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POWERING AGRICULTURE:

AN ENERGY GRAND CHALLENGE FOR DEVELOPMENT

SUSTAINABLE ENERGY FOR FOOD

Massive Open Online Course – Reader

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CHAPTER C

ABBREVIATIONS

CBA	Cost-Benefit Analysis
CAPEX	Capital Expenditures
CDM	Clean Development Mechanism
CHP	Combined Heat and Power
CDM	Clean Development Mechanism
CNG	Compressed Natural Gas
EA	Energy Auditing
EE	Energy Efficiency
FEA	Financial and Economic Analysis
EMS	Energy Management Systems
FA	Financial Analysis
FAO	Food and Agriculture Organization of the United Nations
FEA	Financial and Economic Analysis
FNPV	Financial Net Present Value
GHG	Greenhouse Gases
GI	Galvanized Iron
IFI	International Financing Institutions
IPEEC	International Partnership for Energy Efficiency Cooperation
IRENA	International Renewable Energy Agency
IRR	Internal Rate of Return
ISO	International Standardization Organization
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LCSA	Life Cycle Sustainability Assessment
LCOE	Levelized Cost of Energy
MFI	Micro Finance Institute
MOOC	Massive Open Online Course
NPV	Net Present Value
OPEX	Operating Expenses
PBT	Payback Time
PV	Photovoltaics
RE	Renewable Energy
REN21	Renewable Energy Policy Network
RESCO	Renewable Energy Service Companies
SDG	Sustainable Development Goals
SE4All	Sustainable Energy for All
SPIS	Solar Powered Irrigation Systems
TWh	Terrawatt hours
UASB	Upstream Anaerobic Sludge Blanket
UN	United Nations
UNEP	United Nation Environment Program
WEF	Water-Energy-Food

CHAPTER A

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. 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

Unit A1.1 | 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 must 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. Agriculture is currently the number one consumer of water resources, accounting for 70 percent of all freshwater use. On the one hand, water is required for food production, processing, transport and preparation – and for producing energy: water withdrawals for energy production in 2010 were about 15 percent of the world's total water withdrawals (IEA, 2012). On the other hand, energy is an essential requirement for the withdrawal (pumping), distribution and treatment of water. The nexus approach considers all three sectors – Water-Energy-Food (WEF) – while taking into account that approaches adopted in only one sector might affect the other sectors negatively. The interdependency between the WEF sectors has become more and more evident, as the international

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Project "Powering Agriculture – Sustainable Energy for Food", Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. Support Program to the German Contribution to "Powering Agriculture: An Energy Grand Challenge for Development".

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LINK

FAO Water-Energy-Food (WEF) Nexus Rapid Appraisal
www.fao.org/energy/water-food-energy-nexus/water-energy-food-nexus-ra/en/

debate progresses since the Bonn 2011 nexus conference (FAO, 2014). The WEF nexus 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.

Unit A1.2 | Population Growth and Food Production

In the 1960's, 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. Dependency on fossil fuels creates a high risk of fluctuating food prices, which might then become unaffordable for the economically weak. In addition, fossil fuels cause greenhouse gas emissions. Not to forget population growth. *(Figure A1)*

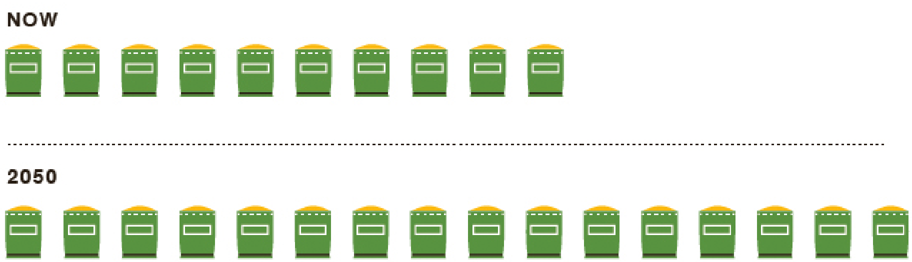

Figure A1 | Global Food Demand by 2050 (CCFAS, 2015)

However, simply repeating the green revolution is highly unlikely. 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 merely be to call for more irrigated land, but it may not be as simple as that. For instance, approximately 40 percent of the global land mass is classified as agricultural land with only very limited opportunities for expansion (FAO, 2011). The FAO estimates that globally every year 25,000 million tons of topsoil are washed away by water erosion. Not only is the area available for food production limited but its suitability for production is continuously being eroded. Solutions are urgently needed. To identify effective changes, stakeholders will have to look at different aspects and segments along the agri-food value chains. Cultivation methods that make efficient use of resources are a major step forward.

CLOSE-UP

The World's Soil Resources

"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." *Donald L. Sparks, University of Delaware, one of US-America´s leading soil scientists* (Chajes, 2015)

CLOSE-UP

The Future of Food and Farming

"If food security is to be provided for a predicted nine billion people substantial changes will be required throughout the different elements of the food syste m and beyond. Action has to occur simultaneously on all of the following four fronts:

- More food must be produced sustainably through the spread and implementation of existing knowledge, technology and best practice, and by investment in new 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)

Unit A1.3 | Agricultural Production and Value Chains

One conclusion to draw from the above analysis is that the agri-food sector must become more efficient. This can be achieved either through ***energy efficiency [» Unit B3]*** measures or through the application of ***renewable energy [» Unit B1]***. In any case, changes need to include the entire agricultural value chain as shown in *Figure A2*. This includes: input providers, farmers, processors, packagers, distributors and retailers.

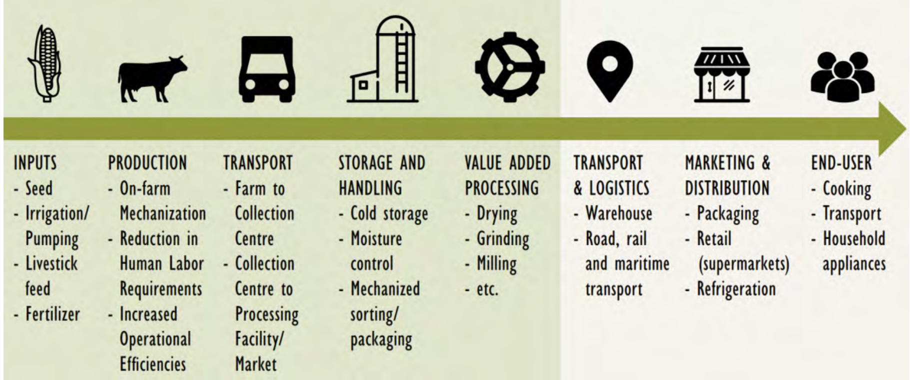

Figure A2 | Agricultural Value Chains (Sims et al., 2015)

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 amounts to an annual cost of US $4bn (FAO, 2011). Losses often occur due to non-existent, inadequate and/or interrupted energy input during storage or transportation and at markets.

Figure A3 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 occur mainly 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 behavior. By joining forces, civil society, private sector and government in high-GDP countries can reduce waste in the retail and consumption sector.

CLOSE-UP
What is a Value Chain?

A value chain is the sequence of productive processes from the provision of specific inputs for a particular product to primary production, transformation, marketing, and up to final consumption (the functional view on a value chain). As these functions are carried out by chain operators, a value chain is also an institutional arrangement linking and coordinating producers, processors, traders and distributors of a particular product. (GIZ, 2008)

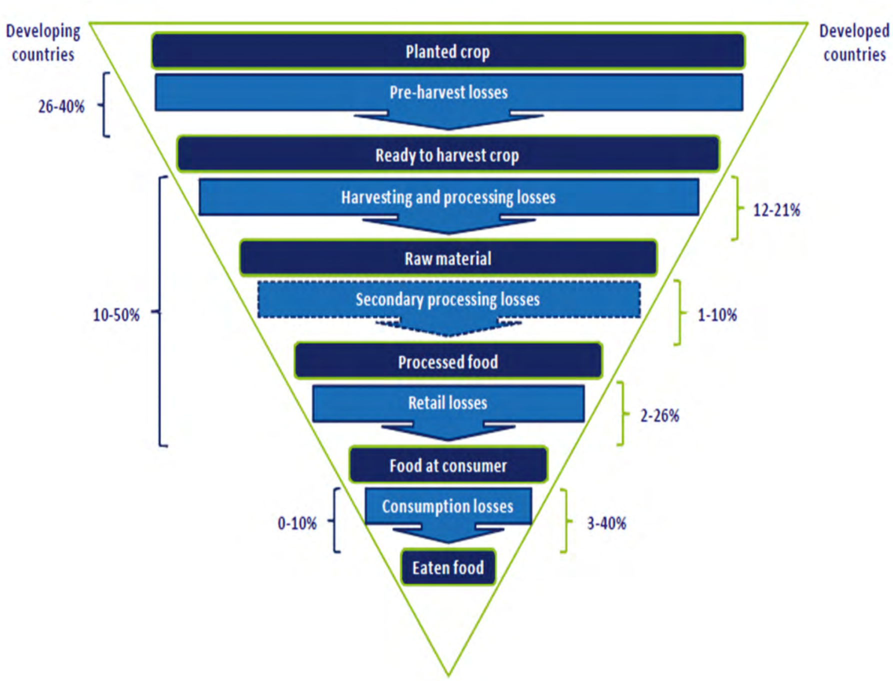

Figure A3 | Food Losses Along Agricultural Value Chains (FAO, 2014)

RECAP

- The population of the world will reach 9 billion by 2050 – demand for food will grow.
- Rapidly growing demand for resources conflicts with planetary boundaries.
- The agri-food sector has to become more efficient to meet growing demand.
- Around 30 percent of global energy consumption can be traced back to the agri-food sector.

UNIT A2 CLIMATE CHANGE

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

Unit A2.1 | Climate Change and Primary Agricultural Production

Meeting 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 agri-business sector and poses a threat to food security.

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

Studies predict the shortage of water and food for billions of people due to climate change (Sims et al., 2015). These changes call for adaptation measures such as new technologies and the cultivation of new crops.

Unit A2.2 | Adaptation to Climate Change

In view of growing food demand, successful adaptation to climate change require increasing production under inferior conditions. Therefore, adaptation strategies need to be broadly supported by institutions, and national frameworks, and international agreements need to be modified as well. Targeted investments will be required, as well as development capacity, in order to achieve integrated action across diverse sectors. The complexity of the challenge has been highlighted in a report by UNEP, which also stresses the central role of the small-scale farming sector. (UNEP, 2009)

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

1. shift to more robust crops or more stress-tolerant varieties,
2. modify land use, e.g. trees in farmland,
3. integrate soil cultivation and conservation,
4. increase irrigated land taking sustainable water management into account,
5. integrate water harvesting technologies.

CLOSE-UP

Conservation Agriculture with Ripper-Furrower System in Namibia

Farmers in the north of Namibia are using conservation agriculture to grow drought-tolerant crops, including millet, sorghum and maize. The farming system uses a tractor-drawn ripper-furrower to rip the hard pan to a depth of 60 centimeters and to form furrows for in-field rainfall harvesting. The harvested water is concentrated in the root zone of crops, which are planted in the rip lines with a mixture of fertilizer and manure. Tractors are used in the first year to establish the system. From the second year onwards, farmers plant crops directly into the rip lines using an animal-drawn direct seeder.

In addition, farmers are encouraged to practice crop rotation with legumes. These techniques lengthen the growing season and improve soil structure, fertility and moisture retention. Average maize yields have increased from 300 kilograms per hectare to more than 1.5 tons. (FAO, 2011)

FAO NAMA LEARNING TOOL

The *FAO Learning tool* on Nationally Appropriate Mitigation Actions (NAMAs) gives more information on agriculture and climate change, GHG emission and mitigating options, as well as funding sources.

Whereas it is a central need to adapt our agricultural production systems to better deal with the effects of climate change, agriculture also contributes to climate change by emitting Greenhouse Gases GHG: carbon dioxide is emitted by burning or mineralizing biomass (e.g. deforestation) and by fossil fuel consumption; methane is produced through enteric fermentation by ruminants, by manure management, as well as in irrigated rice production and, finally, by nitrous oxide from the use of nitrogenous fertilizer (GIZ, 2014).

Unit A2.3 | Climate Neutral Productivity Growth

Agricultural, food and other land use represent 24 percent of total GHG emissions, representing the second largest emitting sector after the energy sector. Agriculture alone contributes 10 – 12 percent (IPCC, 2014). In addition, agriculture must produce more without further increasing the GHG load. However, from 2001 to 2011, carbon dioxide emissions from crop and livestock production increased from 4.7 billion tons to over 5.3 billion tons (Tubiello et al., 2014). The use of fossil-based energy needs to be reduced dramatically. Possible solutions include introducing ***renewables [» Unit B1]***, ***optimizing processes and lowering energy intensity [» Unit B3]*** – but also reducing food losses and waste. 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. Emissions in land and livestock management also have to be mitigated.

Potential optimization of food supplies of is very much linked to the supply of energy. ***Abundant energy resources such as wind, solar, hydro and biomass are available [» Unit B2].*** These technologies make on-site generation of electricity and thermal energy possible. The implementation could be both technically and economically feasible on all scales, from subsistence farming to large-scale agriculture.

Lowering energy intensity builds on behavioral changes, the development and implementation of low-carbon practices, and investment in improved technologies with a particular focus on ***energy efficiency [» Unit B3]***. 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 enable the production of more food per unit of land globally with less energy inputs.

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 and account for up to 30 percent of total production costs. Efficient lighting, upgrading fans, better fuel wood manage-

CLOSE-UP

Carbon Footprint

"A carbon footprint is a measure of the exclusive total amount of carbon dioxide equivalent emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product."
(Wiedmann & Minx, 2007)

CLOSE-UP

Adaptation and Mitigation

Mitigation: "An anthropogenic intervention to reduce the sources or enhance the decrease of greenhouse gases."
Adaptation: "Adaptation to climate change refers to adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities."
(IPCC, 2007)

ment and the use of alternative fuels can save up to 34 percent fuel wood and two percent electricity (***Ethical Tea Partnership***).

RECAP

- Extreme weather events due to climate change impact agricultural production.
- Adaptation and mitigation measures need to be implemented, such as new technologies and cultivation of new crops.
- Introduction of renewable resources, optimization of processes and lowering of energy intensity can design productivity growth in a carbon-neutral way.

CLOSE-UP

Climate Smart Agriculture

Climate Smart Agriculture means
- Sustainably increasing agricultural productivity and incomes
- Adapting and building resilience to climate change
- Reducing GHG emissions, where possible

(FAO, 2011)

UNIT A3 ENERGY INPUT IN AGRICULTURAL VALUE CHAINS

This unit discusses indirect and direct energy inputs along the agricultural value chain, including the financing side of alternative energy solutions.

» Unit B1.1 – Milk value chain

Unit A3.1 | Energy Input in Agricultural Production

Energy is used at every stage of the agricultural value chain: from production over processing, post-harvest and storage to distribution and retail. *(Figure A4)*

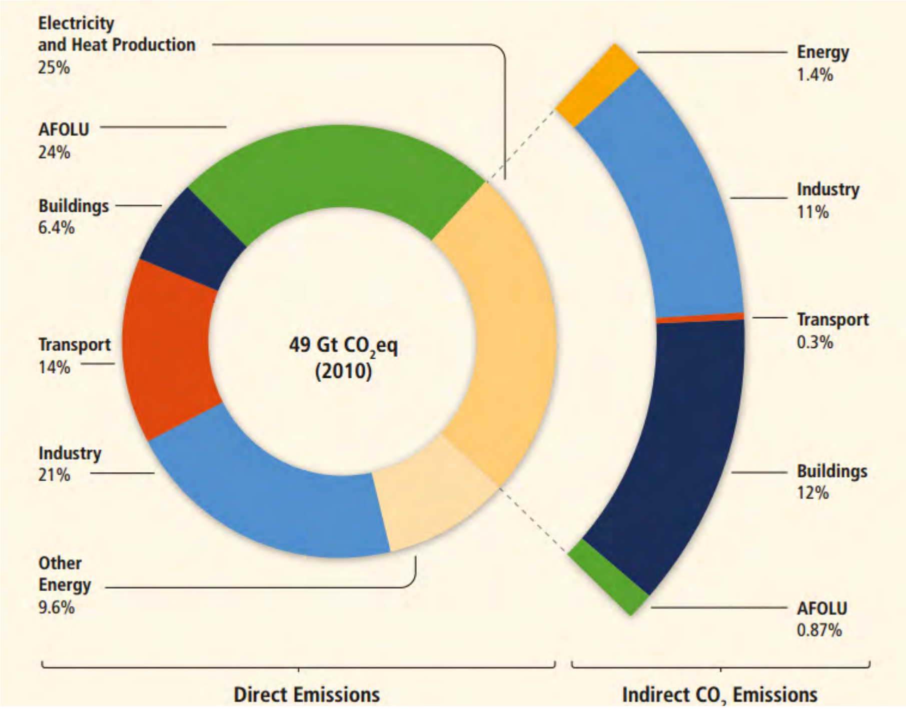

Figure A4 | Energy Inputs in Agricultural Value Chains (Best, 2014)

Direct and indirect energy inputs are equally necessary 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 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 and there is a risk of over-exploitation when low-cost energy is available (see CLOSE-UP of the Rebound Effect for more information).

Indirect energy is applied through the use of machinery, pesticides and fertilizers. Nitrogen fertilizer production alone accounts for about half of the fossil fuels used in primary production. Significant amounts of nitrous oxide can be emitted during the production of nitrate (Sims et al., 2015). Nonetheless, energy-intensive fertilizers can 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.

Unit A3.2 | Energy Input in the Downstream Sector

The downstream sector 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 for over 50 percent of the total on-farm energy demand. 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, the total carbon footprint can amount to up to 10 percent. If electricity input, 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).

The processing and packaging part of agricultural food chains is also a main contributor to overall energy utilization. A retail food product, for instance,

CLOSE-UP

The Rebound Effect

Be aware of the rebound effect: "The rebound effect occurs when reductions in energy demand result in lower energy prices which, in turn, encourage energy purchases in other areas." (Barker & Dagoumas, 2009)

CLOSE-UP

Solar Cooling for Storing Livestock Vaccine in Angola

Animal husbandry is an important source of livelihood in rural Angola and a major agriculture activity. But the livestock are vulnerable to diseases due to a lack of reliable veterinary services and access to vaccination, and vaccines are required to be stored in specific temperatures to survive. The lack of access to energy hampers the storage and distribution of these vaccines across rural Angola resulting in loss of preventable animal life. In 2011 the 'Strengthening of Livestock Services in Angola' project led by FAO, co-funded by the EU and the Institute of Veterinary Services of Angola, installed solar energy systems in refrigeration rooms in 15 municipal veterinary pharmacies. This included four PV systems to power veterinary centers, incl. cold storage rooms, and around 15 absorption refrigerators to store vaccines in different villages. Solar energy systems and solar coolers have made vaccines more available and have provided herders with the right tools to treat their animals, thus reducing livestock mortality (and consequently, the waste of natural resources)." (FAO, 2011) 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. By utilizing thermal and mechanical vapor 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 or less efficient technologies. The possibilities for improvement are abundant. Good maintenance of older processing plants can lead to energy savings of 10 to 20 percent. 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 savings can be achieved (Sims et al., 2015).

Transport is another consumer of energy in agricultural value chains. For instance, when fresh food is transported by air or long distances by road, transport can account for up to 70 percent of the total carbon footprint. While transport is a relevant topic for the Energy Agriculture Nexus, this course does not further elaborate on this topic.

Unit A3.3 | Financing 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. However, alternative energy solutions come at a cost. Whether they are applicable is very much dependent on the individual situation and financial background. ***Cost-benefit analysis and feasibility analysis are [» Unit C2.2; » Unit C1]*** valuable to support decision-making.

RECAP

- Direct and indirect energy inputs are needed in agricultural value chains.
- Each step of the agricultural value chain presents options for mitigating GHG emissions.
- Processing, post-harvest, storage and cooling are energy-intensive steps of many agricultural value chains.
- Viability of investments in clean energy solutions is very much dependent on the individual context and thus requires detailed analysis.

CLOSE-UP

Solar-Powered Refrigeration for Dairy Farms in Kenya

Due to limited electrification in rural areas, 85 percent of Kenya's one million smallholder dairy farming families do not have access to refrigerated storage and transportation. This deficiency 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 may unnecessarily lose significant earning potentials.

Recognizing the need for affordable cold-chain technologies, *SunDanzer* has developed a small-scale portable cooling system. 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 facility. This clean energy solution aims to increase dairy farm productivity and income by significantly decreasing milk spoilage.

» Unit C2.2
» Unit C1

SUMMARY & UNIT WRAP-UP

Population growth, limited resources, increased demand for food. Meeting these developments in a sustainable way poses tremendous challenges, amongst others:

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, as well as 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 using renewable energy.

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 [» Unit B1]***. Further, solar and ***bioenergy [» Unit B2]*** are introduced with a focus on potential technological solutions for agricultural value chains. The final unit of the technological chapter will be on ***energy efficiency [» Unit B3]***.

From Week 5 to Week 7, the MOOC will continue to explore economic aspects on the ***macro- [» Unit C2]*** and ***micro-levels [» Unit C2]*** and will take a closer look at ***business options [» Unit C2]*** and investment planning for clean energy solutions for agricultural value chains. Furthermore, 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.

MATERIALS

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CHAPTER B

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UNIT B1

INTRODUCTION

Unit B1 covers renewable energy technologies and energy efficiency in agricultural value chains. Unit 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. Unit B1 focuses on major RE technologies currently used around the world, followed by a case study. However, ***solar power [» Unit B1.3]*** will be in a unit of its own and ***bioenergy [» Unit B2]*** will be presented in detail in the next chapter of this MOOC reader.

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UNIT B1

RENEWABLE ENERGY RESOURCES AND TECHNOLOGY

FOSSIL AND RENEWABLE ENERGY RESOURCES

Energy is available in many different forms. One group of energy resources – stored in oil, coal and natural gas is depleting and non-renewable – and is called fossil fuels. Another group of energy resources is renewable; most of them are derived from every day's solar radiation (as wind, biomass (photosynthesis) and water are a result of solar radiation at the long end) and either directly or indirectly converted to useful forms. RE resources that do not depend on sunlight are tidal energy (conversion of gravitational energy) and geothermal energy (the earth's internal heat generated from radioactive decay). These renewable energy resources have many advantages over fossil fuels: They are available almost everywhere on earth and do not deplete. Broadly speaking, renewable energy systems are characterized by high investment costs and low operational costs, since operating a power plant often does not require any further resources (except of course maintenance). Energy from fossil fuels in contrast is characterized by lower investment cost and higher operational costs. Converted into different useful forms of final energy (e.g. mechanical, electrical or useful heat), renewable energy can play an important role in 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 a given, renewables can provide access to modern energy for farmers and agribusiness, and even replace existing fossil fuels with more sustainable energy systems.

Unit B1.1 | Renewable Energy and Agricultural Value Chains

Today most energy inputs are based on fossil fuels such as oil, coal or natural gas. This is one reason why agriculture accounts for about 12 percent of global GHG emission (IPCC, 2014).

» Unit A2

Most likely more energy will be needed to support agriculture becoming more resilient to more extreme weather events (*Unit A2* gives more information on the agriculture and climate relationship).

Even though, most farmers or businesses in developed or developing countries may only gain few, if any, direct benefits from simply reducing their GHG emissions - the numerous co-benefits of a technology shift towards renewable energy makes the topic attractive and rethinking current energy use worthwhile. This might not only help to reduce emissions but also to benefit from potential cost savings, improving health, local employment opportunities, improved independency and many other beneficial effects (Sims et al., 2015).

CLOSE-UP

Definition

Renewable energy can be defined as "energy that is collected from resources which are naturally replenished on a human timescale, such as sunlight, wind, rain, tides, waves, and geothermal heat." (Ellabban et al., 2014)

MORE TO LEARN

Opportunities for Agri-Food Chains to Become Energy-Smart (PDF) (Sims et al., 2015)

By presenting renewable energy resources and technologies, 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. *Figure B1* shows a ***common agricultural value chain [» Unit A1.3]*** 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.

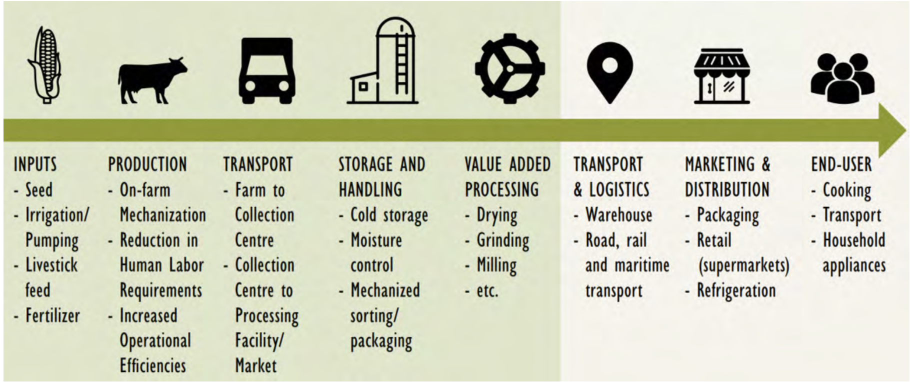


Figure B1 | Agricultural Value Chains (Sims et al., 2015)

Unit B1.1.1 | Example: Milk Value Chain

Milk production is resource intensive in terms of energy inputs and water consumption. Value chains differ based on the country, as well as on the farmer. Consumption of water and energy depend on land conditions, the manner of feeding and milk processing. There are large differences in energy use in the post-harvest stages of milk production in particular.

However, the example *(Figure B2)* shows that energy input appears in different forms. The first energy input is required during land preparation for grazing; fertilizer and irrigation are required. During the feeding process, fuels are used to power machinery to prepare land for feed production, transportation and processing of feed. Especially on farms with larger quantities of livestock, milking is often mechanized and therefore electricity and sometimes heat are needed. Similar requirements can be observed during cooling, transportation and processing of milk. Requirements differ slightly for other dairy products.

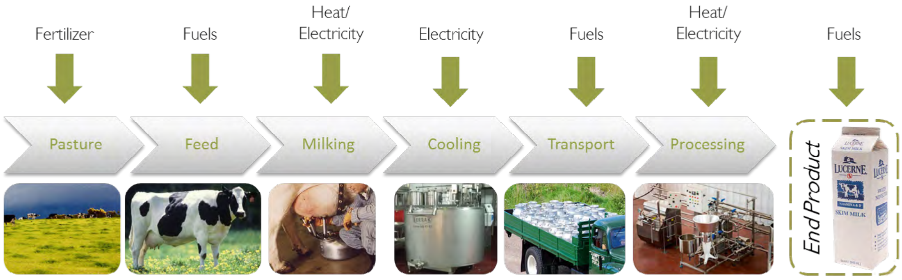


Figure B2 | Steps Along a Milk Value Chain and Energy Inputs (adopted from Sims et al., 2015)

Many of these energy inputs are fossil fuel based. Alternative energy sources for milk production, which are solely based on renewables, are shown in *Figure B3*.

	Energy Demands	Energy Efficiency Options	Renewable Energy Options	Relevance for the Energy Agriculture Nexus
PRODUCTION				
Animal feed production from grazing and crops	Fertilizer use	Precision application Organic fertilizers	Use of crop residues for heat and power	Feed may be produced off-farm and brought in thereby incurring additional transport costs
	Tractor and Machinery performance	Fuel efficient tractors (European standard) Operator education	Biodiesel powered tractors and harvesters	A number of fuel saving options are under the operators' control
	Irrigation	Apply water only as needed Proper pump/motor sizing according to water demands. GPS sprinkler controls	Solar/wind water pumping. Biodiesel-fueled engines for driving pumps	Drip irrigation may be suitable for row crops but not for pasture
On-farm milking	Milk harvesting	Variable speed drive motors on vacuum and milk pumps	Biogas from anaerobic digestion of manure for heat and electricity	Biogas option depends on scale and cost of labor to maintain and operate the plant
	Milk cooling	Pre-cooling of milk and heat exchanger for hot water		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
PROCESSING				
Thermal treatment	Pasteurization, thermization, and homogenization	Real time monitoring of heat energy use. Recovering steam for heating. Recovering waste heat from milk chillers	Concentrating solar power (CSP) or bioenergy for heat generation. Evaporative coolers using solar PV panels	Wide range of standard energy efficiency options for motors, fans
	Drying and cooling	Improved technological designs of dryers	PV-powered refrigerators (solar chillers). Bioenergy heat such as from wood pellets	Drying for milk powder production requires high temperatures and a reliable heat supply
Water usage	Water used in cleaning-in- place (CIP)	Water recycling and re-use. Using on-demand hot water systems rather than storage tanks	Wastewater produced from dairy processing can be recycled to produce biogas for heat, electricity or transport fuels	Raw biogas is corrosive and can therefore be scrubbed of H2S for use in engines
TRANSPORT				
	Diesel fuel use	Implementing sustainability measures (such as EURO standard vehicles). Route optimization. Reducing idle time. Selecting optimum truck size for the load. Driver education	Liquid biofuel or biogas-powered vehicles. Heavy duty electric vehicles beginning to reach the market	Good truck operators use less fuel. Driver training courses exist

Figure B3 | *Alternative Energy Sources for Milk Production (Sims et al., 2015)*

As indicated in *Figure B3* 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 be used directly as an energy source. An integrated energy source will eventually reduce waste, costs and increase the ***sustainability [» Unit B3.4]*** of a product or process.

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 where the process will be based, and concluding by optimizing individual process parameters (week 4).*** 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 essentially about understanding the origins of energy resources. In addition it is important to understand the minutiae of agricultural production and their implications for energy requirements. The next unit will start with a brief summary of renewable energy resources, as well as an overview of technologies used to transform these resources to energy that can actually be used.

Unit B1.1.2 | Renewable Energy Resources

There are three sources for renewable energy on our planet, earth: 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 percent of all energy available on earth, as wind, biomass (photosynthesis) and water are results of solar radiation. With the help of suitable technologies, each of these resources can be converted into useful energy - some examples include: electricity, biogas, heating, cooling and mechanical energy.

Every year the earth receives much more solar energy than the world's annual energy demand. It is even higher than the total known fossil fuel reserves, as illustrated in *Figure B4*. However, due to technological limitations and economic reasons, our global energy supply today is dominated by fossil fuels. Nevertheless, renewable energy technologies are being developed and implemented at a faster pace than ever before. Even if renewable energy resources are distributed throughout the world, location is a crucial factor when deciding which resource should be applied at what intensity.

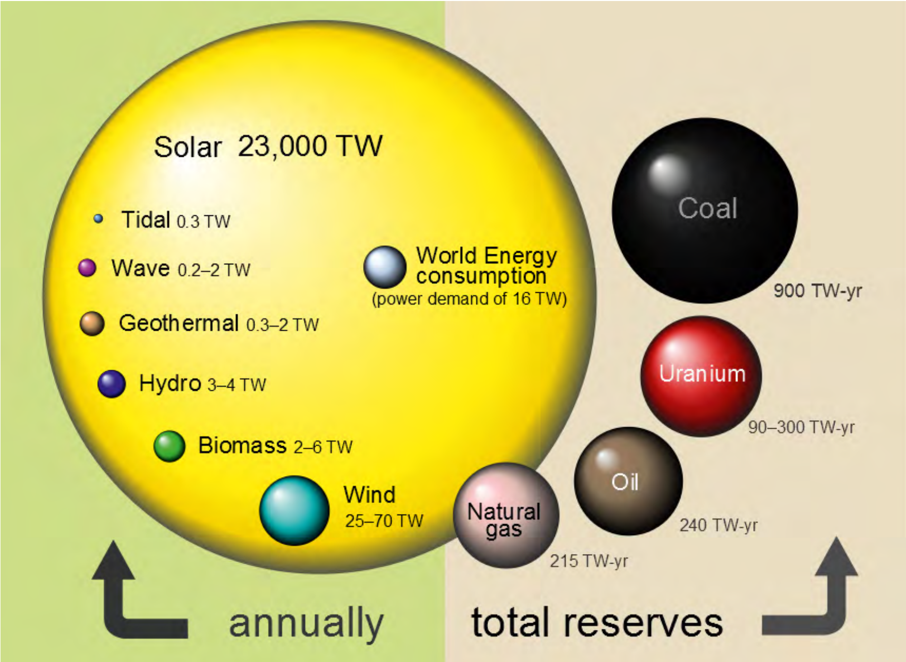


Figure B4 | *Comparing Finite and Renewable Global Energy Reserves (Perez & Perez, 2009)*

Solar and wind energy resources are intermittent in nature - this indicates that not all resources are suitable for each location, purpose or application. Hence site-specific analysis is also crucial. In the case of solar energy, equatorial regions are more suitable than far northern and southern regions. *Figure B5* shows average solar radiation for different regions on earth.

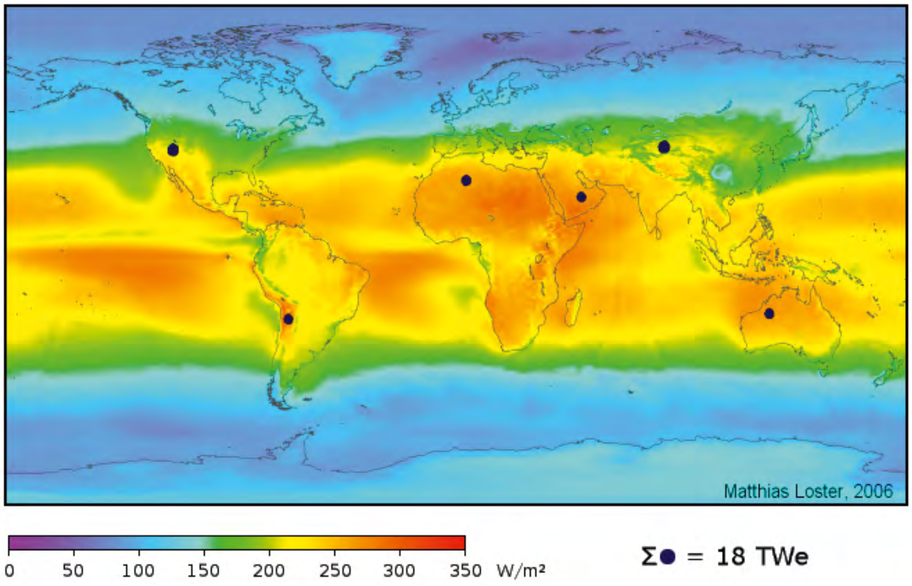


Figure B5 | *Spatially Resolved Solar Irradiance (Loster, 2010)*

Generally speaking, every location has some sort of renewable energy potential. Sometimes this potential is directly visible and at other times different resources must be combined. However, there is almost always a way to tap nature's vast energy supply.

RECAP

- Renewable energy can support farmers in rural remote areas of many developing countries to increase agricultural productivity and income. adding value (e.g. irrigating and drying fruits and vegetables, cheese production)
- There is plenty of potential to use REs in the agricultural value chain. They often have many advantages compared to conventional technologies like diesel generators.
- Integrating RE into agricultural processes can lead to higher efficiency, lower environmental impact and lower production costs.
- There is always some sort of RE resource available in any location, but it is essential to choose an 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.

All energy sources can be transformed into electricity, which is the most versatile form of energy. It can be used to power machinery, for heating or cooling processes, for lightning or powering electronic devices such as pumps. Transformation of energy always entails power losses, so it is important to consider which energy form best suits the purpose.

	Conversion to	Most Applied Technologies and Applications	Relevance for Agricultural Value Chains
Solar Energy	• Heat • Mechanical • Energy • Electricity	• Photovoltaic (PV) driven pumps • Crops, drying of fruits / spices, ice-making and cold storage (through absorption or heat driven refrigeration)	• PV systems are limited to agricultural activities that only require little power • FAO provides an inventory of PV applications
Wind Energy	• Mechanical • Energy • Electricity	• Direct use: grinder, mills, mechanical water pumps • Electrical water pumps	• Option for energy-intensive processing activities
Micro Hydro Energy	• Mechanical • Energy • Electricity	• Direct use: mill, grinder • Electrical motor for processing	• Option for energy-intensive processing activities
Biomass Energy	• Heat • Electricity • Liquid Biofuels Biogas	• Dryer (fruits, herbs, spices) • Fermenter (tea) • Combustion motor or electric motor (fuels like ethanol and biodiesel for transportation) • Anaerobic digester: biogas for lighting, cooking and heating and industrial biogas for decentralized electricity	• Biomass is organic material used to generate electricity, to produce heat or biofuels for transportation. • Bioenergy is derived from wood, agricultural crops, residues, animal by-products, agri-industrial by-products.
Hybrid Power Systems	• Combine fossil fuel-fired generators with wind or solar electrical power	• Wind/PV Hybrid • Wind/Diesel Hybrid(s) • Used in the food-processing sector (grinding of corn, wheat and millet, and milling of grain-hulling paddy)	• Together they provide a more reliable and cost- effective power system than is possible with either wind, solar or diesel alone. • An emerging technology

Figure B6 | Renewable Energies and its Relevance for Agricultural Value Chains

Unit B1.2.1 | 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. The generated electricity can be used along the agricultural value chain.

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. In order to achieve reliable energy production it is important to have good knowledge about local water resources and to design the system accordingly.

Figure B7 illustrates a typical small-scale hydropower system. Its main components are: the weir (where water is raised) and diverted from the main river; the fore bay 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.

POWER EQUATION

P = p*Q*g*h*η
P = power [W]
q = water flow rate [m^3/s]
h = head (falling height) [m]
p = density of water (1000[kg/m^3])
g = gravitational force, 9.81 [m/s^2]
η = efficiency of the system, usually between 50 percent and 75 percent for micro/small hydro

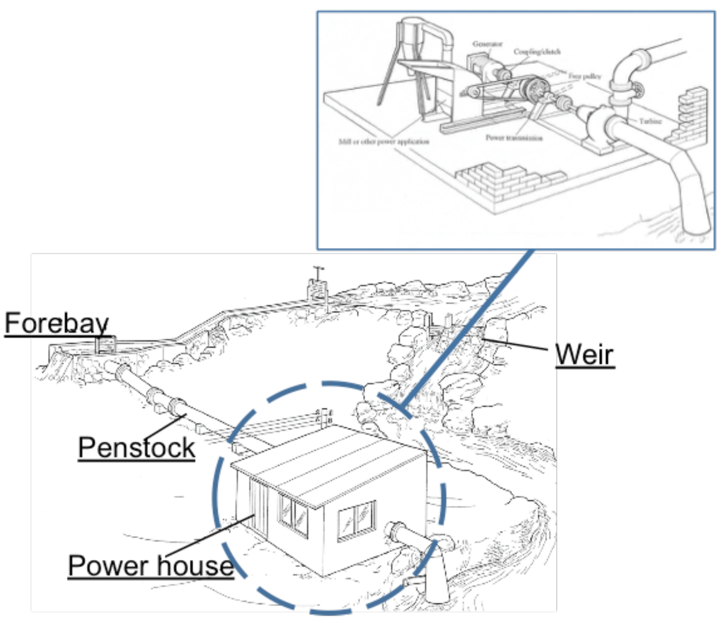


Figure B7 | *Schematic of a Small Scale Hydropower System (adopted from Schnitzer, 2009)*

Small Scale Hydropower Plant in Tajikistan (UNDP/Flickr)

The theoretical power output of such a hydropower system can be estimated by multiplying the water flow of the intake by the height difference from intake to the turbine, the system's 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 hydropower is smart hydro (an in-stream turbine). However, this type has not yet been commercially used on a wider scale.

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 water. 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. No dams and/or height differences are required to operate this device; the river's course 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.

Unit B1.2.2 | Wind Energy

Humankind has been using wind energy since ancient times - to sail, pump water and mill. Today modern wind turbines *(Figure B8)* also produce electricity as well. The global application of wind energy has increased almost exponentially over the past years.

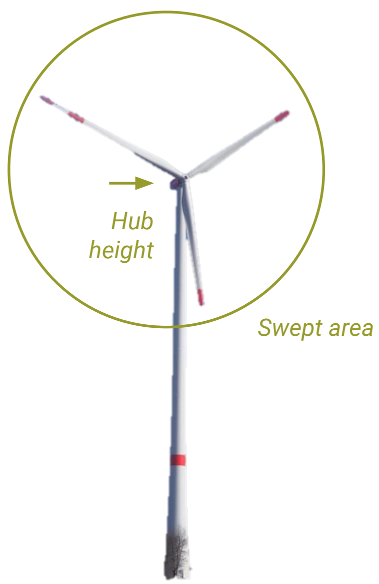


Figure B8 | Modern Wind Turbine (MW Class) (Bhandari, 2016)

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 follows the same principle as hydropower systems. The power output of a wind energy system is generally estimated by multiplying the available wind speed by the area swept by the rotor ***(see MORE TO LEARN)***. Similar to hydropower, the rotational force can be used either directly (irrigation pumps, mills etc.)

CLOSE-UP

Complete Guide to Micro Hydro Power

Micro Hydro Power Scout Guide (PDF) (Schnitzer, 2009)

MORE TO LEARN

Micro Hydro Power Introduction Video (10min)

Smart Hydro Power Video

POWER EQUATION

$$P = 0.5 \cdot p \cdot A \cdot v^3 \cdot C_p \cdot \eta$$

P = power [W]
A = swept area of blades [m^2]
v = wind speed at hub height [m/s]
p = density of air (1,29[kg/m^3])
C_p = power coefficient
η = system efficiency

MORE TO LEARN

Wind Energy Introduction

Animated Wind Pump

Energy Yield Calculation

or to drive a generator and produce electricity. Hence, the possibilities for its use in agriculture are plentiful. Of course the wind does not blow as constantly as a river flows. Therefore, estimating annual energy yield differs slightly. This can be explained with the help of an example:

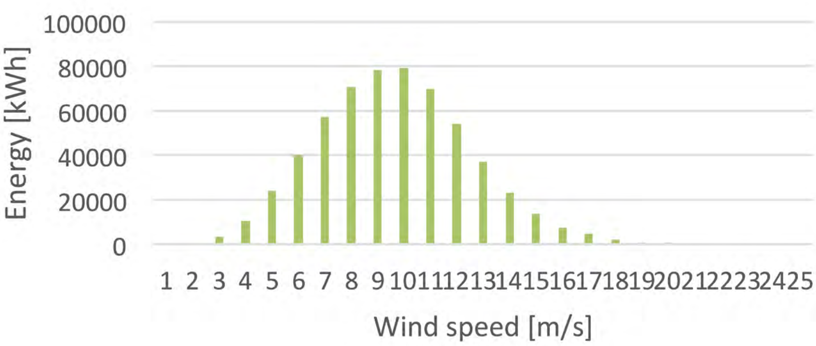


Figure B9 | Frequency Distribution of Wind Speed in a Specific Location (Bhandari, 2016)

To calculate the energy yield of a wind turbine, we multiply the generated power by the amount of time the turbine runs. As a wind turbine produces different power outputs at different wind speeds, the mentioned multiplication is a little more complex. We therefore look at wind conditions in a specific location in detail. Such data can be obtained from wind/weather measurement stations, or from a wind atlas if available for the specific site. *Figure B9* shows which wind speeds are 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.

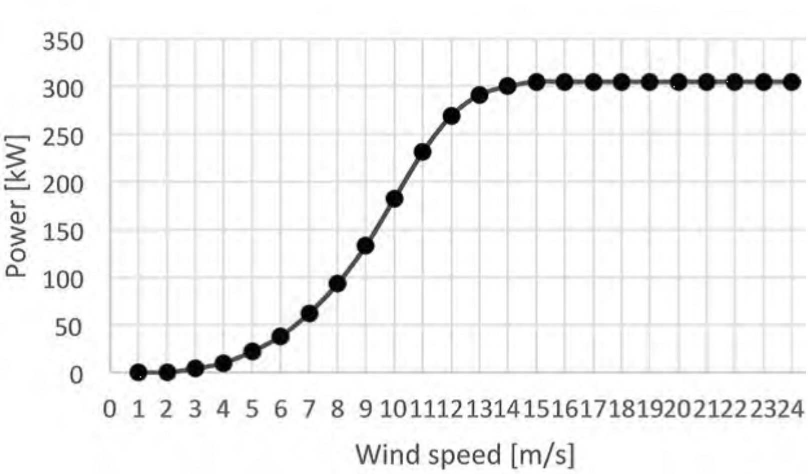


Figure B10 | Wind Turbine Power Curve (Bhandari, 2016)

NOTE

The power passing over the blades is proportional to the cube of the speed of the wind passing over the blades. This means that double the wind speed results in an eightfold increase in the power.

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 curve *(Figure B10)* is specific to every turbine model and normally provided by the manufacturer. It indicates at which wind speed the turbine generates power output. We then 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 B11*. Note that most of the annual energy is produced with a wind speed of 10 m/s even though wind speed of 5 m/s occurs most often. This is due to the power increasing with the cube of the wind speed (Take a look at the power equation above).

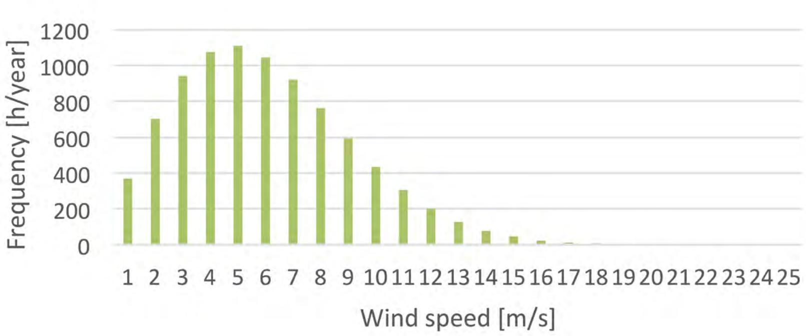


Figure B11 | Energy Production per Wind Class (Bhandari, 2016)

To calculate 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 manually or with software (e.g. Excel):

Equation B1.I: Annual Energy Production

$$AEP = \sum E_i = \sum f_i \times P_i = [(372\,h \times 0\,kW) + (702\,h \times 0\,kW) + (941\,h \times 4\,kW) + (1077\,h \times 10\,kW) + (1107\,h \times 22\,kW) + \cdots] = 578355\,kWh$$

System Example: Wind Pump for Irrigation

Wind pumps have been used since the 9th century – to irrigate fields or to drain the land. Nowadays the technology is mostly used for pumping solutions *(Figure B12)* in areas without a grid connection but with steady wind conditions. The design of a wind pump always depends on the application. Firstly, a distinction between mechanical and electrical wind pumps has to be made. The disadvantage of electrical wind pumps is that they are normally less efficient, but their advantage is pumps can be placed at a distance from the wind turbine. To choose the right wind turbine, considerations about the desired pumping technology and extraction depth have to be made upfront.

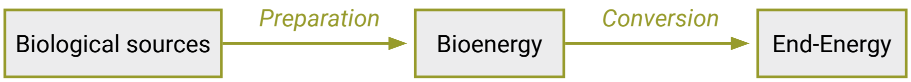
Figure B12 | Wind Pump (Ben Franske/Wikimedia)

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).

Unit B1.2.3 | Bioenergy

» Unit B2

Generally all bioenergy resources are all energy resources derived from biological origin. They can be in solid, liquid or gaseous form. Contrary to coal or gas, which were created over a long timescale (millions of years), they are basically biological material derived from living or recently living organisms. 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.



NOTE

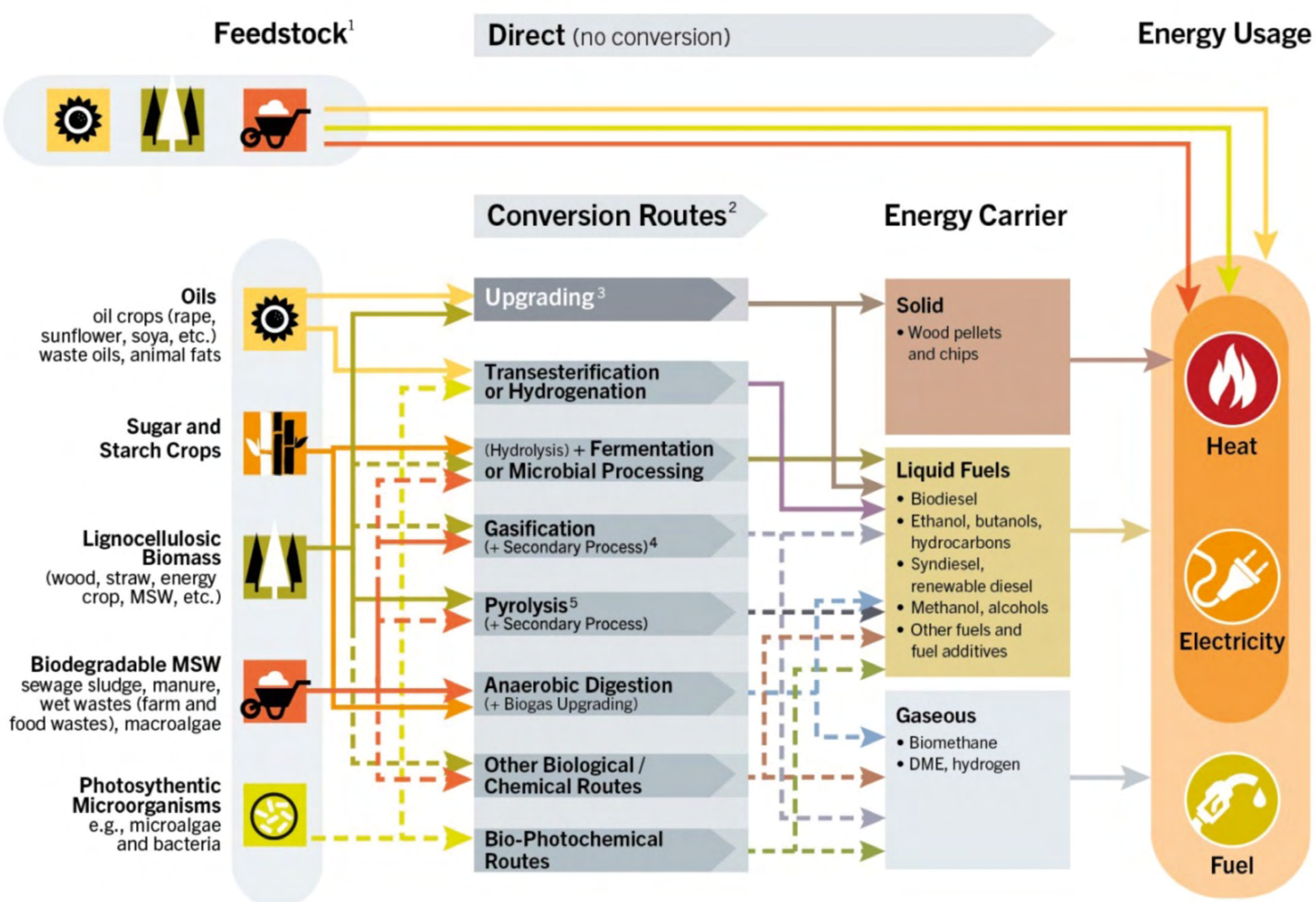
Bioenergy vs. Biofuel

Bioenergy is energy derived from biological resources. It can be in solid (e.g. wood), liquid (e.g. ethanol) or gaseous (e.g. biogas) form.

Generally biofuel refers to liquid (or gaseous) fuel derived from bioenergy resources (e.g. ethanol from corn or sugar cane)

Biomass is often further processed *(Figure B13 and B14)* to increase the energy density, which simplifies its transportation and usage. 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 includes many aspects and can be as simple as burning wood in a stove or very sophisticated such as biogas plants for power production. Bioenergy technologies are especially useful when waste products of agricultural production can be used for power production processes. The generation of biogas from agricultural residues like crops (straw and husk), animal husbandry (manures and slurries) or other organic material from excess production or insufficient market (fruit processing residues, grass silage), is most common. The idea is to have as little waste as possible and therefore a high utilization of resources. ***Circular economy concepts like cradle-to- cradle [» Unit C1.2]*** often involve bioenergy as a core technology. An overview of different ways to convert biomass into biofuels/bioenergy can be seen in *Figure B14* and details on this topic will be presented in ***Unit B2 [» Unit B2]***.

Figure B13 | Small Biogas Plant and Stove (Dishna Schwartz/ GTZ)



Solid lines represent commercial pathways, and dotted lines represent developing bioenergy routes.

Figure B14 | Bioenergy Conversion Pathways (REN21, 2015)

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. *(Figure B15)* 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.

Figure B15 | Evaporative Cooling Project (Powering Ag)

MORE TO LEARN

Lecture on Bioenergy Video

Circular Economy Video

EXPLORE MORE HERE

Unit B1.2.4 | Solar Thermal

Solar thermal technologies *(Figures B16 and B17)* harness solar energy for thermal energy use (heat or cooling). The technologies are comprised of flat plate collectors for low temperature applications. Examples are solar water heaters, solar air heaters for space heating or drying. The concentrating collectors are used for high temperature application (e.g. power production). In this case, incident solar radiation on a larger surface area is concentrated to a receiver with a 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 on a pilot scale. Most common agricultural practice of solar thermal energy use is solar drying.

Figure B16 | Solar Thermal Collector for Water Heating (Cachogaray/Wikimedia)

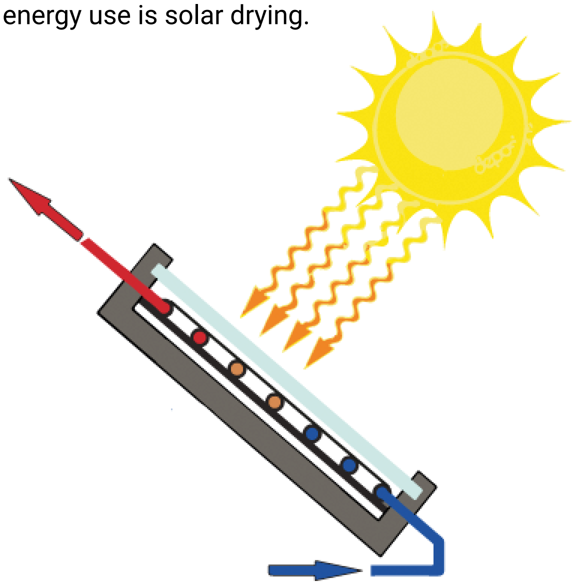


Figure B17 | Process in a Solar Flat Plate Collector (Blue=Cold Liquid, Red=Hot Liquid) (Bhandari, 2016)

MORE TO LEARN

Solar Collectors

Solar Water Heater Overview by Brian Norton

System Example: Sunchill™ Agricultural Product Refrigeration

SunChill™ *(Figures B18 and B19)* 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.

Figure B18 | Sunchill (Powering Ag)

EXPLORE MORE HERE

Unit B1.2.5 | Solar Photovoltaics (PV)

Solar PV is one of the most popular renewable energy technologies. So far it has only been applied on a large-scale 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 independently, with the help of battery storage systems. The use of PV could be expanded beyond lighting, to different agri-processing activities in many countries, for example powering of small loads used in agri-enterprises, like water pumping or product cooling.

Figure B19 | PV modules (David Shankbone/ Wikimedia)

Solar PV is a technology that uses solar cells for energy production. They 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.

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), mounting structure for the modules or array (several modules mounted and interconnected together to produce a desired voltage and current (power capacity), inverter (essential for grid-connected systems and required for many off-grid systems), storage battery and 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 at an example below on how to calculate a required PV system size to supply a demand (load).

Equation B1.II: Required Peak Power of PV Module

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

$$\begin{aligned} P_{peak} &= Peak\ power\ of\ the\ PV\ array\ under\ Standard\ Test\ Conditions\ [W_p] \\ E_{demand,month} &= Monthly\ energy\ demand\ of\ the\ system\ [Wh] \\ Q &= System\ quality\ factor\ (between\ 40\ and\ 70\%\ for\ off\ grid\ projects)\ [\%] \\ I_{STC} &= Irradiance\ at\ Standard\ Test\ Conditions\ [kW/m^2] \\ G_{total,month} &= Monthly\ total\ solar\ radiation\ on\ module\ plane\ [kWh/m^2] \end{aligned}$$

CLOSE-UP

ENERGY 101: SOLAR – PV Video (2 min)

Solar power: An Introduction Video (10 min)

NOTE

Bioenergy vs. Biofuel

Depending on the project size, accurate system sizing could be complex and might require deep knowledge of the technology. However, for many small applications, it can be done in a simple way making it a cost-competitive alternative.

We will now estimate the peak power of a system that is capable of powering a 30W (Watt) light bulb for 3 hours every day for one month in 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 demand from the PV system. We presume a quality factor (Q) of 50 percent for the system used. 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 25 kWh/m[2] in December. You can find these monthly values for your location by using the NASA database *(» Link)*.

By using equation B1.II, we can now calculate the PV size needed to supply light needed in December:

Equation B1.III: Required Peak Power for The Case Scenario

$$P_{peak} = \frac{2790\,Wh}{0.5} \cdot \frac{1\,\frac{kW}{m^2}}{25\,\frac{kWh}{m^2}} = 223.2\,W$$

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

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

Equation B1.IV: Estimation of Battery Capacity

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

$$Bc = \frac{90\,Wh}{80\%} \cdot \frac{3}{80\%} = 422\,Wh$$

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 grid power supply is always available.

RECAP

- There are different renewable energy resources available on earth. However, their quantity and type vary from place to place.
- Hydropower is the most widely used renewable energy resource today. Apart from providing light, many micro hydropower plants used in rural areas of developing countries could power different agri-processing machinery.
- Wind energy is traditionally used in the agricultural sector for processes such as grinding grain and pumping water. Modern wind turbines could be used in grid-connected as well as in off-grid locations for power generation. So far the use of wind power for powering agri-enterprise is limited, only mechanical energy from wind-mills is still used for pumping water.
- Bioenergy has a direct link to agriculture, because agricultural activities/ processes need energy, which also can be generated using agricultural waste products as resources. In recent years this for the efficient use of resources has gained.
- Solar energy can have two applications, solar thermal and solar PV. Different thermal processes in agri industries could benefit from 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.

Unit B1.3.1 | Solar Powered Irrigation

Around the world, agriculture is predominantly situated in rural areas. In these areas, especially in developing and emerging countries, good energy infrastructure often does not exist. As purely rain fed agriculture often is insufficient, groundwater needs to be pumped to the surface to irrigate land. Where grid-based electricity is not available, diesel gas or petrol driven pumps are widely used. The prevailing disadvantage - besides their environmental impact - is the constant need for rather expensive fuel and a high level of maintenance. Using solar powered irrigation systems (SPIS) instead

MORE TO LEARN

Promoting, Financing and Advising on SPIS - Manual and Tools for Development Practitioners, GIZ (PDF) (Hahn, Sass & Frohlich, 2016) can provide a predictable and reliable energy source in most regions and is basically maintenance free after installation, due to its capsulated design. The ***drawback [» Unit C3]*** of rather high initial costs can be compensated by a suitable business model.

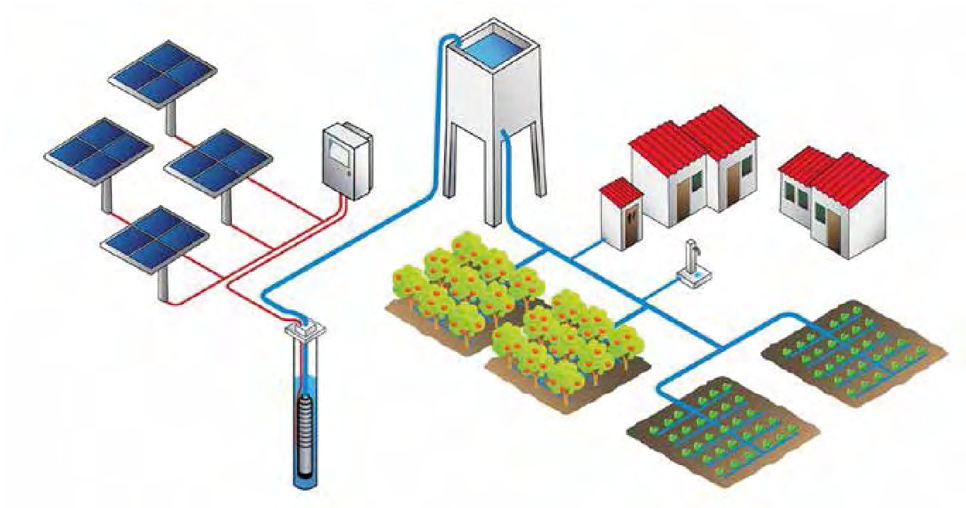


Figure B20 | Schematic Diagram of a Solar Powered Irrigation System (Hahn et al., 2016)

Components of a Solar Powered Irrigation System (SPIS)

Even though the configuration of a SPIS *(Figures B20)* always depends on the local circumstances and available resources, there are some components which all systems have in common. As indicated in *Figure B20*, a SPIS consists of one or more PV panels, connected to a controller unit, which is responsible for adjusting the output frequency according to the irradiation levels. The controller 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 getting clogged.

Design of a SPIS

Before considering designing a SPIS, solid knowledge about the farming system used, the crop's water demand and the general availability of water is needed. These factors strongly influence the decision as to which type of SPIS is suitable takes into consideration.

Figure B21 | Steps for Designing a SPIS

Step 1: Collecting Data

- Daily Crop Water Requirement [m^3/day]
  This should be known by the farmer but can be analyzed or optimized using comprehensive procedures ***(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.
  (See pumping head calculator)
- Mean Daily Global Solar Radiation [kWh/m^2 day].
  This can be measured on site or obtained from the NASA website ***(NASA)***

Step 2: Selecting System Type

Depending on the water resource available (well or surface water) and 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

Choosing the right system type can determine the success or failure of the SPIS, therefore the choice should be made carefully!

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.

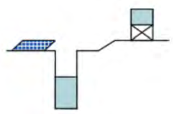
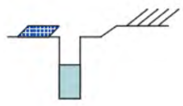
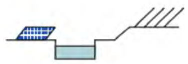
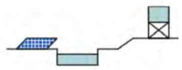
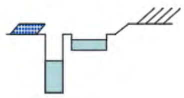
System No:	#1	#2	#3	#4	#5	#6
						
Type	well watertank	well direct irrigation	surface direct irrigation	surface watertank	well, surface direct irrigation	PV on-grid irrigation included
Main characteristics	low head, steady pressure, night reservoir	head varies changing pressure only in daytime	head varies changing pressure only in daytime	low head, steady pressure, night reservoir	head varies changing pressure long-term reservoir	system pressure
Irrigation:	24h/7 days	directly operated by pump	directly operated by pump	gravity fed	directly operated by pump	gravity or direct by AC pump
	drip / micro	drip - sprinkler	drip - sprinkler	drip / micro	drip - sprinkler	all types
Solar generator:	fixed installation	solar tracking or other methods	solar tracking or other methods	fixed installation	fixed installation solar tracking or other methods	fixed or tracked
Fertigation	additional equipment necessary	additional equipment necessary	simple, on suction side	simple, on suction side	simple, on suction side	suction or additional equipm. necessary
Motor pumps:	submersible	submersible	surface	surface	submersible / surface	any AC pump

Figure B22 | SPIS Types and Characteristics (Hahn et al., 2016)

Step 3: Estimate PV System Size

A simplified equation suffices to estimate the system size:

Equation B1.V: PV System Size for Irrigation (Hahn et al., 2016)

$$P_{peak} = 8.0 \times \frac{H_T \times V_{day}}{G_{total,day}}$$

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

As indicated in equation B1.V, the collected data from Step 1 will be used to calculate the power of the required photovoltaic system. The correct size and the amount of solar PV panels can be calculated based on the estimated power requirement. The actual water demand is crucial for choosing the right system size. As water demand is not constant throughout the year, 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

NOTE

For accurate system sizing, please see the tools available in the SPIS manual (Hahn, Sass & Frohlich, 2016) 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 less expensive, but undersized during peak demand.

You will find some additional links for SPIS sizing below

- Meteorological Data Sources
- Crop Water Requirement: CROPWAT
- System Example
- Manufacturers Channel
- Case Study

Unit B1.3.2 | Solar Drying

There are two reasons why ***post-harvest loss of agricultural commodities*** *[» Unit A1.3]* is of significant concern in many developing and emerging countries. People are not aware of the high amount of losses, and they lack proper knowledge on the benefits of using simple post-harvest and conservation technologies. Introducing appropriate post-harvest technology could help in saving wasted food. It also helps to add value to the quality of products that result in a high market price.

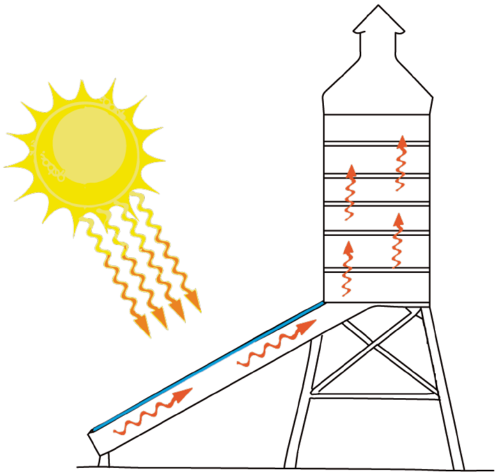


Figure B23 | Schematic of a Solar Dryer (Bhandari, 2016 adapted from http://www.fao.org/docrep/t0522f/T0522F0B.GIF)

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 is accompanied by many problems such as high dependency on weather conditions, slow drying rates, risk of contamination to mention a few. 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. This simple solution has great potential – especially in countries where industrial technologies for preservation are not available or not applicable (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 dryers are based on forced convection (air circulation fan necessary).

MORE TO LEARN

- Fruits of the Nile Solar Drying
- Energypedia on Solar Dryers
- Hohenheim Solar Dryer

Unit B1.3.3 | **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. *(Figure B24)* The inner walls of the box are made of aluminum sheets 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 an air inlet. A chimney made of galvanized iron sheets, attached at the top of the box permits the moist air to 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.

Figure B24 | *Solar Box Dryer (Photo: Bhandari, 2004; Sketch: Bhandari & Amatya, 2003)*

Unit B1.3.4 | **Solar Cabinet Dryer**

The design of a solar cabinet dryer *(Figure B25)* 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 which acts as absorber. The box of the collector is made of galvanized iron (GI) sheet. For insulation purposes, glass wool is inserted in between two covers of the box. The outer cover of the drying chamber is also made of GI sheeting and that of the inner cover is made of aluminum sheeting. Glass wool is inserted between these two covers 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 herbal products, which are sensitive to direct sunlight. These dryers are recommended for community use and small-scale income generating industries.

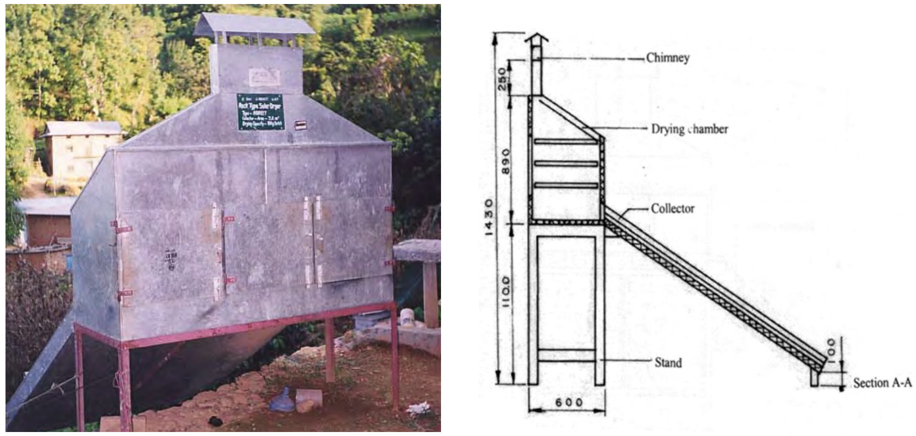


Figure B25 | Solar Cabinet Dryer (Photo: Bhandari, 2004; Sketch: Bhandari & Amatya, 2003)

Unit B1.3.5 | Solar Tunnel Dryer

The solar tunnel dryer *(Figure B26)* 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 commodities themselves. 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 entirely excluded. These dryers are recommended for large scale drying in commercial operations.

Figure B26 | Solar Tunnel Dryer (Bhandari, 2004)

Unit B1.3.6 | Solar-Biomass Hybrid Cabinet Dryer

Biomass resource is the supplementary fuel in the design of the hybrid solar biomass drying system *(Figure B27)*. 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 drying fish and meat products.

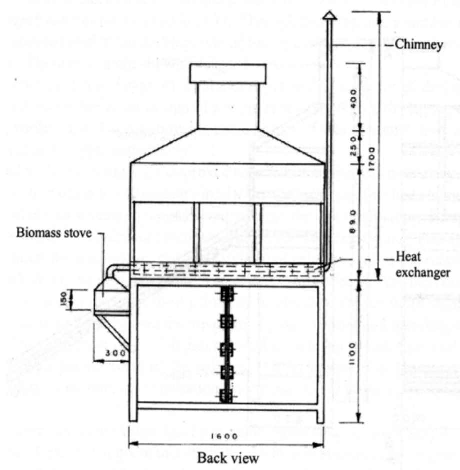


Figure B27 | Hybrid Cabinet Dryer (Bhandari & Amatya, 2003)

RECAP

- Solar energy has significant potential that can be integrated into agricultural value chains, from very small to large-scale applications.
- Solar PV systems are already used in almost all countries worldwide - ranging from large-scale power generation to small-scale solar home systems for lighting. They could play a vital role in pumping water, taking advantage of cheaper (water) storage systems.
- PV pumping could replace fossil fuel or grid electricity based water pumping, and presents an option for farmers without prior access to irrigation solutions to increase agricultural productivity.
- Even if the technology is very simple and can be manufactured locally, solar dryers are important for preservation and value addition of fruit and vegetable products.

SUMMARY & UNIT WRAP-UP

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. About one third of this energy is consumed as a result of food production, supply, and consumption. Today the majority of this energy comes from fossil fuels. Renewable energy resources could mitigate these problems of resource scarcity and emissions. Renewable energy resources are distributed almost everywhere on earth. Access to clean energy solutions for agricultural processes could have multifold benefits, especially in developing countries where subsistence agriculture is a lifeline for many. It could not only displace fossil fuels, but also open up new opportunities for farmers to increase their productivity and add value to produce. And interestingly waste products from agricultural activities could be used to produce energy.

In this Unit B1 you were provided with an overview of these resources and technologies, as well as some practical examples of their implementation in agricultural value chains. In the upcoming Unit 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.

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UNIT B2

INTRODUCTION

Unit B2 will provide you with a technical overview on bioenergy resources and technologies. The focus of this chapter is on 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.

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Anna Perkinson (Tetra Tech)

Please find below links to our materials and references

Video
www.giz.de/gc21/pa_video_lectures

Additional Material
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UNIT B2

BIOENERGY

Unit B2.1 | 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, stimulation of rural development, reduction of the impact of energy use on climate change, and provision of a clean, more environmentally friendly energy source have played a large role in the promotion of bioenergy resource development (Cushion, Whiteman & Dieterle, 2010).

The basic bioenergy process involves the translation of organic material into an end product, which can then be used to produce energy. This sub-chapter provides a general schematic of the biomass to bioenergy conversion process.

Unit B2.1.1 | Bioenergy Resources

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

Wood, straw and other materials containing lignin: Wood, wooden material from landscape management or straw can be used for combustion. Straw can be digested as well.

MORE TO LEARN

Bioenergy Development:
Issues and Impacts for Poverty and Natural Resource Management (PDF)
(World Bank, 2010)

Oily fruits: Biomass with high oil content, like palm fruits, sunflower, rape seeds and even algae can be used to produce bio-oil. Bio-oil can be combusted directly (or in an engine) or further processed to biodiesel.

Agricultural residues: Animal manure or dung has high potential to be used for biogas production. Several parts of plants cannot be sold but can be digested. Examples are leaves and stems from the plants, fruits that cannot be sold due to poor quality, green fertilizer (like clover grass which is mulched to the ground).

Industrial residue, industrial by-products and process water: In food or feed processing organic materials are generated as by-products. Typical industries are fruit or vegetable processing, sugar production, breweries, slaughter houses, potato processing and many others. All of these by-products can be digested.

Disney World Food Waste to Energy

> Disney World has millions of visitors every year; not only do these people enjoy the attractions and rides of the amusement park, but they also eat and drink at many of the parks' restaurants and food vendors. This results in thousands of tons of food waste. Instead of just disposing of this waste in a traditional landfill, Disney decided to put this waste to good use and send the waste to an anaerobic digestion plant that produces 5.4 MW of combined heat and electricity for the resorts' theme parks and hotels.
> (Guardian, 2014)

Municipal waste and residues: Household waste, expired food stuff, materials from canteens and restaurants, and residues from parks and landscape management can be used for bioenergy generation. Wooden material can be combusted; material with high water content and low lignin content can be digested in biogas plants.

Energy crops: Worldwide several fruits are grown for energy production. Examples are palm oil fruit, rage seed, sugar cane, corn and many more. However, the energetic use of fruits is under discussion because of competition with food production and sustainability issues.

A**gri-industrial wastewater and industrial by-products:** Many agri-industries generate wastewater with high levels of organic matter that can be converted to biogas due to typical wastewater treatment and disposal practices. These agri-industries include palm oil mills, sugar processing and refining, ethanol production, and food processing facilities. Industrial by-products are: press cakes from oily seeds, remaining parts of crops after processing and other.

Wastewater treatment sludge: Anaerobic digestion can be used to reduce the organic load in wastewater. The produces' sewage sludge can be digested.

To reach a stable bioenergy production it should be ensured that organic material is constantly available. In the case of harvest seasons biomass might be conserved (e.g. in form of silage) to be stored for months. Securing a guaranteed and regular feedstock supply for bioenergy 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 organic feedstock.

Figure B28 provides examples of several different feedstocks and their associated biogas yield.

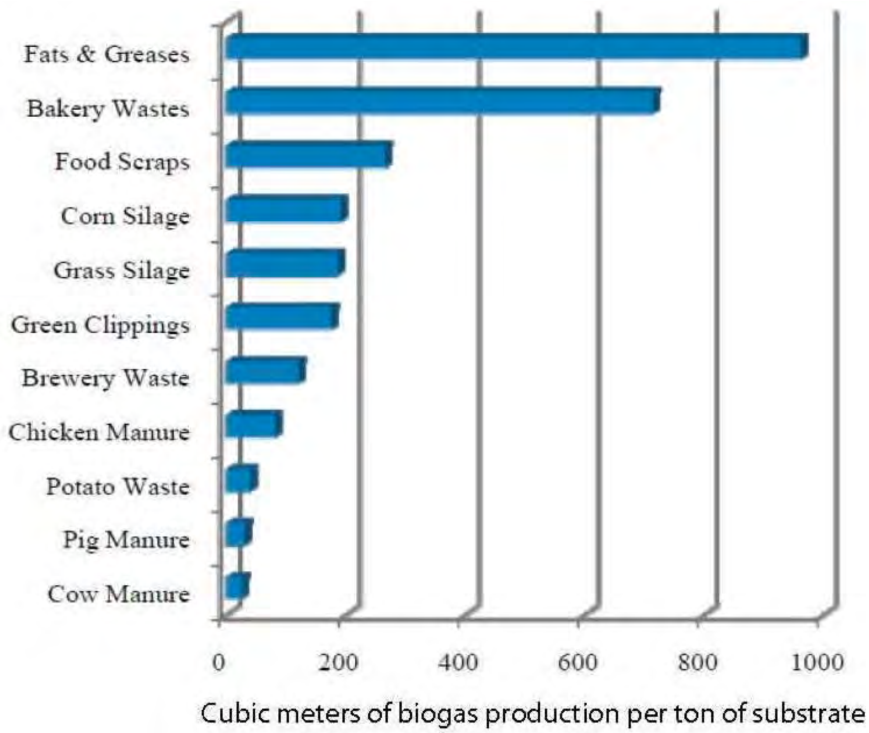

Figure B28 | *Biomass Substrates and Biogas Production Potential (www.americanbiogascouncil.org)*

Unit B2.1.2 | Bioenergy Technologies

Choosing the appropriate technology for converting organic matter into bioenergy is a 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 one common form of bioenergy generation. On household level wood is typically used for cooking. Big, industrial scale plants often use wood as co-fuel to fossil-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 the boiler in order to produce steam, which is then converted to electricity and heat. The heat produced can also be used in direct thermal applications such as to heat buildings or industrial processes (U.S. Environmental, 2009).

Thermochemical and Biochemical Conversion: 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 processes like 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 (U.S. Environmental, 2009).

Unit B2.1.3 | Thermochemical Processes

Pyrolysis: In the absence of oxygen pyrolysis uses high temperatures and pressure to decompose organic matter, which can result in gas, pyrolysis oil (bio-oil), or charcoal (bio-char). Bio-oil is a typical product that can be used to heat buildings or for power generation. The temperature of the reaction determines the end-product (U.S. Environmental, 2009).

Gasification: Gasification converts solid fuel to gas either through a chemical or a 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", consisting mainly of CO, H2 and some other traces like tar. Syngas is then either combusted in a gas engine, in a boiler for electricity, heat generation or thermal applications (U.S. Environmental, 2009).

Unit B2.1.4 | Biochemical Processes

Anaerobic Digestion, often called -Biogas: Anaerobic digestion involves the decomposition of organic material by microorganisms in the absence of oxygen. This process produces a gas composed largely of methane (CH_4) and carbon dioxide (CO_2). The methane produced can combusted directly (e.g. in small stoves) or be used to produce electricity or heat in combined heat and power plants (CHP) (U.S. Environmental, 2009).

Fermentation: Starchy plants are often used in the biochemical fermentation process to convert sugar into alcohol. This is the most common process used to produce ethanol from corn and sugarcane (U.S. Environmental, 2009).

Unit B2.1.5 | Other Processes

Transesterification: Transesterification is a process that converts oils or fats into biodiesel. The process involves removing water and contaminants from the feedstock, and mixing the latter with alcohol (typically methanol) and a catalyst (such as sodium hydroxide). Fatty acid methyl esters and glycerin are produced as by-products 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 (U.S. Environmental, 2009).

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 includes wood, animal excrements, industrial by-products, food waste, agri-industrial wastewater, and energy crops.
- Bioenergy technologies can be divided into three 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 (50–75 percent) and carbon dioxide (25–45 percent). Biogas also has trace amounts of other components such as water vapor, hydrogen sulfide and ammonia.

Biogas production can help to reduce GHG emissions in several ways:

- During the storage of organic material (like manure or palm oil mill effluents) methane emissions occur. Methane has a GHG potential that is a factor about 25 times higher than carbon dioxide. Due to material treatment in a biogas plant, a closed system, and gas utilization (e.g. in a gas engine or boiler) methane emissions are avoided and the methane combusted into carbon dioxide.
- Biogas is a nearly carbon neutral energy generation because during the growth of plants carbon dioxide from the atmosphere is stored in the plant in the form of carbon containing molecules (CO_2 reduction). After combustion about the same amount of carbon dioxide is emitted, as was originally extracted from the atmosphere (CO_2 neutral process).
- Due to energy generation, fossil energy carriers can be substituted and CO_2 emissions avoided in the process.

- Digestate (the effluent of a biogas plant) is a ***good quality fertilizer [» Unit A3]***. Its use helps to substitute synthetic fertilizers. For the production of synthetic fertilizers high amounts of fossil fuels are used. Their CO_2 emissions can be avoided.
- However, methane is a very effective GHG and methane emissions from biogas plants must be limited (e.g. by covering the storage of digestate or installing a flare that burns the methane produced in periods when biogas utilization is not in operation).

There are additional motivations to produce biogas including stench reduction, deactivation of unwanted seeds and pathogen bacteria, and last but not least job creation (about 10 employees per installed MW electricity) and business generation.

The World Bioenergy Association estimates that if fully utilized, biogas could cover close to 6 percent of the global primary energy supply – equal to one quarter of the current consumption of natural gas. The ***agricultural sector contributes almost half of global methane emissions (47 percent) [» Unit A2]***. (FAO, 2014).

Anaerobic digestion “cuts methane emissions from landfill and slurry pits while reducing the use of fossil fuels, commercial fertilizers and chemical inputs” (EBA, 2013). However, biogas deployment at the global level has been slow 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 as long as the environmental damage of CO_2 emissions are not included in the natural gas costs;
- Government policies and programs do not adequately facilitate/support biogas programs.

Global data on current installed capacity of biogas plants does not exist, but REN 21 (2016) estimates that the share of bioenergy in total global primary energy consumption is about 10 percent - and that bio-power generated 464 terawatt hours (TWh) in 2015. In India and China have the most installations with an estimated 4.5 million biogas plants in India and over 40 million biogas plants in China. However, the majority are small household systems that are used to produce gas for cooking, heating water, and lighting (World Bioenergy Association, 2013). The most developed biogas market for bigger,

The Nutrient Cycle

All minerals (like N, P, K, S) in the feedstock remain in the system and are high valuable ***fertilizers [» Unit A3]*** at the end of the process. If derived exclusively from clean, source-separated waste streams, the spent and sanitized digestates are usually spread on agricultural land near the biogas plant and can 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, residues and animal excrements, they are more likely to be sustainable and far less likely to threaten food supplies.

commercial applications is Europe, especially Germany. In Europe about 17,000 biogas plants are installed with a capacity of about 116 TWh biogas production annually. More than half of the installations are in Germany.

The high organic content of municipal solid waste in low- and middle-income countries (up to 60 percent) 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 re-introducing recyclables into value chains, the use of biogas technology that uses waste as feedstock promotes a ***circular economy [» Unit C1.2]***. The advantages are twofold: (1) energy is recovered and (2) the nutrient cycle is closed.

CLOSE-UP

Benefits and co-benefits of anaerobic digestion include:

- Energy recovery
- Nutrient cycle is closed
- Health
- ***Climate change mitigation [» Unit A2]*** & pollution reduction
- Smell reduction

Unit B.2.2.1 | Methane

Methane is combustible gas with the scientific formula CH_4. It has a heating value of 34.4 Mega Joule per cubic meter (MJ/m^3) and a greenhouse gas global warming potential of 25 times that of carbon dioxide when emitted. Methane is also formed in many natural processes such as in wetlands, moors and natural gas seeps. It is part of the natural carbon cycle. When methane is oxidized to the atmosphere it forms carbon dioxide (CO_2) and water (H_2O).

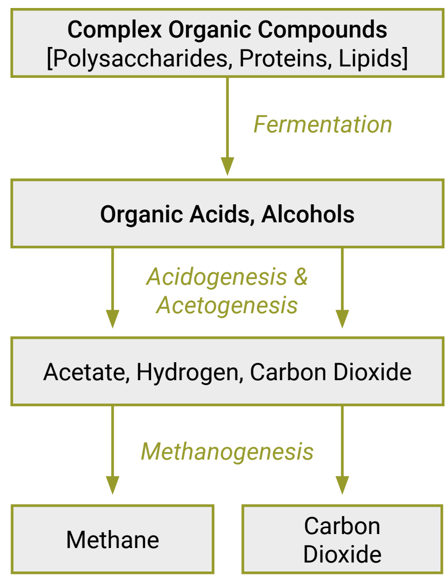

Figure B29 | Methane Formation Process

The methane formation process is comprised of four steps:

1. In the first step, the hydrolysis, complex and long-chain linkages of the feedstock like carbohydrates, proteins and fats are divided into lower molecular organic compounds like amino acids, sugar and fatty acids. The hydrolytic microorganisms involved release hydrolytic enzymes, which decompose the material biochemically outside the microbial cells
2. In the following phase, acidogenesis, the previous intermediate products are transformed into lower fatty acids like propionic acid, butric acid, acetic acid together with carbon dioxide and hydrogen, which are by-products of the degradation process.
3. Subsequently, in acetogenesis, acetonic bacteria convert the propionic and butric acid to acetic acid, hydrogen and carbon dioxide, which are the basic materials for methane production
4. Finally in methanogenis, archaea, which belong to the oldest life forms on earth, produce methane out of hydrogen together with carbon dioxide or by the cleavage of acetic acid.

This process is part of the global carbon cycle. Due to photosynthesis, carbon is fixated in the form of organic molecules, for example as sugar and stored in plants. After processing in the biogas plant, the same amount of CO_2 is exhausted in the CHP or stove as was originally extracted from the atmosphere.

The microorganisms responsible for Steps 1 and 2 reproduce more rapidly than the methane forming bacteria. If the population of methane forming microorganisms is not adequate to reduce organic acids and alcohol as they are produced, accumulation will occur.

Although 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. Thus a good balance of all included microorganisms is key to biogas plant operation.

Unit B2.2.2 | Carbon Dioxide

Carbon dioxide is naturally produced and absorbed by many organisms such as plants, animals, and microorganisms *(Figure B30)*. This CO_2 is part of a natural environmental balance. However, huge amount of carbon are stored in the earth in the form of fossil fuels (coal, oil, natural gas and other). If those fossil fuels are burned (usually by human activities) CO_2 and thus greenhouse gas is generated.

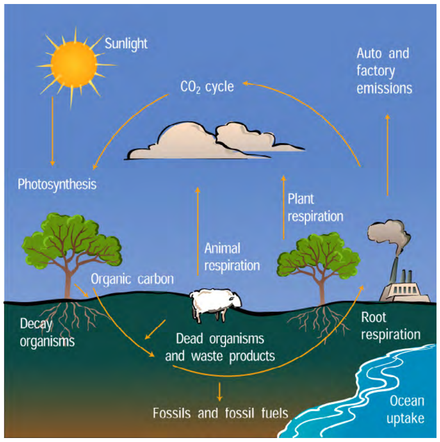

Figure B30 | The Carbon Cycle (www.windows2universe.org)

RECAP

- Biogas is primarily composed of methane (50–75 percent) and carbon dioxide (25–45 percent).
- Biogas is underutilized globally, and there is a lot of potential to increase biogas use.
- Some of the main challenges to biogas implementation are: lack of information, government policies and trained labor force, as well as high costs, and cheaper alternative fuel sources.
- The methane formation process is four steps: hydrolysis, acidogenesis, acetogensis, and methanogenesis.

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 technology that is best suited, 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, logistics (like electricity connection, streets, etc.)*
- Quality of feedstock: *total solid matter, biogas yields*
- Climate: *temperature, rainfall*

The cost of anaerobic digestion systems depends on the complexity of the technology and the size of the system. The cost for a biogas plant ranges from hundreds to thousands of US-$ for domestic scale biogas plants. Typical larger scale investment costs for a complete biogas plants including Combined Heat and Power (CHP) (example completely stirred tank reactor) are (FNR, 2016):

75 /kWel	9,000 €/kWel
250 /kWel	6,000 €/kWel
500 /kWel	4,600 €/kWel
1000 /kWel	3,500 €/kWel

The bigger the size, the lower are the investment costs. A 1 MWel biogas plant costs about US-$ 3.6 million.

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 Takamoto company 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 from US-$1,000 up to US-$1,500, but with the pay-as-you-go scheme, installation is as low as US-$100. Once 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

EPA Combined Heat and Power Partnership

Unit B2.3.1 | Anaerobic Digestion Technologies

Anaerobic digestion technologies *(Figure B31)* can be divided into two categories based on size:

(1) Large scale plants are industrial technologies often operated on a commercial scale. They usually are constructed with a reactor size of hundreds up to thousands of cubic meters and gas storage of a similar size. The gas is often used in a Combined Heat and Power (CHP) unit for commercial electricity and heat production. The size of the CHP usually is between 50 kWel to 20 MWel. The planning and construction of large scale biogas plants requires experienced persons. Robust technology should be used to ensure reliable operation for many years. It is of special importance is to have skilled personnel for biogas plant operation.

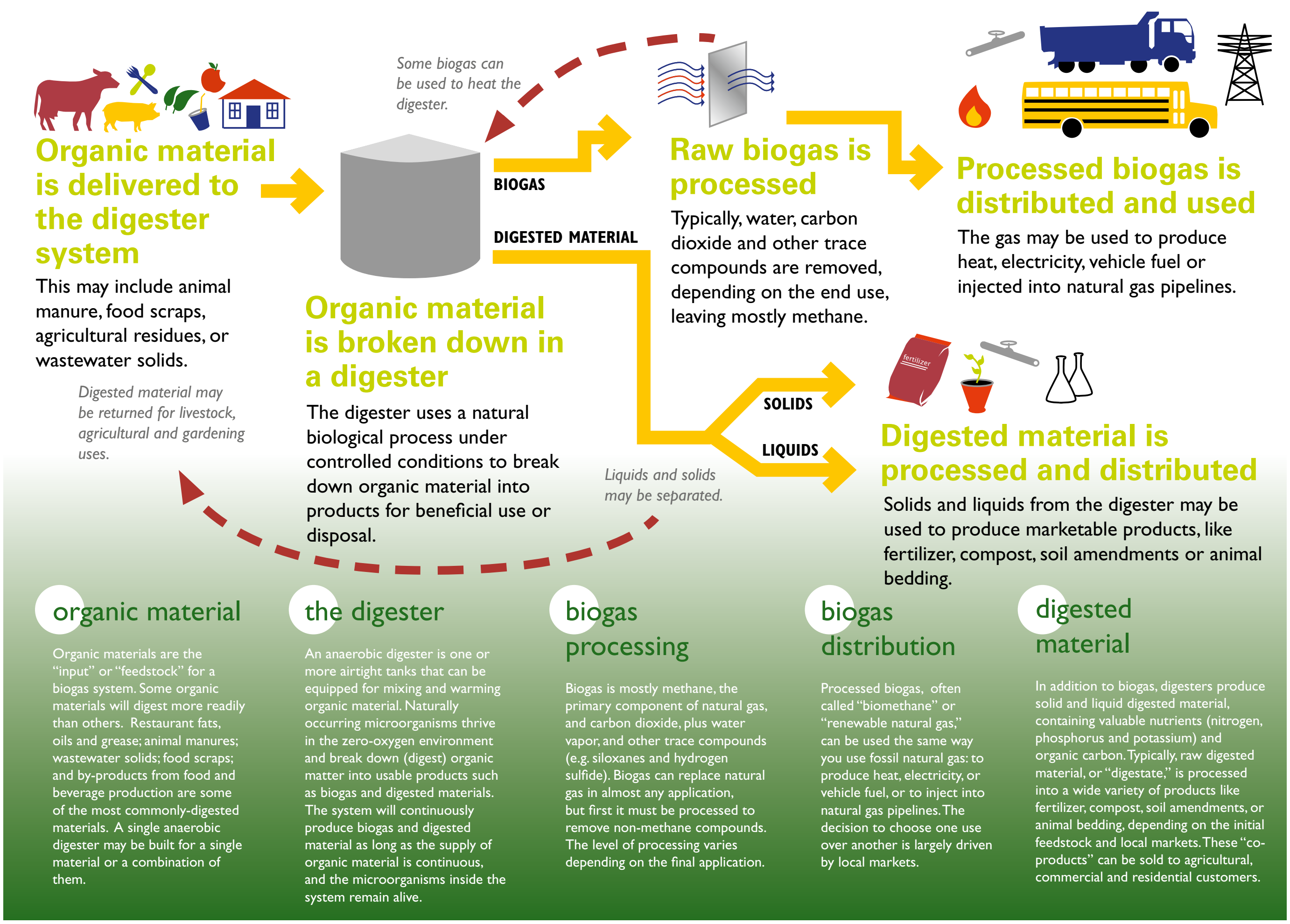

Figure B31 | *Anaerobic Digestion Value Chain*
(Biogas Opportunities Roadmap, USDA, EPA & DOE, 2014; AgStar, 2015; LMOP, 2015)

(2) Small-scale, domestic digesters are small. The reactor volume is usually only some cubic meters and below 100 cubic meters. The technology is relatively cheap and simple. Usually the biogas is burned in a household stove for cooking. It is possible to use if for lighting as well. Small-scale biogas plants produce too little biogas to generate electricity economically. Construction and operation is relatively simple too. However, experiences show that local knowledge and clear responsibilities are key for long term operation.

Biogas plants are operated usually in continuous process, seldom in batch process. Some of the small-scale technologies described below are batch systems though. Commercial scale biogas plants are usually operated continuously. Only some dry systems operate in batch process. 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.

Unit B2.3.2 | Large and Medium Scale Technologies

Complete mix digester: These digesters are fed with a constant volume of feedstock and produce a constant biogas volume rate. They operate at a controlled temperature and consist of a main reactor-tank where the feedstock is heated and mixed. The feedstock is mixed using gas recirculation, mechanical propellers, or liquid circulation. It can handle feedstock up to ~20 percent dry matter and therefore is suited to operations that produce a fairly liquid feedstock such as manure. All kinds of organic material can be used as feedstock. The input material is degraded and thus a liquid medium is produced. This type of digester is the most common technology on a commercial scale (FNR, 2010).

MORE TO LEARN

Guide to Biogas. From Production to Use (PDF) (Fachagentur für Nachwachsende Rohstoffe, 2010)

Covered anaerobic lagoon: The covered anaerobic lagoon *(Figure B32)* is one of the simplest and cheapest technologies available for large scale operations that contain about five percent or less solids. Coarse solids must

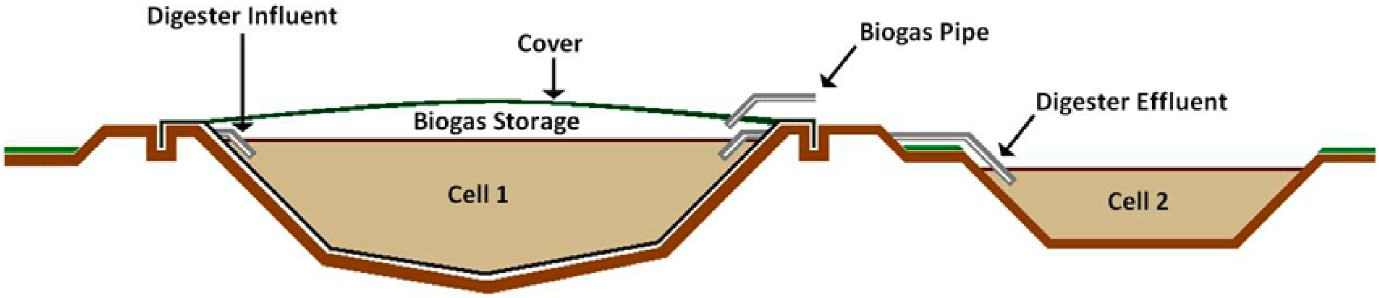

Figure B32 | Covered Anaerobic Lagoon (www.plugflowdigester.com) be separated out or they will form a crust on the surface of the lagoon inhibiting biogas production. It consists of a liquid pool or "lagoon" that is topped by a pontoon or floating cover. Seal plates extend down the sides of the pontoon 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). Covered lagoons are usually not heated and stirred.

Plug-flow digester: A plug-flow digester *(Figure B33)* is a tank where the feedstock is transported horizontally into one end of the digester, pushing the older material out through the opposite end in turn. A robust agitator system helps to stir the biomass and to transport it through the digester. Biogas formed in the tank bubbles to the top where it is collected. This type of digester is usually heated and the cover can either be a fixed rigid top, a flexible inflatable top, or a floating cover (Balsam, 2006).

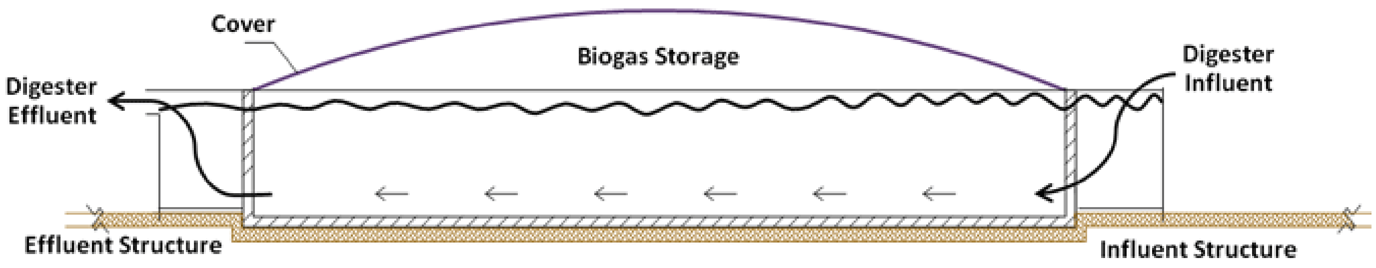

Figure B33 | Plug-flow Digester (www.plugflowdigester.com)

Upflow anaerobic sludge blanket (UASB): In a UASB system *(Figure B34)*, waste- or process-water 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).

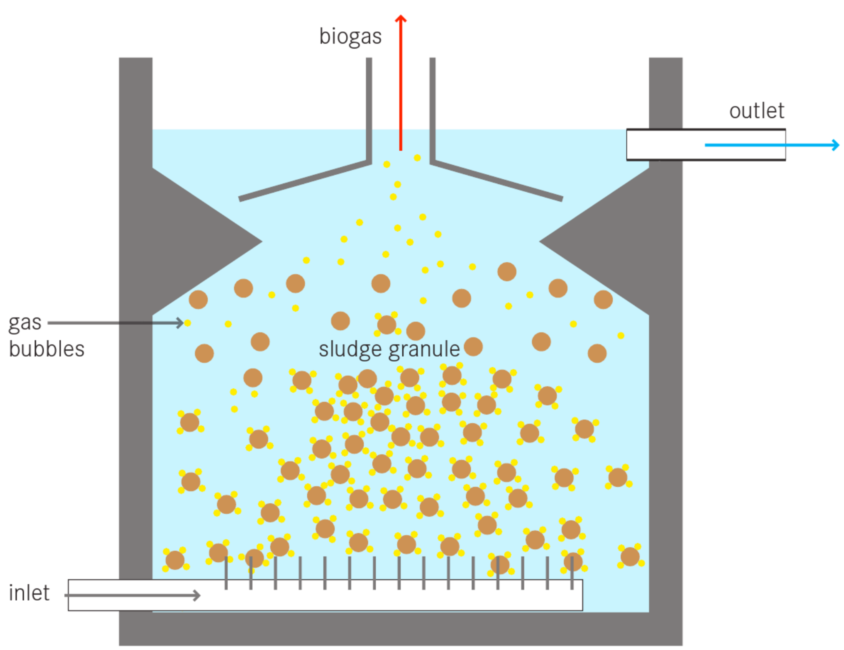

Figure B34 | UASB System (www.grassrootswiki.org)

Unit B2.3.3 | Small-scale Technologies

Fixed dome digester: In a fixed dome digester *(Figure B35)* 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 warm or medium temperature areas because they are partially constructed underground (The GEF Small Grants Program (SGP), n.d.).

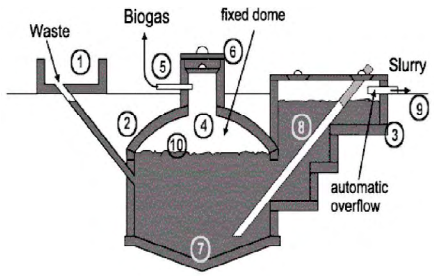

Figure B35 | Fixed Dome Digester (www.sgpindia.org)

Floating drum digesters: Floating drum digesters *(Figure B36)* 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 Program (SGP), n.d.).

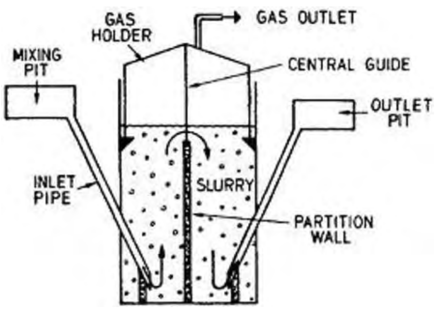

Figure B36 | Floating Drum Digester (www.fao.org)

Bag Digesters: Bag digesters *(Figure B37)* are made from 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 the lifespan depends on the material used. Usually the material must be resistant to UV radiation and corrosive acids (from H_2S).

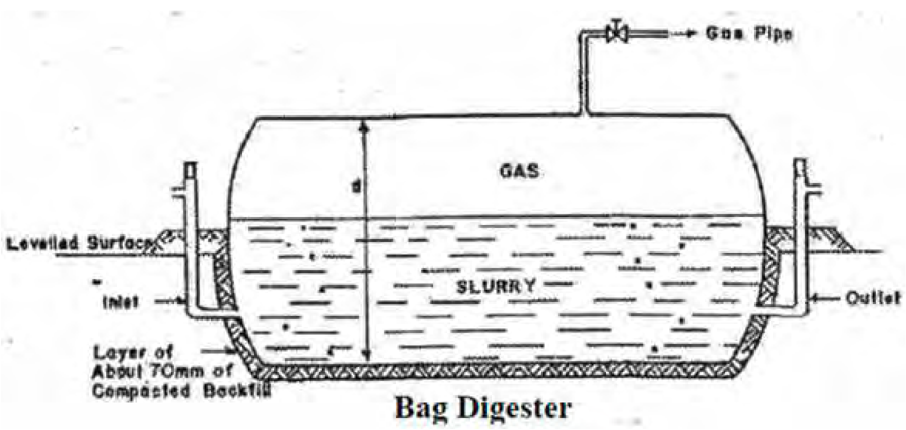

Figure B37 | Bag Digester (www.fao.org/docrep/t0541e/T0541E09.htm)

Figure B38 below highlights the advantages and disadvantages of the anaerobic digestion technologies described above.

Technology	Advantages	Disadvantages
LARGE AND MEDIUM-SCALE TECHNOLOGIES		
Complete-mix digester	• Biogas production is good • Handles wide range of concentration • Mixing within the reactor is good • Retention time is less • Bacteria and liquid have very good contact	• High level of technology: digester is heated and mixed mechanically • Capital and energy costs are usually high • Bacteria loss can be an issue • Mechanical problems
Covered anaerobic lagoon	• Low maintenance requirements • Occurs at ground temperature, no heater need • Good for seasonal harvesting • Very low capital • Good in handling liquid waste	• Methane production follows seasonal patterns • Very high retention times • Much of the fertilizer nutrients, particularly phosphorus, remain trapped for a long time • Slow solids conversion • Bacteria and liquid have limited contact • Biogas production lower • Periodic cleaning is necessary • Maintenance of lagoon is difficult
Plug flow digester	• No mechanical mixing required • Very low capital cost • Simplest digester used • Reasonable retention time • Can be ambient to thermophilic temperature	• Daily system check to verify operation • Slurry does not mix longitudinally • No agitation • Slow solid conversion • Biogas production is low • Periodic cleaning is necessary
Upflow anaerobic sludge blanket (UASB)	• High reduction in organics • Can withstand high organic loading rates (up to 10 kg BOD/m^3/d) and high hydraulic loading rates • Low production sludge (and thus, infrequent desludging required) • Biogas can be used for energy (but usually requires scrubbing first)	• Difficult to maintain proper hydraulic conditions (up flow and settling rate must be balanced) • Long start up time • Treatment may be unstable with variable hydraulic and organic loads • Constant source of electricity is required • Not all parts and materials may be available locally • Requires expert design and construction supervision
SMALL-SCALE TECHNOLOGIES		
Fixed- dome digester	• Low initial costs • No moving or rusting parts involved • Long life of the plant (20 years or more) • Construction creates local employment **Underground construction** • Protects it from physical damage and saves space • Digester is protected from low temperatures at night and during cold seasons • No day/night fluctuations of temperature in the digester positively influence the bacteriological processes (Buffers temperature extremes)	• Masonry gas-holders require special sealants and high technical skills for gas-tight construction • Fluctuating gas pressure. Amount of gas produced is not immediately visible, plant operation not readily understandable • Fixed dome plants require exact planning of levels • Excavation can be difficult and expensive in bedrock **Underground construction** • Digester temperatures are generally low • Sunshine and warm seasons take longer to heat up the digester

Technology	Advantages	Disadvantages
SMALL-SCALE TECHNOLOGIES		
Floating-drum digester	• Easy to understand and operate • They provide gas at a constant pressure, and the stored gas-volume is immediately recognizable by the position of the drum	• The steel drum is relatively expensive and maintenance-intensive • Removing rust and painting has to be carried out regularly • The lifetime of the drum is short (up to 15 years; about five years in tropical coastal regions)
Bag digester	• Standardized prefabrication at low cost • Low construction sophistication • Ease of transportation • Shallow installation suitable for use in areas with a high groundwater table; • Combined Heat and Power (CHP) gh temperature digesters in warm climates • Uncomplicated cleaning, emptying and maintenance • Difficult substrates like water hyacinths can be used. Bag biogas plants are recommended, if local repair is or can be made possible and the cost advantage is substantial	• Low gas pressure may require gas pumps • Scum cannot be removed during operation • Short life-span of plastic balloon, is susceptible to mechanical damage and usually not available locally • Little scope for local employment and, therefore, limited self-help potential

Figure B38 | Advantages and Disadvantages of the Anaerobic Digestion Technologies (Gosh, 2013; Energypedia, 2016; Akvopedia, 2016)

RECAP

- Biogas plants can be created in a huge range of sizes. Domestic biogas plants are usually cheap but limited in size and efficiency. Industrial biogas plants operate at big biogas production scales and are more efficient. But they cost much more and need technical skills for planning, construction and operation.
- When considering an anaerobic digestion system, the main design considerations are: size, cost, technological complexity, operations and maintenance, terrain, feedstock characteristics and climate.
- Biogas systems are expensive, as a rule of thumb, the investment cost ranges from some hundred US-$ for domestic biogas plants to US-$ 2,000 to above $7,000 per kWel installed capacity for large systems, respectively.
- Large and medium scale anaerobic digestion technologies include: complete mix digesters, covered anaerobic lagoons, plug flow digesters, and an upflow anaerobic sludge blanket (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 using the anaerobic digestion process, it can be utilized as an energy source (electricity, heat, vehicle fuel or substitution of natural gas). Industrial, commercial biogas plants usually burn the biogas in a CHP Plant, some upgrade biogas to biomethane quality.

All of the above mentioned uses replace fossil fuel sources; therefore biogas is a sustainable, renewable energy source.

Unit B2.4.1 | Cogeneration

Cogeneration *(Figure B39)* is the production of electricity and heat from biogas. The process uses biogas to fuel a gas motor that in turn drives a generator to produce electricity. Typically engines used to generate electricity through cogeneration have electric efficiency from 30 percent for smaller CHPs (e.g. 100 kWel) up to 40 percent for CHPs above 500 kWel. Heat is generated with the operation of the engine (cooling water and thermal energy in the exhaust). Considering electricity and heat production, the total efficiency can be about 80 percent.

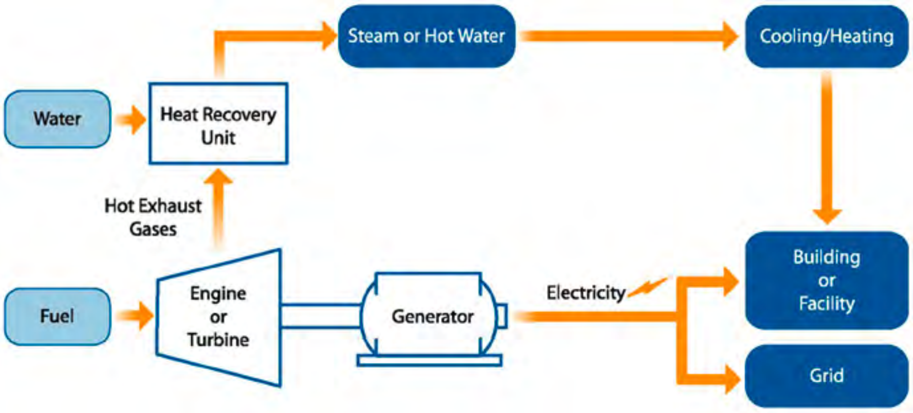

Figure B39 | Cogeneration Process Overview (www.c2es.org/technology/factsheet/CogenerationCHP)

Depending on the size of the operation, there are a variety of engines that can be used in the cogen process. For industrial processes, gas motors (50 kWel – some MWel) are the most efficient. The smaller the motor, the lower the electrical efficiency is, but the higher the thermal efficiency.

The electricity produced can usually be easily used, either directly on location (especially interesting in off-grid situations) to reduce the own electricity bill or indirectly by feeding it into the public electricity grid.

The co-generated heat has two qualities: Cooling water from the motor (about 90-95°C) and exhaust (about 450°C). It is often more difficult to use the co-produced heat efficiently. However, there are several opportunities to use the heat generated:

- Locally on the farm for heating houses, stables
- Drying processes, for fruits (e.g. cereals) or wood
- Greenhouses
- Fish tanks
- Sometimes it is interesting to build a heating system adjacent to the next heat consumer, e.g. a village nearby. Typical users are houses, schools, hospitals, swimming pools.
- Biogas plants can be located close to a location were heat is needed, e.g. close to an industrial process were process heat is needed.

Unit B2.4.2 | Lighting and Cooking with Small Biogas Plants

Biogas can be used as a direct energy source for cooking 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 [» Unit C1.4]***. Small anaerobic digesters can provide a reliable source of biogas and therefore eliminating the need to use firewood for cooking. Cook stoves that burn biogas also provide a much cleaner gas that improves indoor air quality for families that previously relied on firewood, diesel, kerosene or LPG (United States Environmental Protection Agency, 2008).

This type of biogas can also be hooked directly into a gas lantern and provide lighting.

Unit B2.4.3 | Vehicle Fuel

Biogas is becoming increasingly popular as a vehicle fuel in the form of compressed biomethane (CBM). However, in order to produce biomethane the biogas must be 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 methane content (up to 99 percent) than raw biogas, which makes it comparable to conventional natural gas and thus suitable for vehicles that run with Compressed Natural Gas (CNG) (U.S. Department of Energy, 2015).

MORE TO LEARN

SNV: Improved Cookstoves

Biogas-Powered Evaporative Cooling for the Dairy Industry

The University of Georgia Research Foundation (UGARF) program, Powering Agriculture, An Energy Grand Challenge Innovator, 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. These systems provide a practical solution to farmers to ensure their product lasts longer and stays cool while being transported. In addition, the systems can also be used to provide gas to households to power lights and cook stoves. Source: www.poweringag.org

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 replace traditional fuel sources like kerosene and wood.
- Biogas can be converted to vehicle fuel as biomethane and can substitute CNG

MATERIALS

Please find below links to our materials and references

Video
www.giz.de/gc21/pa_video_lectures

Additional Material
www.giz.de/gc21/pa_additional_material

References
www.giz.de/gc21/pa_references

SUMMARY & UNIT WRAP-UP

Bioenergy resources are abundant yet underutilized throughout the world. With the wide range of available feedstocks and many different technologies, there are many opportunities across many sectors to implement bioenergy projects.

In the developing world, 70 percent of people that live in poverty rely on agriculture for their livelihood. This provides ample opportunities for the implementation of family-size biogas operations that would greatly improve these people's quality of life by replacing traditional fuel sources that can be expensive (kerosene or charcoal) or time-consuming and unreliable (wood gathering) with biogas; a consistent clean burning fuel source.
Inevitably by increasing the amount of biogas produced and utilized around the world, the release of harmful greenhouse gases to the atmosphere would be reduced, hence contributing to global efforts to ***mitigate climate change [» Unit A2]***. It would also contribute to the reduction of reliance on natural gas and other fossil fuel sources that are not renewable, with much cleaner, renewable fuel.

UNIT B3

INTRODUCTION

Unit B3 will provide you with a general understanding of the term efficiency and the concept of ***energy efficiency [» Unit B3.1]*** (EE). Furthermore, this chapter will briefly present ***energy auditing [» Unit B3.2]*** (EA) – a tool to identify energy efficiency measures and to assess investment related energy efficiency measures. Typical energy technologies and energy processes that occur in many ***agricultural value chains [» Unit B3.3]*** are thereby also addressed, as well as the concept of ***life cycle assessments and sustainability [» Unit B3.4]***.

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Please find below links to our materials and references

Video
www.giz.de/gc21/pa_video_lectures

Case Study
www.giz.de/gc21/pa_case_studies

Additional Material
www.giz.de/gc21/pa_additional_material

References
www.giz.de/gc21/pa_references

UNIT B3

ENERGY EFFICIENCY IN THE ENERGY AGRICULTURE NEXUS

Unit B3.1 | Energy Efficiency

Unit B3.1.1 | Efficiency

The term efficiency is used in many different fields, for example in engineering, economy, medicine as well as in agriculture. But what does efficiency really mean?

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:

$$Efficiency = \frac{Output}{Input} = \frac{Service\ Output}{Used\ Resource}$$

The equation highlights that efficiency always involves both the resources used and the services provided. 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 respectively as minimization and maximization strategy.

Equation B3.I: Efficiency

$$Efficiency \uparrow = \frac{Service\ Output =}{Used\ Resource \downarrow} \qquad Efficiency \uparrow = \frac{Service\ Output \uparrow}{Used\ Resource =}$$

Let us look at a simple example: One person pushes a rock on a flat surface over a distance of five meters. Here the used resource is the energy of the person while the service or output is pushing the rock five meters. Now let us 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 attempts to extract as much as possible from the resource. As you can conclude, increasing efficiency does not necessarily mean saving resources.

Remember the 'Rebound Effect'
[» Unit A3]

Recommended reading:
The Rebound Effect. An Assessment of the Evidence for Economy-wide Energy Savings due to Improved Energy Efficiency (PDF) (Sorrell, 2007)

Unit B3.1.2 | Energy Efficiency in the Energy System

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 (η), (Greek letter Eta).

WHAT IS 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)

Equation B3.II: Energy Conversion Efficiency

$$\eta = \frac{Useful\ Energy\ Output}{Energy\ Input}$$

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

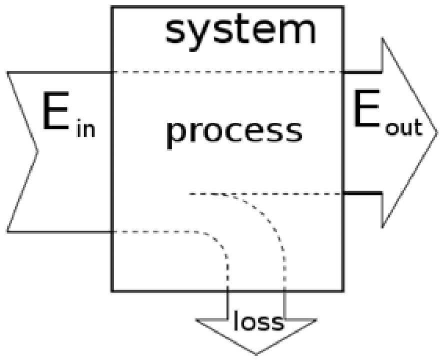

Figure B40 | Illustration of Energy Flows within a System (Wikimedia)

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 to the useful output gained. Both elements are energy flows and can be quantified by using thermodynamic calculations, which result in an absolute value for efficiency.

Unfortunately, such a straight forward procedure is not always applicable as in the example as this *video (week 4)* shows:

As we said, modern light bulbs with LED technology are able to provide light of 1000 lumen with electricity input of 20 Watt whereas the old light bulb technology needs five times more electricity input to provide the same brightness. Using equation B3.I, we can actually see the difference in numbers:

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 the same. In the case of a light bulb, some people say that brightness is the only important factor, but others argue, the LED provides a different light color and hence a different or less valuable service.

$$LED\ bulb = \frac{Output}{Input} = \frac{Brightness}{Power} = \frac{1000\ Lumen}{20\ Watt} = 50\ \frac{lm}{W}$$

$$Incandescent\ light\ bulb = \frac{Output}{Input} = \frac{Brightness}{Power} = \frac{1000\ Lumen}{100\ Watt} = 10\ \frac{lm}{W}$$

"Therefore, it is worth distinguishing between the quality and quantity of output service. Evaluating the quality of services is generally difficult" (Pérez-Lombard et al., 2012). As a result, we tend to focus on evaluating the quantity of output service, which can be measured more easily.

In addition, it is important to look closely at the denominator of the efficiency equation B3.I (the energy input). When comparing different technologies with each other, 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 re-use and heat recovery or b) even to a combined heat & power supply (co-generation facilities) system. See the info boxes for more detailed examples.

Energy production itself should now be incorporated into the evaluation of efficiency.

Nowadays in most countries worldwide, electricity is supplied to the end-user through a distribution grid, which is fed by centralized power plants. Commonly these power plants are powered by fossil resources like coal, gas or oil and in some cases they are nuclear power plants.

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

For 1000 lumen Brightness...	
Incandescent Bulb	LED Bulb
100 Watt	20 Watt

5x more!

Figure B41 | LED Technology

CLOSE-UP

Heat Recovery & Co-generation
[» Unit B3.4]

a) **A system of heat re-use and heat recovery:** This could e.g. mean waste heat from power generation processes in power plants or from industrial production processes or others is used for other nearby cooling/ heating demands.

b) **A combined heat & power supply/ co-generation facilities:** Due to the simultaneous generation of heat & power on-site and in a de- centralized way, co-generation plants reach aggregate efficiencies of up to 80–95 percent compared to efficiencies of separate generation processes of around 50 percent. A 'tri-generation' system can also be applied in agro-food production to cover heat, power and even cooling demands in one combined and efficient generation processes.

Excurse to conventional electricity grids and their relation to energy efficiency

Many processes are involved from mining coal to 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.

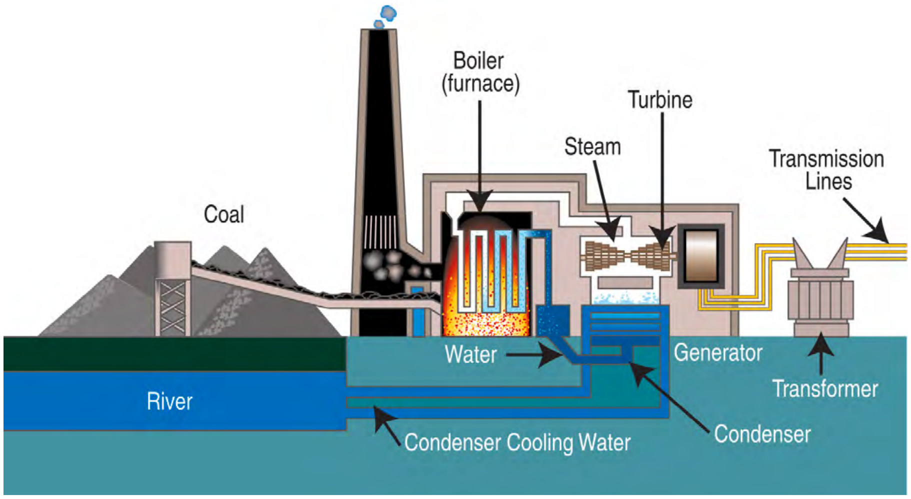

Figure B42 | Schematic of a coal power plant (Tennessee Valley Authority/ Wikimedia)

An equivalent of approximately 15 percent 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 percent 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 percent 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 percent, 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 power generated to the consumer (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. Improving the EE of the supply system should therefore be of high priority to every nation.

CLOSE-UP

Distribution losses of electricity grids

Case: Nigeria
The Nigerian electricity grid has a large proportion of transmission and distribution losses, which goes up to 40 percent. This is attributed to technical losses and non-technical losses such as illegal power capture.
(M.C. Anumaka, Faculty of Engineering, Imo State University, Nigeria)

Unit B3.1.3 | Energy Efficiency – Global Dimension and Co-Benefits

We consider EE as „the world´s first fuel“. The potential is immense. They are not only an important lever to protect the climate, but also an instrument to combat poverty. Agriculture and food production play an important role hereby. After all they are responsible for 30 percent of global greenhouse gas emissions, and use four percent of global fossil energy alone. (Gilbert, 2012) On the other hand crop yield irrigation can increase up to 300 percent and therefore increase small farmers' income (Giordano et al., 2012). If renewables-based water pumping is used, only an unnoticeable increase in emissions ensues.

In the meantime governments, as well as international committees, have recognized the significance of EE and enshrined it as an objective. Hence a higher EE is an important goal of *Sustainable Development Goals (SDGs)*. Apart from this, in the second commitment of the *Paris Declaration* governments, regions and cities issued a target of increasing energy efficiency by 40 percent by 2030 (based on 1990 data). Climate change cannot be stopped without energy efficiency. EE is also a long-term priority for *G20 states*, which consume about 80 percent of all global energy (G20, 2016).

In 2014 they adopted the Energy Efficiency Action Plan, which is being implemented by the International Partnership for Energy Efficiency Cooperation (IPEEC). According to the thinking of the G20 states, increased collaboration on energy efficiency can drive so-called co-benefits (or multiple benefits) like economic activity and productivity, strengthen energy security and improve environmental outcomes. Furthermore it improves energy intensity, for example the energy consumption of a national economy in comparison to its gross domestic product. This key indicator makes it possible to compare EE (G20, 2016). The *Global Tracking Framework*, a Sustainable Energy for All (SE4All) initiative started by the UN and published under the successful EE Models and Milestones, allows a further comparison.

What Agriculture Can Contribute

The nutritional sector continues to be based on fossil energy sources to a high degree, be it in farm mechanization, fertilizer production, food processing or distribution (*remember Chapter 1*). In order to feed 9.7 billion people by 2050 the sector must produce 70 percent more food. If energy consumption is not to increase comparatively, savings potential must be achieved through EE. According to IRENA the potentials lie between ten and twenty percent. There are many possibilities as the *figure B43* illustrates.

Energy (Service) Demand	Agro-Food Processes/ Value Chains *[» Unit A3]*	Common Energy Efficiency Technologies/ Measures
Heat supply	• Greenhouse farming • Food processing (dairy production, drying fruits & vegetables, canned food etc.)	• *Combined Heat and Power / co-generation [» Unit B2.4]* • Waste heat recovery (e.g. by heat exchangers that use 'waste' heat for pre-heating other processes) • Waste heat from (nearby) power plants • Insulation of networks/ pipeline, building facilities • Where possible/ feasible *use of renewable [» Unit B1]* sources for heating demands (e.g. solar thermal, geothermal, also by heat pumps, bioenergy *[» Unit B2]* heat plants etc.)
Cooling & air conditioning / cold storage / cooling chains	• In all agro-food sectors where food quality needs to be maintained after harvesting, while processing and for transporting food/ agro products => *dairy/milk production [» Unit B1.1]*, rice production, vegetable production, beverage industry, drinking water treatment and processing	• CHP/ tri-generation • Insulation of networks/ pipeline, building facilities • Minimizing heat load at the end of the processing phase of the cold chain • Efficient and *'climate friendly' refrigeration systems [» Unit B3.2]* (also with new/ renewable technologies available, such as solar absorption chillers) • Efficient greenhouse ventilation systems
Fertilizer	• In many agro-food sectors/processes	• Reducing heavy energy inputs in fertilizer manufacturing, but also by implementing more accurate application methods
Water supply/ pumping	• Greenhouse farming • Irrigation for all agro-chains • Beverage industry & drinking water treatment • Food processing in general	• For irrigation *[» Unit B1.3]*: using gravity supply where possible; • Using efficient water pump designs (correctly matched to suit the tasks • Applying efficient designs of electric motors for pumps • Sizing pumping systems to actual water requirements • Maintaining all equipment regularly; • Drip irrigation in row crops; • Varying irrigation rates by using automatic regulation control systems • Alternative fuels/ energy sources for driving pumps (e.g. solar and wind-powered pumps)
Machinery	• Many agro-food processes (growing, harvesting, processing)	• Correct gear and throttle selection • Efficient automation: electric drives & motors, as well as monitoring & control systems for production and processing
Transport and distribution of food	• Transport of food commod-ities, partly under controlled atmosphere or refrigeration	• Correct gear and throttle selection • Efficient automation: electric drives & motors, as well as monitoring & control systems for production and processing
Processing & packaging of food	• Many agro-/food chains and their sites for processing agro-products or food/ beverages	• Efficient automation (efficient electric drives & motors, as well as automate monitoring & control systems) for production and processing
Renewable energy and stable energy supply	• All along the value chain in many agro-food sectors • Where good local energy resources exist • Where stable power/ energy supply is need (e.g. for continuous cooling demands; heating at high temperatures)	• Using grid electricity with a growing share of renewables (solar, bioenergy, geothermal etc.) • Improving & modernization of power grid (centralized and decentralized networks)
Lighting	• Greenhouses • Production, processing and storage sites	• Energy saving lighting technologies (e.g. LED) • Efficient automatization of lighting (matching real demands)

Figure B43 | Measures for Increasing Energy Efficiency in Agricultural Value Chains

RECAP

- Generally, efficiency is defined as the ratio of the desired output (useful effect) to the required input (used resources) of any system.
- 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.
- Energy efficiency has been formulated as an important goal in multiple international agreements in the meantime.
- The nutritional sector is currently mainly based on fossil energy. There are many possibilities to thereby increase energy efficiency or replace fossil with renewables.

Unit B3.2 | Energy Auditing

A Tool for Identifying Energy Efficency Potential & Measures

Within the ***agricultural value chain many [» Figure 2 in Unit A1]*** processes need energy, mainly for electricity, heat and cooling demands. A good example in agriculture is irrigation. In India for example, farmers operate around 18 million grid-connected pump sets and seven million diesel pump sets. Replacing these pumps with solar pumps could decrease India´s annual carbon dioxide emissions by nearly six percent (Shah, 2015). However, incentives to buy more efficient pumps or solar pumps are lacking as long as the state subsidizes electricity and diesel for farmers. If one wants to promote energy efficiency, then not only technical aspects, but also socio-cultural and political aspects must be considered.

Energy audits (EA) are an important instrument to analyze potentials of EE. EA 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 o processing entities. (International Standard for EMS: ISO 50001). Regarding EA, ISO 50002:2014 is very important. It specifies not only the process requirements for carrying out an EA in relation to energy performance, but also the procedures of carrying out EA. However, EA for the agricultural value chains of developing countries must be adjusted. Professionals must be trained accordingly.

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 overall performance
- Performing a cost-benefit analysis to identify which energy efficiency measures are best to implement

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

Unit B3.2.1 | Review of Energy Use

In this phase of the auditing process the energy use of the system, is assessed by reviewing energy bills or fuel consumption patterns in the past. Also, a system diagram is sketched showing the energy flows within the system along with a list of equipment used and the energy required to run it. 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). 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 processes.

Unit B3.2.2 | Site Assessment

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

Unit B3.2.3 | Data Analysis

The data analysis step is the most complex part and involves technical and cost analysis. Analyzing methodologies 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 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 energy efficiency measures as well as potential savings are considered. The results of both analyses lead to a hierarchy of the most promising changes from both financial and technical points of view. Guiding indicators are amongst others the payback period, life cycle costs as well as the internal rate of return of energy efficiency measures. More information about such financial analysis will be available in ***Units C2 [» Unit C2]*** and ***C3 [» Unit C3]*** of this Reader.

Unit B3.2.4 | Audit Report

The last phase of the auditing process is creating a comprehensive report.

RECAP

- Energy auditing is the analysis of process or system with 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 determined.
- Energy audit results are useful for economic and environmental betterment of the analyzed processes, thus it is a very important tool in the energy sector.

Unit B3.3 | Energy Efficiency in Agricultural Value Chains

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.

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

Energy Audit in the Kenyan Tea Industry

In the audit of four tea factories proposed suggestions could lead to a savings potential of 10,000 tons of CO_2 per year and corresponding cost savings.

Unit B3.3.1 | Energy Demand Assessment

Energy audits revealed that thermal energy demand incurs 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.

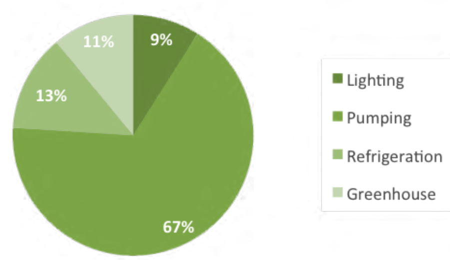

Figure B44 | Share of Energy Consuming Activities (Ogallo, 2015)

Electrical energy demand is generated by multiple activities, as indicated in Figure 4. In our featured case the largest share results from water pumping for irrigation. A typical small scale farm has a monthly energy demand of about 11.5 MWh in total.

Unit B3.3.2 | Recommendations for Energy Efficiency Measures

Several measures were recommended based on the EA. Amongst others, the use of high efficient motors and pumps, LED lighting, better cold curtains, variable speed drives and instituting an energy management system were suggested. Two recommendations can be incorporated in other industries and systems:

1. Replacing existing irrigation pumps with more efficiently sized pumps can improve the efficiency rate from merely 10 up to 65 percent.
2. Incorporating a heat recovery system. Floating drum digesters are comprised of an underground digester and a moving gas holder on top. 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 (The GEF Small Grants Program (SGP), n.d.).

More examples can be found in the recommended ***reading material*** as well as on the ***energypedia website***.

RECAP

- Energy audits are particularly significant when farms or companies with similar processes are compared.
- Re-using 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 a big achievement. However, energy efficiency goes beyond the farm gate. Even more, producing or consuming a product should be sustainable. 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 United Nations' World Commission on Environment and Development 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 sustainability has three pillars: Environment, Economy and Society. If one of the three pillars is not considered adequately, the 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 of a system that 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 scientific tools such as Life Cycle Sustainability Assessment (LCSA) may be used. It systematically analyses the impact of products, processes or services along the entire life cycle. Formerly LCAs were mainly applied to quantify environmental impacts. Nowadays approaches to quantify even the economic and the social impacts exist. These rather new approaches are called life cycle costing and social life cycle assessment.

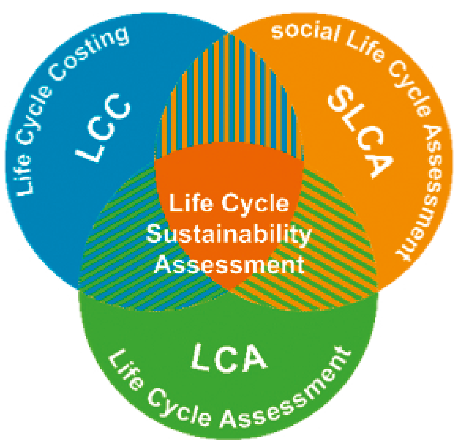

Figure B45 | Life Cycle Sustainability Assessment (SFB sustainable manufacturing/ TU Berlin)

The United Nation Environment Program (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 makes it possible to not only structure all information about a product in a coherent way, but to also illuminate 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. The (environmental) life cycle assessment (LCA) measures negative impacts on nature, life cycle costing addresses economic sustainability and social life cycle assessment assesses impact on societies.

Unit B3.4.1 | The Environmental LCA

Nowadays, 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 performs the LCA in four phases to:

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 data quality requirements.
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):** LCIA refers to the calculation of potential environmental impact, human health impact and effects on resource availability. Impact is calculated based on the inventory results and specific characterization models for each substance.
4. **Interpretation:** The calculated LCI and LCIA results are interpreted with respect to the goal of the LCA study and decision-making recommendations are given.

Unit B3.4.2 | 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 become increasingly important.

LCC is essentially an aggregation of all costs that are directly related to a product or services over its entire life. It also takes external relevant costs and anticipated benefits into account. The four phases, 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)**

Unit B3.4.3 | 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. SLCA focuses on the people involved. It assesses not only working hours per product produced, but also the impact of how a product’s life cycle influences human rights, working conditions, health and safety, as well as socio-economic repercussions.

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 that LCA and LCC cannot capture.

MORE TO LEARN

Guideline for Social Life Cycle Assessment (PDF) (UNEP, 2009)

LCA for Milk Packaging

Life-Cycle Assessment of Energy and Environmental Impacts of LED Lighting Products

LCA of Drinking Water Systems

SUMMARY & UNIT WRAP-UP

- Energy efficiency has the potential to reduce usage of resources, energy costs and environmental impacts often with simple methods or small changes.
- In some cases energy efficiency is achieved by increasing output while maintaining the input resource. However, note that a small change in used input resources (e.g. electrification) can result in much larger resource conservation as the effect multiplies at the beginning of the value chain (e.g. amount of coal that will not 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 regarding its environmental, economic and social impacts and provides the bases for fact-based decision making.

MATERIALS

Please find below links to our materials and references

Video
www.giz.de/gc21/pa_video_lectures

Case Study
www.giz.de/gc21/pa_case_studies

Additional Material
www.giz.de/gc21/pa_additional_material

References
www.giz.de/gc21/pa_references

CHAPTER C

UNIT C1

POLICIES AND REGULATIONS FOR THE ENERGY AGRICULTURE NEXUS

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Please find below links to our materials and references

Video
www.giz.de/gc21/pa_video_lectures

Additional Material
www.giz.de/gc21/pa_additional_material

References
www.giz.de/gc21/pa_references

INTRODUCTION

Unit 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. Following this the concept of ***circular economy [» Unit C1.7]*** 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 energy, 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. 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, resource conservation and more efficient agricultural practices (Edenhofer et al., 2011; Branca et al., 2011).

» Chapter A

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 resides and animal dung for cooking (*IEA, 2015*).

This often leads to women's drudgery, children's lower school performance, health hazards from indoor air pollution, deforestation, soil erosion, loss of biodiversity and negative impacts on ecology and food security (Rehfuess et al., 2005; Rasul, 2014; Mirzabaev et al., 2015). To illustrate: women and children in rural areas of many developing countries are spending an increasing share of their time 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 & Seow, 2012) (*» video*).

Therefore a massive deployment of renewable clean energy sources in rural areas and agricultural value chains is necessary. 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 [» Unit B1.2]*** 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, using ***biogas*** or ***solar panels***, post-harvest losses could be decreased, improving product quality and farmers' incomes.

Exploiting such opportunities in the Energy Agriculture Nexus can thus raise agricultural productivity, incomes, and hence, enhance food security and help to decarbonize the global energy mix. 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 ***agricultural value chains [» Unit A1.3]*** and also through re-location of manufacturing industries into rural areas with more favorable access to land and labor resources, thus energizing broad rural development (*» video*).

Given these opportunities, there is a growing commitment at the global and national levels to increasing the share of renewable energy in 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, it is also necessary to enable institutional, regulatory and policy frameworks to facilitate renewable energy innovations and their wide-spread adoption, as well as to optimize the Energy Agriculture Nexus, by minimizing potential tradeoffs and promoting synergies. The next section elaborates on such regulatory and policy issues.

INTRODUCTION RECAP

- The Energy Agriculture Nexus can serve as a key platform for sustainable development.
- A wider deployment of renewable energy 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 energy in rural areas serves not only for consumptive uses, but also to create 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 have considerable potential to improve sustainability and incomes along ***agricultural value chains [» Unit A1.3]***. However, this potential is not always utilized due to a lack of sufficient political will to challenge fossil-fuel based technologies (Anthoff & Hahn, 2010; Lehmann et al., 2012; Sims et al., 2015).

Economic policy plays a key role in the development of the renewable energy sector. Enabling polices and regulations are often essential to the promotion of renewable energy technologies, especially in early stages when they are not prevalent on a large commercial scale (Sims et al. 2015). For example, the success of bioenergy in a major producing country such as Brazil, is linked to policies promoting biofuel production (***» video***).

However, there are many politically sensitive issues in energy policies and regulation regarding food security, the premise of job creation, reducing dependence on fossil fuels, ***climate change mitigation [» Unit A2]***, preserving 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 in the ***production of biofuels [» Unit B1.2]***. The increase in food prices due to competition between food and biofuels for agricultural crops has significant impacts (von Braun et al., 2008; Ewing & Msangi, 2009). The poor are especially affected negatively because they spend a larger share of their income on food (von Braun et al., 2008). For example, a large-scale introduction of biofuels may substantially increase maize prices (Bryngelsson & Lindgren, 2013).

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 they need to become commercially viable (IEA, 2013; Slade et al., 2009) through supportive regulatory and policy frameworks. This section focuses on policies and regulations used to support the development and deployment of renewable energy technologies.

We can distinguish two ways in which regulations could be viewed in this regard: 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. Ideally the major objectives of regulation target achieving efficiency in energy provision, fair pricing, equality of access and ***environmental sustainability [» Unit B3.4]***. However, the economics-based definition proposes that the role of regulation is to create conditions for markets to function efficiently (Minogue, 2013). However, efficient markets may not necessarily satisfy social equity considerations nor take environmental concerns into account as many ecosystem services have no market price, 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 call for the use of markets and setting clear incentives and standards (***Purkus et al., 2012***). At the same time government action is needed to overcome market failures. Accordingly, implementing innovative renewable energy policies requires proactive government action, societal support and the 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 & 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 in another example Mexico City mandated all new and renovated swimming pools, as well as large commercial buildings must cover 30 percent of their energy needs for water heating with solar energy (Cabre et al., 2015). Renewable energy mandates are being applied by an increasing number of countries. According to Renewable Energy Policy Network (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, targets in Germany are to generate 35 percent of its electricity from renewable energy sources by 2020, reaching 80 percent 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 renewable energy generated 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 a digressive element, when guaranteed prices gradually decline over time in order to stimulate cost-reducing innovations in the renewable energy sector (*» video*). Feed-in-tariffs can also be applied to photovoltaic irrigation schemes, whereby farmers could sell the excess of electricity generated to the central grid. Feed-in-tariffs are one of the most widely applied tools for promoting renewable energy. 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 that exceeds 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 energy. For example, the *International Renewable Energy Agency (**IRENA**)* and the *Abu Dhabi Fund for Development (ADFD)* have recently announced ***US-$ 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; Azuela & Barroso, 2012). Here for convenience, we 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, and stricter environmental standards (Azuela & Barroso, 2012), thereby discouraging 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 energy, which generate new knowledge and provide technical advice, represent the interests of renewable energy producers in political and other forums and mobilize funds for the deployment of renewable energy technologies.

NATIONAL AND INTERNATIONAL INITIATIVES PROMOTING RENEWABLE ENERGY

The United Nations declared 2014-2024 as the Decade of Sustainable Energy for All (***SEE4All***).

- 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**)* is 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.
- ***Powering Agriculture: An Energy Grand Challenge for Development*** seeks to identify and support promising clean energy innovations specifically targeted to the agricultural sector

Policy Tools	Strengths	Weaknesses
Renewable Energy Mandates and Targets	• Market-friendly • Promotes especially more mature technologies	• Requires high administrative and monitoring capacity • Less efficient in case of weak enfocement and low penalties
Feed-in-tariffs	• 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	• Can be very costly • Appropriate design may require continued adjustments through complex administrative procedures
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 enewable energy applications, especially when they are not sufficiently attractive to private markets • Particularly applicable for research and development into renewable energy inno vations • 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

Figure C1 | Comparison of Various Policy Tools for Promoting Renewable Energy

There are no blanket approaches. The choice whether or not to use any of these tools depends on the context of each country (Azuela & Barroso 2012). Moreover, each stage of development of renewable energy 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 *(Figure C1)*.

Among the policy instruments listed above, transfers and subsidies, fiscal incentives, grants, and soft loans are presently more widely applied to promoting renewable energy in the agricultural sector in numerous countries. For example, China is a prime example of a country that strongly promotes biogas production through various national plans and initiatives, such as the National Rural Biogas Construction Plan (2006–2010), and the 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 on their farms (Xiarchos & Vick, 2011).

Ethiopia instituted the Rural Electrification Fund to promote off-grid renewable energy adoptions in rural areas, and since 2010 also exempts import duties on renewable energy equipment. In many developing countries international donor grants serve as important sources for promoting renewable energy in rural areas and agricultural value chains (GIZ, 2012).

RECAP

- Renewable energy regulations and policies are often outcomes of complex political and social bargaining.
- Policy tools promoting renewable energy are numerous and varied. They include options such 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 disposal are not included in their price. Externalities are the costs or benefits that affect the third parties who did not choose to incur these costs or benefits. In general the concept of externalities is a crucial one in environmental economics and in environmental ***sustainabilityy*** ***[» Unit C3.4]*** (*» video*).

The true social cost – that includes all externalities - of the linear economy is very high, making it unsustainable. For example, in agriculture the unsustainable use of soils and land resources could lead to their degradation and erosion. In relation to human lifetimes, fertile soils are non-renewable resource, as it takes hundreds of years to form one centimeter of fertile topsoil. As a result not only land users themselves are affected negatively. Degraded soils not only provide 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 negatively affects not only direct land users but all of society. Eroded soils could be flushed to rivers, increasing their siltation filling up downstream reservoirs and reducing their hydro-energy production. The producers of ***hydro-energyy [» Unit B1.2 Hydro]*** 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, the deployment of renewable energy technologies, such as ***solar panels [» Unit B1.2 PV]*** for decentralized ***off-grid [» Unit C3.2]*** electricity, could create positive externalities by enabling rural households to use it not only 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 [» Unit B2]*** 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 C2)*.

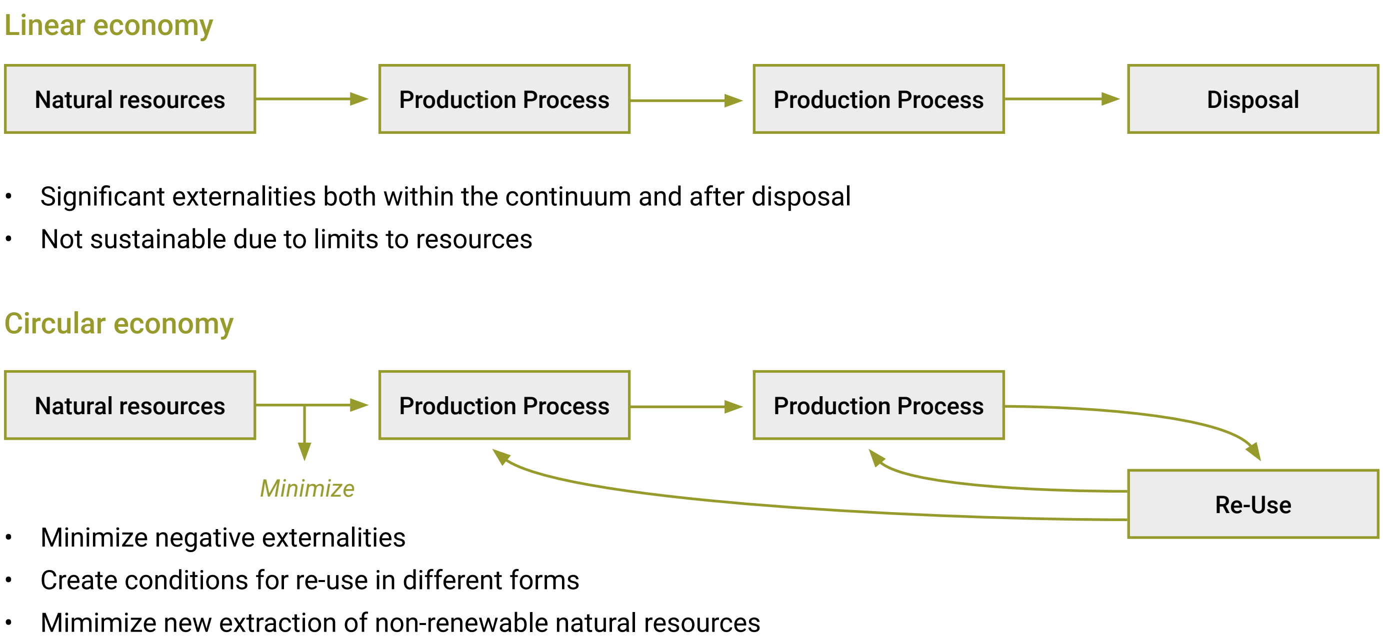

Figure C2 | Comparison of Linear and Circular Economic Models

Circular economy calls for minimizing new resource extraction and maximizing the re-use and recycling of already extracted resources instead. 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 be produced from renewable or otherwise sustainable sources.

Major conceptual directions in circular economic thinking are given below.

Cradle-to-Cradle Approach: opposes the so-called cradle-to-grave approach when natural resources are extracted, used, and then disposed of. The 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 a zero waste objective remains elusive for now.

Biomimicry: seeks to organize production processes in ways that emulate nature. For example, studying the structure of leaves to create 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 waste 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 the 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 [» Unit A1.1]*** thinking partially overlaps with the circular economy concept, as it also seeks to minimize negative externalities between 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 water pumping for irrigation, integrated crop-livestock management, and re-use of organic waste for producing compost can help to reduce the environmental impact of agricultural production and food systems in general. ***Deployment of renewable energy sources to replace fossil-fuel energies in post-harvest management [» Unit B1]*** (e.g. solar energy for the refrigeration of dairy products), transportation (biofuels) and along other components of ***food value chains [» Unit A1.3]*** can provide promising opportunities for their de-carbonization.

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 regulating 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.

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 [» Unit B3]*** as well. For example, even beyond more energy-efficient farm buildings, there is significant scope for reducing energy consumption in crop production by measures of conservation agriculture 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, as also indicated earlier there are opportunities for agriculture-energy synergies in the livestock production sector related to ***biogas production [» Unit B2]*** , with 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 process. The stakes of 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, conceptualizes energy choice as a linear step by step transition process: as incomes increase 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 & Dowd, 1987). In contrast, energy stacking states that there is no unique and monotonic energy transition process, but rather energy consumers use multiple energy sources and their choice is dictated by a multitude of socio-economic and cultural preferences (Guta, 2014; Heltberg, 2004).

Recently, “energy leapfrogging” has gained increasing policy attention. It refers to a process of energy transition that involves bypassing conventional energy and leaping directly to more efficient, safe and environmentally friendly energy technologies (Murphy, 2001). Accordingly developing countries have the opportunity to borrow advanced energy technologies from industrialized countries to “leapfrog” from less sophisticated energy technologies to modern, cleaner energy alternatives without the necessity of going through more polluting energy sources such as coal and oil (Marcotullio & Schulz, 2007). In practical terms however, a rapid and fast energy transition from traditional biomass and coal to electricity may be difficult to enact (Zhang, 2014; Guta, 2014). Recently the most successful “leapfrogging” has taken place in mobile phone technology, as the millions of people in developing countries have bypassed 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) and is often limited by lack of technological capabilities (Murphy, 2001; Gallagher, 2006). Therefore, in developing countries energy transition has been constrained by the 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 energy in agriculture [» Unit B1]*** and its varied applications in agricultural value chains can provide substantial benefits, as indicated in the introductory section. Presently many rural communities in developing ***countries do not have access to centralized grids [» Unit C3.2]***. In this context, decentralized off-grid or community-based mini-grid access to electricity using renewable sources could help to improve rural welfare and increase agricultural productivity. Promising uses of ***solar energy [» Unit B1]*** already exist at various stages of agricultural value chains, including using it to pump irrigation water, desalinate water, dry crops and forages, heat greenhouses and refrigerate produce in post-harvest management.

Energy Transition

> **Case: Germany**
> Germany serves as an example for gradual, policy-driven energy transition – "Die Energiewende" – initiated in 2010 (Stegen and Seel, 2013). One of the targets is to increase the share of renewables in energy production to 80 percent by 2050 (BMU, 2012). In order to trigger investments in renewable energy, above-market minimum prices are mandated for renewable energy sources. The minimum prices (per kWh) differ according to the energy source. In the context of globally inter-linked energy markets long term cost-effectiveness needs to be achieved to compete internationally and will be a key factor for the long-term success of the project. Experience with the energy transition so far provides lessons for policies that target the expansion of renewable energy. For instance, charging higher energy prices to final consumers, as done in Germany, is not likely to be feasible 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 those living close to new energy lines. This emphasizes the scope for decentralized energy grids where energy can be produced on a much smaller scale. Even in the short-term net economic growth and positive employment effects of energy transition, should encourage the adoption of policies that foster investments in biomass (Blazejczak et al., 2011; *» video*).

RECAP

- Regulation of energy use pursues two objectives: increasing energy 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 energy may require similar rapid progress in institutional frameworks governing energy production and use.

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

Access to energy is a key component of ***sustainable development [» Unit B3.4]*** (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 & Cleveland 2004). Lack of access to modern energy technologies, especially electricity, limits the expansion of income-generating activities along ***agricultural value chains [» Unit A1.3]*** in many developing countries. Access to clean, reliable and affordable energy would enhance food security, lead to healthier lives, and promote gender equity (Mirzabaev et al., 2014). In addition modern renewable energy can reduce poverty, by creating employment opportunities, for example (IRENA, 2015, 2016; Jacob et al., 2015). However, the renewable energy sector's job creation potential 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).

By contrast, the employment effect of renewable energy 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 Powering Agriculture Initiative *projects*. Such innovative uses of renewable energy could increase the incomes of rural households; stimulate entrepreneurial dynamics through micro- to small-sized rural business creation. Furthermore, renewable energy projects could also increase agricultural productivity.

Besides these economic dimensions, the deployment of renewable energy has considerable effects on society and gender. By some estimates the use of traditional biomass for domestic cooking with inefficient cooking stoves account for up to 4 million premature deaths annually worldwide, which mainly affects women and children (Lim & Seow, 2012; Rehfuess et al., 2006).

Improved access to clean bioenergy sources, such as using biogas for cooking and adopting more efficient cooking stoves, could thus have substantial health benefits which, in turn affect labor productivity, incomes and savings positively (Duflo et al., 2008; *» video*). For example, better access to clean energy could facilitate boiling water before consumption thus lowering the risks of waterborne diseases (Rehfuess et al., 2006) and may also reduce medical expenses for poor households, and improve school and work attendance (Duflo et al., 2008).

Access to electricity also facilitates broad rural development. Many poor communities do ***not have access to centralized grids [» Unit C3.2]***, and are especially likely to benefit from local small-scale renewable energy projects, such as local mini-hydro or solar and wind energy for mini-grids (Gerber, 2008; Chakrabarty et al., 2013). Access to electricity through decentralized mini-grids could facilitate a wider fuel switch to modern renewable energy (Heltberg, 2004). In Assam, India, access to electricity was found to increase literacy rates from 63.3 to 74.4 percent (Kanagawa & Nakata, 2007); similarly, in Brazil, rural electrification was found to reduce poverty by 8 percent and the Gini coefficient of inequality from 0.39 to 0.22 (Pereira et al., 2008).

BIOGAS PLANTS PRODUCE GAS AND MANURE

» B2

Biogas projects make manure available to fertilize fields, PV lighting extends daylight hours for field work, ***renewable energy-based mechanization technologies*** improve agricultural labor productivity.

RECAP

- Access to clean, reliable and affordable energy, especially in rural areas of developing countries would help reduce poverty, enhance food security, lead to healthier lives, and promote gender equity.
- Major ways to achieve these objectives deploying renewable energy in rural areas are to generate employment, add value to agricultural and rural businesses and raise agricultural productivity.
- Deployment of modern renewable energy is also likely to have significant

gender dividends, improving women's health and expanding their employment opportunities in income-generating activities.

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

The Energy Agriculture Nexus provides substantial business development opportunities along ***agricultural value chains***. ***[» Unit A1.3]*** 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 & Morris, 2001). ***Dairy value chain [» Unit B1.1.1]*** for example 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, experts (Virchow et al., 2014) argue that this conventional view of value chains is no longer sufficient. Since synergistic links among value chains in agriculture exist, 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 must seek to minimize inefficiencies in the entire value web (ibid.), if we take maize value web, for example, maize produced on the farm could be fed to various value chains; it can be used either in food production, feed production, or fuel production. Each of these represent distinct value chains however, price changes in any of these would affect the rest of the value web.

Modern renewable energy solutions could help increase productivity, efficiency and incomes by providing opportunities to increase the generation of added value. There are numerous, promising uses of ***renewable energy [» Unit B1]*** to increase the value added along various stages of agricultural value chains. At the production level crop and livestock production are already being used to produce energy ***(biofuels, biogas [» Unit B1])***, and due to various policy incentives and technological innovations this is likely to continue to grow. Solar energy is being used for ***irrigation water pumping***, water desalination, for heating greenhouses. ***At postharvest stage*** there are opportunities to use renewable energy to dry crops and forages, to refrigerate produce and to reduce food losses (***REEEP 2015***). There are also opportunities for wider use of ***biomass to combine heat and electricity generation***, to process ***wood products thermally, and to gasify rice husks***.

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 [» Unit C2]*** of renewable energy applications in agriculture depends on effective demand availability, which can pay for the delivered goods and services, cost competitiveness of renewable energy with fossil fuels, enable 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 [» Unit C3.2]*** conventional diesel electricity generation can be less cost-effective compared to renewable sources. Alfaro & Miller (2014) find that in Liberia, small hydropower, small biomass projects and solar panels generate electricity at lower prices even though small diesel units have the lowest capital costs.

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).

RECAP

- Renewable energy provides opportunities to increase incomes by developing higher valued added agricultural value chains in rural areas.
- Various agricultural value chains often form complex inter-linkages in value webs.
- 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 C1.6 | Financing for Renewable Energy and Energy Efficiency Solutions in the Agricultural Sector

To reiterate, over 1.2 billion people today still lack access to electricity and 2.7 billion people are without clean cooking technology (IEA, 2015). Agriculture in developing countries is hardly mechanized.

Evidently, financing needs to overcome these challenges are substantial. According to the International Energy Agency (2011), 49 billion US-$ 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 US-$ for clean cooking). Fischedick et al. estimate

(2010) that between 2021–2030 annual global financing needs for renewable energy to keep CO_2 concentration below 450 ppm (parts per million) – corresponds to a 50 percent chance of keeping global warming under 2°C – are about 750 billion US-$. In order to double the global rate of energy efficiency an additional 30-35 billion US-$ is needed in low-income countries, and 140–170 billion US-$ 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 or health care), the government budget may not be able to finance energy infrastructure at necessary levels (Terrapon-Pfaff et al., 2014).The key barriers to many renewable energy projects' long-term sustainability are financial constraints and lack of credit for costs of operation and management of projects over time. By contrast capital markets, which prefer to work with large actors to limit operational costs and better manage risk, often discriminate against small-scale renewable energy projects, like those we have seen in the agricultural sector, –, making the role of government and development partners indispensable.

There are numerous financial and organizational tools to fund renewable energy projects in rural areas and agricultural value chains, including soft loans, subsidies, venture capital and private equity, ***renewable energy service companies (RESCOs) [» Unit C1.7]***, and ***microfinance [» Unit C3.1]*** . ***Microfinance*** and RESCOs are most often used approaches to ***finance small-scale renewable energy, especially for solar panels***. RESCOs are innovative organizational forms that sell their renewal energy services for a monthly fee instead of selling the actual technology. RESCOs are especially suitable for small rural solar energy technologies, for example PV solar home systems (Liming, 2009).

These various sources of funding for renewable energy could be combined innovatively through public-private-community partnerships (ibid.). Such funding tools as ***venture capital***, corporate bonds and private equity could fund large-scale agricultural value chains. Initiatives to improve energy use efficiency in agricultural value chains are often funded through public or international sources. The ***Clean Development Mechanism*** (CDM) can be a funding tool for using agricultural by-products as an energy source, for example (Larson et al., 2011); however, the extent of funding the CDM gives to agricultural energy projects remains relatively limited.

In summary, successfully deploying clean energy businesses in the agricultural sector requires a good understanding of how related ***value [» Unit A1.3]*** chains and the broader value web function. Sound business and financial planning *[» Unit C2; » Unit C3]* could ensure the economic viability of the business, its access to funding, technologies, inputs: a good knowledge of the business outputs' demand characteristics, and last but not least, a careful study of relevant regulations and policies.

RECAP

- The financing needs to provide universal access to modern energy are substantial and often exceed local funding capacities.
- There are several financing tools to fund renewable energy in the agricultural sector, such as microfinance, soft loans and loan guarantees, subsidies and grants, venture capital and private equity, and various combinations thereof through public-private-community partnerships.
- Government and international donors must often play an indispensable role in promoting renewable energy in agricultural value chains, as private funding sources tend to avoid these investment sectors due to high administrative and monitoring costs.

MATERIALS

Please find below links to our materials and references

Video
www.giz.de/gc21/pa_video_lectures

Additional Material
www.giz.de/gc21/pa_additional_material

References
www.giz.de/gc21/pa_references

Unit C1.7 | 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): This denotes small-scale and local transformation of renewable resources (wind, solar radiation, biomass, small hydropower) into electricity or thermal energy used for different activities by communities or households in diverse 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 costs or benefits that affect 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 generated renewable energy with a long-term contract and at cost-based purchase prices. Feed-in-tariffs often have a digressive element, when guaranteed prices gradually decline over time in order to stimulate cost-reducing innovations in the renewable energy 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 exceeding their own needs to the central grid.

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

RESCOs: renewable energy service companies are innovative organizational forms that sell their services for a monthly fee instead of selling the renewable energy technology itself. RESCOs are especially suitable for small rural solar energy technologies.

Transfers and Subsidies: direct or indirect monetary support to producers or other actors involved in renewable energy production.

UNIT C2

ENERGY AND AGRICULTURE ON A MICRO LEVEL

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INTRODUCTION

Unit 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 [» Unit A1.3]*** 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 different scales of agricultural enterprises, which show differing management and potential to adopt ***renewable energy [» Unit B1]*** and ***energy efficiency [» Unit B3]*** interventions, and that 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 an energy investment cost-benefit analysis and identifies decision making tools that can be easily adopted by farmers and food processors.

MATERIALS

Please find below links to our materials and references

Video
www.giz.de/gc21/pa_video_lectures

Additional Material
www.giz.de/gc21/pa_additional_material

References
www.giz.de/gc21/pa_references

Traditionally agricultural production has 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 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, pumping water, lighting, animal comfort, mechanical power, etc. (Sims et al., 2015).

Indirect energy embedded in further agricultural activities such as machinery or fertilizers is also considered. It is estimated that around one third of total end use energy is consumed by the agriculture and food sector globally (FAO, 2011).

Sustainable energy interventions could reduce fossil dependency as well as CO_2 emissions along the agriculture value chain. This could be achieved by introducing renewable energy technologies as well as energy efficiency and thus improve energy intensity.

Renewable energy technology [» Unit B1] may be very relevant for rural communities still without access to modern energy services or where conventional energy is particularly expensive due to poor road infrastructure and unreliability of the national electricity grid for example. In such remote locations, small-scale hydro, wind, and solar power systems can replace fossil fuel generators to produce electricity for the production, storage, handling and processing of food products.

Investment in renewable energy and energy-efficient technologies [» Unit C1.6] that address the food-energy nexus can target different stages of the food value chain, therefore it is appropriate to adopt a value chain approach *(Figure C3)*. In fact each step of the value chain presents different challenges to ensure relevant energy services are provided efficiently, cost-effectively and minimize reliance on the fossil fuel market.

This lecture refers to investments in renewable energy and energy efficiency options from the agricultural production stage to food processing activities, leaving aside intervention in transport and logistic sectors, marketing and distribution phases, and food preparation and consumption.

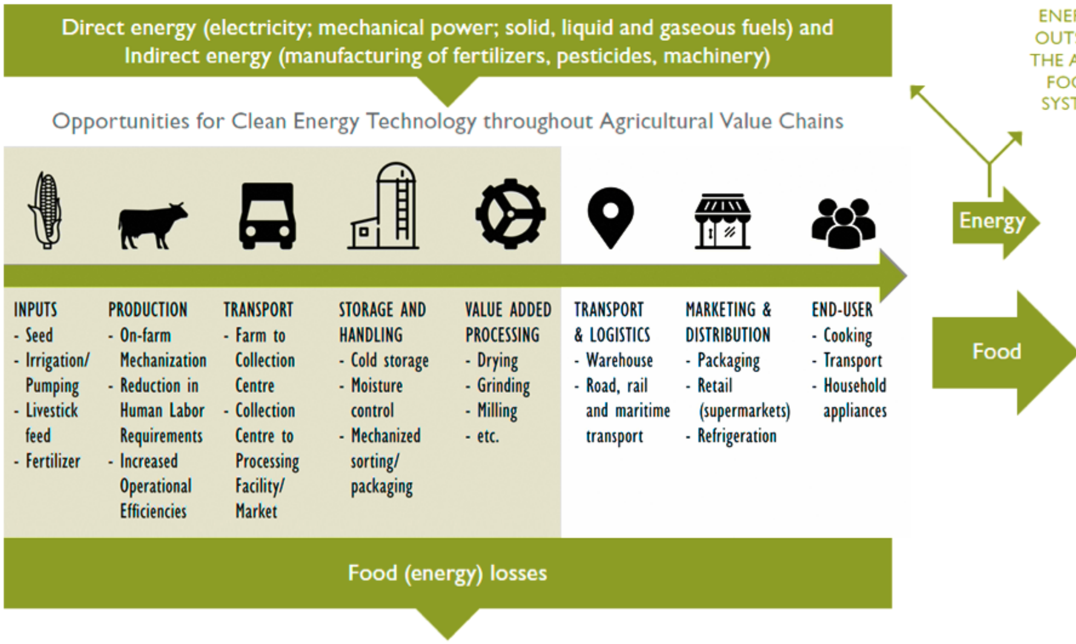

Figure C3 | *Food Value Chains in the Agricultural Production and Processing Sector (Sims et al., 2015)*

Applying a value chain approach, it becomes evident how the value of food products tends to increase as more processing occurs and more inputs (energy, water, packaging materials) are consumed. Taking ***milk [» Unit B1.1 – Milk value chain]*** as an example *(Figure C4)*; producing, pasteurizing and bottling fresh milk requires around one tenth of the total energy input of 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 mill-

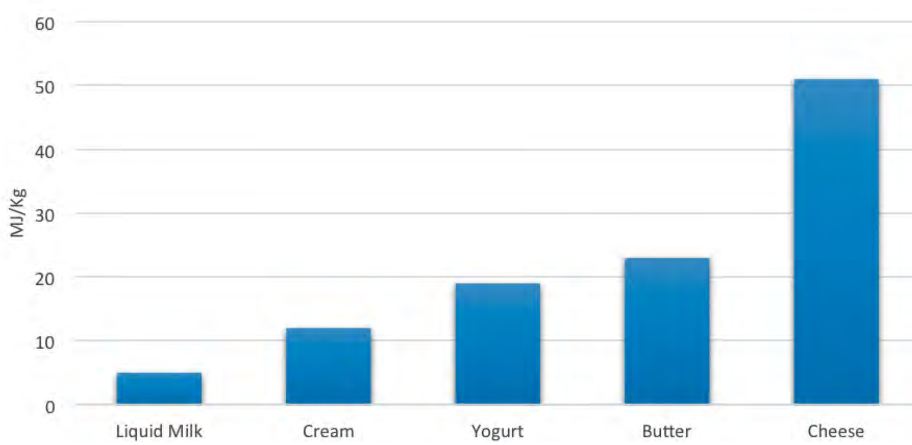

Figure C4 | *Differences in Energy Consumption of Different Milk Products (Sims et al., 2015)*

Energy inputs along the food chain (MJ/kg) tend to increase the value of the product for which the consumer is willing to pay more in terms of USD/calorie delivered.

ing 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.) (Sims et al., 2015).

Introduction 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 an improvement in energy intensity.
- Each step of the value chain presents different challenges to ensure that relevant energy services are provided efficiently, cost-effectively and minimize reliance on the fossil fuel market.
- Applying a value chain approach, it becomes evident how the value of food products tends to increase as more processing occurs and more inputs (energy, water, packaging materials) are consumed.
- The energy interventions considered span solar-power irrigation systems to cooling and cold storage facilities, and the use of residues for energy production to geothermal energy for food processing.

MORE TO LEARN

An overview of energy technologies that can be introduced along the relevant 'hot points' in the production chain of selected food products is provided in Sims et al., 2015. (PDF)

Unit C2.1 | Scales of Agri-Food Enterprises

The spectrum of agricultural enterprises is complex and diverse. They range from basic subsistence smallholder farmers 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 differ in managing and incorporating renewables.

Human and animal power are commonly used in small-scale operations for instance, but are increasingly substituted with fossil fuels in other systems. Obviously the adoption of fossil fuels depends on availability and prices, so it will be favored in regions where these are relatively inexpensive. At the same time ***renewable energy technologies [» Unit B1]*** increasingly substitute fossil fuels in several medium and large-scale agricultural production and processing activities.

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).

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

In order to represent the various levels and intensities of energy inputs, agri-food enterprises can be divided between industrial large-scale farming systems, small business and family farms, and small-scale subsistence farming *(Figure C5)*. These differences in impact scale rely on the ability to manage and incorporate ***renewable or energy-efficient technologies [» Unit B1.2]*** and are therefore taken into consideration throughout the techno-economic analysis of agri value chains/projects.

Scale of Producer	Overall Input Intensity	Human Labor Units	Animal Power Use	Fossil Fuel Dependence	Capital Availability	Major Food Markets	Energy Intensity
Subsistence level	Low	1–2	Common	Zero / low	Microfinance	Own consumption	Low
Small family unit	Low / medium	2–3	Possible	Low / medium	Limited	Local fresh / process / own use	Low / high
	Medium / high	2–4	Rarely	Medium / high	Limited	Local fresh / regional process / own use	Low / high
Small business	Low / medium	3–10	Rarely	Medium / high	Medium	Local / regional / export	Low / high
	Medium / high	3–10	Never	High	Medium	Local / regional / export	Low / high
	High	10–50	Never	High	Good	Regional / regional / export	Low / high
Large corporate business	Medium / high	3–10	Never	High	Medium	Local / regional / export	Low / high

Figure C5 | *Levels and Intensities of Energy Inputs in Farms and Fisheries (FAO, 2011)*

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.

Subsistence Level: This is the smallest system in which households are engaged in basic forms of small-scale agricultural activities. They produce solely for their own consumption. Subsistence farmers use very low energy inputs, usually derived from human and animal power. These energy inputs are difficult to measure and not included in world energy statistics (FAO, 2011). For subsistence farmers priorities 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. Nevertheless, coordinated networks of subsistence farmers can benefit from renewable energy systems such as small-scale hydro, wind and solar powered systems.

Small Family Units: They 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. 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. Since these businesses have more capital available, they have opportunities to reduce their fossil fuel dependence by investing in on-farm renewable energy, which could also provide additional benefits to the surrounding local community.

Large Corporate Businesses: ‘Corporate’, ‘industrialized’, ‘market-based’, ‘commercial’ and ‘multinational’ are terms used to describe modern, large-scale food systems that produce food, fish, feed or fiber. These systems are usually dependent on high direct and indirect energy inputs throughout the supply chain and have access to finance renewable energy technologies and energy-efficient equipment. Therefore, their potential to substitute fossil fuels with renewable energy sources and energy- efficient options for production or processing activities, such as solar/wind irrigation systems, storage facilities, and drying operations is large. Energy may be used on-farm or sold off-farm for additional revenues (FAO, 2011).

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 agri value chains/projects.

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

» Unit C3

Unit C2.2.1 | 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 value chains, and analyzes their feasibility and financial and economic cost-benefits in relation 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. It analyzes whether a project can be completed successfully, taking legal, economic, technological, scheduling and other factors into account. It permits the investigation of possible positive and negative outcomes of a project before too much time and money is invested.

A first step is to contextualize the investment into an economic, institutional, social and technical framework. Constraints and challenges to the use of sustainable energy in agricultural and food industries in developing countries can indeed stem from these areas. *Figure C6* summarizes the main constraints on biomass supply and barriers to sustainable bioenergy supply chain mobilization. A preliminary test for the value of the investment requires clear ***identification of financial, economic, institutional, social and technical opportunities and risks [» Chapter C]***.

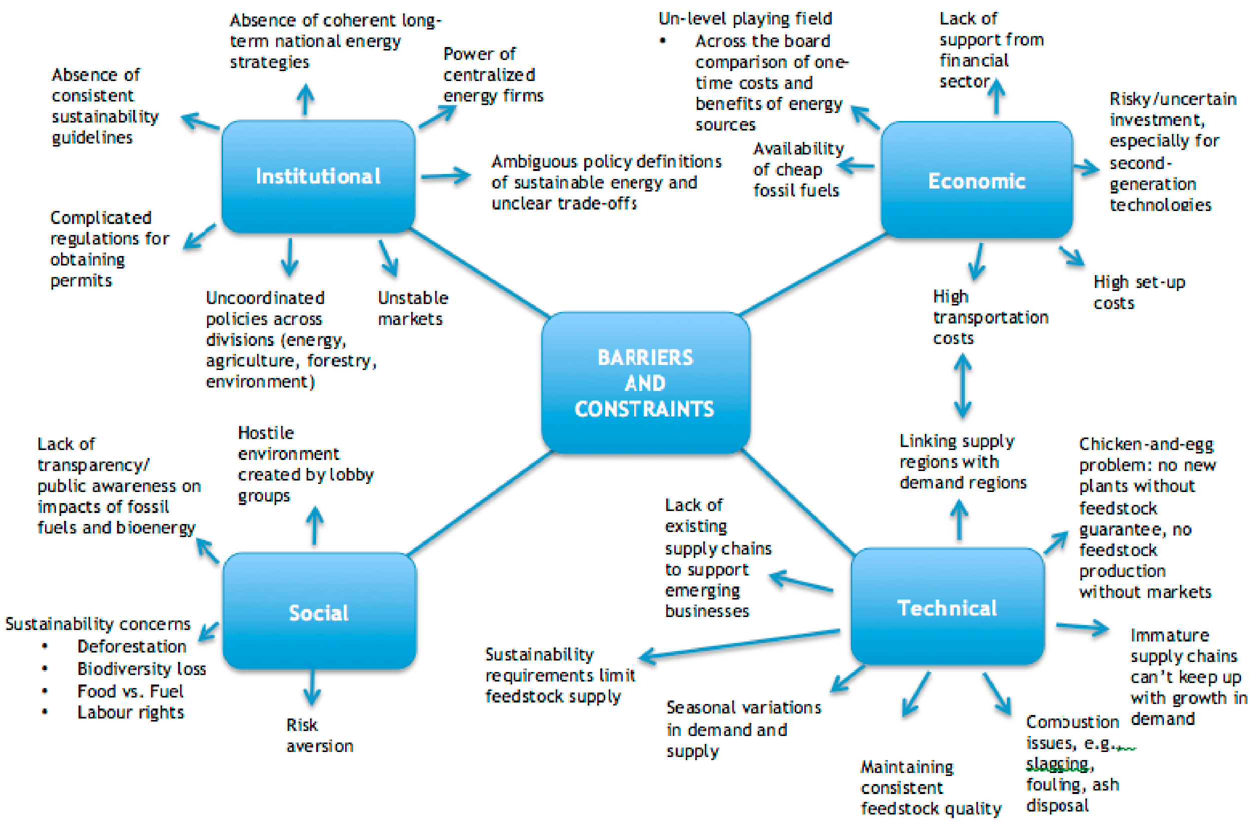

Figure C6 | Constraints and Barriers to Sustainable Bioenergy Supply Chain Mobilization (IEA Bioenergy, 2015)

Some of these barriers would be considered in detail in the economic analysis, but first an identification of constraints 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 might seem financially attractive. In the 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 also depends 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 commercialization (*Figure C7*).

MORE TO LEARN

An overview of energy technologies that can be introduced along the relevant 'hot points' in the production chain of selected food products is provided in Sims et al., 2015. (PDF)

Figure C7 | *Examples of Clean Energy in the Agri-Food Value Chain (REEP, 2015)*

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

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 project costs are very site-specific (*Figure C8*). Levelized costs of many renewable energy technologies are becoming more and more competitive with current average costs of fossil-fuel powered electricity,

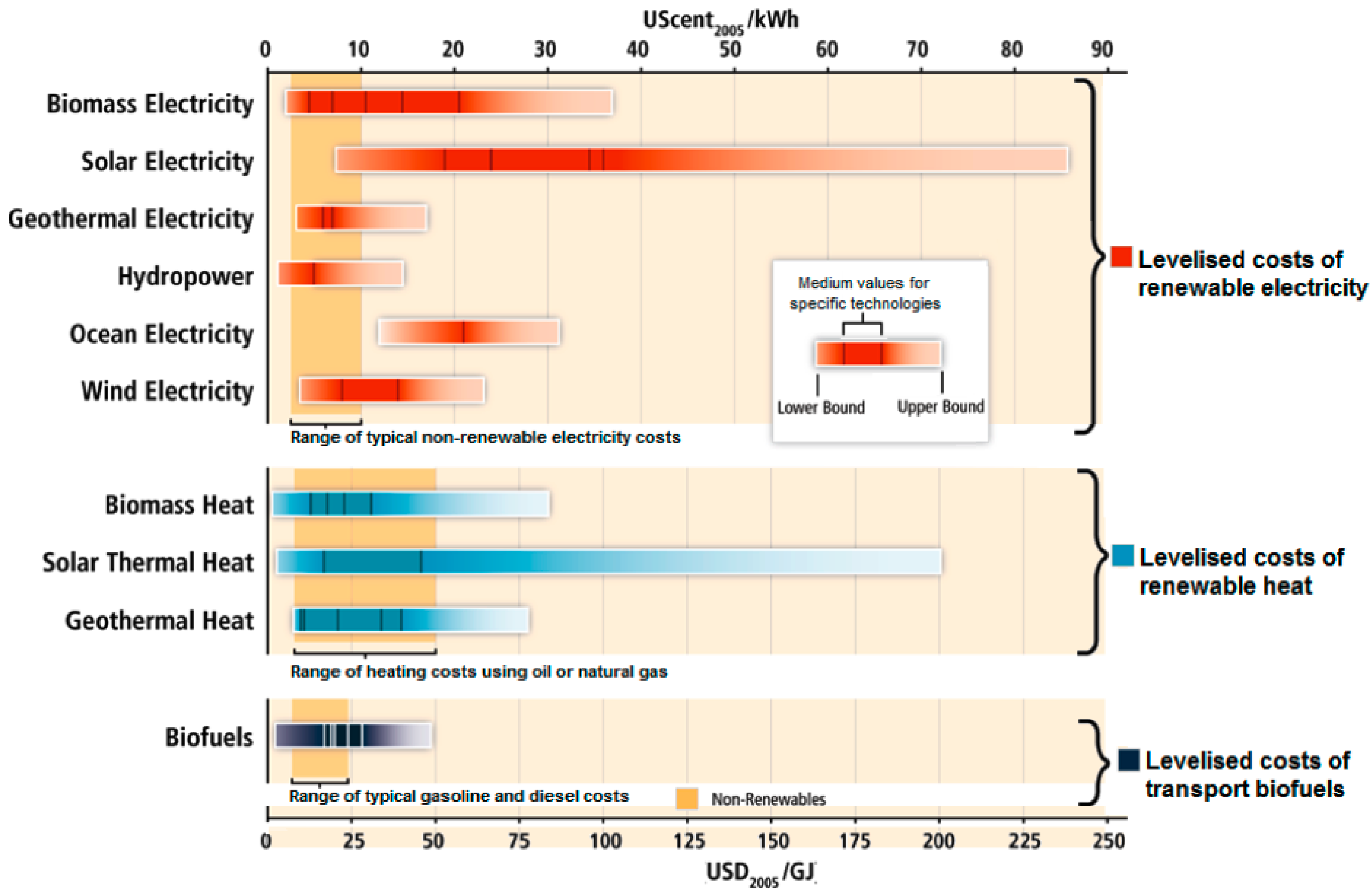

Figure C8 | *Cost Comparison of Fossil and Renewable Energy Products (based on IPCC, 2011)*

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).

heat and transport fuels they displace. Moreover, costs for renewable energy technologies decline as the size of their markets increases. In remote rural regions ***with no electricity grid access [» Unit C3.2]*** for example, autonomous renewable energy systems avoid expensive grid connection costs and are already competitive.

In order to quantitatively assess the attractiveness of an investment 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 to perform 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

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 competiveness 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.

order to demonstrate that the incentive of all actors is high enough 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 (FAO). 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 agents (farmers, retail traders, primary assemblers); it includes the analysis of production-utilization 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.

Most governments and International Financing Institutions (IFIs) usually require a financial and economic analysis (FEA) of investment projects 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 investigating 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 [» Unit C1.4]***.

In the paragraph below, we will explore these two steps in more detail.
In agricultural and food enterprises, ***renewable energy technologies [» Unit B1]***

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 thus 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 of 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 outcomes, including capital and operating costs, and 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 determining the project’s incremental net flows (financial and/or economic), which results from comparing costs and benefits of the project with the benchmark scenario. It is possible to calculate the corresponding project profitability indicators with these elements.

Unit C2.2.2 | 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 of monetizing all major benefits and all costs generated by the investment and presenting their streams over the lifetime of the technology, usually expressed in number of years (cash flow). Costs and benefits can then be compared directly 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: Net Present Value (NPV), Internal Rate of Return (IRR), benefit/cost (B/C) ratio and the payback time. These indicators assess attractiveness of investment by comparing the present value of money to the future value of money, 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, Rt).

Unit C2.2.3 | NPV equation

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

$R_t = Sum\ of\ all\ the\ discounted\ future\ cash\ flows$
$R_0 = (Negative)\ cash\ flow\ at\ time\ zero, representing\ the\ initial\ investment$
$t = Time\ of\ the\ cash\ flow, depending\ on\ the\ project\ lifetime$
$i = Discount\ rate\ or\ rate\ of\ return$

Therefore, the NPV of a project depend on its net benefits, project lifetime and discount rate. Whenever the NPV is positive (NPV > 0), the project is considered worthwhile or profitable. Comparing the NPV of several possible investments permits identification of 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 positive cash flow for the project equals the present value of its costs. If IRR exceeds cost of capital, the 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 invest-

MORE TO LEARN

NPV Equation

MORE TO LEARN

IFAD'S Internal Guidelines Economic and Financial Analysis of rural investment projects. Basic concepts and rationale. The International Fund for Agricultural Development (PDF) (IFAD, 2015).

ment in absolute terms, while IRR expresses the return in percentage. A project with an IRR of 500 percent on US-$ 1 is less attractive than a project with an IRR of 20 percent on US-$ 100, although the former has a higher IRR for example. 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) *[» Unit C3.1]*: (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 indicate the magnitude of the investment, and in contrast to 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 costs and benefits flows 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 that require minimum expertise in statistics and probabilities, together with user-friendly computer programs. 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 project dynamics and uncertainties. The insights gained by quantitative risk analysis may be useful for project design and evaluation.

MORE TO LEARN

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 results obtained and the benchmark scenario in order to determine net incremental benefits of proposed interventions.
3. Calculate the financial profitability indicators of each project scenario (i.e. financial NPV, financial IRR, B/C ratio, payback time), applying these investment criteria to make an investment decision (positive or negative).

Unit C2.2.4 | 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, 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 economic analysis deals with costs and benefits to society. 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 [» Unit C1.4]*, and net benefits to society as a whole.

An economic analysis takes energy *subsidies and taxes [» Unit C1]*, the impacts of the renewable energy project on land, labor and human rights, local people livelihood, environment, GHG emission, etc. into account (FAO, 2015). These and other externalities and co-benefits are context specific and can be inserted in the analysis in order to modify the project's structure of economic costs and benefits. These include for example economic incentives to renewables or fossil fuels, or costs to *mitigate climate change [» Unit A2]*, or to ensure more efficient use of water and land, costs accrued in water treatment, measures to contain negative environmental impact, which are part of the picture, although not present in the financial investor business plan.

The FAO Nexus Assessment [» Unit A1.1] (FAO, 2014) is a tool that can be used to introduce basic social and environmental externalities of a technical intervention into the analysis. This assessment consists of an easily applicable methodology to quickly evaluate possible interventions in a specific context against overarching development goals, such as food security, and the sustainability of energy and water supply, use and management. A simplified version of this tool, the Water-Energy-Food (WEF) Nexus Rapid Appraisal, can be used for a desk assessment of the impacts of an intervention on water, energy, food, labour and costs in the context of a specific country.

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. Deriving "shadow" and economic prices net of transfer payments are therefore not easy tasks, but leading factors to calculate economic performance indicators adopting a social discount rate: economic NPV (ENPV), IRR, B/C ratio and payback time.

MORE TO LEARN

Walking the Nexus Talk: Assessing the Water-Energy-Food Nexus in the Context of the Sustainable Energy for All Initiative (PDF) (FAO, 2014)

FAO Water-Energy-Food (WEF) Nexus Rapid Appraisal.

CLOSE-UP

Main differences between financial and 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 "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.

Unit C2.2.5 | Cost-Benefit Analysis Tools

Cost-Benefit Analysis can be difficult for non-professionals. 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 on 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 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 permits calculation and comparisons of different projects' alternative scenarios (with–project versus without-project). The WinDASI program is downloadable from the FAO EASYPol website: *» HERE*

VCA Tool - a software for Value Chain Analysis to assess socioeconomic and environmental policy impacts: developed by FAO, this tool allows different scenarios to be built and to analyze 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 intervention is exogenous and can come from other sources. Among other things, the tool permits: 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: *» HERE*

Power Irrigation Tool: this FAO tool evaluates economic, environmental and social aspects of different energy sources for irrigation in order to help operators 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 cost, price, and payback time. It can be accessed: *» HERE*

Rural Invest - 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 materials. More information: *» 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), taxes, environmental characteristics of energy displaced (e.g. grid electricity), environmental credits and/or subsidies (e.g. GHG credits, deployment incentives), indicators such as payback period, ROI, NPV, energy production costs. It has been developed by CanmetENERGY and can be downloaded *» HERE*

The journey from financial to economic analysis is not always smooth and according to the focus of the analysis the investigator has to make a decision on political, economic, social and environmental factors to be included in the analysis. Regarding 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 social and environmental factors of the analysis is the already mentioned FAO Nexus Assessment, which assesses the performance of some energy interventions in terms of water, energy, food, labor and costs in a specific context (FAO, 2014).

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 goods.
2. Remove transfer payments (taxes and subsidies) and quantify externalities (positive and negative).
3. Compare a project's costs and benefits with the benchmark scenario to obtain the project's incremental net flows.
4. Calculate economic performance indicators adopting a social discount rate: ENPV, IRR, B/C ratio and payback time.
5. Perform sensitivity analysis in order to deal with the main risks and uncertainties that could affect a proposed project.

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 monetized benefits.

- The third step is determining the project's incremental net flows, which result from comparing costs and benefits of the project with costs and benefits of the benchmark scenario. Then 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 economic flows.
- Perform Sensitivity Analysis in order to deal with the main risks and uncertainties that could affect the proposed project (optional).

SUMMARY & UNIT WRAP-UP

This unit 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 literature and references.

MORE TO LEARN

Opportunities for Agri-Food Chains to Become Energy-Smart (PDF) (Sims et al., 2015)

IEA/IRENA Joint Policies and Measures database.

MATERIALS

Please find below links to our materials and references

Video
www.giz.de/gc21/pa_video_lectures

Additional Material
www.giz.de/gc21/pa_additional_material

References
www.giz.de/gc21/pa_references

UNIT C3

BUSINESS MODELS FOR PROJECTS IN THE ENERGY AGRICULTURE NEXUS

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References
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INTRODUCTION

Building on the previous chapters 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 do not thereby necessarily refer to a completely 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 will hopefully help you in implementing your own clean energy solutions for agricultural activities.

Unit C3.1 | Business Models

Unit C3.1.1 | Introduction to Business Models

Although a business model is a fundamental part of economic activity, the term is understood and defined in many different ways. To put it simply 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. A business model can also be defined as "the specific combination of the product made and sold by the firm, the technology utilized, and the scale of production, backward and forward market linkages and financing arrangements" (ValueLinks Association, 2009).

Usually everything 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 established businesses also 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 added-value. Developing a new business or a start-up into a long-term successful business 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 C9*) (Osterwalder, 2010). By answering the questions for each key point provided in *Figure C10*, you can specify your individual business model. This is an important step before conducting financial calculations or starting to implement any business activity.

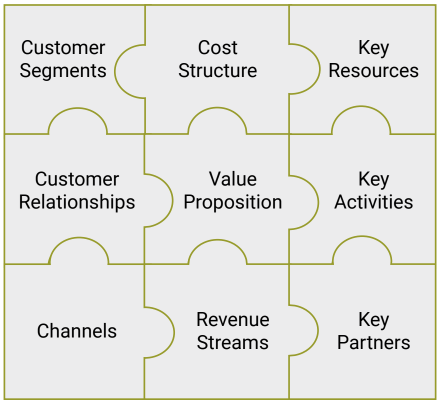

Figure C9 | *Key Elements of the Business Model Canvas (according to Osterwalder, 2010)*

Customers	Customer Segments	Who are your target customers? How big is the potential customer group? How willing are they t o pay for this product/service?
	Customer Relations	Which type of relationship should exist between you and the customers? Are any costs connected with this?
	Distribution Channels	Which channels do you want to use to distribute and communicate to the customers? Which channels exist, are suitable and cost-efficient?
Value Proposition	Value Proposition	What do you want to offer to your customers, what kind of service or product? Which of their problems or needs are you addressing?
Infrastructure and Organization	Key Resources	Which resources do you need to produce, market, cultivate, etc. customer relations?
	Key Activities	Which activities are necessary to produce, market, cultivate, etc. customer relations?
	Key Partners	Who are your main partners and suppliers?
Finances	Cost Structure	Which fixed and variable costs must be considered?
	Revenue Streams	What are customers willing to pay? How much do they pay for alternatives?

Figure C10 | *Sample Questions for Defining the Key Elements of a Business Model (Osterwalder, 2010)*

To be able to answer these questions, it is recommended that market research and analysis be carried out. 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. 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 production costs you have and what profit margin can be reached by selling the product or service.

Of course, macro-economic aspects also need to be considered – these have been presented in *Unit C1 [» Unit C1]*, so that this Unit 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 no single model that fits all types of business. You have to define your own model that specifically fits your intended economic activity.

Let us look at some examples for business ideas at the interface of energy and agriculture. You see market potential to sell dried fruits to the market for instance – hence, you decide to purchase a solar dryer. Using the business canvas (see above) you define your target customers and your value proposition, analyze finance structures and identify key partners.

Another possibility is that you are already operating a business. Integrating a *clean energy solution [» Unit B1.2]* in your processes could be an option to increase the energy-efficiency and/or productivity of your business. Changing processes might impact 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 do not need to buy diesel anymore. Instead you have to consider the purchase and operating costs of the PV plant. If you have not had an irrigation system before, the installation of a *PV irrigation system [» Unit B1.2]* will enhance your agricultural productivity. All these factors will of course affect your economic calculations. With the help of specific economic methods that will be explained in this document, you can analyze whether such a clean energy solution is profitable for your agri-business, considering the costs as well as productivity gains.

Unit C3.1.2 | 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 *Unit C2 [» Unit C2]* of this MOOC reader).

TOOLS

Tools that support you in developing a business model:

Boston Matrix: to support your decisions on which products you could invest in analysing their market share.

PEST(LE) (political, economic, social, technological, legal, and environmental): the framework helps to analyze external macro environmental factors that might influence your business. Results can be used for the SWOT Analysis.

SWOT Analysis (strengths, weaknesses, opportunities, threats): for planning and marketing strategy. It helps you to analyze your internal business capabilities against the realities of the business environment, to lay the foundations for a successful business.

MORE TO LEARN

Define your own business model

Term	Definition
Direct cost	Costs that are directly related to the production of a particular service or good, e.g. material, labor, and other expenses attributed to the production.
Indirect cost	Costs that arise but cannot be assigned to a particular produced good or service. They are necessary to keep the business running. Examples are electricity, rent for buildings, plant maintenance, administration, etc.
Opportunity cost	Value of the best alternative forgone, when choosing between several mutually exclusive alternatives given limited resources. It is the 'cost' incurred by losing the benefits of the second-best choice available.
Capital cost	This is a one-time expense to set 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. The latter result s in cost of debt. This means that interest is added to the loan and has to be paid back in addition to the borrowed amount of money (see "Interest rate").
Interest rate / Interest	It is basically the cost of borrowing money. This rate is usually given as an annual percentage of the total amount of the loan.
Profit	Profit = total revenue – total costs. Profits can be further divided into before and after tax profit.
Revenue	This is the income earned by a business typically through selling services or goods. Revenue = quantity of items sold * retail price
Cash flow	Incoming and outgoing cash of a business. Costs are considered as negative cash flows and revenues as positive ones. Cash flow of one period = revenues of the period – costs of the period
Discount rate	This rate is generally used to bring future cash flows to their market value at the present time. It expresses the present value of future cash flows. It is an indicator for the riskiness of an investment.

Figure C11 | Definition of Common Financial Terms (FAO, 1995a; FAO, 1995b; FAO, 1998)

Unit C3.1.3 | Financial Profitability

To assess the financial profitability of your business idea, you must begin by making several considerations and assumptions. Some examples of relevant questions (HCC, 2009):

- Who are the potential customers? 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 that have to be taken into consideration?
- Further factors such as cost and amount

In general a financial analysis first defines total costs and then determines total revenues. 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 in above to come up with a concrete business model. Before discussing 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

When calculating costs, costs should by divided into two categories (HCC, 2009):

- **Capital expenditures** (CAPEX): are one-time expenses. Normally they are long-term investments in non-consumable parts of the business, e.g. money that is spent on inventory.
- **Operating expenses** (OPEX): are the ongoing costs to run and maintain a business. They are the expenses 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 during periods when the business is not operating.
  - **Variable costs:** vary with the change of the output/activity of an organization. Consequently, they change during the production period.

The following illustration (*Figure C12*) shows the distribution of cost types. However, note that the points mentioned are only generalized examples and thus should be revised for each specific project.

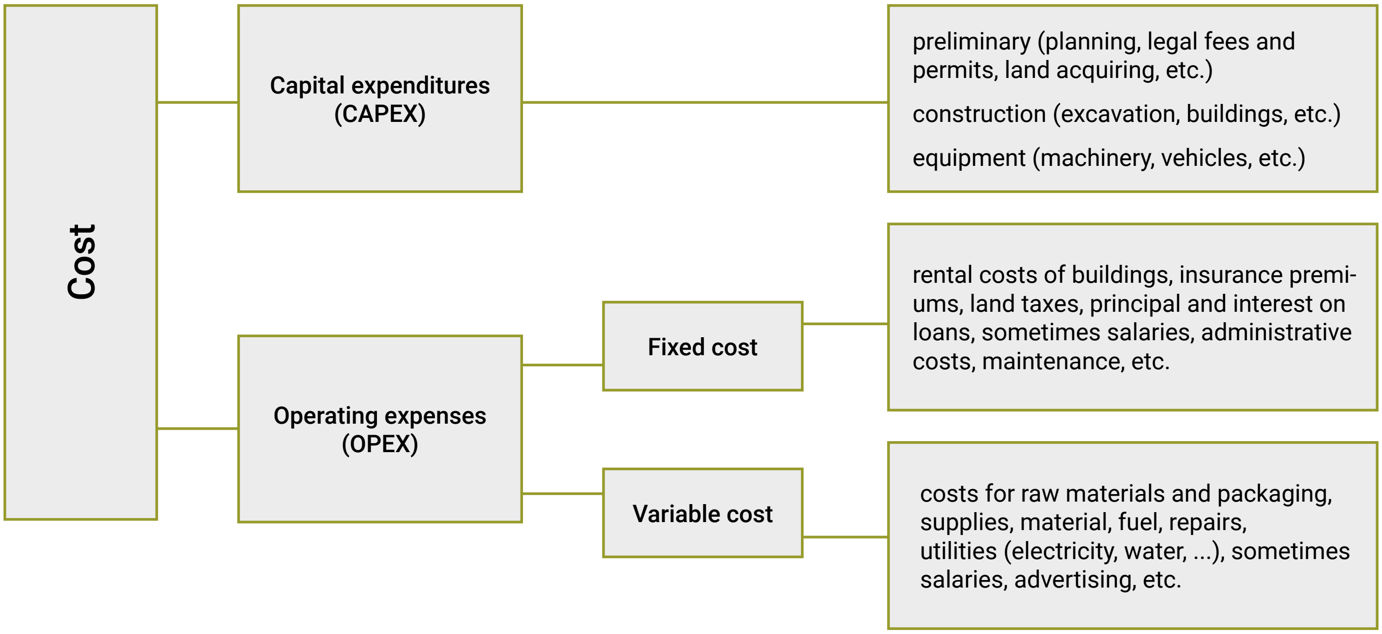

Figure C12 | Cost Types (HCC, 2009)

Unit C3.1.4 | Common Methods of Capital Budgeting

Making a decision on a capital investment can be difficult, especially if a high investment is required, if it is a long-term investment, or if several investment alternatives are available. However, using Capital Budgeting can support you in the decision-making process as it provides you with an overview about eventual returns on investment. Through it you will discover if the investment is worth pursuing. A project is worth pursuing if it increases the value of the company. Furthermore, it helps you to identify the most profitable investment options.

DEFINITION

> "Capital budgeting is the process in which a business determines and evaluates potential expenses or investments that are large in nature" Investopia

» Unit C2.2

So let's start with the theory of ***Capital Budgeting***. First of all you should be aware that there are two principal approaches to assess 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 payback time (PBT). Examples of the dynamic appraisal procedure are net present value (NPV) and internal rate of return (IRR) methods. All of them can be used to compare several investment options as well as to assess one individual investment.

Since you have learned about these profitability indicators already in ***Unit C2 [» Unit C2]***, the most common methods will only be presented briefly in the following pages. The focus is on practical examples.

Payback Time (PBT)

This static approach is recommended to get a first, quick overview regarding investment options and / or when looking at very short periods between cash flows.

As explained, 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 until the investment will start to be paid back"*. It allows 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 depending on the type of annual repayment (Rudolf, 2008):

AVERAGE METHOD:
If annual repayment is constant over the project life time (meaning $Cf_1 = Cf_2 = Cf_n$):

$$PP = \frac{I_0}{Cf_1}$$

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 I_0:

$$\sum (Cf_1 + Cf_2 + Cf_3 + \cdots) = I_0$$

$$Cf_t = R_t - C_t$$

Cf_t = Cash flow in year t
I_0 = Initial investment cost
R_t = Revenues in year t
C_t = Costs in year t

Example
Let's calculate 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 avoid payment for Liquefied Petroleum Gas (LPG), assuming the household had been cooking with LPG and biogas would replace it). As you have the same cash flow each year, you can use the *average method*.

Annual cash flow: Cf = 170 € - 20 € = 150 €

Payback: PBT = 600 € /150 € = 4 years.

Therefore, your initial investment will be recovered after 4 years. After this time you will make a 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. It also 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*.

Net Present Value (NPV) *[» Unit C2.2]*

An important point to consider especially for long-term investments is the time value of money, 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

CLOSE-UP
Dynamic Approach

d=1/(1+r)

which the initial investment is realized) to receive the present time value. Therefore, 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.

$$NPV = \sum_{t=1}^{n} \frac{Cf_t}{(1+r)^t} - I_0 + S$$

NPV EQUATION

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

Where

N is lifetime of the project in years

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 period of cash flow, depending on the project lifetime

i is the discount rate or rate of return

NET PRESENT VALUE (NPV)

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

Example

Let’s take the same biogas plant example 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 percent (so: (1 + i) = (1 + 0.1) = 1.1). Using the equation above we can now calculate NPV as:

$NPV = [150/(1.1)^1 + (150/(1.1)^2 + \dots + 150(/1.1)^{10}] - 600 + 0 = 322$ € $\rightarrow NPV > 0$

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 C13.*

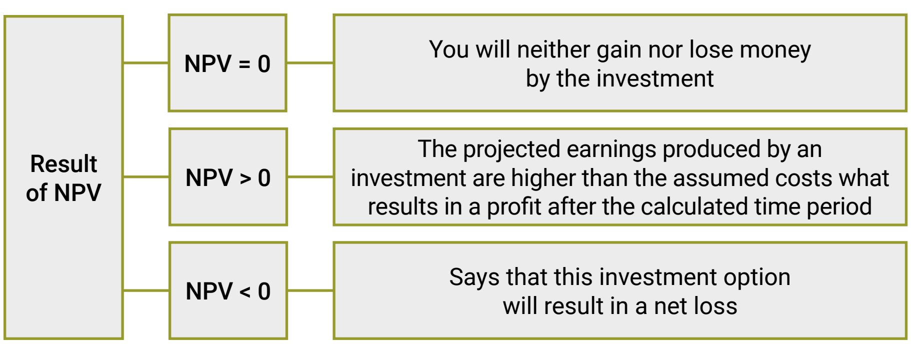

Figure C13 | Interpretation of NPV results

Internal Rate of Return (IRR)

As described in Chapter C2, the IRR indicator is defined as "the discount rate at which NPV equals zero". The IRR gives you an answer to the question how much you get in return for your investment. The favored project should have an IRR equal to or higher than the predefined discount rate, i.e. you would earn less by depositing your money in the bank. Comparing the rates of return of different investment options, the one with the highest IRR is the most profitable one from an economic perspective. To calculate the IRR, the NPV needs to be set at zero in the previous NPV equation (Rudolf, 2008).

$$NPV = 0, or$$

$$\sum_{t=1}^{n} \frac{Cf_t}{(1 + IRR)^t} - I_0 + S = 0$$

Example

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

0 = [150/(1 + IRR)^1 + (150/(1+IRR)^2 + … + 150/(1 + IRR)^{10}] - 600
IRR = 21.41 %

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

Once again your investment decision should not be made solely based on the result of IRR. Its results might not present an accurate picture since it is not designed to make a comparison between investment options of different timing or duration.

To recapitulate; all of the investment assessment methods presented have their strengths and weaknesses. To achieve reliable results, which one can base investment decisions on, it is advisable to apply at least two of the methods explained to calculate your investment (options). However, NPV is always a good choice to reduce the risk of losing money.

Unit C3.1.5 | Project Financing: Example of Microfinance

In most cases clean energy solutions for agricultural value chains ***require a significant investment [» Unit C1.6]***. Access to finance is hence crucial – and often the biggest challenge for rural farmers, as well as for renewable energy project developers and service providers. Generally there are two ways to source capital: either by borrowing it from a bank, or through equity capital (i.e. selling a stake in the business). Of course there is a ***wide scale of investment sizes [» Unit C2.1]***, ranging from e.g. small biogas plants for smallholder farmers, via bigger PV-powered cold rooms for vegetables, up to wind parks for generating energy for flower farms.

Large-scale renewable energy investments include large power generation projects, involving the construction and operation of power plants. The main actors are project developers, power plant operators, financiers and governments.

The **industrial energy efficiency** ***[» Unit B3]*** field consists of projects that aim to reduce the use of electricity or other forms of energy in an industrial context. The main protagonists are industrial companies, energy service companies, financiers and governments (GIZ, 2014).

In this chapter we limit the focus to small-scale investments in renewable energy and energy efficiency like the ones in the examples. These aim to provide solutions to low-income populations, mostly in rural contexts – in our case the Energy Agriculture Nexus, specifically with connections to productive agricultural activities. The key stakeholders in this field are households or small businesses served, businesses providing solutions and products, financiers (often ***microfinance [» Unit C1.6]*** institutions) and government (GIZ, 2014).

Microfinance can be an attractive source of financing in these cases for example a solar powered irrigation system, a biogas plant or payment of capital cost. The relatively high capital cost of renewable solutions also requires access to **end-user financing** adapted to the consumers' income. 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 is one of the instruments provided. Sometimes special credit schemes for one specific technology are offered (FAO, 2005).

MORE TO LEARN

About financing large-scale energy projects for agriculture

- AFD ***"Green Credit Line"***: Providing commercial banks with an incentive to explore the renewable energy and energy efficiency markets.
- Energypedia ***"Financing Portal"***: Information on funding and financing possibilities to bridge gaps in the financial renewable energy sector.
- GIZ ***"Financing Green Growth"***: A review of green financial sector policies in emerging and developing economies (covering both small- and large-scale renewable energy and energy efficiency investments).
- PAEGC ***"An Energy Grand Challenge for Development"***: Supports new and sustainable approaches to accelerate the development and deployment of clean energy solutions in developing countries.
- UNEP ***"Financing Renewable Energy in Developing Countries"***: Drivers and barriers for private finance in sub-Saharan Africa.
- UNEP ***"Private Financing of Renewable Energy – A Guide for Policymakers"***: How finance generally works / the role of different parts of the finance sector / what issues financiers consider when investing, including the role of policy and regulation / others.
- World Bank ***"Readiness for Investment in Sustainable Energy"***: Compares the investment climate of countries across energy access, energy efficiency and renewable energy.

Microfinance splits the often relatively high initial investment costs into smaller monthly rates. This can make an energy project affordable. The interest rates of MFIs vary broadly. If you want to finance your intended project by a MFI, compare credit conditions and interest rates of nearby MFIs. To find out if the project is viable for you, include the capital costs in your calculations with the methods of capital budgeting (see above). Sometimes *financial support [» Unit C1]* is tied to specific pre-conditions e.g. use of drip irrigation for pumping water to support sustainable water management (IRENA, 2016).

RECAP

- A business model describes the core strategy of an organization on how to make money. To define key elements of your business model, it is recommended that you 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 methods of Capital Budgeting (e.g. Payback Period, NPV and IRR are the most common ones) help 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

Several existing on- and off-grid installations prove that *renewable energy can easily be integrated into agricultural value chains [» Unit B1.2]* to enhance agricultural activities/productivity. Good examples for this are wind turbines installed on agricultural fields without much effect on crop growth or livestock grazing. Solar PV systems are able to pump water and farmers can dry crops, vegetables and fruits with solar thermal systems. Solar cooling is also promising. Furthermore, *biomass [» Unit B2]* resources provide sources for addressing heat energy demands (Sims, Mercado, Krewitt et al., 2011).

In the following sections three examples of on-grid and off-grid energy projects in agricultural value chains are discussed. You are already familiar with these technologies from the previous chapters. So this chapter focusses on aspects of financial analysis you should consider when planning to implement a clean energy solution – either as a new business or as an adaptation/add-on to your existing business. The examples combine the most important content from this chapter to show you how financial analysis of energy projects for agricultural value chains can be conducted and help you to make business decisions.

FIND MORE INFORMATION ABOUT THIS TOPIC

- An interesting study about a three continent comparison of microfinance for energy service was prepared by The SEEK Network: *» Link*
- FAO (Food and Agriculture Organization 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 (week 2): *» Link*

REMINDER

As presented in *Unit B3 [» Unit B3]* measures to increase energy efficiency in agricultural processes are relevant investment options as well. Have another look at the tea factories in Kenya *case study* that invested in several measures that resulted in energy savings, costs reductions, and GHG emission savings. Profitability of such investments can be calculated in the same way as presented here.

Unit C3.2.1 | Grid vs. Off-Grid Energy Projects in Agricultural Value Chains

Until population densities and/or urbanization rates increase considerably, grid extension is not likely to be a cost-effective way to provide remote areas with access to electricity. Hence, extension requires large subsidies. ***Off-grid solutions [» Unit C1]*** could be an alternative on an individual basis (i.e., for consumers e.g. PV solar dryers) or for a groups of beneficiaries (e.g. remote isolated village with a mini grid).

Deciding whether to select an on- or off-grid solution should be based on social considerations, cost-effectiveness criteria or a combination of both. Typically cost-effectiveness criteria include distance to the existing grid, population size, affordability and productive potential. However, while using cost-effectiveness criteria supports financial sustainability, it often leads to promoting the connection of less affluent communities (Energypedia, 2015).

Unit C3.2.2 | 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 not shining, wind not blowing). Consequently, expenses for electricity storage devices like batteries can be avoided.

In developed countries typical grid-connected renewable energy solutions for agricultural activities are e.g. biogas, PV or wind plants. Excess electricity – electricity that is generated but cannot be consumed instantly – can be fed into the grid. In many countries ***feed-in tariffs [» Unit C1]*** have been introduced. 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 (excess electricity that is fed into the grid reduces the electricity bill) is implemented.

In order to feed electricity into the public / local grid, legal requirements given by the grid operator and technical requirements for the connection of your system to the grid must be verified. Obviously this information is relevant to your business model, since revenues are impacted.

Also many developing countries face a rising demand for grid-connected power to meet manufacturing and industrial energy need (as well as to provide electricity in rapidly-growing urban areas and extend basic electrical services to rural areas). For urban customers based within a reasonable distance to the grid, extending the central power grid remains the most cost-ef-

GENERAL ASPECTS

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 keep transportation costs low? Are there competitors who are interested in the same resource? What is the current market price for the resource?
- Is the required gasifier type available and is it also appropriate for existing local conditions?
- Logistics: storage requirements, appropriate site for the plant, supply of feedstock?
- Financial aspects: is the project financially viable? Consider the costs (e.g. initial investment + costs for feedstock purchase + transport + pre-processing + repaying credit taken including interest + maintenance and operation costs, including labor, other fees and/or taxes etc.) in comparison to possible revenue (avoided payment for fuels + sale of by-products + electricity sale into the grid). Do incentives exist?
- Technical plant parameter: full load hours, internal rate of use, life time?
- Legal issues: are permissions required? Is the connection to the grid allowed?
- Regulation issues: Ownership and operation? Maintenance responsibility? Expertise available?

fective solution. Supplying grid-based electricity is also cheaper than installing off-grid options when transmission and distribution lines are nearby (PWC, 2016).

Case Study of Grid-Connected Energy Agriculture Projects

An example of grid-connected technology is *gasification technology [» Unit B3]* to convert biomass to power, heat and biofuels. These systems generate synthesis gas that can be burned in gas engines for power production or in boilers for heat generation (ECN, SNV, 2014). They can be used as grid-connected systems to feed the total or surplus electricity produced into the grid to obtain financial remuneration. However, small-scale gasifiers also present a promising option, since off-grid systems for rural settlements are not connected to the national grid.

NOTE

Detailed calculations can be found in *Annex I [» Annex I]* .

Unit C3.2.3 | Off-Grid Energy Projects in Agricultural Value Chains

Off-grid systems are not connected to the public utility grid for electricity, water or gas supply. The off-grid sector presents a huge potential 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 (IRENA, 2015). Hence, off-grid renewable energy systems are often the best economical solution for the *1.4 billion people without access to electricity [» Unit C1]* (Energypedia, 2014b). Most of these people live in developing countries and a large portion of them works in the agriculture sector. The countries with the largest populations without electricity are India, Nigeria, Ethiopia, Côte d'Ivoire, Democratic Republic of Congo and Bangladesh (PWC, 2016).

MORE TO LEARN

A study by IRENA analyzes the impact of decentralized renewable energy solutions on the livelihoods of communities, covering technologies that can be used along the agri-food chain. *» Link*

Generally, off-grid systems require battery storage and often a backup generator to ensure access to electricity at all times. Typically batteries are expensive and need to be replaced at some point.

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 fluctuating availability of these resources. Solar home systems are quite popular for this type. Various different off-grid energy projects can be found in the agricultural sector. Very common ones are *biogas plants [» Unit B2]* on different scales and PV powered irrigation systems. Moreover, ***PV and sometimes also small-scale wind power or micro-hydro power [» Unit B1.2]*** 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 to supply heat, e.g. to sterilize fruits and vegetables.

Case Studies of Off-Grid Energy-Agriculture Projects

1. Small -Biogas Plant

You want to have your own ***biogas plant [» Unit B2]*** to convert your organic waste into biogas? First think about your intended business model type (following the list above), including the following points:

"Turn your organic waste into energy and reduce your energy costs in the process."

- 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 course of the year?
- What do you want to generate? Biogas, electricity, heat or biofuel? Do you want to use this to meet your own needs and/or do you want to sell it?
- In the event 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 **potential profit** of your biogas plant by subtracting all costs from the total revenue. The list in Table 3 provides an indication about important items that should be taken into account. However, consider that revenue and OPEX occur annually whereas CAPEX is generally a one-time expense. Nevertheless, you should apply the methods of capital budgeting to obtain a reliable financial result. To do so you need to know the lifetime of the biogas plant (ask the producer!) and the current interest rate (ask your bank!).

REMINDER

Have a look at chapter B2 again, which provides detailed information on biogas and bioenergy technologies. ***» Chapter B2***

Regarding costs considerations, generally it can be said that capital expenditures for an anaerobic digester are moderate. To prevent failures an expert should assist in planning. The required effort for operation and maintenance is quite small. If construction is properly designed, maintenance costs should be minimal. In most cases you can maintain the plant by yourself and save money.

To **calculate the revenue**, use the amount you currently pay for the items that will be replaced by biogas (e.g. electricity bill), and for the sales calculation, use current market prices. You can collect 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 also be very helpful. Over and above this your bank might be able to inform you about the capital costs.

Financial Benefits	
Revenue	• Avoided payment for fertilizer, kerosene, cooking gas, fuelwood, etc. These direct savings goes into the calculation as indirect revenue. • Revenues from the sales of biogas, electricity and heat or biofuel depending on plant size and type • Sale of quality fertilizer
Costs Considerations	
CAPEX	Initial investment: • purchasing costs or opportunity costs for land needed for the biogas plant and slurry storage • model of the biogas plant (the digester) and other required parts like 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 and install the plant (excavation-work, construction of the digester and gas-holder, etc.) • your own labor costs in the event 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, for example substrate from your own livestock, then no costs have to be considered to purchase it) • water supply to clean the stable and mix the substrate • feeding and operating 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 the plant operates smoothly • in case of sale, additional costs occur for example transport, packaging, advertising, etc. • maybe credit costs (interest) in the event a loan was taken out

Figure C14 | Important Aspects to Consider in the Financial Analysis of a Small Biogas Plant (Energypedia, 2015; ECN, 2011)

MORE TO LEARN

- Energypedia Biogas Portal: *» Link*
- GTZ Biogas Report: *» Link*

NOTE

Detailed calculations can be found in *Annex II [» Annex II]* .

2. Solar dryer

Solar Dryers [» Unit B1.3] do not depend on fuel and in general they present a simple and cheap way to preserve vegetables and fruits for weeks or months. Their advantage is that you can use the dried products for your own needs, as well as trade them throughout the year.

"Ensure long-term storage of your fruits and vegetables and convert them into high quality goods."

Therefore, if you store them appropriately, your dependence on the harvest time to generate profit decreases and you prevent the spoilage of those products. By offering dried products outside the harvest season, you might be even able to sell them for higher prices than fresh products at harvest time when there is often an oversupply. 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 mentioned in Table 4. For a more reliable assessment of profitability, apply the methods of capital budgeting. To define 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 customers for the product do you estimate? How much would they pay for these products? Are there competitors?

Financial Benefits	
Revenue	• Avoided payment for food that you would need to buy for your personal consumption. These savings go into the calculation as indirect revenues. • Revenues from the sales of dried fruits and vegetables
Costs Considerations	
CAPEX	Initial investment: • Costs for solar dryer • labor input and wages for people who plan and set up the solar dryer, in the event you do not do it yourself • equipment needed to prepare fruits and vegetable, such as knifes • Investments for storage requirements: for example a sealer for sealing plastic bags, a storage space • your opportunity costs for labor in the event you assist in or carry out the construction • Reinvestment costs for replacement of components with a shorter life time than the whole project
OPEX	• your opportunity costs for cultivating and preparing vegetables and fruits for drying + opportunity costs for fruits and vegetables that you dry instead of selling them while there is sufficient market demand • costs connected with the cultivation of the fruits and vegetables like seeds, irrigation water, fertilizer and pesticides, maybe labor costs, transportation, rent for the field in the event it is not your property, etc. • costs for fruits and vegetables if you do not cultivate them yourself • costs connected with preparation for drying, such as clean water to wash products, labor costs for hired workers, maybe rental costs for a room to carry out the preparation • 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 • costs connected with selling the dried products such as quality control, distribution of the product, transport to market, advertising • maybe credit costs (interest) in the event a loan was taken out • others: cleaning, maintenance and repair of appliances, electricity

Figure C15 | Important Aspects to Consider in the Financial Analysis of a Solar Dryer (Teach A Man To Fish, 2010)

NOTE

Detailed calculations can be found in *Annex III [» Annex III]* .

RECAP

- In principle, clean energy projects distinguish 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. If a feed-in tariff exists, income from the energy project can also 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 agri 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 a project's profitability, one needs to sum up all relevant factors that make up total revenue and total cost, and compare the results. More reliable results can be achieved by applying capital budgeting methods.
- 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 payments spared 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 market value for dried foods. Consider the initial investment and additional cost items during operation to calculate the costs.

SUMMARY & UNIT WRAP-UP

In this unit, you were provided with an overview on the basic aspects of a business model and the basic methods of capital budgeting to assess the profitability of projects. The case studies described gave you an idea about how to draft a detailed list of cost and revenue factors for specific projects.

The potential for implementing renewable energy technologies for agricultural activities is enormous. To ensure a long-term, sustainable and profitable energy project, a well-defined business model is required. It describes the core strategy of how an organization plans to generate income. This decision should be based on a detailed market analysis to determine 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 to estimate the required initial investment and 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 often replace fossil fuels in the agricultural sector, but also contribute to the economic and social development of local communities.

MATERIALS

Please find below links to our materials and references

Video
www.giz.de/gc21/pa_video_lectures

Additional Material
www.giz.de/gc21/pa_additional_material

Top5 Team Assignments
www.giz.de/gc21/pa_assignments

References
www.giz.de/gc21/pa_references

ANNEX I

"Example of a Financial Analysis for a Grid-connected Energy Project"
Let us discuss one simplified example of a grid-connected gasification power plant fueled with rice husk in Vietnam. In order to apply the described methods of capital budgeting, we will assume the following data (please note: the numbers used are simplified and are not representative):

Revenue

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

Cost

CAPEX

- Initial investment cost (planning, construction, equipment, insurance, fee and interest) of 3000 €/kW. 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 Parameters

- 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 lifetime of 15 years
- Internal use rate of plant is 10 % (that is 10 % of the produced electricity is used by the plant itself)

We can calculate the profitability of this project with the data provided (see next page):

FINANCIAL ANALYSIS	
Project lifetime (years)	15
Used quantity of rice husk as feedstock (kg/year)	500,000
Heating value of rice husk (MJ/kg)	14
System efficiency (assumed 30 %)	0.3
Annual electricity generation (kWh)	**583,333**
Acquisition price for electricity from the grid (€/kWh)	0.082
Own annual household electricity demand (kWh)	4,000
Avoided payment for electricity (€/year)	**328**
Internal use rate of the plant (%)	0.1
Annual electricity fed into grid (kWh)	521,000
Feed-in tariff rate (€/kWh)	0.058
Annual income from electricity feed-in (revenue) (€)	**30,218**
Initial investment (€)	**300,000**
Feedstock price (incl. transport) €/kg	0.025
Annual feedstock cost	12,500
O&M (3 % of investment)	9,000
Total annual cost (€)	**21,500**
Annual cash flow (€)	**9,046**
Payback time (years)	**33.16**
Discount rate (10 %)	0.1
Net present value (NPV) (€)	**-231,195**

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 lifetime of 15 years. Since the NPV is negative, we did not calculate its IRR here, as the project is not profitable.

ANNEX II

"Example of a Financial Analysis for an Off-Grid Energy Project – BIOGAS PLANT"

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. In order to apply the described methods of capital budgeting, we will assume the following data (Please note: The numbers used are simplified and are not representative on site. They vary greatly depending on which type and size the biogas plant is, which substrate you use, your current used fuel for cooking, and how much of the work you do yourself):

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 Parameters

- 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 feces/urine/day --> 0.06 m³/day
- 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

We can calculate the profitability of this project with this provided data.

CAPEX	
Biogas Plant (3m³) (incl. Construction) ($)	400
Equipment (incl. biogas stove)($)	60
Total initial investment ($)	**460**
OPEX	
Substrate cost ($)	0
Annual Operation, maintenance, replacement cost ($) (5 % of invest.)	23
Annual operational cost ($)	**23.00**
REVENUE	
Avoided payment for fertilizer (0.4 $/kg)	155.73
Avoided payment for LPG (1 $/kg; 12 kg/month)	144.00
Total avoided payment ($/year)	299.73
Sale of fertilizer (0.04 $/kg)	77.87
Annual revenue ($)	**377.60**
Annual cash-flow ($)	**354.60**
Payback period (years)	**1.30**
Discount rate (10 %)	0.1
Net present value (NPV) ($)	**1,718.86**
Internal Rate of Return (IRR) (%)	**76.83**
Additional Calculations	
Biogas generation by cow dung (m³/day)	1
Biogas generation by pig dung (m³/day)	0.48
Biogas generation by people's dung (m³/day)	0.24
Total daily biogas generation (m³/day)	1.72
Biogas required for cooking (m³/day)	1.6
Water requirement (for 32 kg dung/day)	16
Overall inlet into reactor (kg/day)	48
Required biogas plant size (m³) based on 60 days residence time and assumed density of 1000 kg/m³	2.88
Generated fertilizer (1/5 of bio-waste quantity)	6.4
Own consumption of fertilizer is 1/6 of generation (kg/day):	1.07
Remaining fertilizer for sale (kg/day)	5.33

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 pre-defined minimum acceptable rate for this example of 10 % (discount rate).

ANNEX III

"Example of a Financial Analysis for an Off-Grid Energy Project – SOLAR DRYER"

Let us now discuss one simplified example of a solar dryer to dry bananas and mangos to produce 4000 bags of dried fruits per year, assuming that you carry out most of the work yourself. In order to apply the described methods of capital budgeting, we will assume the following data (please note: the numbers used are simplified and are not representative on-site). They vary greatly depending on which type and size of solar dryer you need, which fruits and vegetable you want to dry, labor 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): 4,000

Cost

CAPEX

- Simple Solar Dryer: 1,000 $
- Build-up (Labor 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 $
- Labor costs (incl. maintenance): 0.35 $/bag

Other Parameters

- No land purchase cost or rent payment considered
- Project lifetime of 10 years
- Discount rate: 10 %

We can calculate the profitability of this project with this provided data.

CAPEX	
Simple Solar Dryer ($)	1,000
Build-up (Labor cost) ($)	20
Sealing machine for bags ($)	80
Total initial investment ($)	**1,100**
OPEX	
Cost per bag ($)	0,10
Amount of bags per year (pieces)	4,000
Packaging ($)	400
Costs for mangos ($)	1,066.67
Costs for bananas ($)	666.67
Labor cost (incl. maintenance) ($/bag)	0,35
Labor cost ($/year)	1400
Annual operational cost ($)	**3,533.33**
REVENUE	
Dried fruit bag (100g) sale price ($)	1.00
Amount of sold bags per year ($)	4,000
Annual revenue ($)	**4,000**
Annual cash-flow ($)	**466.67**
Payback period (years)	**2.36**
Discount rate (10 %)	0.1
Net present value (NPV) ($)	**1,767.46**
Internal Rate of Return (IRR) (%)	**41.06**
Additional Calculations	
2,000 bags of dried mango slices, 2,000 bags of dried banana slices	
1 bag = 100 g of dried fruit, either banana or mango	
4,000 bags = 400,000 g dried fruit	
1 mango (30g) ($)	0,16
1 banana (30g) ($)	0.1
Bananas required or 2,000 bags	6,666.67
Mangos required for 2,000 bags	6,666.67

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 lifetime 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).

IMPRINT

This product is made possible through the support of the "Powering Agriculture: An Energy Grand Challenge for Development" Founding Partners: the United States Agency for International Development (USAID), the Swedish International Development Cooperation Agency (Sida), the German Federal Ministry for Economic Cooperation and Development (BMZ), Duke Energy, and the Overseas Private Investment Cooperation (OPIC).

Published by
Deutsche Gesellschaft für
Internationale Zusammenarbeit (GIZ) GmbH

Registered offices
Bonn and Eschborn

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Global Programme Sustainable Energy for Food – Powering Agriculture
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Editing
netzhammer & breiholz, Hamburg
Laura Jakobeit; Monika Grossmann; Kerstin Lohr, GIZ

Layout
creative republic, Frankfurt am Main

Bonn, 2017

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