basic elements forming a business model (illustrated in Figure 1) [Osterwalder, 2010]. By answering the questions for each key point provided in Table 1 you can specify your individual business model. This is an important step before conducting financial calculations or starting to implement any business activity.

<table>
<thead>
<tr>
<th>VALUE PROPOSITIONS</th>
<th>Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customer segments</td>
<td>Who are your target customers? How big is the potential customer group? How is their willingness to pay for this product/service?</td>
</tr>
<tr>
<td>Customer relationship</td>
<td>Which type of relationship should exist between you and the customers? Are any costs connected with this?</td>
</tr>
<tr>
<td>Channels</td>
<td>Which channels do you want to use to communicate and deliver to the customers? Which channels exist, are suitable and cost-efficient?</td>
</tr>
<tr>
<td>Offer</td>
<td>What do you want to offer to your customers, what kind of service or product? Which of their problems or needs are you addressing?</td>
</tr>
<tr>
<td>Key resources</td>
<td>Which resources do you need for the production, marketing, cultivating the customer relations, etc.?</td>
</tr>
<tr>
<td>Key activities</td>
<td>Which activities are necessary for the production, marketing, cultivating the customer relations, etc.?</td>
</tr>
<tr>
<td>Key partners</td>
<td>Who are your main partners and suppliers?</td>
</tr>
<tr>
<td>Cost structure</td>
<td>Which fixed and variable costs have to be considered?</td>
</tr>
<tr>
<td>Revenue streams</td>
<td>What are customers willing to pay for? How much do they pay for alternatives?</td>
</tr>
</tbody>
</table>

Table 1 Sample questions for defining the key elements of a business model [Osterwalder, 2010]

To be able to answer these questions, it is recommended to carry out market research and analysis. Talk to people who do similar business and ask them to share their experiences. Talk to potential clients and find out what they think about your business idea, and what additional services or product features they would value. The market analysis also includes identifying competitors and characteristics of potential customers, including their willingness to pay. In addition, you have to figure out at what cost you can produce and what profit margin can be reached by selling the product or service.

Of course, also macro-economic aspects need to be considered – these have been presented in Chapter C1, so that this Chapter C3 will focus on hands-on knowledge of business models.
Different kinds of business models exist around the world, and new and innovative ones are being developed continuously, interdependent with market demand and companies’ attempts to increase their competitiveness.

You should be aware that there is not a single model that fits all kind of businesses. You have to define your own model that specifically fits to your intended economic activity.

An energy project can be the basis for your business and you have to develop the business model according to it. An example would be the purchase of a solar dryer for selling dried fruits on the market. The other possibility is that you already have an operating business. In this case the integration of an energy project would be an option for increasing the energy efficiency and productivity of your business. This will probably also change your business model, as aspects like cost structure and key resources need to be adopted. For instance, if you replace the diesel generators of your irrigation system by a PV plant, you don’t require diesel anymore, instead you have to consider purchase and operating costs of the plant. If you have not had any irrigation system before, the installation of a PV irrigation system will enhance your agricultural productivity (see Chapter 1). This will of course affect your economic calculations. With the help of specific economic methods that will be explained in this document, you can analyze if such a clean energy solution is profitable for your agri-business, considering the costs as well as productivity gains.

**Definition of Financial Terms**

Let us start with some financial terms that commonly occur when talking about business models. The following table contains brief definitions of relevant terms (some were mentioned in the MOOC material of week 6, e.g. remember the Cost-Benefit Analysis and calculations for the Net-Present Value, some in this week’s video, others may appear later in this document).
<table>
<thead>
<tr>
<th>TERM</th>
<th>DEFINITION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct cost</td>
<td>Costs that are directly related with the production of a particular service or good, e.g. material.</td>
</tr>
<tr>
<td>Indirect cost</td>
<td>Costs that arise but cannot be assigned to a particular produced good or service. They are necessary for keeping the business running. Examples are electricity, rent for buildings, plant maintenance, administration, etc.</td>
</tr>
<tr>
<td>Opportunity cost</td>
<td>Costs for the next best alternative that has to be given up in order to take the desired action. You could have used your resource (for example land, money) for something else and could have made profit with it.</td>
</tr>
<tr>
<td>Capital cost</td>
<td>This is the one-time expense for setting up a plant or project. For example, capital costs include purchasing land, buildings, machinery, and administrative expenses (e.g. for permits). They can be paid by equity or by taking a loan from a financial institution. Latter result in cost of debt. This means that an interest is added to the loan and has to be paid back in addition to the borrowed amount of money (see &quot;Interest rate&quot;).</td>
</tr>
<tr>
<td>Interest rate / Interest</td>
<td>It is basically the cost for borrowing money. This rate is usually given as an annual percentage of the total amount of the loan. For example, if you take a loan of 1000 € at an annual interest rate of 10%, then you have to pay 1100 € at the end of the year. Consequently, the pure interest would be 100 €. If you borrow the 1000 € for 5 years, this means the simple interest is: 1000 € * 10% * 5 = 500 €.</td>
</tr>
<tr>
<td>Profit</td>
<td>Profit = Total revenue – Total costs. Profits can be further divided into before and after tax profit.</td>
</tr>
<tr>
<td>Revenue</td>
<td>This is the income earned by a business typically through selling services or goods. Revenue = Quantity of items sold * Retail price</td>
</tr>
<tr>
<td>Cash flow</td>
<td>Incoming and outgoing cash of a business. Costs are considered as negative cash flows and revenues as positive ones. Cash flow of one period = Benefits of the period – Costs of the period</td>
</tr>
<tr>
<td>Discount rate</td>
<td>This rate is generally used to bring future costs or revenues to their market value at the present time. It expresses the time value of money. It is an indicator for the riskiness of an investment.</td>
</tr>
</tbody>
</table>

Table 2: Definition of common financial terms [FAO, 1995a] [FAO, 1995b] [FAO, 1998]
For assessing the financial profitability of your business idea, you have to start with making several considerations and assumptions. Some examples of relevant questions [HCC, 2009]:

- Who are the potential costumers? What is the market potential (number of potential clients, current market prices, possible future market prices)? How to access this market?
- Do you possess the necessary land, buildings or other things that you need for your business idea or do you have to buy, rent or construct these assets?
- Do you have access to capital for the required investment (funding) or do you have to take a loan to cover the expenses (fully or partly)?
- Are there any taxes or fees connected with your business that have to be taken into considerations?
- Further factors such as cost and amount of required material and labor, operational parameters, etc.

The general way for a financial analysis is at first to define the total costs and to determine the total revenues – as you have learned in the previous week with the FAO. Subsequently, you need to apply one or even more methods of capital budgeting (as described later in this document). Additionally, you should answer the questions of Table 1 to come up with a concrete business model. Before discussing the capital budgeting, let's now take a look at the following simplified definitions [HCC, 2009]:

- Cost = anything that decreases your business profit
- Benefit = anything that increases your business profit

As calculating the costs can be a quite complex issue, they can be divided into two main groups [HCC, 2009]:

- Capital expenditures (CAPEX): are one-time expenses. Normally they are long-term investments in non-consumable parts of the business, for example money that is spent on inventory.
- Operating expenses (OPEX): are the ongoing costs for running a business that are related with the operation and maintenance of it. They are the expenses related to the production activity of the business and they are divided into:
Fixed costs: are independent from the output of goods or services generated by a business. They do not change during the production period. So these costs have to be paid even in times of non-operation of the business.

Variable costs: vary with the change of the output/activity of an organization. If more is produced, the total variable costs rise. Consequently, they change during the production period.

The following illustration (Figure 2) shows the distribution of cost types. However, be careful that the mentioned points are only generalized examples and thus should be revised for each specific project.

Common Methods of Capital Budgeting

Making a decision on an investment of capital can be difficult, especially if a high investment is required, if it is a long-term investment, or if several investment alternatives are available. But using Capital Budgeting can support you in the decision process as it gives you an overview about the eventual returns on investments. By this you will know if the investment will provide a profit after a certain period of time. Further, it helps you identifying the most profitable investment options.

So let’s start with the theory of Capital Budgeting. First of all, you should know that there are two principal approaches for assessing the profitability of investment projects: the static and the dynamic approach. Both are subdivided into several methods. A common example of the static appraisal procedure is the payback time (PBT). Examples of the dynamic appraisal procedure are the net present value (NPV) and the internal rate of return (IRR) methods [Rudolf, 2008] –
these profitability indicators have been briefly introduced by the FAO in Chapter C2.

In the following, the most common methods will be presented. All of them can be used for comparing several investment options as well as for assessing one individual investment.

1. Static Approach
   This approach is recommendable for getting a first, quick overview about investment options and / or when looking at very short periods between occurring cash flows. As the following profitability indicators have been presented in last week’s reader C2, the focus here is on practical examples.

Payback Time (PBT)
As explained, the payback time is “the number of years required for the discounted sum of annual savings to equal the discounted investment costs, or in other words the time span after which the investment will start to pay back”.

It enables a comparison of different investment options, as well as an evaluation of the risk of an investment. In general, the investment option with the shortest payback period is the most favorable one.

The method for calculating the payback period differs based on the type of annual repayment [Rudolf, 2008]:

\[ PP = \frac{I_0}{C_{F_1}} \]

**AVERAGE METHOD:**
If annual repayment is constant over the project life time (meaning \( C_{F_1} = C_{F_2} = C_{F_3} \)):

\[ PP = \frac{I_0}{C_{F_1}} \]

**CUMULATIVE METHOD:**
If the annual repayments fluctuate, the payback time is determined by adding up the annual repayments until their sum equals the initial investment:

\[ \sum (C_{F_1} + C_{F_2} + C_{F_3} + \cdots) = I_0 \]
EXAMPLE

Let’s calculate the PBT for a simplified example of a household size biogas plant. Assume an initial investment of 600 €, annual operating expenses of 20 €, and an annual revenue of 170 € (pseudo income equivalent to avoided payment for Liquefied Petroleum Gas (LPG)), assuming the household was cooking with LPG and biogas could replace it. As you have the same cash flow each year, you can use the average method.

So your annual cash flow is: \( \text{Cf} = 170 \, \text{€} - 20 \, \text{€} = 150 \, \text{€} \)

**PAYBACK:**

\( \text{PBT} = \frac{600 \, \text{€}}{150 \, \text{€}} = 4 \, \text{years} \). So, after 4 years your initial investment will be recovered. After this time you will gain profit (assuming the annual cash flows stays the same).

This method is useful for a first impression about investment options, as well as for ranking different investment options. However, you should not base your investment decision only on the result of the payback time method since it does not include cash flows after the payback period. Also, it does not consider the value of cash flows over time. It is highly recommended to further assess promising investment options by using methods of the Dynamic Approach.

2. **Dynamic Approach**

An important point to consider especially for long-term investments is the **time value of money (TVM)**, meaning that the value of money changes with time. In simple terms, one Euro today is worth more than one Euro tomorrow. The argument being that the money could be invested and generate interest. This aspect is considered by the dynamic approach [Rudolf, 2008]. Consequently, future payments and revenues have to be discounted if they occur after the base year (in which the initial investment is realized) to receive the present time value. Therefore, the future cash flows have to be multiplied by the so-called discount factor \( d \) which depends on the discount rate \( r \) (equaling the rate for an alternative investment) as well as on the time difference between the cash flow occurring and the base year.

\[ d = \frac{1}{(1+r)} \]
Net Present Value (NPV)

As described in Chapter C2, the NPV is defined as “the sum of the results when the initial costs of the investment are deducted from the discounted value of the net benefits”. This method transforms all future cash flows to their present value to enable a comparison of different investments [Rudolf, 2008].

\[
NPV = \sum_{t=1}^{N} \frac{C_{f,t}}{(1 + r)^t} - I_0 + S
\]

NPV EQUATION

\[
NPV = \sum_{t=0}^{N} \frac{R_t}{(1 + i)^t} + R_0
\]

Where
- \( R_t \) is the sum of all the discounted future cash flows
- \( R_0 \) is the (negative) cash flow at time zero, representing the initial investment
- \( t \) is the time of the cash flow, depending on the project lifetime
- \( i \) is the discount rate or rate of return.

Please note: this NPV equation is presented slightly different than the equation presented in Chapter C2. Both presentations are commonly used.
EXAMPLE

Let’s take the same example of biogas plant discussed above. Initial investment was 600 € and annual cash flow was 150 €. For “n” let’s assume a life time of the plant of 10 years. We assume the salvage value of zero, as we don’t expect to earn any money by selling the components of biogas plant after its operational life time is over. Take a discount rate of 10 % (so: \((1+r)=\(1+0.1\)=1.1\)). Using the above equation we can now calculate the NPV as:

\[
\text{NPV} = \left(\frac{150}{1.1}\right)^1 + \left(\frac{150}{1.1}\right)^2 + \ldots + \left(\frac{150}{1.1}\right)^{10} - 600 + 0 = 322 \text{ €} \quad \rightarrow \text{NPV} > 0
\]

General economic rule: reject an investment project option if its NPV is less than 0, and accept it if its NPV is above 0. Usually, the most attractive project is one with the highest NPV. Interpretation of NPV results is explained in Figure 3:

![Figure 3 Interpretation of NPV results]

Internal Rate of Return (IRR)

As described in Chapter C2, the IRR indicator is defined as “the discount rate at which the NPV equals zero”. I.e. the IRR gives you an answer to the question on how much you get in return for your investment in the project. By applying this method, the interest rate \( r \) of the invested capital can be defined. The favored project should be the one, whose IRR equals or is higher than the predefined discount rate. That means you would earn less by depositing your money in the bank. When you compare the rates of return of your different investment options, the one with the highest IRR is the most profitable one from the economic perspective. To calculate the IRR, the NPV

Cf\(_t\): Cash flow in year \( t \)
C\(_0\): Initial investment cost
C\(_t\): Cost in year \( t \)
R\(_t\): Revenue in year \( t \)
r: Discount rate
t: Number of years counting from the base year
n: Life time of the project in years
S: Salvage value of the project, if any
needs to be set zero in previous NPV equation. Calculations could be made with the help of a computer, e.g. using spreadsheet [Rudolf, 2008].

\[
NPV = 0, \text{ or} \sum_{i=1}^{n} \frac{Cf_i}{(1 + IRR)^i} - I_0 + S = 0
\]

**EXAMPLE**

Use the numbers provided in the NPV example for calculating the IRR of the biogas plant:

\[
0 = \left[\frac{150}{(1+IRR)} + \frac{150}{(1+IRR)^2} + \ldots + \frac{150}{(1+IRR)^{10}}\right] - 600
\]

\[
IRR = 21.41\%
\]

The resulting IRR at which the NPV is zero is about 21.41%. This percentage is higher than the predefined minimum acceptable rate for this example of 10% (discount rate). Thus, investing in the biogas results in higher capital gains.

Once again your investment decision should not be made solely based on the result of the IRR. Its results might present a wrong picture as it is not appropriated for making a comparison between investment options of different timing, duration and amounts of projects.

To sum up, all of the presented investment assessment methods have their strengths and weaknesses. To receive reliable results on which one can base investment decisions, it is advisable to apply at least two of the explained methods for the calculations of your investment (options). However, the NPV is always a good choice to reduce the risk of losing money!
Microfinance
If you do not have enough money for purchasing e.g. a solar powered irrigation system, a biogas plant or for paying the capital cost, financial services of microfinancing are an option. Microfinance includes diverse services such as insurance, leasing, savings, cash transfer and credits; provided by microfinance institutes (MFI) that can be NGOs, banks, credit and savings cooperatives and associations. Their target groups are generally low-income households and small businesses who normally would not be offered a credit from a traditional bank due to the lack of guarantees or higher administrative expenses. A microcredit, meaning a small loan, is one of the provided instruments. Sometimes special credit schemes for one specific technology are offered, e.g. for a solar home system [Energypedia, 2014a] [FAO, 2005].

Microfinance splits the often relatively high initial investment costs into smaller monthly rates. This can make an energy project affordable. But do not forget that you also have to pay an interest on the borrowed money. The interest rates of MFIs vary broadly. If you want to finance your intended project by a loan from a MFI, compare the credit conditions and interest rates of nearby MFIs. To find out if the project is rentable for you, you have to include the capital costs in your calculations with the methods of capital budgeting (see above). That means you have to add the annual interest to the costs for the period of time until the loan is paid back. For more information on this topic, you can read the following documents:

- An interesting study about a three continent comparison of microfinance for energy service was prepared by The SEEO Network: Link
- FAO (Food and Agriculture Organisation of the United Nations) prepared a paper about Guidelines and Case Studies for Microfinance in Fisheries and Aquaculture: Link
- Microfinance and forest-based small-scale enterprises: Link
- Energypedia Financing and Funding Portal: Link
- Watch the MOOC expert video with Katie Kennedy Freeman from the World Bank: Link

REMINDER
Remember the expert video with Katie Kennedy Freeman from the World Bank. Amongst other challenges, Katie talks about finance as a main challenge in the Energy Agriculture Nexus and points out approaches to address the issue.

Link: Watch the Video here!
C3.1 RECAP

• A business model describes the core strategy of an organization for how to gain money. For defining the key elements of your business model, it is recommended to carry out a detailed market analysis.

• The total costs of a project can be divided into capital expenditures (CAPEX) and operating expenses (OPEX), whereby the latter can be subdivided into fixed and variable cost.

• The method of Capital Budgeting (e.g. Payback Period, NPV and IRR as the most common ones) helps to ascertain the profitability of planned projects.

• The services of microfinance (e.g. microcredits) can help low-income households to finance small-scale energy projects.

UNIT C3.2 CLEAN ENERGY PROJECTS IN THE AGRICULTURAL SECTOR

Renewable energy presents a valid option for replacing fossil fuels in several ways in the agro sector (as outlined in previous Chapters). Several existing on- and off-grid installations prove that renewable energy can easily be integrated into agricultural value chains to enhance agricultural activities/productivity. Good examples for this are wind turbines installed on agricultural fields without affecting much the crop growth or livestock grazing. Solar PV systems are able to pump water and solar thermal systems can be used for water heating or drying of crops, vegetables and fruits. Also solar cooling is promising. Furthermore, biomass resources provide sources for addressing heat energy demands and agricultural residues that can be used for biogas production [Sims, Mercado, Krewitt, et al., 2011]. See Chapter B1 for more details on clean energy technologies for agricultural value chains.

MORE TO LEARN

LINK: Energypedia Powering Agriculture Portal
In the following sections three examples for on-grid and off-grid energy projects in agricultural value chains are discussed. From the previous weeks you are already familiar with these technologies. So this week’s focus lies on aspects that you should consider for the financial analysis when planning to implement a clean energy solution – either as a new business or as a adaptation/add-on to your already existing business for increasing agricultural productivity and/or energy efficiency. The points mentioned in the examples are also relevant for developing a business model. Additionally, each example contains a case study, in which the explained methods of capital budgeting were applied in order to give you a better understanding of their applicability and usefulness.

Grid-connected Energy Projects in Agricultural Value Chains

The advantage of grid-tied systems is that the grid can be used as back-up. When the renewable energy source is not available (e.g. sun is not shining, wind is not blowing), electricity can be obtained from the grid. Consequently, expenses for electricity storage devices like batteries can be avoided. Furthermore, excess electricity – electricity which is generated by the renewable energies but cannot be consumed instantly – can be fed into the grid. In many countries a feed-in tariff has been introduced (have a look at Chapter C1 for more details on policies and regulations). It varies from country to country, but principally a price based on the kWh of renewable electricity fed into the grid is paid, or net metering (the excess electricity which is fed into the grid is subtracted from the electricity drawn from the grid, resulting in a reduced electricity bill) is implemented.

For feeding electricity into the public / local grid, you have to check the legal requirements given by the grid operator and technical requirements for the connection of your system to the grid (again, see Chapter C1).

Gasification technologies are one possibility to convert biomass to power, heat and biofuels. These systems generate a synthesis gas that is applicable for being burned in gas engines for power production or in boilers for heat generation [ECN, SNV, 2014]. Small-scale gasifiers present a promising option as off-grid systems for rural settlements that are not connected to the national grid. An alternative is to use them as grid-connected systems for feeding the produced electricity totally or just the surplus into the grid for obtaining a financial remuneration.
General aspects that you should consider for an on-grid gasification system are (amongst others):

- Feedstock issues: is a reliable source of feedstock available? If so, is it suitable for usage in a gasifier? Which quantity is available and is there a fluctuation of the quantity over the different seasons? Is the source considered as “waste” and might therefore be available “for free” or little money? Is the resource available in an area close to the plant for keeping transportation efforts low? Are their competitors who are interested in the same resource? What is the current market price for the source?

- Is the required gasifier type available and is it also appropriate for the given local conditions?

- Logistics issues: storage requirements, appropriate site for the plant, distribution of feedstock to the plant?

- Financial aspects: is the project financially viable? Consider the costs (e.g. initial investment, costs for feedstock purchase in addition to its transport and pre-processing, repaying the taken credit including interest, maintenance and operation costs including labor, other fees and/or taxes etc.) in comparison to the possible revenue (avoided payment for fuels, sale of by-products and electricity sale into the grid). Do incentives exist?

- Technical plant parameter: full load hours, internal rate of use, life time?

- Legal issues: is the permission required? Is the connection to the grid allowed?

- Regulation issues: Ownership and operation? Maintenance responsibility? Expertise available?
EXAMPLE

Let us discuss one simplified example of grid connected gasification power plant fueled with rice husk in Vietnam. To be able to apply the described methods of capital budgeting we will assume the following data (please note that the numbers used are simplified for this example and are not representative on-site):

REVENUE:

- Own annual household electricity demand: 4000 kWh
- Electricity price: 0.082 €/kWh
- Feed-in tariff: 0.058 €/kWh

COST:

CAPEX

- Initial investment cost (including planning, construction, equipment, insurance, fee and interest, etc.) of 3000 €/kW. So for a gasifier of 100 kW capacity this means investment cost of 300,000 €.

OPEX

- Feedstock (rice husk) price including transport: 0.025 € / kg
- Operation and maintenance cost: assumed 3 % of investment cost

OTHER PARAMETER:

- Assumed plant capacity (assuming about 67% capacity factor): 100 kW
- Used quantity of feedstock: 500 tons/year
- Heating value of rice husk: 14 MJ/kg
- No land purchase cost or rent payment considered
- Project life time of 15 years
- Internal use rate of plant is 10% (meaning that 10% of the produced electricity is used for the operation of the plant itself)

With the provided data we can calculate the profitability of this project (see next page):
**EXAMPLE**

### FINANCIAL ANALYSIS

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project life time (years)</td>
<td>15</td>
</tr>
<tr>
<td>Used quantity of rice husk as feedstock (kg/year)</td>
<td>500000</td>
</tr>
<tr>
<td>Heating value of rice husk (MJ/kg)</td>
<td>14</td>
</tr>
<tr>
<td>System efficiency (assumed 30%)</td>
<td>0.3</td>
</tr>
<tr>
<td><strong>Annual electricity generation (kWh)</strong></td>
<td>583333</td>
</tr>
<tr>
<td>Electricity buying price from the grid (€/kWh)</td>
<td>0.082</td>
</tr>
<tr>
<td>Own annual household electricity demand (kWh)</td>
<td>4000</td>
</tr>
<tr>
<td>Avoided payment for electricity (€/year)</td>
<td>328</td>
</tr>
<tr>
<td>Internal use rate of the plant (%)</td>
<td>0.1</td>
</tr>
<tr>
<td>Annual electricity fed into grid (kWh)</td>
<td>521000</td>
</tr>
<tr>
<td>Feed-in tariff rate (€/kWh)</td>
<td>0.058</td>
</tr>
<tr>
<td><strong>Annual income from electricity feed-in (revenue) (€)</strong></td>
<td>30218</td>
</tr>
<tr>
<td>Initial investment (€)</td>
<td>300000</td>
</tr>
<tr>
<td>Feedstock price (incl. transport) €/kg</td>
<td>0.025</td>
</tr>
<tr>
<td>Annual feedstock cost</td>
<td>12500</td>
</tr>
<tr>
<td>O&amp;M (3% of investment)</td>
<td>9000</td>
</tr>
<tr>
<td><strong>Total annual cost (€)</strong></td>
<td>21500</td>
</tr>
<tr>
<td>Annual cash flow (€)</td>
<td>9046</td>
</tr>
<tr>
<td><strong>Payback time (years)</strong></td>
<td>33.16</td>
</tr>
<tr>
<td>Discount rate (10%)</td>
<td>0.1</td>
</tr>
<tr>
<td><strong>Net present value (NPV) (€)</strong></td>
<td>-231195</td>
</tr>
</tbody>
</table>

The applied methods of capital budgeting assess the considered gasifier plant as non-profitable. The calculated payback time is 33.16 years, which is higher than estimated project life time of 15 years. Since the NPV is negative, we did not calculate its IRR here, as the project is not profitable.

Nevertheless, do not forget that the stated numbers were given as an example and might vary significantly for your specific project.
Off-grid Energy Projects in Agricultural Value Chains

The off-grid sector presents a huge potential for using renewable resources for energy generation. Worldwide about 1.4 billion people are living without access to electricity [Energypedia, 2014b]. Most of these people live in developing countries and a large portion of them works in the agriculture sector.

Decentralized energy supply in these countries presents various options with the prospective of an enormous potential in the future [IRENA, 2015]. Off-grid systems are systems that are not connected to the public utility grid for electricity, water or gas supply. Off-grid energy supply can be an alternative for regions with unreliable and / or expensive supply from the national grid or for remote areas that will not be connected to the national grid within the next years. A broad range of off-grid energy supply systems is available. Mini-grids can supply several houses or even a small town with electricity. They are based on fossil fuels or renewable energy, or a combination of both (e.g. diesel-PV hybrid system). Another possibility is a stand-alone system. Direct-use systems are without battery storage (e.g. PV-powered water pumping or ventilation) whereas most other renewable energy systems include storage to compensate the fluctuating availability of these resources. Quite popular for this type are solar home systems. In the agriculture sector various different off-grid energy projects can be found. Very common ones are biogas plants on different scales and PV (or in some cases also wind) powered irrigation systems. Moreover, PV and sometimes also small-scale wind power or micro-hydro power can be used for livestock watering, electric fences, lighting, aquaculture and fishing, as well as for refrigeration systems for meat and dairy products. Solar water heaters or biogas plants can be used for heat supply, e.g. for sterilization of fruits and vegetables.

Case Studies from Agriculture

1. Small biogas plant

“Turn your organic waste into energy and by doing so reduce your energy costs”

You want to have your own biogas plant to convert your organic waste into biogas? First think about your intended business model type (following table 1 above), including the following points:

- Do you have access to organic material (such as animal manure, sewage, food and organic waste, human excreta, plants or any residues from agricultural production that you
could use to feed the biogas plant? Is it for free or do you have to pay for it? How much is the available quantity per day and over the year?

- What do you want to generate? Biogas, electricity, heat or biofuel? And do you want to use this to meet your own needs or do you want to sell it?

- In case that you want to sell it, how big is the market? How many possible customers? What is the current market price for your product? How and via which channels do you want to sell it?

After this you can try to predict the possible profit of your biogas plant by subtracting all costs from the total revenue in order to see the possible profit. The list in Table 3 provides an indication about important items that should be taken into account. But take into consideration that revenue and OPEX occur each year whereas CAPEX is generally a one-time expense. Nevertheless, for obtaining a reliable financial result, you should apply the methods of capital budgeting. For applying them, you need the life time of the biogas plant (ask the producer!) and the current interest rate (ask your bank!).

For the costs considerations, generally it can be said that the capital expenditures for an anaerobic digester are moderate and you can reduce them by using your own human power for planning and constructing, although you still should consider consulting an expert to assist you in order to prevent failures. The required effort for operation and maintenance is quite small. If the construction is designed properly, maintenance cost should be minimal. In terms of maintenance in most cases you can carry it out by yourself and save money.

For calculating the revenue, use the prices that you currently pay for the items to be replaced by biogas, and for the sales calculation, use the current market prices. You can collect a part of the required cost information from producers of biogas plants. The advice of your neighbors or friends who already use such a plant can be very helpful. Besides, your bank might be able to inform you about the capital costs.
## Financial Benefits

<table>
<thead>
<tr>
<th>Revenue</th>
</tr>
</thead>
</table>
| • Avoided payment for fertilizer, kerosene, cooking gas, fuelwood, etc. This direct saving goes into the calculation as indirect revenue.  
• Revenues from the sales of biogas and electricity and heat or biofuel depending on the plant size and type  
• Sale of quality fertilizer |

## Costs Considerations

### CAPEX

- **Initial investment:**
  - Purchasing costs or opportunity costs for land which is needed for the biogas plant and slurry storage
  - Model of the biogas plant (the digester) and other required parts like a dung storage, gas storage, safety provisions, mixing equipment, piping system including liquid-manure and gas lines, biogas stove etc.
  - Planning and dimensioning, construction supervision, licensing fees, etc.
  - Labor input and wages for the people who plan the plant and install it (excavation-work, construction of the digester and gas-holder, etc.)
  - Your opportunity costs for labor in case that you assist in or carry out the construction

Reinvestment costs for replacement of components with a shorter life time than the whole project (for example pumps, floating gas holder, etc.)

### OPEX

- **Acquisition** (purchase, collection and transportation) of the substrate (If you get something for free, like for example if substrate is from your own livestock, then no costs have to be considered for purchasing it)
  - Water supply for cleaning the stable and mixing the substrate
  - Feeding and operating of the plant
  - Supervision, maintenance, cleaning and repair of the plant
  - Storage and disposal of the slurry
  - Gas distribution and utilization
  - Administration
  - Your opportunity costs for carrying out the necessary activities to ensure a well operation of the plant
  - In case of sale, additional costs occur for example for transport, packaging, advertising, etc.
  - Maybe credit costs (interest) in case that a loan was taken out

---

Table 3: Important aspects to consider in the financial analysis of a small biogas plant [Energypedia, 2015] [ECN, 2011]
EXAMPLE

Let us now discuss one simplified example of a biogas plant for your farm (2 cows, 8 pigs, 4 adult persons), assuming that you carry out most of the work yourself and that sufficient water is available for free. It is assumed that your farm and household generate enough substrate to run the biogas plant. The generated biogas is used for cooking and 1/6 of the produced fertilizer is used for your farm land and the rest for sale. For being able to apply the described methods of capital budgeting we will assume the following data (Please note that the numbers used are simplified for this example and are not representative on site. They vary a lot depending on which type and size of the biogas plant, on which substrate you use, on your current used fuel for cooking, on how much of the work you do yourself, etc.):

REVENUE:

- Avoided payment for fertilizer: 0.4 $/kg, amount 1/6 of fertilizer amount generated by biogas plant
- Avoided payment for LPG: price 1 $/kg, amount 12 kg/month

COST:

CAPEX

- Bio gas plant (3 m³) incl. construction: 400 $
- Equipment incl. biogas stove: 60 $

OPEX

- Annual substrate cost: 0 $
- Annual cost for operation, maintenance, replacement: 5 % of initial investment

OTHER PARAMETER:

- No land purchase cost or rent payment considered
- Project life time of 10 years
- Discount rate: 10 %
- 1 cow: 10 kg dung/day and 1 kg manure/day --> 0.5 m³ biogas/day
- 1 pig: 1 kg dung/day and 1 kg manure/day --> 0.06 m³ biogas/day
- 1 adult person: 1 kg faeces/urine/day --> 0.06 m³/day
- For cooking (3 times/day): 0.4 m³ biogas/person/day
- Water requirement in plant (bio-waste: water): 1 : 0.5
- Assumed residence time: 60 days
- Assumed density: 1000 kg/m³
EXAMPLE

With this provided data we can calculate the profitability of this project.

### FINANCIAL ANALYSIS

#### CAPEX

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biogas Plant (3m³) (incl. Construction)</td>
<td>400</td>
</tr>
<tr>
<td>Equipment (incl. biogas stove)</td>
<td>60</td>
</tr>
<tr>
<td><strong>Total initial investment</strong></td>
<td><strong>460</strong></td>
</tr>
</tbody>
</table>

#### OPEX

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substrate cost</td>
<td>0</td>
</tr>
<tr>
<td>Annual Operation, maintenance, replacement cost</td>
<td>23</td>
</tr>
<tr>
<td>(5% of invest.)</td>
<td></td>
</tr>
<tr>
<td><strong>Annual operational cost</strong></td>
<td><strong>23.00</strong></td>
</tr>
</tbody>
</table>

#### REVENUE

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avoided payment for LPG (1 $/kg; 12 kg/month)</td>
<td>144.00</td>
</tr>
<tr>
<td>Total avoided payment ($/year)</td>
<td>299.73</td>
</tr>
<tr>
<td>Sale of fertilizer (0.04 $/kg)</td>
<td>77.87</td>
</tr>
<tr>
<td><strong>Annual revenue ($)</strong></td>
<td><strong>377.60</strong></td>
</tr>
<tr>
<td><strong>Annual cash-flow ($)</strong></td>
<td><strong>354.60</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Payback period (years)</strong></td>
<td><strong>1.30</strong></td>
</tr>
<tr>
<td><strong>Discount rate (10%)</strong></td>
<td><strong>0.1</strong></td>
</tr>
<tr>
<td><strong>Net present value (NPV) ($)</strong></td>
<td><strong>1718.86</strong></td>
</tr>
<tr>
<td><strong>Internal Rate of Return (IRR) (%)</strong></td>
<td><strong>76.83%</strong></td>
</tr>
</tbody>
</table>

#### Additional calculations

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biogas generation by dung of cows (m³/day)</td>
<td>1</td>
</tr>
<tr>
<td>Biogas generation by dung of pigs (m³/day)</td>
<td>0.48</td>
</tr>
<tr>
<td>Biogas generation by dung of persons (m³/day)</td>
<td>0.24</td>
</tr>
<tr>
<td>Total daily biogas generation (m³/day)</td>
<td>1.72</td>
</tr>
<tr>
<td>Biogas required for cooking (m³/day)</td>
<td>1.6</td>
</tr>
<tr>
<td>Water requirement (for 32 kg dung/day)</td>
<td>16</td>
</tr>
<tr>
<td>Overall inlet into reactor (kg/day)</td>
<td>48</td>
</tr>
<tr>
<td>Required biogas plant size (m³) based on 60 days residence time and assumed density of 1000 kg/m³</td>
<td>2.88</td>
</tr>
<tr>
<td>Generated fertilizer (1/5 of bio-waste quantity)</td>
<td>6.4</td>
</tr>
<tr>
<td>Own consumption of fertilizer is 1/6 of generation (kg/day):</td>
<td>1.07</td>
</tr>
<tr>
<td>Remaining fertilizer for sale (kg/day)</td>
<td>5.33</td>
</tr>
</tbody>
</table>

The applied methods of capital budgeting assess the considered biogas plant project as profitable. The calculated payback time is 1.3 years. The NPV is positive and the IRR is with 76.83 % much higher than the predefined minimum acceptable rate for this example of 10 % (discount rate).

Nevertheless, do not forget that the stated numbers were given as an example and might vary significantly for your specific project.
2. Solar dryer

“Store your fruits and vegetables for long-time and convert them into high quality goods”

In the second week of this course (B1) you have learned about different types of solar dryers. They do not depend on fuel and they present in general a simple and cheap way for preserving vegetables and fruits for many weeks or months. Its advantage is that you can use the dried products for your own needs as well as trade them all over the year. So if you store them appropriately, your dependence on the harvest time for generating profit is less and you prevent the spoilage of those products that you were unable to sell during the harvest times. By offering the dried products outside the harvest season, you might be even able to sell them for higher prices than the fresh products during the harvest time when there is often an oversupply in the market. All in all, a solar dryer could generate profit for you, but first think about the following points and sum up the possible revenue and costs, including the issues of Table 4. For getting a more reliable assessment of the profitability, apply the methods of capital budgeting.

For defining your business model (following Table 1) in detail consider the next points:

- Which of the vegetables and fruits that you grow is suitable for drying?
- Which amount can you use for drying?
- Does a market for dried food products exist? How many possible costumers do you estimate? How much would they pay for these products? Are there competitors?

**MORE TO LEARN**

1. **Link**: Example business plan for solar processing of tomatoes
2. **Link**: Example business plan for solar processing of vegetables and fruits.
3. **Link**: Example business plan for solar processing of vegetables and fruits.
4. **Link**: Practical Guide Series for Food processing
### Financial Benefits

<table>
<thead>
<tr>
<th>Revenue</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Avoided payment for food that you would need to buy for your personal consumption and what you can now replace by the dried fruits and vegetables. This saving goes into the calculation as indirect revenue.</td>
</tr>
<tr>
<td>• Revenues from the sales of dried fruits and vegetables</td>
</tr>
</tbody>
</table>

### Costs Considerations

<table>
<thead>
<tr>
<th>CAPEX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial investment:</td>
</tr>
<tr>
<td>• Costs for solar dryer</td>
</tr>
<tr>
<td>• Labor input and wages for people who plan and set up the solar dryer, in case you do not do it yourself</td>
</tr>
<tr>
<td>• Equipment needed for preparing the fruits and vegetable for the drying process, like knifes for slicing them</td>
</tr>
<tr>
<td>• Investments for storage requirements: for example a sealer for sealing plastic bags, a room for storage</td>
</tr>
<tr>
<td>• Your opportunity costs for labor in case that you assist in or carry out the construction</td>
</tr>
<tr>
<td>• Reinvestment costs for replacement of components with a shorter life time than the whole project</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OPEX</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Your opportunity costs for cultivating and preparing the vegetables and fruits for being dried (for example slicing them) + opportunity costs for fruits and vegetables that you dry instead of selling them while there is sufficient market demand</td>
</tr>
<tr>
<td>• Costs connected with the cultivation of the fruits and vegetables for drying like seeds, irrigation water, fertilizer and pesticides, maybe labor costs for hired workers, transportation, rent for the field in case that it is not your property, etc.</td>
</tr>
<tr>
<td>• In case that you do not cultivate them yourself, you have to consider purchasing costs for the products required for drying</td>
</tr>
<tr>
<td>• Costs connected with the preparation of the fruits and vegetables for drying such as clean water for washing the products, maybe labor costs for hired workers, maybe rent for a room for carrying out the preparation</td>
</tr>
<tr>
<td>• Costs connected with the storage of the dried products like plastic bags that can be sealed or other material for packaging, maybe rent for a storage room</td>
</tr>
<tr>
<td>• Costs connected with selling the dried products such as quality check, distribution of the product, transport to the market, advertising</td>
</tr>
<tr>
<td>• Maybe credit costs (interest) in case that a loan was taken out</td>
</tr>
<tr>
<td>• Others: cleaning, maintenance and repair of the appliance, electricity</td>
</tr>
</tbody>
</table>

Table 4 Important aspects to consider in the financial analysis of a solar dryer [Teach A Man To Fish. 2010.]
EXAMPLE

Let us now discuss one simplified example of a solar dryer for drying banana and mango for producing 4000 bags of dried fruits per year, assuming that you carry out most of the work yourself. For being able to apply the described methods of capital budgeting we will assume the following data (please note that the numbers used are simplified for this example and are not representative on-site). They vary a lot depending on which type and size of solar dryer you need, which fruits and vegetable you want to dry, labour costs in your country and how much of the work you do yourself, etc.):

REVENUE:
- Sale price per bag (with 100 g of dried fruit): 1.00 $
- Amount of produced and sold bags (pieces): 4000

COST:

CAPEX
- Simple Solar Dryer: 1000 $
- Build-up (Labour cost): 20 $
- Sealing machine for the bags: 80 $

OPEX
- Cost per bag: 0.10 $
- Costs per mango (30g): 0.16 $
- Costs per banana (30g): 0.10 $
- Labour costs (incl. maintenance): 0.35 $/bag

OTHER PARAMETER:
- No land purchase cost or rent payment considered
- Project life time of 10 years
- Discount rate: 10 %

With this provided data we can calculate the profitability of this project.
## EXAMPLE

### FINANCIAL ANALYSIS

<table>
<thead>
<tr>
<th><strong>CAPEX</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple Solar Dryer ($)</td>
<td>1000</td>
</tr>
<tr>
<td>Build-up (Labour cost) ($)</td>
<td>20</td>
</tr>
<tr>
<td>Sealing machine for bags ($)</td>
<td>80</td>
</tr>
<tr>
<td><strong>Total initial investment ($)</strong></td>
<td><strong>1100</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>OPEX</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost per bag ($)</td>
<td>0.10</td>
</tr>
<tr>
<td>Amount of bags per year (pieces)</td>
<td>4000</td>
</tr>
<tr>
<td>Packaging ($)</td>
<td>400</td>
</tr>
<tr>
<td>Costs for mangos ($)</td>
<td>1066.67</td>
</tr>
<tr>
<td>Costs for banana ($)</td>
<td>666.67</td>
</tr>
<tr>
<td>Labour cost (incl. maintenance) ($/bag)</td>
<td>0.35</td>
</tr>
<tr>
<td>Labour cost ($/year)</td>
<td>1400</td>
</tr>
<tr>
<td><strong>Annual operational cost ($)</strong></td>
<td><strong>3533.33</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>REVENUE</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Dried fruit bag (100g) sale price ($)</td>
<td>1.00</td>
</tr>
<tr>
<td>Amount of sold bags per year ($)</td>
<td>4000</td>
</tr>
<tr>
<td><strong>Annual revenue ($)</strong></td>
<td><strong>4000</strong></td>
</tr>
<tr>
<td><strong>Annual cash-flow ($)</strong></td>
<td><strong>466.67</strong></td>
</tr>
<tr>
<td><strong>Payback period (years)</strong></td>
<td><strong>2.36</strong></td>
</tr>
<tr>
<td><strong>Discount rate (10%)</strong></td>
<td><strong>0.1</strong></td>
</tr>
<tr>
<td><strong>Net present value (NPV) ($)</strong></td>
<td><strong>1767.46</strong></td>
</tr>
<tr>
<td><strong>Internal Rate of Return (IRR) (%)</strong></td>
<td><strong>41.06%</strong></td>
</tr>
</tbody>
</table>

### Additional calculations

- 2000 bags of dried mango slices, 2000 bags of dried banana slices
- 1 bag = 100 g of dried fruit, either banana or mango
  - 0.48
- 4000 bags = 400,000 g dried fruit
  - 1 mango (30g) ($) | 0.16 |
  - 1 banana (30g) ($) | 0.1 |
- Required bananas for 2000 bags | 6666.67 |
- Required mangos for 2000 bags | 6666.67 |

The applied methods of capital budgeting assess the considered solar dryer project as profitable. The calculated payback time is 2.36 years, which is about one fourth of the estimated project life time of 10 years. The NPV is positive and the IRR is with 41.06 % higher than the predefined minimum acceptable rate for this example of 10 % (discount rate).

Nevertheless, do not forget that the stated numbers were given as an example and might vary significantly for your specific project.
C3.2 RECAP

- In principle, clean energy projects are distinguished between on-grid and off-grid systems.

- Grid-tied energy systems can use the grid as back-up in cases of temporary unavailability of the renewable energy source. Besides, if a feed-in tariff exists, income from the energy project can be generated by supplying electricity to the grid.

- Gasification technology is one possibility to convert biomass to power, heat and biofuels. A possible feedstock for a gasifier can be agro waste, e.g. rice husks.

- Off-grid systems are decentralized energy systems that are not connected to the national grid. They present a huge potential especially for not yet electrified remote areas in developing countries, and can supply individual households or whole communities.

- Common renewable off-grid systems are solar home systems, biogas plants, solar water heaters, small-scale wind power and micro-hydro power plants.

- For a first impression of the profitability of a project, one needs to sum up all relevant factors that make up the total revenue and the total cost, and compare the results. By applying the methods of capital budgeting more reliable result can be achieved.

- The economic viability of a small-scale biogas plants depends on the availability of organic material, the type of end product and its market demand. The revenue is composed by sales of the end products and the avoided payments for formerly used fuels. The initial investment constitutes the main part of the total cost.

- The profitability of a solar dryer depends mainly on the demand and market value for dried fruits and vegetables. For the costs you have to consider the initial investment and additional cost items during operation.
Summary & Chapter Wrap-Up

In this week, you were provided with an overview on the basic aspects of a business model and the basic methods of capital budgeting for assessing the profitability of projects. The described case studies were meant to give you an idea about how to make a detailed list of cost and revenue factors for the specific considered projects.

The potential for implementing renewable energy technologies for agricultural activities is enormous. For ensuring a long-term sustainable and profitable energy project, a well-defined business model is required. It describes the core strategy of how an organisation plans to generate income. This decision should be based on a detailed market analysis for determining the key elements of the business model. To find out if the investment in the considered project is profitable in the long run, the capital budgeting method presents a helpful tool. First of all, necessary information needs to be gathered about the relevant revenue and cost items for getting an idea about the required initial investment and the annual cash flows. It is important to know that renewable energy technologies can be used on-grid as well as off-grid. Examples considered in this reader were small-scale gasifiers, biogas plants and solar dryers. Implementation of these energy projects developed with a carefully designed business model can not only replace often used fossil fuels in the agricultural sector, but also contribute to economic and social development of the local communities.
REFERENCES


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