Module 7

Renewable energy technologies

SUSTAINABLE ENERGY REGULATION AND POLICYMAKING FOR AFRICA

CONTENTS

1. MODULE OBJECTIVES

1.1. Module overview

The themes dealt with in this module include:

- Outline and brief description, including fundamentals, of the different renewable energy technologies, wind, solar, bioenergy, hydro, and geothermal energy;
- General overview of renewable energy technologies and applications;
- Information on the costs of different renewable energy technologies;
- Discussion regarding common technical and non-technical barriers and issues limiting wide spread use/dissemination of renewable energy.

1.2. Module aims

The aims of the present module are as follows:

- Enable understanding of renewable energy in the broadest terms;
- Present the different technology options that fall within the definition of renewable energy, in a developing country context;
- Provide an overview of the different renewable energy technologies and their applications;
- Show the strengths and weaknesses of renewable energy technologies;
- Outline the expected costs for different renewable energy technologies;
- Review the issues affecting effective deployment of renewable energy systems.

1.3. Module learning outcomes

The present module attempts to achieve the following learning outcomes:

- To be able to define the different key renewable energy technologies;
- To have a broad appreciation of the potential applications for renewable energy technologies;
- To understand the strengths and weaknesses of the different renewable energy technologies and hence to have a better grasp of the benefits of renewable energy;
- To understand the basic costs for the different technologies;
- To gain an appreciation of the issues and barriers that renewable energy projects face.

2. INTRODUCTION

This module provides an outline and brief description, including fundamentals, of the different renewable energy technologies, wind, solar, bioenergy, hydro and geothermal energy. It provides a general overview of the technologies and their applications.

Electricity generation from wave and tidal energy is not discussed. The use of this technology is less relevant for developing countries as mostly these technologies are still at the prototype stage. While these technologies are not fully proven yet, promising research and development is being conducted.

The module also reviews the costs of the different technologies and discusses common technical and non-technical barriers and issues limiting the wide spread use/dissemination of renewable energy in developing countries.

The information in this module is of general interest to explain the basics of renewable energy technologies, to understand their strengths and weaknesses and hence to have a better grasp of the benefits available from, and the barriers faced by, these technologies.

3. OVERVIEW OF RENEWABLE ENERGY TECHNOLOGIES

This section provides an overview and brief description, including fundamentals, of the different renewable energy technologies, wind, solar, bioenergy, hydro, and geothermal energy.

One of the first aspects to consider is the cost of renewable energy technologies. However, this is not an easy question to answer because, as with many energy technologies, many factors affect cost and different sources of information use different criteria for estimating cost. In many cases, the environmental benefits of renewable energy technologies are difficult to take into account in terms of cost savings through less pollution and less damage to the environment. When trying to calculate the cost of these technologies is often best to take a life cycle cost approach, as these technologies often have high up-front capital costs but very low operation and maintenance costs. And of course, there is usually no fuel cost!

Table 1 below shows average energy generation costs (in kWh) for a variety of renewable energy technologies in Europe. The table clearly shows that the minimum to average generation costs for these technologies vary widely between different technologies, and within the same technology, according to differences in national markets and resource conditions. This means that one technology can be cheaper in one country than in another.

Table 1. Minimum to average generation costs for the main green electricity technologies in EU15[a]

Technology	Range (minimum to average) of electricity generation cost (€/MWh)[b]
Wind onshore	50-80
Small-scale hydro	40-140
Biomass using forestry residues	40-80
Agricultural biogas	60-100
Photovoltaics	› 450

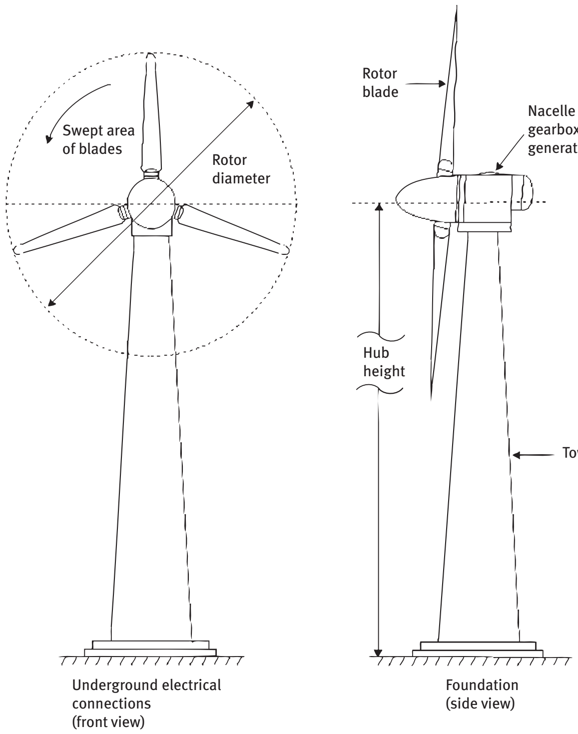
[a]COM (2005) 627 final—Communication from the European Commission – The support of electricity from renewable energy sources—annex 3 (December 2005).

[b]The calculation of generation costs and feed in tariffs is further elaborated in module 8, annex I, "Methodology and examples on how to calculate the level of feed in tariffs".

3.1. Wind energy

A wind turbine produces power by converting the force of the wind (kinetic energy) acting on the rotor blades (rotational energy) into torque (turning force or mechanical energy). This rotational energy is used either within a generator to produce electricity or, perhaps less commonly, it is used directly for driving equipment such as milling machines or water pumps (often via conversion to linear motion for piston pumps). Water pumping applications are more common in developing countries. A schematic of a wind energy system is presented in figure I.

Figure I. Wind energy system schematic



Source: Canada Center for Mineral and Energy Technology (Ottawa, Canada, 1999).

Wind power by its nature is variable (or intermittent), therefore some form of storage or back-up is inevitably involved. This may be through:

(*a*) connection to an electricity grid system, which may be on a large or small (mini-grid) scale;

(b) incorporating other electricity producing energy systems (from conventional generating stations through diesel generators to other renewable energy systems);

(c) or the use of storage systems such as batteries or, for mechanical systems, storage via water held in a tank.

So long as the system is designed to have sufficient storage capacity, whether for energy or product (e.g. water pumped), to cover the periods when the supply is unable to meet the full level of demand, then an output is always available. The strengths and weaknesses of this technology are presented in table 2.

Table 2. Strengths and weaknesses of wind energy systems

Strengths	Weaknesses
Technology is relatively simple and robust with lifetimes of over 15 years without major new investment	Site-specific technology (requires a suitable site)
Automatic operation with low maintenance requirements	Variable power produced therefore storage/back-up required.
No fuel required (no additional costs for fuel nor delivery logistics)	High capital/initial investment costs can impede development (especially in developing countries)
Environmental impact low compared with conventional energy sources	Potential market needs to be large enough to support expertise/equipment required for implementation
Mature, well developed, technology in developed countries	Cranage and transport access problems for installation of larger systems in remote areas
The technology can be adapted for complete or part manufacture (e.g. the tower) in developing countries	

Usually wind energy systems are classified in three categories: grid-connected electricity generating, stand-alone electricity generating (often subdivided into battery-based or autonomous diesel, the later having automatic start-up when the wind speed falls, although diesel generators may also be used within stand-alone battery systems) and mechanical systems. Examples of wind power applications are illustrated in table 3.

Table 3. Examples of wind power applications and system type

Technology type (electrical/mechanical)	System	Application
Wind power – electrical	Grid connected	Supplementing mains supply
Wind power – electrical	Stand-alone, battery charging	Small home systems Small commercial/community systems Water pumping Telecommunications Navigation aids
Wind power – electrical	Stand-alone, autonomous diesel	Commercial systems Remote settlements Mini-grid systems
Wind power – mechanical	Water pumping	Drinking water supply Irrigation pumping Sea-salt production Dewatering
Wind power – mechanical	Other	Milling grain Driving other, often agricultural, machines

Wind turbines generating electricity

Several turbine types exist but presently the most common configuration has become the horizontal axis three bladed turbine (as shown in figure I above). The rotor may be positioned up or downwind (although the former is probably the most common). Modern wind turbines vary in size with two market ranges: small units rated at just a few hundred watts up to 50-80 kW in capacity, used mainly for rural and stand-alone power systems; and large units, from 150 kW up to 5 MW in capacity, used for large-scale, grid-connected systems.

Grid-connected wind turbines

Grid-connected wind turbines are certainly having a considerable impact in developed countries and in some developing countries, namely Argentina, China and India. This is mainly through large-scale installations either on land (on-shore) or in the sea on the continental shelf (off-shore). In addition, in developed countries, more smaller machines are now being grid-connected. These are usually installed to supply power to a private owner already connected to the electricity grid but who wishes to supply at least some of their own power. This principle can be used in developing countries to contribute to a more decentralized grid-network and/or to support a weak grid.

Wind turbines do, however, generate electricity intermittently in correlation to the underlying fluctuation of the wind. Because wind turbines do not produce power constantly and at their rated power (which is only achieved at higher wind speeds) capacity factors (i.e. actual annual energy output divided by the theoretical maximum output) are typically between 20 per cent to 30 per cent. One of the principal areas of concerns of wind energy is its variable power output, which can create network problems as the share of intermittent generation on the grid rises.

Stand-alone wind turbines

The most common type of stand-alone small wind electric system involves the use of a wind generator to maintain an adequate level of charge in an electrical storage battery. The battery in turn can provide electricity on demand for electrical applications such as lights, radios, refrigeration, telecommunications, etc., irrespective of whether or not the wind is blowing. A controller is also used to ensure that the batteries are not damaged by overcharging (when surplus energy is dissipated through a dump load) or excessive discharge, usually by sensing low voltage. Loads connected to the battery can either be DC or AC (via an inverter).

Small wind battery charging systems are most commonly rated at between 25-100 W for a 10m/s wind speed, and are quite small with a rotor diameter of 50 cm to 1 m. These systems are suitable for remote settlements in developing countries.

Larger stand-alone systems, incorporating larger wind electricity generators and correspondingly larger battery banks (at an increased cost) are also available, these may include other renewable energy technologies, such as PV, as well as diesel generators to ensure that the batteries are always charged and that power availability is high.

Less common is the stand-alone system which does not incorporate a battery back. This involves the use of a wind turbine with, at least, a diesel generator, which will automatically supply power when required. This has the advantage of not requiring a battery bank but the required control systems are complex.

Wind turbines for water pumping

The most common type of a mechanical wind turbine is the wind pump which uses the wind's kinetic energy to lift water. Wind pumps are typically used for water supply (livestock or human settlements), small-scale irrigation or pumping seawater for sea salt production. Here we look at the two main uses which are irrigation and water supply. There are two distinct categories of wind pump, because the technical, operational and economic requirements are generally different for these two end uses. That is not to say that a water supply wind pump cannot be used for irrigation (they quite often are) but irrigation designs are generally unsuitable for water supply duties.

Most water supply wind pumps must be ultra-reliable, to run unattended for most of the time (so they need automatic devices to prevent over-speeding in storms), and they also need the minimum of maintenance and attention and to be capable of pumping water generally from depths of 10 m to 100 m or more. A typical farm wind pump should run for over 20 years with maintenance only once every year, and without any major replacements; this is a very demanding technical requirement since typically such a wind pump must average over 80,000 operating hours before anything significant wears out; this is four to ten times the operating life of most small diesel engines or about 20 times the life of a small engine pump.

Wind pumps to this standard therefore are usually industrially manufactured from steel components and drive piston pumps via reciprocating pump rods. Inevitably they are quite expensive in relation to their power output, because of the robust nature of their construction. But American, Australian and Argentine ranchers have found the price worth paying for wind pumps that run and run without demanding much attention to the extent they can almost be forgotten about for weeks at a time. This inherent reliability for long periods is their main advantage over practically any other form of pumping system.

Irrigation duties on the other hand are seasonal (so the windmill may only be useful for a limited fraction of the year), they involve pumping much larger volumes of water through a low head, and the intrinsic value of the water is low when compared with drinking water. Therefore any wind pump developed for irrigation has to be as cheap as possible and this requirement tends to override most other considerations. Since irrigation generally involves the farmer and/or other workers being present, it is not so critical to have a machine capable of running unattended. Therefore windmills used for irrigation in the past tend to be indigenous designs that are often improvised or built by the farmer as a method of low-cost mechanization.

Most farm wind pumps, even though still in commercial production, date back to the 1920s or earlier and are therefore heavy and expensive to manufacture, and difficult to install properly in remote areas. Recently, various efforts have been made to revise the traditional farm wind pump concept into a lighter and simpler modern form. Modern designs are fabricated from standard steel stock by small engineering companies and cost (and weigh) only about half as much as traditional American or Australian machines of similar capability. It is possible therefore that through developments of this kind, costs might be kept low enough to allow the marketing of all-steel-wind-pumps that are both durable, like the traditional designs, yet cheap enough to be economic for irrigation.

However, although there have been a number of attempts to transfer this technology to developing countries, (which should in theory be an ideal transfer, the technology being a relatively low-tech, artisan based system) experiences have been mixed with only few, very small, niche markets developing.

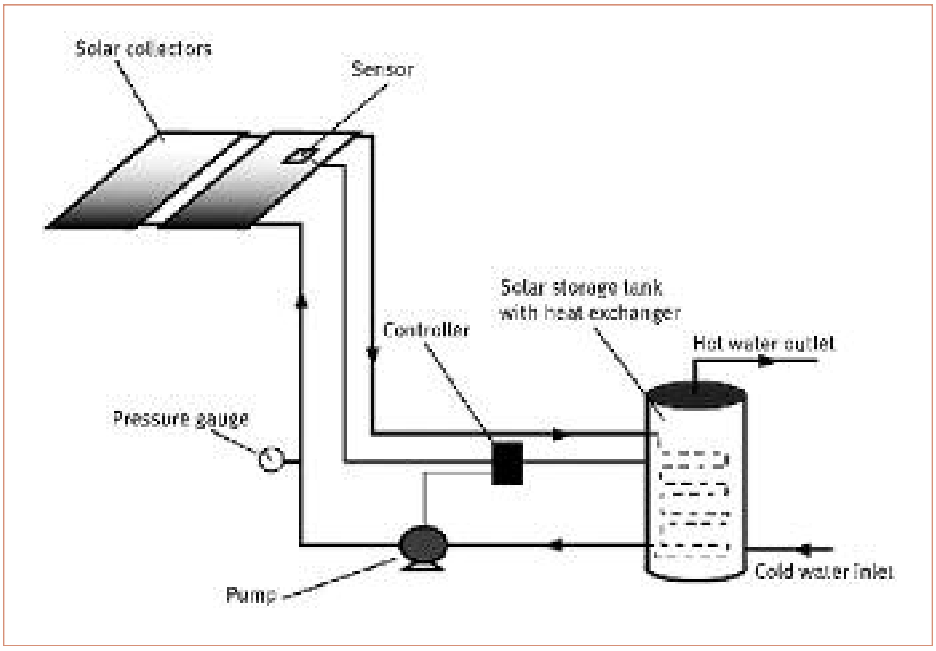
Review questions

1. What are the key advantages and disadvantages of wind energy technology?
2. What is meant by the term "stand-alone" and what is the key difference between the two different stand-alone systems described?
3. What are the key differences in the requirements for a wind pump for irrigation and a wind pump for water supply?

3.2. Solar energy

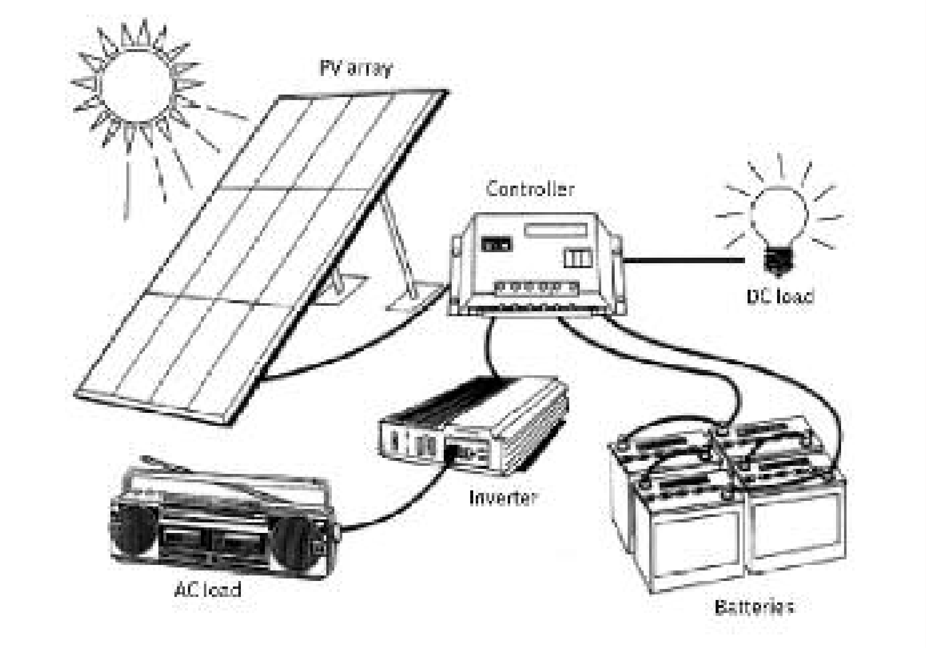
Solar energy technologies can be loosely divided into two categories: solar thermal systems (figure II shows a solar water heating system, one example of the use of solar thermal energy) and solar electric or photovoltaic (PV) systems (figure III). Examples of solar power applications are illustrated in table 4.

Figure II. Schematic of a typical solar water heating system



Source: Home energy magazine online, 1995.

Figure III. A typical PV system



Source: www.solardirect.com/pv/pvbasics/pvbasics.htm

Table 4. Examples of solar power applications and system type

Technology type (PV/solar thermal)	System	Application
PV (solar electric)	Grid connected	Supplementing mains supply
PV (solar electric)	Stand-alone	Small home systems for lighting, radio, TV, etc. Small commercial/community systems, including health care, schools, etc. Telecommunications Navigation aids Water pumping Commercial systems Remote settlements Mini-grid systems
Solar thermal	Connected to existing water and/or space heating system	Supplementing supply of hot water and/or space heating provided by the electricity grid or gas network
Solar thermal	Stand-alone	Water heating, i.e. for rural clinics Drying (often grain or other agricultural products) Cooking Distillation Cooling

Box 1. **REN21 global status report: rural (off-grid) renewable energy/water pumping: wind and solar PV**

Solar PV and wind power for water pumping, both irrigation and drinking water, are gaining widespread acceptance, and many more projects and investments are occurring. In the order of one million mechanical wind pumps are in use for water pumping, primarily in Argentina, following decades of development. Large numbers of wind pumps are also used in Africa, including in South Africa (300,000), Namibia (30,000), Cape Verde (800), Zimbabwe (650) and several other countries (another 2,000).

There are now more than 50,000 solar-PV pumps worldwide, many of these in India. Over 4,000 solar pumps (ranging from 200–2,000 W) were recently installed in rural areas as part of the Indian Solar PV Water Pumping Programme. There are an estimated 1,000 solar water pumps in use in West Africa. Donor programmes for PV-powered drinking water have appeared in Argentina, Brazil, Indonesia, Jordan, Namibia, Niger, the Philippines, Tunisia and Zimbabwe, among others.

A growing cohort of commercial projects for solar PV powered drinking water, including both pumping and purification, has appeared in recent years, notably in India, the Maldives and the Philippines. In the Maldives, a commercial pilot project anticipates sales of 1,000 litres/day, with a long-term delivered price of water to households expected to reach 0.2–0.5 cents per litre. Another recent example is on the Philippine island of Cebu. A 3-kW solar PV water pump distributes filtered and chlorinated surface water to 10 village locations. The 1,200 residents use prepaid debit cards to purchase potable water at a cost of about 3 PHP (5.5 cents) for 20 litres, or 0.3 cents/litre, a tenth of the cost of bottled water supplies. Fees collected from water sales are used to pay back an unsubsidized 10-year bank loan. The scheme could be duplicated on 10 more Philippine islands, providing potable water to 200,000 people in 40 municipalities.

Source: www.ren21.net/globalstatusreport/g2005.asp – Accessed September 2006.

Photovoltaic (PV) systems

Photovoltaic or PV devices convert sun light directly into electrical energy. The amount of energy that can be produced is directly dependent on the sunshine intensity. Thus, for example, PV devices are capable of producing electricity even in winter and even during cloudy weather albeit at a reduced rate. Natural cycles in the context of PV systems thus have three dimensions. As with many other renewable energy technologies, PV has a seasonal variation in potential electricity production with the peak in summer although in principle PV devices operating along the equator have an almost constant exploitable potential throughout the year. Secondly, electricity production varies on a diurnal basis from dawn to dusk peaking during mid-day. Finally, short-term fluctuation of weather conditions, including clouds and rain fall, impact on the interhourly amount of electricity that can be harvested. The strengths and weaknesses of this technology are presented in table 5.

Table 5. Strengths and weaknesses of PV energy systems

Strengths	Weaknesses
Technology is mature. It has high reliability and long lifetimes (power output warranties from PV panels now commonly for 25 years)	Performance is dependent on sunshine levels and local weather conditions
Automatic operation with very low maintenance requirements	Storage/back-up usually required due to fluctuating nature of sunshine levels/no power production at night.
No fuel required (no additional costs for fuel nor delivery logistics)	High capital/initial investment costs
Modular nature of PV allows for a complete range of system sizes as application dictates	Specific training and infrastructure needs
Environmental impact low compared with conventional energy sources	Energy intensity of silicon production for PV solar cells
The solar system is an easily visible sign of a high level of responsibility, environmental awareness and commitment	Provision for collection of batteries and facilities to recycle batteries are necessary
The user is less affected by rising prices for other energy sources	Use of toxic materials in some PV panels

PV devices use the chemical-electrical interaction between light radiation and a semiconductor to obtain DC electricity. The base material used to make most types of solar cell is silicon (approx. 87 per cent). The main technologies in use today are:

- Mono-crystalline silicon cells are made of silicon wavers cut from one homogenous crystal in which all silicon atoms are arranged in the same direction. These have a conversion efficiency of 12-15 per cent);
- Poly-crystalline silicon cells are poured and are cheaper and simpler to make than mono-crystalline silicon and the efficiency is lower than that of mono-crystalline cells (conversion efficiency 11-14 per cent);
- Thin film solar cells are constructed by depositing extremely thin layer of photovoltaic materials on a low-cost backing such as glass, stainless steel or plastic (conversion efficiency 5-12 per cent);
- Multiple junction cells use two or three layers of different materials in order to improve the efficiency of the module by trying to use a wider spectrum of radiation (conversion efficiency 20-30 per cent).

The building block of a PV system is a PV cell. Many PV cells are encapsulated together to form a PV panel or module. A PV array, which is the complete power-generating unit, consists of any number of PV modules/panels. Depending on their application, the system will also require major components such as a battery bank and battery controller, DC-AC power inverter, auxiliary energy source etc. Individual PV cells typically have a capacity between 5 and 300 W but systems may have a total installed capacity ranging from 10 W to 100 MW. The very modular nature of PV panels as building blocks to a PV system gives the sizing of systems an important flexibility.

Box 2. **PV for rural schools in South Africa**

A European Commission project aimed to provide off-grid electricity using PV systems to 1000 schools in the Republic of South Africa. The project started in 2000 and was completed in 2002. The firm IT Power acted as the technical assistance unit.


Photo: Chris Purcell, IT Power South Africa

The PV systems are located in remote areas of Northern Province and Eastern Cape Province (880 kWp total installed capacity). The project is the EC contribution to an existing programme by the South African Government to supply off-grid electricity to 16,400 schools in remote areas. As well as providing electricity for lighting between three and five classrooms in each school, the PV systems also provide power for audio-visual teaching aids.

Source: www.itpower.co.uk, international development section.

Solar thermal systems

Solar thermal systems use the sun's power in terms of its thermal or heat energy for heating, drying, evaporation and cooling. Many developing countries have indigenous products such as solar water heaters, solar grain dryers, etc. These are usually local rather than international products, specific to a country or even to a region. The main solar thermal systems employed in developing countries are discussed briefly below.

Solar thermal power plants

Solar thermal engines use complex concentrating solar collectors to produce high temperatures. These temperatures are high enough to produce steam, which can be used to drive steam turbines generating electricity. There is a wide variety of different designs, some use central receivers (where the solar energy is concentrated to a tower) whilst others use parabolic concentrator systems.

Although the first commercial thermal power plants have been in operation in California since the mid-1980s, many of the newer designs are still at the prototype stage being tested in pilot installations in the deserts of the United States and elsewhere. The Global Environment Facility (GEF) has supported the first planning phase of a project that is developing a concentrating solar power plant in Egypt in 2004. There are also projects in India, Mexico and Morocco that have been supported by GEF as part of a strategy to accelerate cost reduction and commercial adoption of high temperature solar thermal energy technology.

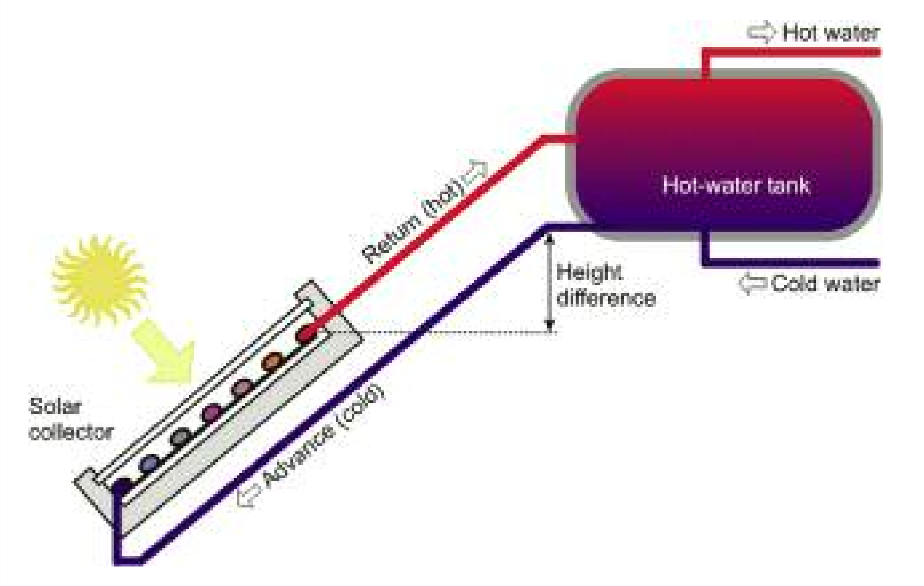
Solar water heating

Solar water heating systems (see figure II above) may be used in rural clinics, hospitals or even schools. The principle of the system is to heat water, usually in a special collector and store it in a tank until required. Collectors are designed to collect the heat in the most efficient, but cost effective way, usually into a heat transfer fluid, which then transfers its heat to the water in the storage tank. The two main types of collector are: flat plate and evacuated tube.

For example, to heat 100 litres of water through a temperature rise of 40° C with a simple flat plate solar collector requires only approximately 2.5 m^2 of collector area but saves approx. 10 kg of woodfuel that would normally be required to heat this quantity of water.

The cheapest technology available and the simplest to install is a thermosiphon system, which uses the natural tendency of heated water to rise and cooler water to fall to perform the heat collection task. As the sun shines on the collector, the water inside the collector flow-tubes is heated. As it heats, this water expands slightly and becomes lighter than the cold water in the solar storage tank mounted above the collector. Gravity then pulls the heavier, cold water down from the tank and into the collector inlet. The cold water pushes the heated water through the collector outlet and into the top of the tank, thus heating the water in the tank. An example of a thermosiphon system is shown in figure IV.

Figure IV. A thermosiphon solar water heating system



Solar drying

Solar drying, in the open air, has been used for centuries. Drying may be required to preserve agricultural/food products or as a part of the production process, i.e. timber drying. Solar drying systems are those that use the sun's energy more efficiently than simple open-air drying. A comparison of drying technologies is illustrated in table 6.

Table 6. Comparison of drying technologies

	Sun drying	Solar drying	Fuelled drying
Initial cost	None	Medium	High
Operating cost	Low	Low	Medium
Temperature control	None	Poor	Good
Continuous operation	No	No	Yes
Speed of drying	Slow	Medium	Fast
Protection from pests	No	Yes	Yes

In general, solar drying is more appropriate when:

- The higher the value per ton of products dried;
- The higher the proportion of the product currently spoiled in the open air;
- The more often the drier will be used.

Solar cookers

Solar cookers can be important because of the increased scarcity of wood fuel and the problems of deforestation in many developing country regions. Solar cookers can also promote cleaner air where there is a problem with indoor cooking. There are basically two types of solar cooker: oven or stove type. As with conventional cooking stoves, solar stoves apply heat to the bottom of the cooking pot while solar ovens apply a general heat to the enclosed area which contains the cooking pot. However, there are important social issues related to the effective use of solar cookers. There will always be some change of habits required and readiness to change is an important factor that affects the potential impact of this technology.

Solar distillation

Solar distillation is a solar enhanced distillation process to produce potable water from a saline source. It can be used in areas where, for instance, drinking water is in short supply but brackish water, i.e. containing dissolved salts, is available. In general solar distillation equipment, or stills, is more economically attractive for smaller outputs. Costs increase significantly with increased output, in comparison to other technologies which have considerable economics of scale.

Solar cooling

Several forms of mature technologies are available today for solar-thermally assisted air-conditioning and cooling applications. In particular for centralized systems providing conditioned air and/or chilled water to buildings, all necessary components are commercially available. The great advantage of this solar application, especially in tropical and equatorial countries, is that the daily cooling load profile follows the solar radiation profile (i.e. office buildings).

Review questions

1. What are the similarities and what are the differences between solar thermal and PV?
2. What are the four different PV technologies in use today?
3. What are the different services that solar thermal systems can provide?

3.3. Bioenergy

Bioenergy is a general term that covers energy derived from a wide variety of material of plant or animal origin. Strictly, this includes fossil fuels but, generally, the term is used to mean renewable energy sources such as wood and wood residues, agricultural crops and residues, animal fats, and animal and human wastes, all of which can yield useful fuels either directly or after some form of conversion. There are technologies for bioenergy using liquid and gaseous fuel, as well as traditional applications of direct combustion. The conversion process can be physical (for example, drying, size, reduction or densification), thermal (as in carbonization) or chemical (as in biogas production). The end result of the conversion process may be a solid, liquid or gaseous fuel and this flexibility of choice in the physical form of the fuel is one of the advantages of bioenergy over other renewable energy sources.

The basis for all these applications is organic matter, in most cases plants and trees. There is a trend towards purposefully planted biomass energy crops, although biomass can also be collected as a by-product and residue from agricultural, forestry, industry and household waste. Bioenergy can be used for a great variety of energy needs, from heating and transport fuel to power generation.

There are numerous commercially available technologies for the conversion processes and for utilization of the end-products. Although the different types of bioenergy have features in common, they exhibit considerable variation in physical and chemical characteristics which influence their use as fuels. There is such a wide range of bioenergy systems that this module does not aim to cover and describe each one. Examples of bioenergy applications are illustrated in table 7.

Table 7. Examples of bioenergy applications

Fuel state	Application
Biogas	Supplementing mains supply (grid-connected)
Biogas	Cooking and lighting (household-scale digesters), motive power for small industry and electric needs (with gas engine)
Liquid biofuel	Transport fuel and mechanical power, particularly for agriculture; heating and electricity generation; some rural cooking fuel
Solid biomass	Cooking and lighting (direct combustion), motive power for small industry and electric needs (with electric motor)

Until the nineteenth century, biomass was the predominant fuel for providing heat and light all over the world. In industrialized countries it was then displaced by coal and later by petroleum, but in developing countries it remains the most important fuel. Some strengths and weaknesses of bioenergy, in general, are summarized in table 8.

Table 8. Strengths and weaknesses of bioenergy systems

Strengths	Weaknesses
Conversion technologies available in a wide range of power levels at different levels of technological complexity	Production can create land use competition
Fuel production and conversion technology indigenous in developing countries	Often large areas of land are required (usually low energy density)
Production can produce more jobs than other renewable energy systems of a comparable size	Production can have high fertilizer and water requirements
Conversion can be to gaseous, liquid or solid fuel	May require complex management system to ensure constant supply of resource, which is often bulky adding complexity to handling, transport and storage
Environmental impact low (overall no increase in carbon dioxide) compared with conventional energy sources	Resource production may be variable depending on local climatic/weather effects, i.e. drought.
	Likely to be uneven resource production throughout the year

Review question

1. What are the various applications associated with the different fuel states in bioenergy production?

3.4. Hydro

Hydropower is the extraction of energy from falling water (from a higher to a lower altitude) when it is made to pass through an energy conversion device, such as a water turbine or a water wheel. A water turbine converts the energy of water into mechanical energy, which in turn is often converted into electrical energy by means of a generator.

Alternatively, hydropower can also be extracted from river currents when a suitable device is placed directly in a river. The devices employed in this case are generally known as river or water current turbines[1] or a “zero head” turbine. This module will review only the former type of hydropower, as the latter has a limited potential and application.

Hydropower systems can range from tens of Watts to hundreds of Megawatts. A classification based on the size of hydropower plants is presented in table 9. However, there is no internationally recognized standard definition for hydropower sizes, so definitions can vary from one country to another.

Table 9. Classification of hydro-power size

Large-hydro	More than 100 MW and usually feeding into a large electricity grid
Medium-hydro	10 or 20 MW to 100 MW—usually feeding into a grid
Small-hydro	1 MW to 10 MW or 20 MW—definitions vary, Europe tends to use 10 MW as a maximum, China uses 20 MW and Brazil 30 MW. Usually feeding onto a grid
Mini-hydro	100 kW to 1 MW—either stand alone schemes or more often feeding into a grid
Micro-hydro	5 kW to 100 kW—usually provide power for a small community or rural industry in remote areas away from the grid.
Pico-hydro	50 W to 5 kW—usually for remote rural communities and individual households. Applications include battery charging or food processing

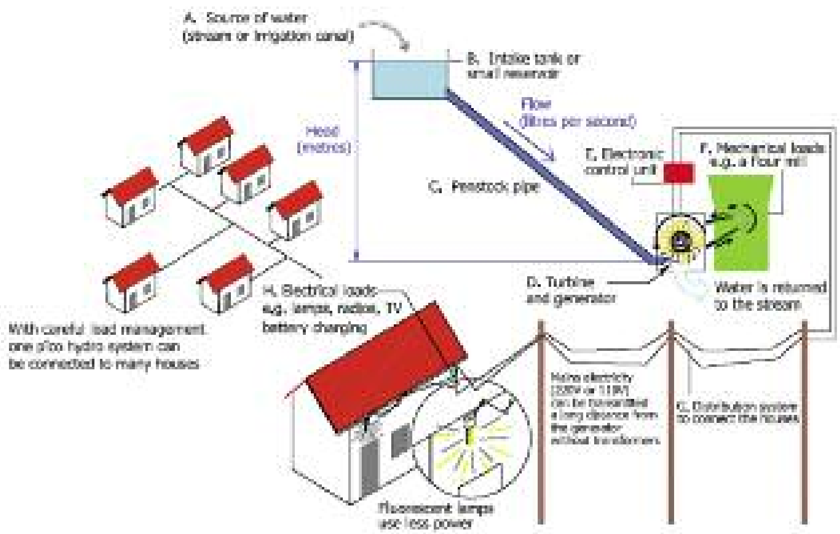
Large hydropower schemes often have outputs of hundreds or even thousands of megawatts but function similarly to small hydropower plants (SHP), which use the energy in falling water to produce electricity or mechanical energy using a variety of available turbine types (e.g. Pelton, Francis, Kaplan) depending on the characteristics of the river (e.g. flow, head[2]) and installation capacity. SHP is defined in many countries, though not universally, as any hydro installation rated at less than 10 MW.

[1]Alternating Current Project, Peru, August 2000, www.tve.org/ho/doc.cfm?aid=656

[2]“Head” is the difference in elevation between upstream level (reservoir or tank) and the downstream level (usually turbine) in a hydropower scheme. It is possible to express head in either units of height (e.g. metres) or in units of pressure such as Pascals (the SI unit). See also figure V below.

On a smaller scale, used more often in rural and remote areas, micro-hydro schemes can have capacities up to 500 kW and are generally run-of-the-river developments for villages. On an even smaller scale pico-hydro systems tend to be between 50 W to 5 kW and are generally used for individual homes or clusters of households. Figure V shows a typical high head pico-hydro scheme, although this configuration is also typical of larger small-scale hydro schemes. Such small community-based systems demand a different approach to larger (SHP) hydro schemes and require a broad understanding of all the diverse technical and social elements in order to contribute successfully to the energy needs of a rural community.

Figure V. Schematic of a pico-hydro system



Hydropower, under the right circumstances, can be one of the most reliable and cost-effective renewable energy sources. The applications of small-hydro facilities include base, peak and stand-by power production or stand-alone applications. Hydroelectric plants typically generate power between 15 to 100 per cent of the time. In base loading applications, units must be able to operate at least 85 per cent of the time. SHP installations commonly last without the need for major replacement costs for 30+ years. Within the limits of water resources available, SHP installations are characterized by reliability and flexibility of operation, including fast start-up and shut-down in response to rapid demand changes. SHP electricity can be tailored to the needs of the end-use market, avoiding balance and power reliability concerns.

SHP does not have the same kinds of adverse effects on the local environment as large hydro. Nevertheless, SHP has some adverse impacts on the environment. For example when water levels in reservoirs change abruptly to meet electricity demands or in times of low flow, the short stretch of by-passed river can run dry, which might dry out aquatic organisms. Power plants often obstruct the natural migration of fish through the river system. Such effects could result in the extinction of fish populations, a fundamental change of natural flow regimes, the loss of aquatic habitats, sinking groundwater levels and a deterioration of landscapes. In order for hydropower plants to be socially and environmentally sustainable, the local and regional impacts need to be evaluated, reduced and minimized.[3] Therefore, modern construction designs typically implement mitigation measures.

The Eugene Standard[4] provides a set of criteria that hydropower plants (regardless of their installed capacity, age or mode of operation) need to comply with in order to be an environmentally sound form of power supply. Under the Standard, three basic conditions have to be met:

1. The basic requirements include (non-exhaustive list):
   - *(a)* Hydropower utilization should not lastingly impair the ability of fish to migrate unimpeded through the affected river system.
   - *(b)* Hydropower utilization should not result in long-term degradation in the natural diversity of plants and animals.
   - *(c)* Power plant constructions should not irreversibly destroy protected habitats.
   - *(d)* Power plant operation should not endanger fish or benthic organisms in affected river reaches.
2. Secondly the sustainable hydropower plant should invest money (for instance a fixed rate per kilowatt-hour produced or sold) to restore, protect or upgrade the environment surrounding the hydropower plant (so-called eco-investments).
3. Thirdly, to assess to which extent the basic requirements were met and what the eco-investments were used for, an audit and certification procedure should be carried out every year.

The strengths and weaknesses of SHP technology are presented in table 10.

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[3]The issue of hydropower and sustainability is described in full detail in the CLEAN-E report “Development of ecological standards for hydropower”. This report is available at www.eugenestandard.org/index.cfm?inc=page&id=62

[4]www.eugenestandard.org

Table 10. Strengths and weaknesses of small hydropower systems

Strengths	Weaknesses
Technology is relatively simple and robust with lifetimes of over 30 years without major investment	Very site-specific technology (requires a suitable site relatively close to the location where the new power is needed)
Overall costs can, in many cases, undercut all other alternatives	For SHP systems using small streams the maximum power is limited and cannot expand if the need grows
Automatic operation with low maintenance requirements	Droughts and changes in local water and land use can affect power output
No fuel required (no additional costs for fuel nor delivery logistics)	Although power output is generally more predictable it may fall to very low levels or even zero during the dry season
Environmental impact low compared with conventional energy sources	High capital/initial investment costs
Power is available at a fairly constant rate and at all times, subject to water resource availability	Engineering skills required may be unavailable/ expensive to obtain locally
The technology can be adapted for manufacture/use in developing countries	

Review question

1. What size of hydropower plant is considered small? mini? micro? pico?

3.5. Geothermal

Geothermal is energy available as heat emitted from within the earth, usually in the form of hot water or steam. Geothermal heat has two sources: the original heat produced from the formation of the earth by gravitational collapse and the heat produced by the radioactive decay of various isotopes. It is very site dependent as the resource needs to be near surface and can be used for heating and power generation purposes. High temperature resources (150° C+) can be used for electricity generation, while low temperature resources (50-150° C) can be used for various direct uses such as district heating and industrial processing. Since the earth's crust is continuously emitting heat towards its surface at a rate of 40 million megawatts, geothermal is in principle an inexhaustible energy source, with the centre of the earth having cooled down by only about 2 per cent over the earth's lifetime of about 4 billion years.

The extraction of energy from geothermal aquifers uses naturally occurring ground water from deep porous rocks. Water can be extracted via a production borehole and, generally be disposed of via an injection hole. Another method is the extraction of heat from hot dry rock (HDR) which uses reservoirs created artificially by hydraulic fracturing. Heat is extracted by circulating water under pressure via production wells.

There are no problems of intermittency in the utilization of geothermal energy sources for direct heat applications or for electricity generation. A developed geothermal field provides what is essentially a distributed heat source, since the input to a power plant normally consists of the integrated outputs of several wells. Thus one or more wells may be shut for repairs or maintenance while others produce. Proper dimensioning of the generating plant ensures that there is always enough steam or hot water available for operation. This feature and the low operational costs are the reasons why geothermal power plants are normally used for base load power.

Natural variations of geothermal resources occur over extremely long periods, millennia or even longer time scales. However, man-induced processes lead to variations with shorter time scales, typically in the range of decades. Unwanted effects of over-exploitation and improper reinjection have been observed, especially in the early years of geothermal technology development. However, present-day geothermal technology for field characterization and modelling makes it possible to avoid improper practices, or at worst to detect their effects at an early stage before they become significant.

Environmentally, geothermal schemes are relatively benign, but typically do produce a highly corrosive brine which may need special treatment and discharge consents. There is also a possibility of noxious gases, such as hydrogen sulphide, being emitted.

Review question

1. What temperature resource is used for electricity generation in geothermal systems?

3.6. Summary

In summary, table 11 presents an overview of the technologies and applications:

Table 11. Renewable energy technologies and applications

Renewable energy technology	Energy service/application	Area of application
Wind turbines – grid-connected	Residential and industrial electricity, supplementing mains supply	Mostly urban
Wind Turbines – stand-alone	Power for lighting (homes, schools, streets), refrigeration (vaccine) and other low-to medium electric power needs (telecommunications, etc.) Occasionally mechanical power for agriculture.	Urban and rural
Wind pumps	Pumping water (for agriculture and drinking)	Mostly rural
PV (solar electric) – grid-connected	Residential and industrial electricity, supplementing mains supply	Mostly urban
PV (solar electric) – stand-alone	Power for lighting (homes, schools, streets), refrigeration (vaccine) and other low- to medium-voltage electric needs (telecommunications, etc.)	Urban and rural
Solar PV pumps	Pumping water (for agriculture and drinking)	Mostly rural
Solar thermal power plant – grid-connected	Residential and industrial electricity, supplementing mains supply	Mostly urban
Solar thermal – water heaters	Heating water	Urban and rural
Solar thermal – cookers	Cooking (for homes, commercial stoves, and ovens)	Mostly rural
Solar thermal – dryers	Drying crops	Mostly rural
Solar thermal – cooling	Air-conditioning (centralized system for buildings, etc.) Cooling for industrial processes	Mostly urban
Solid biomass	Cooking and lighting (direct combustion), motive power for small industry and electric needs (with electric motor)	Mostly rural
Liquid biofuel	Transport fuel and mechanical power, particularly for agriculture; heating and electricity generation; some rural cooking fuel	Urban and rural
Large hydro – grid-connected	Residential and industrial electricity, supplementing mains supply	Mostly urban
Small hydro	Lighting and other low-to-medium voltage electric needs (telecommunications, hand tools, etc.), process motive power for small industry (with electric motor)	Mostly rural
Geothermal	Grid electricity and large-scale heating.	Urban and rural
Village-scale	Mini-grids usually hybrid systems, solar and/or wind energy with diesel engines. Small-scale residential and commercial.	Mostly rural, some peri-urban

Discussion question/exercise

Consider the strengths and weaknesses of all of the renewable energy technologies. What are the main similarities/differences? Why do these exist?

4. OVERVIEW OF COSTS OF DIFFERENT TECHNOLOGIES

The paragraphs below present typical costs of energy generated by different technologies and also the cost per kW installed. These costs are intended to be indicative and it should be noted that costs vary greatly from country to country, or even from region to region within the same country, as they are dependent on many local factors.

4.1. Wind

Power production costs of wind-generated electricity have fallen steadily as the technology has developed. The European Wind Energy Association (2004) estimates that in Europe the cost of large-scale wind power in 2003 ranges from approximately 0.04-0.06 euro/kWh at sites with very good wind speeds to 0.07-0.1 euro/kWh at sites with low wind speeds. This calculation assumes a medium-sized turbine of 850-1,500 kW capacity, investment costs ranging from 900 to 1,150 euro/kW, O&M costs averaging 0.012 Euro/kWh over a lifetime of 20 years, and a discount rate of 7.5 per cent per annum. The cost of capital (discount or interest rate) is a particularly important factor. Wind power is a very capital intensive technology with about 75 per cent of total costs as capital up front (for a natural gas plant the share is typically 40-60 per cent). Therefore, the economic performance of a wind power project is highly dependent on the level of interest rates.

4.2. PV

Reported prices for entire PV systems vary widely and depend on many factors including system size, location, customer type, connection to an electricity grid, technical specification and the extent to which end-user prices reflect the real costs of all the components.

According to the International Energy Agency's Photovoltaic Power Systems programme (IEA PVPS), on average, system prices for the lowest cost off-grid applications are double those for the lowest cost grid-connected applications. This is attributed to the fact that the latter do not require storage batteries and associated equipment. In 2005, the lowest system prices in the off-grid sector, irrespective of the type of application, ranged from about $US 10-20 per watt. The large range of reported prices is a function of country and project specific factors. The lowest achievable installed price of grid-connected systems in 2005 also varied between countries. The average price of these systems was $US 6.6/W in 2005. In 2005 the average price of modules was around $US 4.5/W.[5]

On the basis of a payback period of 20 years (which is also the anticipated average lifetime of a system), the electricity cost is approximately $US 0.9-2/kWh for a stand-alone system and $US 0.25-0.7/kWh for a grid connected system. The most important barrier for the implementation of PV is therefore the relatively high cost. It is hoped further improvements in efficiencies and technologies will bring the cost down over the next 5 to 10 years, though for several markets, PV is already competitive, in particular for small-scale generation of electricity in off-grid remote rural areas.

4.3. Biomass

According to calculations made by the Dutch firms ECN and KEMA, stand-alone plants using biomass typically generate electricity at a cost of $US 0.06-0.09/kWh (using bio-oil CHP, 50 MW_e), and around $US 0.14/kWh (using wood chips, around 30 MW_e), up to $US 0.19/kWh for smaller power plants (< 5 MW_e, using wood chips). Investment costs are typically at $US 1000-1300/$kW_e$.

Co-firing of bio-oil or wood pellets in coal or gas fired power plants is generally cheaper, with electricity generation costs typically ranging between $US 0.05-0.08/kWh.

4.4. Hydro

Power station construction costs typically vary from about $US 1,500-4,400/kW depending on site conditions, head, water conveyance and necessary mitigation measures. According to the European Small Hydropower Association (ESHA), the average production cost in the EU-15 is $US 0.06-0.18/kWh. Maintenance costs are typically very low while no fuel costs apply.

4.5. Geothermal

According to the IEA (2004), the cost of geothermal electricity depends on a number of factors, particularly on the temperature of the geothermal fluid, which influences the size of the turbine, heat exchangers and cooling system. The IEA estimates production costs in Europe at $US 0.06-0.11/kWh for traditional geothermal plants (i.e. liquid-steam water resource) and $US 0.25-0.37/kWh for hot

[5] Trends in photovoltaic applications in selected IEA countries between 1992 and 2005, IEA PVPS, September 2006.

dry rock systems, whereas the installed system costs range from $US 880-3,500/kW (WEA, 2000). Due to the high capital cost of such systems and their dispatchable qualities as a source of power, they are an ideal provider for base load supply.

Discussion question/exercise

What factors might cause variations of these costs in your country, i.e. subsidies, specific technology factors, such as wind speed?

5. OVERVIEW OF COMMON BARRIERS AND ISSUES LIMITING WIDESPREAD USE/DISSEMINATION OF RENEWABLE ENERGY

There are a number of issues and barriers which impede the large-scale implementation of renewable energy technologies. This section aims to summarize the key technical and non-technical issues.

5.1. Technical issues

Design and installation skills

Correct design and installation is an important factor with all renewable energy systems. Systems which have not been designed and installed correctly are unlikely to operate satisfactorily. Design may not be a problem if the renewable energy system is in simple kit form, or designed by experts, although this does pose the problem of ensuring that it is understood at the local level.

The main obstacle in developing countries comes in the area of installation and maintenance skills at the local-level. Although installing some small-scale renewable energy systems, such as wind or PV solar home systems, may not usually pose serious problems in some countries (especially when they are sold in kits which contain all the necessary components, along with instructions in the appropriate language), there are definite skills shortages in many countries and unevenness in skills capacity across a country. For example, there is a much higher concentration of installation and maintenance skills in urban areas than there is in rural areas.

Installations of small-scale renewables may in some cases be completed by the owner/user (if provided with a good instructions manual), however, a skilled technician is usually still needed in the area for maintenance and technical problem solving. For larger renewable energy installations, e.g. for a community hospital, the installation should be carried out by qualified technicians with the same thoroughness as for a conventional power supply system. This can be a problem if there is a shortage of skilled people in the country. When training technicians and end-users to install and maintain their systems there may be some hesitancy to adapt to unfamiliar technology, which will also needs to be overcome.

Quality control and warranties

Renewable energy systems available world-wide can range in quality. It is important to select systems of adequate quality, preferably approved systems (i.e. following a defined standard). Systems should be well-designed and properly sized for the specific need. They also need to be long-lasting, user-friendly and repairable by local technicians. The warranty of the renewable energy apparatus, components and overall system also needs to be considered.

Box 3. **Standards for PV technology**

Most PV modules are manufactured according to USA or European standards, and their quality is very high. International standards also exist for certain other system components. For example, the World Health Organisation, in collaboration with UNICEF, has set international standards for PV refrigerators. WHO/UNICEF funded projects will now only use PV refrigerators that have received WHO approval, which has raised the standard of available products.

Standards do not always exist for system components. This has led to the situation where the quality can vary significantly between several apparently similar devices, or between the various components within a single system. To avoid purchasing inadequate systems or components, it is advisable to prepare a set of technical specifications to define the standard required for a given application.

Maintenance and after-sales service

Maintenance of any system is vital. Some systems require little more than occasional checking of apparatus and components whilst others will require a full maintenance schedule. Preventative maintenance should be planned in full, including the arrangement of the finance necessary to complete this and to cover the costs of repairs and replacements. Maintenance is often a problem for renewable energy systems placed off-grid in rural and remote areas. In these areas, financial resources to fund maintenance are usually lacking as most rural populations have incomes too low to save money for maintenance costs, and human resources, in terms of availability skilled technicians in the field, are also lacking.

Training

Training local people to install, maintain and repair renewable energy systems is essential. There needs to be extensive training of technicians at the local level, often existing electricians, to be able to also deal with small-scale renewable energy systems (especially solar home systems). Users also may need to be educated about the renewable energy system: what it does, how it works and how to look after it. A user-manual should always be given to the end-user along with the renewable energy system. Information dissemination can also play an important role. First, it gives accurate information about what a system can or cannot do. If dissemination of information is undertaken before any system is installed, then there is less likelihood that there will be over-optimistic expectations. At the same time, raising awareness of renewable energy systems can stimulate local markets.

Local technical infrastructure development

Renewable energy projects must include infrastructure development strategies. These need to be undertaken in collaboration with the private sector and local communities. Experience has shown that there are many advantages to be gained if local businesses are involved in any project. The provision of local infrastructure support including training, parts supply and service capability is therefore vital to the success of a project.

5.2. Non-technical issues

Awareness

Most renewable energy systems are now technically mature and proven but they are sometimes still regarded as risky and complicated, as well as expensive and it is often thought that they do not work effectively. This view prevails from the early days of development when there were indeed sometimes such problems. Now renewable energy systems are affordable and often cheaper than conventional alternatives. Moreover these systems offer social (i.e. providing power for income-generating activities) and environmental benefits. The lack of awareness and understanding often reaches across the board from local (potential customers) to institutional level (government departments who might otherwise implement activities/funds to support projects) and there is a need for information dissemination at all levels.

Policy/regulatory issues

There is a lack of government support (although there are signs that this is beginning to change) both at the budgetary and regulatory levels for small and medium renewable energy technologies, especially when compared to the conventional energy sector. However, government policies promoting renewable energy technologies have increased significantly in recent years. At least 48 countries worldwide now have some type of renewable energy promotion policy, including 14 developing countries.[8] Lessons learnt indicate that the best policies are those which promote production-based incentives. Power sector regulatory policies for renewable energy should support IPP (independent power producer) frameworks that provide incentives and long-term stable tariffs.

Institutional capacity-building for micro-finance

People in rural areas want the benefits which electricity brings. However, a major problem is often a lack of capital to pay for renewable energy equipment and/or services. This can be overcome by access to appropriate local credit schemes. There are many successful financial models around the world which utilize micro-enterprise credit to finance small purchases in rural areas. Although these particularly relate to the agriculture sector, there are a number of revolving funds which are providing credit in rural areas for renewable energy purchases. These are beginning to be successfully implemented in some developing countries, but this is rather limited thus far. Financing for renewable power projects is crucial but elusive; there is a real lack of low-cost, long-term financing options.

Community involvement

Community involvement is often critical to the success of a local renewable energy project. Many such projects in developing countries have failed because the needs and wishes of the local community were not considered before the project went ahead and systems installed. If there is no feeling of community involvement or ownership, then failure rate of equipment and theft are likely to be high. Where a technology, such as a water pump or a grinding mill, will benefit an entire community, a local organization needs to take responsibility for ensuring that the technology is managed and utilized according to the needs and preferences of the entire community. Such an organization must be representative of the entire community so that all community members have the right to use the system. The organization may need to define the hours of operation of the system, the tariffs that might be levied (e.g. for water, battery-charging or milling), the maintenance to be carried out and by whom. The presence of such an organization can help to ensure that the system, and any revenue it generates, will benefit the entire community, not just a privileged few. Such a community organization is essential in situations where the local people will be contributing to

[8] *Renewables 2005: Global Status Report*, REN21 Network Report, 2005.

the financing of the system. It will need to be set up well in advance of system installation, probably during the planning phase with community representatives.

Women in development

The vital role which women play in development is often underestimated or ignored. However, it is often women who benefit most from renewable energy systems.

Box 4. **Women and renewable energy**

Local water pumps, powered by wind or solar, mean less distance to travel to fetch water, and mean that the water is potable. Such systems can be used by the women for drinking water and irrigating their market gardens, thus providing fresh vegetables for their families, with the excess sold and bringing in additional capital for the family.

PV-powered lighting in a healthcare facility can provide better birthing facilities; increased immunization programmes, meaning lower infant mortality which lessens the perceived need for large families.

In other instances, power for lighting or machinery (e.g. sewing machines) enables women to undertake other income-generating activities. Where lighting has been provided in community centres or schools, literacy classes for women can break the poverty trap by enabling them to learn to read, write and count.

Discussion question/exercise

Based on the discussion of the strengths and weaknesses of all of the renewable energy technologies consider how these points might affect the implementation of the technologies from the social, technological and regulatory viewpoints?

6. CONCLUSION

Renewables can be used for both electricity and heat generation. There is a wide range of renewable energy technologies suitable for implementation in developing countries for a whole variety of different applications, as summarized in table 12. Renewable energy can contribute to grid-connected generation but also has a large scope for off-grid applications and can be very suitable for remote and rural applications in developing countries.

Table 12. Summary of technologies and applications

Renewable energy technology	Energy service/application
Wind – grid-connected and stand-alone turbines, wind pumps	Supplementing mains supply. Power for low to medium electric power needs. Occasionally mechanical power for agriculture purposes.
PV (solar electric) – grid-connected, stand-alone, pumps	Supplementing mains supply. Power for low electric power needs. Water pumping
Solar thermal – grid-connected, water heater, cookers, dryers, cooling	Supplementing mains supply. Heating water. Cooking. Drying crops.
Bioenergy	Supplementing mains supply. Cooking and lighting, motive power for small industry and electric needs. Transport fuel and mechanical power.
Micro and pico hydro	Low-to-medium electric power needs. Process motive power for small industry.
Geothermal	Grid electricity and large-scale heating.
Village-scale	Mini-grids usually hybrid systems (solar-wind, solar-diesel, wind-diesel, etc.). Small-scale residential and commercial electric power needs.

LEARNING RESOURCES

Key points covered

The major points covered in this module are as follows:

- Outline and brief description, including fundamentals, of the different renewable energy technologies: wind, solar, bioenergy, hydro, and geothermal energy;
- General overview of the technologies and applications;
- Information on the costs of different renewable energy technologies;
- Discussion regarding common technical and non-technical barriers and issues limiting the widespread use/dissemination of renewable energy.

Answers to review questions

Question: What are the key advantages and disadvantages of wind energy technology?

Answer: See table 2 for strengths and weaknesses

Question: What is meant by the term "stand-alone" and what is the key difference between the two different stand-alone systems described above?

Answer: Stand-alone refers to the fact that the system supplies power without support from the grid. It may be as a single technology or a hybrid (with other technologies, i.e. PV or even a diesel generator). One system incorporates energy storage via a battery bank whilst the other does not. The autonomous diesel system is designed to automatically supply power as required. It has a complex control system.

Question: What are the key differences in the requirements for a wind pump for irrigation and a wind pump for water supply?

Answer: A wind pump developed for irrigation has to be as cheap as possible. Since irrigation generally involves the farmer and/or other workers being present, it is not so critical to have a machine capable of running unattended. Therefore windmills used for irrigation in the past tend to be indigenous designs that are often improvised or built by the farmer as a method of low-cost mechanization.

Most water supply wind pumps must be ultra-reliable, to run unattended for most of the time and they also need the minimum of maintenance and attention and to be capable of pumping water generally from depths of 10 m to 100 m or more. A typical farm wind pump should run for over 20 years with maintenance only once every year, and without any major replacements.

Question: What are the similarities and what are the differences between solar thermal and PV?

Answer: Solar thermal and PV systems both convert energy from the sun into useful energy. PV devices convert sun light directly into electrical energy whilst solar thermal systems use the sun's power in terms of its thermal or heat energy for heating, drying and evaporation.

Question: What are the four different PV technologies in use today and what are their conversion efficiencies?

Answer: Mono-crystalline silicon (conversion efficiency 12-15 per cent), polycrystalline silicon (conversion efficiency 11-14 per cent), thin film (conversion efficiency 5-12 per cent), multiple junction (conversion efficiency 20-30 per cent).

Question: What are the different services that solar thermal systems can provide?

Answer: Electricity, hot water, drying, cooking, distillation, cooling

Question: What are the various applications associated with the different fuel states in bioenergy production?

Answer: See table 7: examples of bioenergy applications.

Question: What size of hydropower plant is considered small? mini? micro? pico?

Answer: See table 9: classification of hydropower plants.

Question: What temperature resource is used for electricity generation in geothermal systems?

Answer: High temperature resources (150° C and greater) can be used for electricity generation.

Presentation/suggested discussion topics

Presentation:

ENERGY REGULATION – Module 7: Renewable energy technologies

Suggested discussion topics:

1. Consider the strengths and weaknesses of all of the renewable energy technologies. What are the main similarities/differences? Why do these exist?
2. What factors might cause variations of these costs in your country, i.e. subsidies, specific technology factors, such as wind speed, etc?
3. Based on the discussion of the strengths and weaknesses of all of the renewable energy technologies consider how these points might affect the implementation of the technologies from the social, technological and regulatory view points?

Relevant case studies

1. Wind power in local government: Denmark's renewable energy island
2. Solar water heating in local government in the UK

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Use of biomass in stand-alone small scale installations for electricity generation, ECN, 2005. ECN-C—05-016

Water Lifting Devices: A Handbook for Users and Choosers, Peter Fraenkel and Jeremy Thake, Intermediate Technology, December 2006, ISBN 1853395382

INTERNET RESOURCES

International Energy Agency: www.iea.org

United Nations Development Programme—Energy: www.undp.org/energy

World Bank Group Energy Program: worldbank.org/energy

Renewable Energy Policy Network for the 21st Century: www.ren21.net

Danish Wind Industry Association: www.windpower.org/en/core.htm

IT Power website, international section: www.itpower.co.uk

Renewable Energy Case Studies: www.martinot.info/case_studies.htm

Renewable Energy for rural schools, health clinics and water applications: www.enable.nu

Best practice on green energy: www.eugenestandard.org

Technical brief on solar distillation: practicalaction.org/docs/technical_information_service/ solar_distillation.pdf

More information on energy for developing countries: practicalaction.org/?id=energy_for_the_poor

The Global Environment facility: www.gefweb.org

More information on solar thermal power plants: www.solarpaces.org

More information on solar-assisted air-conditioning of buildings: www.iea-shc-task25.org/english/index.html

GLOSSARY/DEFINITION OF KEY CONCEPTS

Biofuels	Liquid fuels and blending components produced from biomass (plant and animal) feedstocks, used primarily for transportation.
Biogas	Gaseous fuel produced from animal and crop residues. A mixture of methane, carbon dioxide and water vapour.
Developing countries	Countries which fall within a given range of GNP per capita, as defined by the World Bank.
Energy services	The end use ultimately provided by energy, e.g. lighting.
Energy sources	Any substance or natural phenomenon that can be consumed or transformed to supply heat or power.
Geothermal energy	Natural heat from within the earth, captured for production of electric power, space heating or industrial steam.
Geothermal plant	A plant in which the prime mover is a steam turbine that is driven either by steam produced from hot water or by natural steam that derives its energy from heat found in rocks or fluids at various depths beneath the surface of the earth. The fluids are extracted by drilling and/or pumping.
Independent power producers (IPPs)	Privately owned power companies that produce electricity and sell it for a profit to the national grid or to a distribution utility.
Inverter	An inverter is an electronic circuit for converting direct current (DC) to alternating current (AC). Inverters are used in a wide range of applications, from small switched power supplies for a computer to large electric utility applications to transport bulk power.
Legal and regulatory framework (LRF)	Combination of the laws, institutions, rules and regulations governing the operations of the electricity industry.
Micro hydro	Small-scale power generating systems that harness the power of falling water (above 100kW but below 1MW).
Run-of-the-river	Hydropower schemes that use natural flow of river to generate power without obstructing the flow of the river with a dam or similar structure and with little or no storage.

Semiconductor	A semiconductor is a solid whose electrical conductivity varies depending on certain conditions. Semiconductors are tremendously important technologically and economically. Silicon is the most commercially important semiconductor, though dozens of others are important as well. Silicon, in combination with a small amount of another chemical, is used in photovoltaic cells to convert sunlight to electricity.
Small hydro	Small-scale power generating systems that harness the power of falling water (< 10 MW).
Solar dryer	A special structure that uses the sun's energy to dry agricultural produce (fruits, vegetables, meat).
Solar photovoltaic (PV) technologies	Devices that convert the sun's energy into electricity for use in lighting, refrigeration, telecommunications, etc.
Solar thermal technologies	Devices that use the sun as the primary source of energy for heat appliances, e.g. solar water heaters, solar dryers.
Solar water heaters	Devices that use solar energy to heat water for domestic, institutional, commercial and industrial use.
Solar-assisted air-conditioning and cooling	The basic scheme of solar-thermally assisted air-conditioning and cooling systems consists of a solar collector field that traps sunlight energy, converts it to heat, and conveys that heat to a working fluid such as water. The heated water coming from the solar collector represents the heat source for the thermally driven air-conditioner or chiller. Thermally driven chiller cooling is the first and oldest form of air-conditioning and refrigeration.
Wind turbines	Devices used to generate electricity using kinetic energy from wind.
Wind pumps	Devices that use wind energy to lift water from underground sources.

Case study 1.

WIND POWER IN LOCAL GOVERNMENT: DENMARK'S RENEWABLE ENERGY ISLAND

CONTENTS

1. SUMMARY

In 1997 Samsø was appointed by the Ministry of Energy and Environment as "Denmark's Renewable Energy Island". The objective is that Samsø will be self-sufficient using renewable energy within a decade. As part of the plan, a wind turbine park will be erected offshore south of the island, consisting of ten 2.3 MW wind turbines, in order to compensate for energy consumed by the transport sector. The installation was completed at the beginning of 2003.

The project has been successful as a result of the initiative and enthusiasm of the local government and people and as such, the principles which lead to the establishment of an area of renewable energy development could be replicated and applied elsewhere.

The success of the work has been integrated into local educational programmes and has generated enthusiasm and awareness within the local population.

2. THE SCHEME

In 1997, as part of the Danish Energy Plan, "Energi21", Samsø was selected by the Ministry of Energy and Environment to represent Denmark's Renewable Energy Island with the aim of having a 100 per cent renewable energy supply for both heating and electricity within ten years. Forming part of the plan is the establishment of an off-shore wind turbine park (23 MW) to produce electricity to compensate for the fossil energy consumption in the transport sector. It is planned that fifty per cent of private cars will be converted to electricity and use the energy produced from the wind turbines.

There are already 15 x 750 kW onshore turbines on the island and so it is very difficult to get permission to build more turbines onshore. This is the case for the whole of Denmark, and is why future wind turbines are likely to be erected offshore.

3. TECHNOLOGY

Wind turbines use the energy in the wind to generate electricity. The advantages of erecting wind turbines offshore include higher average wind speeds and fewer obstructions (such as hills, buildings, etc.), which create turbulence and reduce the power the turbines produce.

The erection of 10 x 2.3 MW offshore wind turbines (Bonus Energ A/S) started in September 2002. The rotor diameter is 82.4 metres, the hub height above sea level is 61.2 metres and the weight of one unit is 3000 tons. The annual energy production of the wind farm will be 77,650 MWh/year.

The turbines have been put up in a straight row (direction north to south) at Paludans Flak, which is a reef 3.5 km south of Samsø.

4. PROJECT TEAM

In order to be able to implement and organize the "Renewable Energy Island" project, Samsø Energy Corporation (Samsø Energiselskab) was created. This is an association of representatives from the Council of Industry, the Association of Agriculture, the Board of Samsø Municipality and citizen representatives chosen by the Association of Energy and Environment of Samsø. A separate company has been established to implement the wind power project, and the local government is also a partner in this.

The initiative to apply to be Denmark's Renewable Energy Island was taken by the Chairman of the Economic Council of Samsø. In order to secure political and commercial support for the project it was decided to present the idea to the Economic Council, the Farm Holder Union and all the representatives of the local council. They all supported the idea and the three groups chose two representatives each to be part of the steering group for the project.

5. FINANCING

In general, wind turbines in Denmark are owned by private cooperatives or companies. The situation in Samsø is quite unique since the municipality owns five of the 10 turbines. Four turbines are owned by private investors and the last turbine is owned by a cooperative, in which private individuals can buy shares.

The total investment cost is approximately €34 million. The project is divided into 7765 shares each of which represent an estimated annual production of 1000 kWh and cost €426 each.

The conversion to renewable energy will become important for the local economy. An estimated saving in fuel costs of €7 million per year will be achieved. The savings will be used to purchase biofuels, manpower, services and to provide finance for local initiatives.

6. LOCAL CONDITIONS FOR RENEWABLE ENERGY

There is great potential for renewable energy on Samsø since the solar radiation and the mean wind speed are above the national average and there are also good opportunities for biomass. In addition to this, the people of the island have gained extensive experience of renewable energy through the many projects that have now been implemented.

Before the "Renewable Energy Island" project, there was already a substantial amount of renewable energy exploitation on Samsø, such as biomass and a district heating plant that has operated reliably since 1993. This helped to prevent possible uncertainties amongst the population about the project. An example of the public interest in renewable energy is that in 1997 the Council received applications for a total of 17 wind turbines from private persons. Furthermore, there had been requests for an additional 10 wind turbine projects from local Samsø inhabitants. The total electric capacity would exceed the current needs of the island.

7. OVERCOMING BARRIERS

In Denmark wind turbines cannot simply be erected anywhere as the placement of the turbines has to fit within regional and municipal planning regulations. The planning takes place at three levels in Denmark: the Ministry of Energy does national planning, the counties are responsible for regional planning and the municipalities produce local plans. After the municipality has decided whether there is space for wind power turbines, private companies can build the actual wind turbines.

Another barrier is that consideration has to be given to nature protection associations and noise transmission. This project was realizable because it was part of the "Renewable Energy Island" project, which received subsidies from the Danish Energy Agency, but also because of the close cooperation between the local authorities, energy agencies and local citizens. At the time of writing, there is very little governmental financial support for renewable energy systems, which means that local initiatives will have to keep the Samsø project running.

8. RESULTS AND IMPACTS

8.1. Environmental and educational benefits

Since the energy production of the offshore turbines is intended to be used in the transport sector, it is necessary to calculate the amount of coal needed to produce 77,650 MWh/year. The following pollution will be avoided on an annual basis:

- Carbon dioxide (CO_2) 66,300 tonnes
- Sulphur dioxide (SO_2) 226 tonnes
- Nitrogen oxides (NO_x) 223 tonnes
- Ashes and cinders 4,290 tonnes

The offshore wind turbine park will create employment of 65 man-years for the construction period and five man-years over its lifetime for the running and maintenance of the turbines.

It is intended to work with the local educational establishments to include the renewable energy project as part of the curriculum and to establish a course in the adult college concerning self-sufficiency strategies for energy combined with economic expansion initiatives in Danish councils. There is a possibility of aiming the activities towards the international market. As this is one of the first offshore wind parks in Europe, it is a very useful demonstration of the feasibility of this technology that others will be able to replicate.

8.2. Economic benefits

The economics of the wind turbine park is based upon a lifetime calculation of ten years where the actual price (including operation and maintenance) is approximately €0.1/kWh. If the turbines last for a longer period (normal turbine lifetime being at least 20 years) they will be profitable for the owners.

The more than 15,000 tourists that visit the island annually are presented with a number of brochures, exhibitions at selected renewable energy plants and offers for special energy arrangements according to season. Samsø has already become interesting for many outsiders, who are not tourists, but have heard about the initiatives for renewable energy exploitation and would like to know more.

9. REPLICATION

Two factors which mean that developments of this type are becoming more easily replicated are firstly, the economies of scale associated with the expansion of the wind energy market have resulted in lower costs and, secondly, planning issues are more widely understood and dealt with as a result of the precedents being set by projects like this.

In addition, this project has been successful mainly as a result of the initiative and enthusiasm of the local government and local people and as such, the principles which lead to the establishment of an area of renewable energy development could be replicated and applied elsewhere.[1]

[1]For further information please contact Søren Hermansen, Samsø Energi- og Miljøkontor, Søtofte 24, 8305 Samsø, Denmark, Telephone: +45 86 59 23 22, Fax: +45 86 59 23 11, E-mail: samso@sek.dk

Case study 2.

SOLAR WATER HEATING IN LOCAL GOVERNMENT IN THE UK

CONTENTS

1. SUMMARY

Leicester City Council has introduced an innovative scheme to encourage building managers within the Council to install solar water heating systems on their properties. The Solar Rental Scheme offers them the chance to rent rather than purchase a system. The rental cost is linked to the amount of money saved through not purchasing gas or electricity to heat the water, thus there is no additional cost for the building manager.

The rent from panels is paid to the City Council's Energy Management billing team who use it to fund further installations by rotating the fund.

In the first instance, panels were installed in three schools within the city boundary through a partnership of Leicester City Council's Energy Team and the management of the schools as well as the Education Department. The project has also become part of the educational work within the school.

Although the scheme builds on work previously carried out by Leicester City Council, it has an easily replicated methodology which can be used, not only for solar thermal, but also for other sustainable energy technologies.

2. THE SCHEME

Leicester City Council has installed several solar thermal panels on various buildings over the past decade. However, as with many other solar installations, the cost was such that only a few panels could be installed. The Solar Rental Scheme takes advantage of a financing mechanism which is often used in the installation of energy efficiency measures—a rotating fund. This methodology allows for financing of solar panels with no additional cost to building managers, and allows money that is made from one project to be reused to finance the next project.

The barrier of cost is one of the main reasons why solar panels are not installed in much larger numbers and this project goes some way towards removing that barrier and opening up the potential for further installations.

3. TECHNOLOGY

Solar water heating systems collect energy from the sun and convert it into useful heat for many domestic and commercial applications. There are a number of different systems available, ranging from cheap self-installed models to complex, evacuated tube technologies that maximize solar potential.

There are now over 42,000 solar water heating systems operating in the UK, with the majority being used to produce domestic hot water or for heating swimming pools. Currently, about 2000 new systems are added each year. Most systems are robust and reliable, giving on average 20 years useful service.

4. PROJECT TEAM

Leicester City Council's Energy Team has experience in the implementation of solar thermal in its own buildings, having installed systems in swimming pools and on the central headquarters of the Council. The expertise of the team includes heating engineering, public awareness, policy development and energy management.

The team was able to use its engineering skills to design a system for installation in specific schools. The schools were identified through existing work in energy management audits and the installations were justified financially through the sustainable energy policies which the team had previously helped to develop. The scheme was then publicized, both inside and outside the authority.

The team also draws on experience from consultants and other partner organizations such as the manufacturer, Riomay, and a local installation company which has now developed the expertise to install further systems.

5. FINANCING

The total investment cost of the project was €48,000. The investment cost of solar systems can seem prohibitive to a building manager with limited resources and where investments, which do not payback within 2 to 3 years, they tend to get overlooked. The Solar Rental Scheme shifts the issue of initial capital outlay from the building manager to the Energy Management Team. The Energy

Management Team sources the funding to pay for the installation of the panels while the building manager pays for the service provided by these panels (i.e. hot water). The building manager can budget for the rent within a single financial year.

The Energy Management Team can source the financing in various ways:

- As part of overall building maintenance programme;
- From savings received from previous energy efficiency improvements;
- Through other sources such as utilities.

The greatest advantage of the scheme is the way it allows funding to be recycled and utilized beyond its original intention. The system of recycling funding is based on the logic of rotating funds for energy efficiency investment where savings resulting from a small investment in energy efficiency are "ring fenced" and used as investment for further improvements.

As the savings in energy costs are many times larger than the investment, the rotating fund increases in size. Smaller projects with short paybacks tend to be invested in first as a way of quickly increasing the investment fund, which allows for investment in larger and longer payback projects.

It is possible to combine the longer payback of a renewable energy system with the shorter payback of some energy efficiency investments in order to have an overall project with a larger revenue stream in proportion to a smaller capital outlay.

6. LOCAL CONDITIONS FOR RENEWABLE ENERGY

Leicester City Council was the first Unitary Council in the UK to achieve full Environmental Management Audit Scheme (EMAS) certification. Leicester City was granted the status of "Britain's First Environment City" in 1990. Leicester Energy Strategy has a target for a 50 per cent reduction in CO_2 emissions from 1990 to 2025 and 20 per cent of all City energy coming from renewable sources by 2020. The Council's Chief Executive made a corporate commitment to energy efficiency in 1992.

The East Midlands region's target is 9.4 per cent of electricity to be derived from renewable energy systems by 2010. The current UK Government is developing an integrated energy policy that places emphasis on low carbon technologies and its recent review suggests that the aim will be for renewable energy systems to make a significant contribution to energy supply by 2020.

The achievement of the title of Environment City and the development of the Leicester Energy Strategy were initiated by enthusiastic staff within the organization before being adopted at a top level. This continues with delivery of targets since the work is usually initiated by the staff and then endorsed by the top level management and elected representatives.

7. OVERCOMING BARRIERS

Having worked with solar energy systems previously, the Energy Management Team has a good level of knowledge of the technology. However, where it was felt that knowledge or experience may have been lacking, this was brought in through the engineers and manufacturers who supplied and fitted the systems. As time progresses and staff become more familiar with new technologies there are savings to be made in external expertise.

The Energy Management Team has become familiar with the decision-making processes within the municipality. They have also networked closely with other staff and have become sympathetic to the priorities of other departments and individuals. This has enabled the team to approach departments and individuals in such a way that they help them achieve their energy targets while helping other partners reach their targets. For example, the installation of solar panels in schools via a rental scheme provides the school with an educational tool at no additional cost.

The Energy Management Team have used the development process to their advantage in other ways by gaining political support at a high level and having renewable energy incorporated into corporate policy.

Awareness of the new installations was maximized by publicizing the work to the local community and also to other municipalities. This was achieved by working closely with the local press and radio and through established channels of communication with other municipalities such as national, regional and local fora.

8. RESULTS AND IMPACTS

The three initial installations in schools have been completed successfully. The trial has enabled the Energy Management Team to determine various parameters of real usage of the systems, e.g. the level of energy generated by the solar water heating systems, how much water was used, how much will need to be charged for a rental scheme to be viable. The data gathered and successful completion of the trial mean that further installations are now going ahead during 2003.

Whilst the project is still ongoing, it has already produced significant benefits. Through the installation of solar water heating systems on council buildings, local contractors develop skills which can then be used in other sectors. Following the success of the initial phase, the methodology has been extended to the domestic sector where solar water heaters are installed on homes in conjunction with energy efficiency measures, helping to reduce fuel costs and alleviate fuel poverty.

The carbon savings resulting from this work are relatively small in the short-term. However, they are significant because, having broken down the main barrier of cost, the scheme opens up huge potential for further installations across the city and beyond.

9. REPLICATION

Replication of this project by other local governments would be straightforward because the technology used in this installation is not new and there are numerous experienced installation companies in most European countries. Many local governments will have experience of this type of funding mechanism because it has been widely used in the financing of energy efficiency improvements. For those without previous experience, it is straightforward and simple to implement once the initial capital investment is secured.

It should be noted that while the experience of the team certainly helped with this scheme, it is possible to replicate this without the staff numbers or experience because this can be bought in from other organizations.

SUSTAINABLE ENERGY REGULATION AND POLICYMAKING FOR AFRICA

Renewable Energy

Module 7:
RENEWABLE ENERGY TECHNOLOGIES

Module 7

SUSTAINABLE ENERGY REGULATION AND POLICYMAKING FOR AFRICA

Module overview

- Outline and brief description of renewable energy technologies
- General overview of technologies and applications
- Information on costs
- Common barriers and issues limiting wide spread use/dissemination

Module 7

SUSTAINABLE ENERGY REGULATION AND POLICYMAKING FOR AFRICA

Module aims

- Enable understanding of renewable energy in the broadest terms
- Present the different technology options, in a developing country context
- Provide an overview of the technologies and their applications
- Show the strengths and weaknesses
- Outline the expected costs
- Review the issues affecting effective deployment

Module 7

SUSTAINABLE ENERGY REGULATION AND POLICYMAKING FOR AFRICA

Module learning outcomes

- To be able to define the different key technologies
- To have a broad appreciation of potential applications
- To understand the strengths and weaknesses, hence to have a grasp of the benefits
- To understand the outline costs of different technologies
- To gain an appreciation of issues and barriers

Module 7

SUSTAINABLE ENERGY REGULATION AND POLICYMAKING FOR AFRICA

Wind Power Applications

Technology type	System	Application
Wind power - electrical	Grid connected	• Supplementing mains supply
Wind power - electrical	Stand-alone, battery charging	• Small home systems • Small commercial/community systems • Water pumping • Telecommunications • Navigation aids
Wind power - electrical	Stand-alone, autonomous diesel	• Commercial systems • Remote settlements • Mini-grid systems
Wind power - mechanical	Water pumping	• Drinking water supply • Irrigation pumping • Sea-salt production • Dewatering
Wind power - mechanical	Other	• Milling grain • Driving other, often agricultural, machines

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SUSTAINABLE ENERGY REGULATION AND POLICYMAKING FOR AFRICA

Wind systems: Strengths & Weaknesses

Strengths	Weaknesses
Technology is relatively simple and robust with lifetimes of over 15 years without major new investment	Site-specific technology (requires a suitable site)
Automatic operation with low maintenance requirements	Variable power produced therefore storage/back-up required.
No fuel required (no additional costs for fuel nor delivery logistics)	High capital / initial investment costs can impede development (especially in developing countries)
Environmental impact low compared with conventional energy sources	Potential market needs to be large enough to support expertise/equipment required for implementation
Mature, well developed, technology in developed countries	Cranage and transport access problems for installation of larger systems in remote areas
The technology can be adapted for complete or part manufacture (e.g. the tower) in developing countries	

Module 7

SUSTAINABLE ENERGY REGULATION AND POLICYMAKING FOR AFRICA

Solar Power Applications

Technology type	System	Application
PV (solar electric)	Grid connected	• Supplementing mains supply
PV (solar electric)	Stand-alone	• Small home systems for lighting, radio, TV, etc. • Small commercial/community systems, including health care, schools, etc. • Telecommunications and navigation aids • Water pumping • Commercial systems • Remote settlements • Mini-grid systems
Solar thermal	Connected to existing water and/or space heating system	• Supplementing supply of hot water and/or space heating provided by the electricity grid or gas network
Solar thermal	Stand-alone	• Water heating, i.e. for rural clinics • Drying (often grain or other agricultural products) • Cooking • Distillation • Cooling

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SUSTAINABLE ENERGY REGULATION AND POLICYMAKING FOR AFRICA

PV systems: Strengths & Weaknesses

Strengths	Weaknesses
Technology is mature. It has high reliability and long lifetimes (power output warranties from PV panels now commonly for 25 years)	Performance is dependent on sunshine levels and local weather conditions
Automatic operation with very low maintenance requirements	Storage/back-up usually required due to fluctuating nature of sunshine levels/no power production at night
No fuel required (no additional costs for fuel nor delivery logistics)	High capital/initial investment costs
Modular nature of PV allows for a complete range of system sizes as application dictates	Specific training and infrastructure needs
Environmental impact low compared with conventional energy sources	Energy intensity of silicon production for PV solar cells
The solar system is an easily visible sign of a high level of responsibility, environmental awareness and commitment	Provision for collection of batteries and facilities to recycle batteries are necessary
The user is less effected by rising prices for other energy sources	Use of toxic materials is some PV panels

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SUSTAINABLE ENERGY REGULATION AND POLICYMAKING FOR AFRICA

Bioenergy: Strengths & Weaknesses

Strengths	Weaknesses
Conversion technologies available in a wide range of power levels at different levels of technological complexity	Production can create land use competition
Fuel production and conversion technology indigenous in developing countries	Often large areas of land are required (usually low energy density)
Production can produce more jobs that other renewable energy systems of a comparable size	Production can have high fertiliser and water requirements
Conversion can be to gaseous, liquid or solid fuel	May require complex management system to ensure constant supply of resource, which is often bulky adding complexity to handling, transport and storage
Environmental impact low (overall no increase in carbon dioxide) compared with conventional energy sources	Resource production may be variable depending on local climatic/weather effects, i.e. drought.
	Likely to be uneven resource production throughout the year

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SUSTAINABLE ENERGY REGULATION AND POLICYMAKING FOR AFRICA

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SUSTAINABLE ENERGY REGULATION AND POLICYMAKING FOR AFRICA

Hydropower

- Hydropower is reliable and cost-effective
- Large hydropower schemes hundreds of MWs
- Small hydropower (SHP), rated at less than 10 MW
- Micro and pico hydro from 500 kW to 50W
- Lifetime of 30+ years
- Characteristics:
  - Reliable
  - flexible operation, fast start-up and shut-down

Module 7

SUSTAINABLE ENERGY REGULATION AND POLICYMAKING FOR AFRICA

Hydropower: Strengths & Weaknesses

Strengths	Weaknesses
Technology is relatively simple and robust with lifetimes of over 30 years without major new investment	Very site-specific technology (requires a suitable site relatively close to the location where the power is needed)
Overall costs can, in many case, undercut all other alternatives	For SHP systems using small streams the maximum power is limited and cannot expand if the need grows
Automatic operation with low maintenance requirements	Droughts and changes in local water and land use can affect power output
No fuel required (no additional costs for fuel nor delivery logistics)	Although power output is generally more predictable it may fall to very low levels or even zero during the dry season
Environmental impact low compared with conventional energy sources	High capital/initial investment costs
Power is available at a fairly constant rate and at all times, subject to water resource availability	Engineering skills required may be unavailable/expensive to obtain locally
The technology can be adapted for manufacture/use in developing countries	

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SUSTAINABLE ENERGY REGULATION AND POLICYMAKING FOR AFRICA

Geothermal

- Energy available as heat from the earth
- Usually hot water or steam
- High temperature resources (150°C+) for electricity generation
- Low temperature resources (50-150°C) for direct heating: district heating, industrial processing
- No problems of intermittency

Module 7

SUSTAINABLE ENERGY REGULATION AND POLICYMAKING FOR AFRICA

RE Applications: Summary

RE Technology	Energy Service/Application
Wind – grid-connected & stand-alone turbines, wind pumps	Supplementing mains supply. Power for low-to medium electric power needs. Occasionally mechanical power for agriculture purposes.
PV (solar electric) – grid--connected, stand-alone, pumps	Supplementing mains supply. Power for low electric power needs. Water pumping.
Solar thermal – grid-connected, water heater, cookers, dryers, cooling	Supplementing mains supply. Heating water. Cooking. Drying crops.
Bio energy	Supplementing mains supply. Cooking and lighting, motive power for small industry and electric needs. Transport fuel and mechanical power.
Micro and pico hydro	Low-to-medium electric power needs. Process motive power for small industry.
Geothermal	Grid electricity and large-scale heating.
Village-scale	Mini-grids usually hybrid systems (solar-wind, solar-diesel, wind-diesel, etc.). Small-scale residential and commercial electric power needs.

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SUSTAINABLE ENERGY REGULATION AND POLICYMAKING FOR AFRICA

Barriers and Issues

- Technical issues
  - Design and installation skills
  - Quality control and warranties
  - Maintenance and after-sales service
  - Training
  - Local technical infrastructure development
- Non-technical issues
  - Awareness
  - Policy/regulatory issues
  - Institution capacity-building for micro-finance
  - Community involvement
  - Women in development

Module 7

SUSTAINABLE ENERGY REGULATION AND POLICYMAKING FOR AFRICA

CONCLUSIONS

- Renewables can be used for both electricity and heat generation. There is a wide range of renewable energy technologies suitable for implementation in developing countries for a whole variety of different applications.
- Renewable energy can contribute to grid-connected generation but also has a large scope for off-grid applications and can be very suitable for remote and rural applications in developing countries.

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