Chapter 3

Sustainability Criteria for Selecting the Best Mix

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CHAPTER 3

Sustainability Criteria for Selecting the Best Mix

3.1. Energy Demand Criteria

Many rural areas in East Asia are faced with the problem of insufficient supply of electricity or energy not just for household use but for livelihood activities as well. This may be attributed to the problem of accessibility of the energy supply to the area due to its very far distance from its energy source. This is typical in remote areas such as those in the mountains or in remote islands.

Adequate energy supply must be available before undertaking the development of suitable structures for trade and industry. Energy supply must be based not only on imported fuel but also on locally available energy sources for security reason. In the Philippines, just like in other ASEAN countries, where RE is abundant, there is a need to tap local sources of energy by developing its own RE systems, or adopting technologies that suit its local conditions.

RE technologies contribute to the improvement of living conditions in areas where conventional energy supplies are a problem. For some isolated and very far areas that currently do not have access to electricity, RE sources are often the only economical way to overcome the energy supply problem. Unlike conventional energy, RE often plays a bigger role in a typical rural setting. However, despite efforts and support of government agencies concerned, the use of RE is still very limited and its significance is not being felt even in the rural areas where it has the economic advantage over the conventional fuel. This may be due to the undeveloped RE market. Moreover, the choice of potential energy resource and technology depends on the energy demand of the rural community. For this reason, the methodology for energy demand assessment is needed. The different components or procedures in demand assessment are presented in the succeeding sections.

3.1.1. Measuring the Demand for Energy

The different components or procedures in demand assessment include the following:

i) Existing Energy Supply

Existing energy supply refers to the available energy sources for electricity (from grid or generator) and non-electricity for other activities in the area, such as diesel and gasoline.

In some rural communities, the supply of electricity to households may be insufficient or none at all. Limited electricity supply from generators being run by private individuals may also be available for a fee to households in the community. Other energy sources are diesel and gasoline for engines used for farming, fishing, and others; and kerosene and candles for lighting that may be bought from the nearest municipality or community. Other energy resources available within the community include dry cell battery, wood, and other biomass residues.

To determine the current supply of electricity in an area, these data are needed: number of hours of electricity supply from main grid, and number of hours of electricity supply from diesel generators.

For non-electricity sources, data include: quantity of diesel, gasoline, LPG, kerosene, dry cell, candle, wood or wood charcoal.

Table 3.1 presents the summary matrix of the data needed to quantify the current supply of energy in the rural community. Table 3.1requires the enumeration of the different sources or suppliers of energy and the corresponding quantities for each activity. This will indicate the total available energy in the community.

Table 3.1: Energy Use by Type, Source, and Activity

ENERGY TYPE	NO. OF HOURS	TIME OF THE DAY	SOURCE
Electricity			
Grid			
Diesel Generator			
Non -Electricity	**PURPOSE/ ACTIVITY**	**QUANTITY/ WEEK**	**SOURCE**
Diesel			
Gasoline			
Kerosene			
LPG			
Wood			
Others			

Source: Authors.

ii) Energy Demand

The market size for RE can be measured by looking at the total energy demand in off-grid communities. This demand includes the current energy consumption plus the unsatisfied or potential energy needs in the rural community. Current energy demand, in turn, is expressed in terms of existing total energy consumption and/or expenditure in the community. This energy demand includes household energy consumption; energy for livelihood activities; and energy for street lighting and recreational activities in the community, health centres, and other public offices. Household energy demand may comprise electricity or energy for lighting, cooking, appliances, and transportation. Data on average energy consumption/expenditure per household, and the number of households per community, will be gathered and data extrapolated to get the total energy demand. Data on the current energy demand can also be summarised to show the energy usage by activity.

On the other hand, potential energy demand refers to the unsatisfied current and future energy needs for other activities in the community. This will be discussed in the succeeding section.

iii) Additional Energy Needs Based on Development Needs

This additional energy need or future energy demand refers to the potential applications of RE technologies in existing/potential livelihood activities in upland, lowland, coastal, and island rural communities. These livelihood activities may include the following:

- Ice-making projects for fish storage and cold drinks
- Fish processing
- Crop drying and seed production
- Telecommunications
- Video-cine
- Coconut oil processing
- Ecotourism
- Water pumping for drinking and/or irrigation
- Handicraft
- Sewing machine
- Milling
- Others

The review of database/profiling and market studies shall also identify the existing or typical livelihood activities in all types of rural communities. The different un-electrified communities shall be classified by type of community—coastal, upland, and others. The total energy required for livelihood or development activities needs to be determined.

iv) Energy Gaps/Needs

The current energy demand and the energy needs for future development activities will provide the total potential energy demand. Part of this energy demand can be supplied by the existing electricity or energy available in the area, which is already measured as the current energy supply. The difference between the total energy demand and the current energy supply is the energy gap in the area. This energy gap is needed energy to be supplied by other energy sources and can serve as the basis for determining the market opportunities for the RE project.

v) Capacity to Pay

Data on the capacity and willingness to pay for electricity service in communities without electricity is needed in assessing the market opportunities for energy. Households' capacity to pay is based on their current expenditure on energy consumption from candle, kerosene, battery and others for electricity or lighting. The overall households' ability to pay is measured in terms of their current monthly energy expenditures and from the net cash balance/savings of the households. Net cash balance is the amount the household has after paying all the expenses—in other words, the amount of savings of the households. This amount could be used to partly pay for electricity services once available.

On the other hand, data on the households' willingness to pay will come from their responses to market survey to be conducted. This will include the consumers' preferences and attitude on RE. Increasing the consumers' awareness on the merits of using RE may increase the market size for RE. The willingness to pay as determined by the results of surveys conducted is a true indication of the households' willingness to avail of the electricity service available in the area. A household may not be able to pay for the cost of electricity at the present time based on its current income/savings. However, the household may still avail of the electricity service in the future if the household income improves.

vi) Net Energy Demand

The households/community may have a total energy demand as determined by their current and future activities. However, their net cash balances may not be able to cover their increased energy needs. The capacity to pay of the households in the community will determine the amount of additional energy they can pay. The net energy demand will be the current energy usage plus the additional energy they need that they can still afford to pay. This can be computed on a daily or weekly basis.

3.1.2. Survey for energy demand assessment

i) Survey Levels

There are two levels to determine the demand for energy in rural communities.

1. Community Survey – This is to develop the community profiles and at the same time, identify the characteristics and potential demand at the community level.
2. Household Survey – This is to determine the socioeconomic characteristics, demand for electricity, ability and willingness to pay, attitude towards electricity, availability of energy sources, perceived benefits of electricity, etc. of the residential sector.

A questionnaire must be designed for this survey. A sample questionnaire is shown in the Appendix.

The questionnaire must contain questions that are sufficient to generate the following information:

1. Describe and assess the socioeconomic status of the household, including assets, income (from agriculture, non-agriculture, other sources), and expenditures.
2. Determine the monthly expenditures and quantity consumed for lighting, such as kerosene, LPG, dry cell batteries, car battery, electric generators, solar PV, candles, wood torch, and others.
3. Identify the electric appliances and type of non-electric lighting appliances owned by the household.
4. Determine the household's capacity and willingness to pay for electricity.
5. Determine the levels of awareness on RE, preferences and attitudes towards RE, electricity, and other lighting energy.
6. Existing and potential livelihood activities and corresponding energy needs.

ii) General Categories in the Survey Instruments

Basically, the community- and household-level questionnaires comprise different issues or general categories, including the socioeconomic data, energy utilisation, perceptions on REs, RE potential at sample sites, and others. The general categories contained in the questionnaire are discussed below.

iii) Socioeconomic Data

The questionnaire was designed to gather socioeconomic data, such as livelihood activities and associated income levels of the respondents, housing units and characteristics, household expenditures, asset/appliance purchasing history and plan, outstanding and past credit sources, and capacity to pay for electrical services. These socioeconomic data are captured at the household level.

This section aims to classify households according to income levels and determine their main sources of income. The rest of the information cited are supplementary details to be used in determining the household's actual capacity to pay.

On the other hand, the community-level survey consists of data that include population and age distribution, proportion of population by industry/economic activity, community services and recreational facilities available, current projects, existence of local organisations, and the development needs of the community.

The bulk of the socioeconomic data from the community survey is intended primarily for profiling purposes—to have a picture of the characteristics of each of the communities that are still without electricity.

iv) Energy Usage

This portion of the survey basically measures the level of energy utilisation at the household level, and the ultimate energy source of industries operating within the community. This data generated will be utilised in estimating the level of demand for specific fuel, and matched with the supply available—based on figures gathered from questions describing the number of suppliers and volume of sales at the community level.

The actual energy consumption would include the type/source of energy and uses and cost/expenditure on fuel per household per week. Data to be gathered include the number of households that own battery, the cost of using battery for transistor radio per household, the cost of purchasing kerosene, the cost of transport, and of charging the battery,

v) Energy Needs and Priority

The current energy required for lighting, for livelihood activities, and other livelihood activities that will make use of energy or light will determine the total energy demand in the future. This energy demand will also depend on the economic development in the area and the potential energy sources.

3.2. Resource Availability Criteria

At least half of the energy consumption in developing countries takes place in the rural areas, which is where the majority of the population lives. In the rural areas, energy is required to meet the basic needs of the rural populations, and to induce structural change and economic growth.

Thus, the availability of adequate and convenient energy is essential to address the priorities of rural development. The energy needs of households are mainly for cooking, lighting, and for the operation of household appliances and devices. The energy needs of rural industries are for lighting, process heat, and motive power requirements. Lighting requirements are invariably met by electricity from the grid and/or from diesel generators operated by businessmen, and by kerosene in communities without electricity. The principal supply sources for process heat in the rural industries are met by petroleum products like diesel, gasoline, LPG, kerosene (if available in the area), but mostly by using fuelwood and biomass. Motive power requirements are met by electricity, where available, and by human labour using mechanical equipment, where there is no electricity.

It is in this context that the role of RE systems using biomass, solar, wind, small-scale hydro resources, and low enthalpy geothermal energy assume importance in the rural community. They can provide a bridging role between traditional and conventional energy sources, including grid-based electricity. The selection of the RE sources and technologies that will complement the limited available electricity and non-electricity supply in the rural community is dictated by its social, economic, and environmental impact. However, RE sources and the corresponding technologies available have their own applications and limitations that may be used as criteria in the selection process. The applications and limitations of the RE sources, together with the technologies for each, are discussed below. These are used as guide in considering the type of resources and available technology to be selected for a given rural community.

3.2.1. Factors influencing the presence of RE in a given area

The volume and characteristics of RE resources are determined to a large extent by the climate, topography, and other natural features of a region.

i) Climate and Atmospheric Processes

The general circulation of the atmosphere and large-scale currents in the Pacific Ocean are the predominant climatic features that control the availability of wind, solar, biomass, and hydro resources in the EAS countries.

The subtropical regions are dominated by large, high-pressure systems. These high pressure systems are particularly strong during summer months over the eastern part of the ocean. The climate associated with these subtropical high pressure systems is generally of sunny skies and relatively light winds.

On the equator side of these high pressure systems are westward-flowing winds resulting in ideal wind resources over many subtropical regions, particularly in the

Philippines, Indonesia, and northern New Zealand.

Closer to the equator, the outflow from these high pressure systems converges, causing warm air and, consequently, frequent clouds and heavy rainfall. In these equatorial regions, solar resources are abundant and wind resources are typically low, but good in areas along the shorelines. Due to the presence of tropical rain forests in this region, biomass resources are most abundant because of its warm and moist climate.

On the mid-latitude side of the subtropical anticyclones, the warm outflowing air meets the colder air moving towards the equator from the arctic and subarctic regions, resulting in the highly variable climate. This region is characterised by frequent storms moving west to east, particularly during the months of December to February. Thus, wind, solar, biomass, and hydro resources can all be abundant during these seasons.

ii) Influence of Topography and Shape of Land Mass

In all cases, local topography and the proximity to large bodies of water will significantly influence the availability of wind, solar, biomass, and hydro resources.

Local winds can be quite strong where land–sea contrasts occur. The geology and topography also dictate optimal locations for geothermal resources.

Topographic features such as mountain ranges, ridge crests, and shorelines can significantly alter the regional characteristics of solar and wind resources, and the distribution of rainfall that affects hydro and biomass resources. However, major considerations on the availability of RE resources are the local features of the area that may influence the weather patterns.

3.2.2. Resource availability criteria

The energy resources that may be available in the rural communities are electricity from the grid (either from the main grid or mini-grid from other energy sources); fossil fuel such as diesel, gasoline, kerosene, or LPG for lighting or for livelihood activities such as in farming, fishing, metal works, and others; and RE resources such as solar energy, wind energy, hydro, biomass, and geothermal energy.

The most common source of energy for use in lighting, household appliances, and electric motors, is electricity from the grid. However, there are instances when electricity supply from conventional sources is limited, or when extending the electricity grid to the rural community is very costly due to the distance. Electricity may also be provided by diesel generators in the area but its ability to supply electricity is very limited and costly. This is where RE resources play a bridging role for conventional energy sources such as diesel, kerosene, LPG, and grid-based electricity. Hence, RE resources could provide the basic energy needs of the people in rural communities, especially in remote areas and islands.

A future rural energy development strategy emphasising decentralised energy options does not, however, imply that conventional energy options should be ruled out. It is more appropriate to view the role of RE resources as a complement to conventional energy supply systems wherever the coexistence of both proves advantageous for the rural people. The balance between the two is based on several factors to include the cost of energy or electricity relative to the income levels of the rural people and their willingness to pay.

The energy resources that may be available in the rural community are as follows:

1. Electricity from the main grid or mini-grid from diesel generators;
2. Fossil fuel, such as diesel, gasoline, kerosene, and LPG for lighting and fuel for household and livelihood activities; and
3. RE such as solar energy, wind energy, hydro, biomass, and geothermal energy.

The potential energy resources that may be available in the rural communities and the corresponding options for RE systems are the following:

A) **Solar energy—**is radiant light and heat from the sun harnessed through a range of ever-evolving technologies, such as solar heating, photovoltaic (PV) panels, solar thermal energy, solar architecture, and artificial photosynthesis.

   Solar power is an important source of RE and its technologies are broadly characterised as either passive solar or active solar depending on the way solar energy is captured, distributed, or converted into solar power. Active solar techniques include the use of PV systems, concentrated solar power, and solar water heating to harness the energy. Passive solar techniques include orienting a building to the sun, selecting materials with favourable thermal mass or light dispersing properties, and designing spaces that naturally circulate air.

Solar resources may generate

a. Solar energy for electrification from mini solar power plant, individual solar home system, or communal battery-charging stations; and
b. Solar energy for space and/or water heating, and solar driers.

B) **Wind energy—**is energy derived from wind; it is used to generate electricity or mechanical power.

Wind resources may power

a. wind turbines, and
b. windmills/pumps.

C) **Hydroelectric power—**is electricity generated by hydropower. Hydropower is harnessed through the gravitational force of falling or flowing water. The electricity is typically created when the water is passed over large mechanical turbines; the water pressure forces the turbines to turn, the mechanical energy created is then converted into electricity.

Hydro resources such as small dam, water from high creek or waterfalls, are for

a. mini/micro/pico hydro power plants, and
b. hand/foot pumps.

D) **Biomass—**is the energy contained inside plants and animals. This can include organic matter of all kinds—plants, animals, or waste products from organic sources. This sort of energy source is known as biomass fuel and typically includes wood chips, rotted trees, manure, sewage, mulch, and tree components. The chlorophyll present in plants absorbs carbon dioxide from the atmosphere and water from the ground through the process of photosynthesis. The same energy is passed on to animals when they eat these plants. Biomass is considered to be a renewable source of energy because the carbon dioxide and water contained inside plants and animals are released back to the atmosphere when they are burned and more plants and crops can be grown to create biomass energy.

Biomass resources, such as agricultural wastes, wood wastes, animal manure, tree plantation, and food wastes are used for

a. Biomass power plants
b. Thermal plants/systems
    i. Gasifiers
    ii. Combustors/furnaces/stoves/boilers
    iii. Biogas
c. Biofuels for transportation and engine.

E) **Geothermal energy—**is the energy obtained from the earth (geo), from the hot rocks present inside the earth**.** It is produced due to the fission of radioactive materials in the earth's core, and some places inside the earth become very hot. These are called hot spots. They cause water deep inside the earth to form steam. As more steam is formed, it gets compressed at high pressure and comes out in the form of hot springs, which produces geothermal power. Small geothermal resource for heat is called low enthalpy geothermal well.

There are indicators that energy developers in the rural community may use to determine the kind of RE resource(s) that may be available in the area. These indicators are (i) presence of waterfalls/creeks for hydro power plants, (ii) long periods of strong wind in the area (at least 5 m/s average wind speed), (iii) abundance of agricultural crops or presence of milling facilities, (iv) presence of extreme solar radiation in the area, and (v) presence of geothermal wells or hot springs in the area.

Since the role of RE is to complement the electricity and conventional energy available in the area, the first priority will be to make use of such available electricity or conventional energy. In cases where additional energy is needed to meet the energy gap in the community, RE may be utilised.

Although the choice of RE is dictated by economic, social, and environmental sustainability considerations, other criteria may also be used in selecting energy resources for rural communities. Aside from those indicators mentioned above, the following could be used as additional indicators or criteria in prioritising the utilisation of available energy resources in the rural community. These are capacity, reliability, applicability, and ease of operation of the system.

Each RE resource has its own advantages and disadvantages or strengths and weaknesses. These strengths and weaknesses can be used as a gauge in selecting the RE resource that is appropriate for a particular rural community.

i) Capacity

Amongst all RE sources, biomass resource is the most abundant since it comes from plants being grown for food, feeds or for other purposes. These by-products will never run out, as long as there are living matters. Its level of conversion efficiency is low but the large volume of biomass can still produce large amount of energy.

Another RE source that can be depended on in terms of capacity is hydropower. It has high efficiency of conversion compared to other RE sources. As for solar energy, it can provide a small amount of energy. Although energy from the sun is abundant, solar panel efficiency level is low compared to the efficiency levels of other RE systems.

Each resource requires a specific data to estimate the available capacity that can be derived from it. This information can be gathered from available secondary data, such as metrological data from the nearest weather station for solar and wind resources, hydrologic data for hydro, crop production data or data from the mill, and record of hot spring in the area. For some resources, more accurate measurement is required for better estimation of capacity. Below are the data needed for each RE source.

- Solar radiation data
  a. Hourly solar radiation in $W/m^2/day$
  b. Monthly solar radiation at sample sites
  c. Clearness index (*k*) per month at a given site
- Wind data
  a. Hourly wind speed in m/s

b. Monthly wind speed plus the following parameters
    - Weibull distribution parameter *k* value
    - Auto-correlation factor
    - Diurnal pattern strength
    - Hour of peak wind speed

- Hydrological data
  a. Maximum dependable head
  b. Volume during high flow
  c. Volume during low flow
  d. Duration period of low flow in months
  e. Duration period of high flow in months
- Biomass data
  a. Type of biomass fuel
  b. Quantity of each biomass
  c. Source of biomass
  d. Distance of the source of biomass fuel to the proposed plant
  e. Cost of biomass fuel
- Miscellaneous data

  Other data needed at the sample sites include the following:
  a. Latitude and longitude
  b. Load characteristics of residents

ii) Reliability

Biomass energy can always be relied on provided there is sufficient biomass material for energy conversion. Hydro power has a high level of reliability. Although the volume of water varies, water is always available as long as the watershed is well maintained. Solar energy can be made available almost anywhere where there is sunlight. However, solar energy is only available during daytime and there may be clouds that could lessen solar radiation or make solar energy unavailable during rainy weather. Consequently, intermittency and unpredictability of solar energy make solar energy panels less reliable. The limitation of wind power is that no electricity is produced when the wind is not blowing. Wind availability is occasional and varying. Thus, it cannot be used as a dependable source of base load power. This means that wind turbines do not produce the same amount of electricity all the time. There will be times when they produce no electricity at all. As for geothermal energy, it is not dependent on weather.

iii) Applicability

Because solar energy coincides with energy needs for cooling, PV panels can provide an effective solution to energy demand peaks—especially in hot summer months when energy demand is high. As for biomass, it can be used to produce different energy products such as heat, electricity, clean gas, and biofuels. There are only a few sites with potential for geothermal energy. Most of the sites where geothermal energy is produced are far from markets or cities, where this energy is most needed.

iv) Ease of operation and maintenance

PV panels have no mechanically moving parts, except in cases of sun-tracking mechanical bases; consequently, they have far less breakages or require lesser maintenance than other RE systems (e.g. wind turbines). Biomass, wind, and hydro energy conversion systems are complicated and more difficult to operate and maintain. Special training is needed not just in the operation but also in maintaining the unit and in replacing damaged parts. Of the three RE sources, the biomass and the wind energy are the more complicated systems.

3.3. Technology Availability Criteria

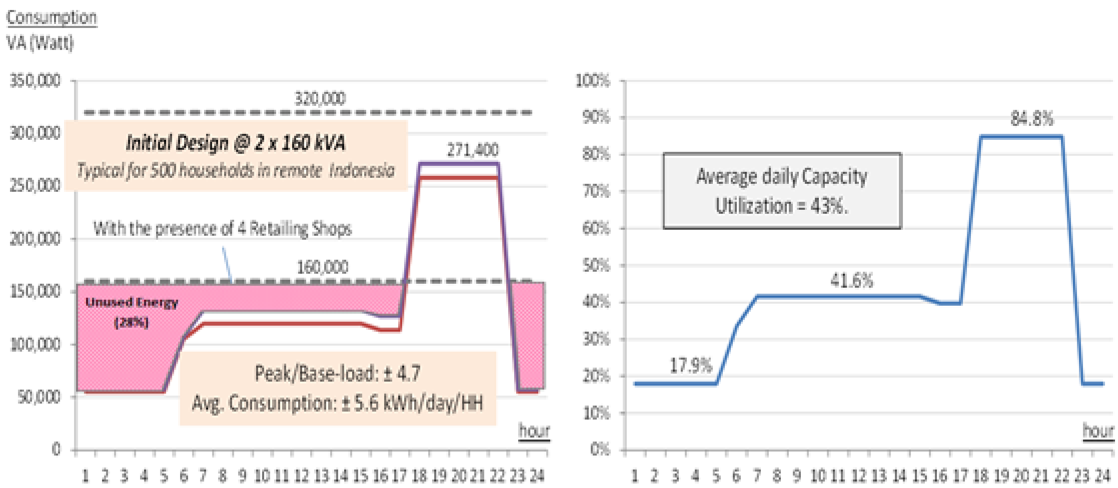
Power-generation capacity-growth is essential to support economic growth and to accelerate the improvement of the Human Development Index (HDI). Introducing electric power in rural areas will provide access to basic energy services and enable the provision of quality human needs, as well as and the promotion of economic activities, e.g. processing of agricultural and marine products. This processing business will create new job opportunities and economic value-added in remote areas.

RE potentials (geothermal, hydro, biomass, wind, and solar) are still largely unutilised for electricity generation in remote areas. Only a small percentage of these potentials have been utilised. The remaining untapped RE opportunities have been left out mainly because the appropriate technology for utilising these resources has been largely unavailable and economically unfeasible. Investigating the demand profile of electricity in remote areas, the best technology that matches this demand, and the resources of locally available RE is very important. On available technology, a variety of methods are used to convert these renewable resources into electricity. Each energy resource comes with its own unique set of technologies, benefits, and challenges. RE utilisation has a great potential to electrify remote areas using cost-competitive and suitable technologies while at the same time abating greenhouse gas (GHG) emissions.

Populations without access to electricity are mostly those who live in remote and sparsely populated areas. They earn their living using basic facilities and are not sufficiently supported by modern economic activities. Source: Indonesia Climate Change Center (2014).

Figure 3.1 shows a simulated electricity demand profile for a remote area with 500 households. It reflects the potential electricity demand with the presence of four retailing shops, a school building, a clinic, a village administration office, an internet-telecommunication services facility, and others.

Figure 3.1: Electricity Demand Profile of a 500-Household Village in Remote Areas (left) and Capacity Utilisation of 2 x 160 kVA Installed Capacity (right)



Source: Indonesia Climate Change Center (2014).

The electricity demand profile shows a high peak-to-base load ratio at about 4.7 times. The simulated consumption is 5.6 kWh/household/day. This number is higher than the average electricity consumption reported by PT. PLN (a state-owned electricity company of Indonesia), which was at 4.3 kWh/household/day in 2012.[1] This number indicates that a significant part of the electrified households still have lower consumption than what was estimated, most notably due to limited service hours. The simulation was derived from electricity demand of households (85 percent), commercial (10 percent), and community services (5 percent). With overall average electricity consumption at 5.6 kilowatt-hour (kWh)/day/household and peak-to-base-load ratio of around 5, the capacity utilisation of 2 x 160 kilovolt-ampere (kVA) power plant is only 43 percent for the 500 households (ICCC, 2014).

3.3.1. Available technology

Based on the demand profile, not all available RE technologies are appropriate to fulfil the energy demand in remote and sparsely populated areas. The electricity demand profile in Figure 3-1 will forego excess electricity generation during the day and will carry higher operating costs unless industrial demand can be grown. On the other hand, wind-, hydro-, and geothermal-powered grid electricity will have greater loss than fast-transient-time generators, such as gas- or diesel-powered ones. Electricity demand profile in remote areas is characterised by small capacity with high peak-to-base load ratio. This condition suits some technology.

The following screening criteria were used to select the most appropriate technology option:

1. Fast transient time to reach optimum capacity/output.
2. Capability to be installed and to be operated on a modular basis.
3. Application of locally available resources.

Based on these criteria, wind, hydro, and geothermal still have the best chance to fulfil the energy demand in remote and sparsely populated areas by combining with other available resources in the area. By considering existing technologies, the solar and biomass energies have higher potential to fulfil the electricity demand in remote and sparsely populated areas. Solar energy can be used to directly generate heat, lighting, and electricity.

[1] PLN Statistic 2012 reported the number of electricity customer for residential application in 2012 was 46,219,780 with a total connected power of 40,869.15 megavolt-ampere (MVA) (average 884 VA) and a total electricity consumption of 72,132.54 gigawatt-hour (GWh) (average 4.28 kWh/day).

Biomass can be used to generate electricity by way of thermochemical and biochemical conversion. Thermochemical technologies use direct combustion and gasification technologies, while biochemical technologies use anaerobic digestion to produce biogas. In addition, biomass can also be converted to liquid fuels (biodiesel or bioethanol).

i) Solar Energy Technology

Passive Solar Design for Buildings

One simple, obvious use of the sun is to light and heat residential and commercial buildings. If properly designed, buildings can capture the sun's heat in the winter and minimise it in the summer, while using daylight year-round. Buildings designed in such a way utilise passive solar energy; or a resource that can be tapped without mechanical means to help heat, cool, or light a building. The capacity of energy collected depends on the intensity of sunlight in the area.

Solar Heat Collectors

To maximise their use of the sun, some buildings have systems that actively gather and store solar energy. Solar collectors, for example, sit on building rooftops to collect solar energy for space heating, water heating, and space cooling. Most are large, flat boxes painted black on the inside and covered with glass. In the most common design, pipes in the box carry liquids that transfer the heat from the box into the building. This heated liquid, usually a water–alcohol mixture to prevent freezing, is used to heat water in a tank or is passed through radiators that heat the air.

Solar Thermal Concentrating Systems

By using mirrors and lenses to concentrate the rays of the sun, solar thermal systems can produce very high temperatures, as high as 3,000 degrees Celsius. Solar concentrators come in three main designs: parabolic troughs, parabolic dishes, and central receivers. The intense heat that they produce can be used in industrial applications or to produce steam that drives an electric turbine. One of the greatest benefits of large-scale solar thermal systems is the possibility of storing the sun's heat energy for later use, which allows the production of electricity even when the sun is no longer shining. Properly sized storage systems, commonly consisting of molten salts, can transform a solar plant into a supplier of continuous base load electricity. Solar thermal systems now in development will be able to compete in output and reliability with large coal and nuclear plants.

Photovoltaic System

The most important components of a PV cell are two layers of semiconductor material generally composed of silicon crystals. On its own, a crystallised silicon is not a very good conductor of electricity, but when impurities are intentionally added, a process called doping, the stage is set for creating an electric current. The bottom layer of the PV cell is usually doped with boron, which bonds with the silicon to facilitate a positive charge (P). The top layer is doped with phosphorus, which bonds with the silicon to facilitate a negative charge (N).

The surface between the resulting 'p-type' and 'n-type' semiconductors is called the P-N junction. Electron movement at this surface produces an electric field that only allows electrons to flow from the p-type layer to the n-type layer.

When sunlight enters the cell, its energy knocks electrons loose in both layers. Because of the opposite charges of the layers, the electrons want to flow from the n-type layer to the p-type layer, but the electric field at the P-N junction prevents this from happening. The presence of an external circuit, however, provides the necessary path for electrons in the n-type layer to travel to the p-type layer. Extremely thin wires running along the top of the n-type layer provide this external circuit, and the electrons flowing through this circuit provide the cell's owner with a supply of electricity.

Most PV systems consist of individual square cells averaging about four inches on a side. Alone, each cell generates very little power (less than two watts), so they are often grouped together as modules. Modules can then be grouped into larger panels encased in glass or plastic to provide protection from the weather. These panels, in turn, are either used as separate units or grouped into even larger arrays. The three basic types of solar cells made from silicon are single-crystal, polycrystalline, and amorphous silicon (a-Si)**.**

a) **Single-crystal cells** are made in long cylinders and sliced into round or hexagonal wafers. While this process is energy-intensive and wasteful of materials, it produces the highest-efficiency cells as high as 25 percent in some laboratory tests. Because these high-efficiency cells are more expensive, they are sometimes used in combination with concentrators such as mirrors or lenses. Concentrating systems can boost efficiency to almost 30 percent. Single-crystal cells account for 29 percent of the global market for PV panels (US DOE, 2006).

b) **Polycrystalline cells** are made of molten silicon cast into ingots or drawn into sheets, then sliced into squares. While production costs are lower, the efficiency of the cells is also lower—around 15 percent. Since the cells are square, they can be packed more closely together. Polycrystalline cells make up 62 percent of the global PV market (US DOE, 2006).

c) **Amorphous silicon (a-Si)** is a radically different approach. Silicon is essentially sprayed onto a glass or metal surface in thin films, making the whole module in one step. This approach is by far the least expensive, but it results in very low efficiencies—only about 5 percent (US DOE, 2006).

A number of exotic materials other than silicon are being developed, such as gallium arsenide (Ga-As), copper-indium-diselenide (CuInSe2), and cadmium-telluride (CdTe). These materials offer higher efficiencies and other interesting properties, including the ability to manufacture amorphous cells that are sensitive to different parts of the light spectrum. By stacking cells into multiple layers, they can capture more of the available light. Although a-Si accounts for only 5 percent of the global market, it appears to be the most promising in terms of growth potential and for future energy cost reductions. In the 1970s, a serious effort began to produce PV panels that could provide cheaper solar power. Experimenting with new materials and production techniques, solar manufacturers cut costs for solar cells rapidly. One approach to lowering the cost of solar electric power is to increase the efficiency of cells, producing more power per dollar. The opposite approach is to decrease production costs, using fewer dollars to produce the same amount of power. A third approach is lowering the costs of the rest of the system. For example, building-integrated PV (BIPV) integrates solar panels into a building's structure and earns the developer a credit for reduced construction costs.

ii) Biomass Energy Technology

Direct Combustion

Direct combustion converts biomass energy by burning biomass materials, mostly in the form of wood. Biomass is externally burned in a boiler specialised for biomass, providing high pressure and high temperature vapour for steam turbine unit to generate electricity. Almost all commercial crop-to-electricity systems are combustion with stokers or fluidised bed. The important features of this technology are biomass pre-treatment, boiler's adaptability to multiple biomass resources, and efficiencies of boiler and steam turbine. The overall conversion efficiency of a combustion system is in the range of 15 percent–35percent for power only, and 60percent–70percent for combined heat and power (CHP) system. Power capacity using this technology is usually in the high range, and may go to as big as 110 megawatts (MW).Smaller systems (1–15 MW) still have poor economics. Generating biomass electricity using direct combustion needs long start-up (transient) time. Therefore, it is not suitable for small capacity (below 1 MW) or modular operation.

Gasification

Biomass gasification converts wood and solid biomass residues into a combustible gas mixture. The gasification system consists of a gasifier unit, purification system and energy converters (burner or engine). The gasifier is essentially a chemical reactor that burns fuel (wood chips, charcoal, and coal) in a process of incomplete combustion owing to controlled air supply.

Products of gasification process include generator gas, solid ashes, soot (which should be removed periodically from the gasifier), and water vapour (which is to be dried from the gas). The main flammable components of a generator gas are carbon monoxide (CO), hydrogen (H_2), and methane (CH_4). After cleaning, the gas can be used to fuel an internal combustion engine for electricity generation. Without cleaning, the gas can be used for external combustion boiler.

Biomass gasification is more efficient than direct combustion. A conversion efficiency of 30 percent–40 percent is achievable using rebuilt diesel or natural gas engine. Biomass gasification is also potentially better suited to smaller scales. However, until recently, the status of biomass electricity through gasification is still pre-commercial or at early demonstration stage. Another important thing to consider is that a generator gas needs to be cleaned prior to use in internal combustion engine. The cleaning process is still expensive.

Crop-to-Liquid Fuels Conversion

Other conversion of biomass involves biofuel production (biodiesel and bioethanol). Biofuel can be injected into the generators' engine, replacing fossil fuel (biodiesel for diesel fuel and bioethanol for gasoline). This liquid fuel path, however, has a longer path of conversion and needs electricity in advance. Therefore, these fuels are more difficult to develop locally in remote areas.

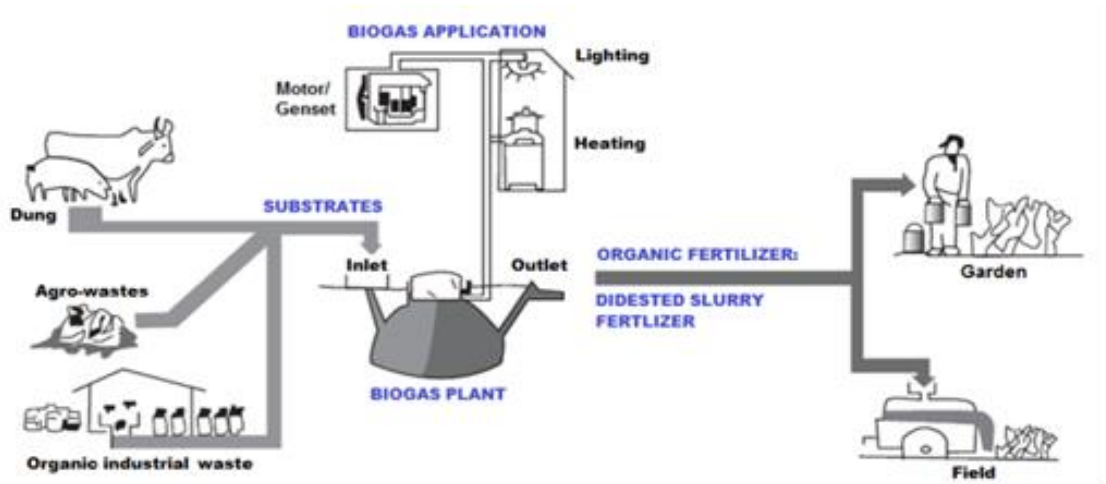
Crop-to-Biogas Conversion

Biogas obtained through anaerobic fermentation of organic matters (liquid or solid) can be utilised as fuel for internal combustion engine, gas turbine, or boiler. Biogas has an important impact because it can replace fossil fuels for heat and power generation or as fuel in the transportation sector after purification treatment. Controlled anaerobic digestion of organic matter can be harnessed to generate biogas. Biogas can be used in specially designed internal combustion engines to generate electricity or in combination with heat and power (CHP). The key features of this technology include high-efficiency anaerobic fermentation and gas engine technology. Biogas power (electricity) plants can be an important factor in RE.

Numerous technical solutions for biogas conversion are offered by the industry. Principally, there are six steps in energy crop digestion processes. These are (i) crop harvesting or waste collection, (ii) pre-processing (pre-treatment) of substrate, (iii) storage of substrates, (iv) feeding control (dosage) and fermentation (digestion), (v) treatment of biogas, and (vi) treatment of digestate. Biogas electricity is widely available—from small capacity (<500 kW) to high capacity (large MW size).

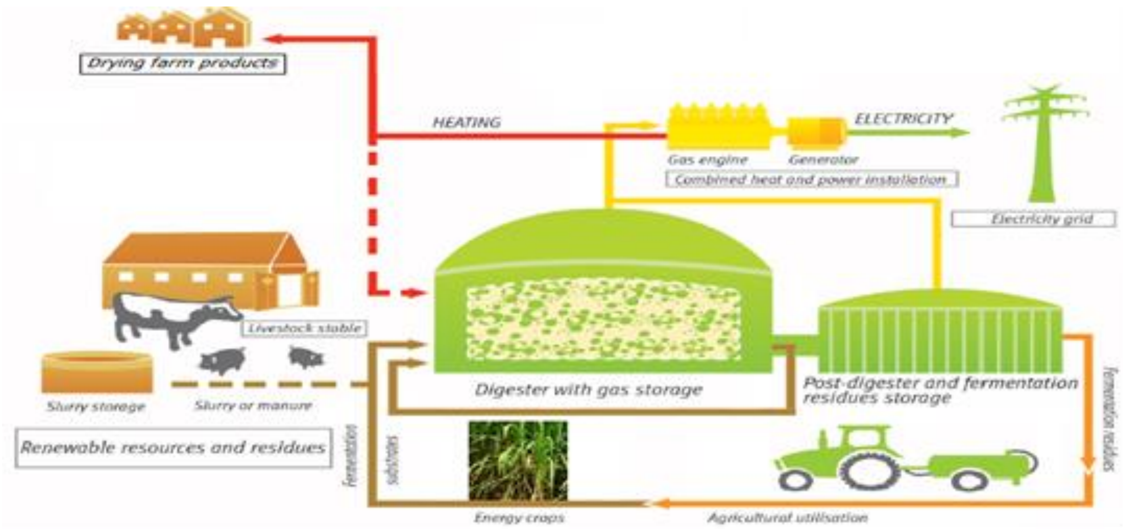
Based on the moisture content or total solid content of a feedstock that is being processed, anaerobic digestion can be classified into two types—wet fermentation (traditional or conventional) (Figure 3.2) and dry fermentation or solid state fermentation (Figure 3.3).

Figure 3.2: Typical Configuration for Biogas System Using Wet Fermentation Technology



Source: Werner et al. (1989).

Figure 3.3: Typical Configuration for Biogas System Using Dry Fermentation Technology



Source: Modified from FachagenturNachwachsendeRohstoffe (FNR), 2013.

Wet fermentation uses input material that has a moisture content of greater than 75 percent, whereas dry fermentation uses input material that has a moisture content of less than 75 percent. Dry fermentation enables quick and easy methanisation of stackable biomass, both from agriculture products and from municipal biological waste, without complex processing. The materials for fermentation must not be converted to a pumpable, liquid substrate, which means that the fermentation of biomasses can be achieved with up to a 50 percent dry material mixture. On the other hand, a wet fermentation system requires the addition of liquid for the movement of organic material.

Biogas technology has primarily been focused on wet fermentation of liquid manure in agricultural or wastewater sectors. The drawback of such a system is that the raw material can only be mixed to a limited extent with additional dry substance contents, such as maize, grass, or straw. For small-capacity applications, wet fermentation is expensive.

Dry fermentation technology is capable of using numerous biomass streams as input. Dry anaerobic digestion is chosen over wet anaerobic digestion because the digestate can be easily composted for use as fertilizer or soil conditioner. Over the past 5 years (Baere and Mattheeuws, 2012), constructions of solid-state anaerobic digesters significantly grew and accounted for about 70 percent of new installations in Europe.

Dry fermentation is especially important for small-scale installations (Bartacek, 2012) and for feedstock that is difficult to handle. Dry fermentation offers some advantages compared to wet fermentation (Chen, 2013), as follows:

- *Simpler and smaller reaction volume*. Dry fermentation works through a batch process in which feedstock is loaded into individual fermenters (digesters) of the biogas plant on a 28-40-day cycle. The digesters are mostly made of gas-tight concrete and can be loaded and unloaded with a wheel loader or a front-end loader. The digesters can be elongated and garage shaped, with a large gate at one end. After the biomass has been introduced, the gates are shut gas-tight. No stirring of the organic matter is necessary during the dry fermentation process, as it is in conventional wet fermentation systems.

- *Efficient use of water.* Dry fermentation works on organic waste inputs that typically have a moisture content of less than 75 percent or high solid content (typically 15 percent–40 percent) and, in contrast to traditional wet fermentation systems, does not use the addition of liquid to create a fluid mixture that can be pumped through the system.
- *Efficient energy requirement*. In wet fermentation, the solid content is low and the energy is mainly used to maintain reaction temperature. The parasitic energy required by dry fermentation technology was reported to be within 3 percent–5 percent of the generated electricity.
- *Low investment cost*. Working on batch mode with no agitation makes dry fermentation a simple system with minimum cost, minimum maintenance, and low energy losses.
- *Low operation and processing cost.* The absence of moving parts like rotating shaft or impeller in the dry fermentation greatly reduces the operating and maintenance cost. The process finishes with almost no slurry that reduces the cost of digestate treatment.
- *Possibility of modular expansion*. This characteristic is important in relation to a low electricity load with high peak-base ratio and short start up time.

However, there could be some disadvantages for dry digestion systems if suitable conditions for anaerobic microbial habitat are not properly monitored and maintained. The improper habitat for microbial growth of dry digestion system will yield lower volume of methane compared to wet digestion systems. In addition, there are some technical issues, such as the following: (Pytlar, 2013)

- Special technologies are required for loading and unloading.
- Cargo not evenly mixed.
- The intermittent (modular) system requires repeated microbial process for each batch.
- In many cases, the system needs large quantities of structure material.

iii) Other Potential Energy Technologies

Other potential technologies for fulfilling energy demand in remote areas are wind, hydro, and low enthalphy geothermal energy. These kind of energies are dependent on the availability of sources. Therefore, it is better to mix them with solar and/or biomass energy if their sources are not enough to fulfil the energy demand in the remote area.

Wind Energy Technology

In practice, many electric utilities are already demonstrating that wind can make a significant contribution to their electric supply without reliability problems. Dealing with the variability of wind on a large scale is by no means insurmountable for electric utilities. Grid operators must already adjust to constant changes in electricity demand, turning power plants on and off, and varying their output second-by-second as power use rises and falls. Operators always need to keep power plants in reserve to meet unexpected surges or drops in demand, as well as power plant and transmission line outages. As a result, operators do not need to respond to changes in wind output at each wind facility. In addition, the wind is always blowing somewhere, so distributing wind turbines across a broad geographic area helps smooth out the variability of the resource. The challenge of integrating wind energy into the electric grid can increase costs, but not that much. However, because wind has low variable costs, it can reduce overall system operating costs by displacing the output of units with higher operating costs (e.g. gas turbines). Increasing utilisation of wind power can actually contribute to a more reliable electric system. Today's modern wind turbines have sophisticated electronic controls that allow continual adjustment of their output, and can help grid operators stabilise the grid in response to unexpected operating conditions, like a power line or power plant outage. This gives grid operators greater flexibility to respond to such events. Promising developments in storage technology could also improve the reliability of wind energy in the future, although there is plenty of room to greatly expand wind use without storage for at least the next couple of decades.[2]

Hydro Energy Technology

To generate electricity from the kinetic energy in moving water, the water has to move with sufficient speed and volume to spin a propeller-like device called a turbine,

[2]Union of Concerned Scientist. *Renewable Energy Technologies.*http://www.ucsusa.org/clean_energy/our-energy-choices/renewable-energy/how-wind-energy-works.html?_ga=1.100643166.1118731882.1401506087#.VWkKw0YYOP4

which in turn rotates a generator to generate electricity. Roughly speaking, one gallon of water per second falling from 100 feet can generate one kilowatt of electricity. To increase the volume of moving water, impoundments or dams are used to collect the water. An opening in the dam uses gravity to drop water down a pipe called a penstock. The moving water causes the turbine to spin, which causes magnets inside a generator to rotate and create electricity. Hydropower can also be generated without a dam, through a process known as run-of-the-river. In this case, the volume and speed of water is not augmented by a dam. Instead, a run-of-river project spins the turbine blades by capturing the kinetic energy of the moving water in the river. Hydropower projects that have dams can control when electricity is generated because the dams can control the timing and flow of the water reaching the turbines. Therefore, these projects can choose to generate power when it is most needed and most valuable to the grid. Because run-of-river projects do not store water behind dams, they have much less ability to control the amount and timing when electricity is generated.[3]

Another type of hydropower technology is called pumped storage. In a pumped storage plant, water is pumped from a lower reservoir to a higher reservoir during off-peak times when electricity is relatively cheap, using electricity generated from other types of energy sources. Pumping the water uphill creates the potential to generate hydropower later on. When the hydropower power is needed, it is released back into the lower reservoir through turbines. Inevitably, some power is lost, but pumped storage systems can be up to 80 percent efficient. The need to create storage resources to capture and store for later use the energy that was generated from high penetrations of variable RE (e.g. wind and solar) could increase interest in building new pumped storage projects (Ela et al., 2013).

Geothermal Energy Technology

Heat from the earth can be used as an energy source in many ways—from large and complex power stations to small and relatively simple pumping systems. This heat energy, known as geothermal energy, can be found almost anywhere.

Currently, the most common way of capturing the energy from geothermal sources is

[3]Union of Concerned Scientist,*Renewable Energy Technologies*. http://www.ucsusa.org/clean_energy/our-energy-choices/renewable-energy/how-hydroelectric-energy.html?_ga=1.3595760.1118731882.1401506087#.VWkX30YYOP4

to tap into naturally occurring 'hydrothermal convection' systems, where cooler water that seeps into the earth's crust is heated up and then rises to the surface. Once this heated water is forced to the surface, it is a relatively simple matter to capture that steam and use it to drive electric generators. Geothermal power plants drill their own holes into the rock to more effectively capture the steam.

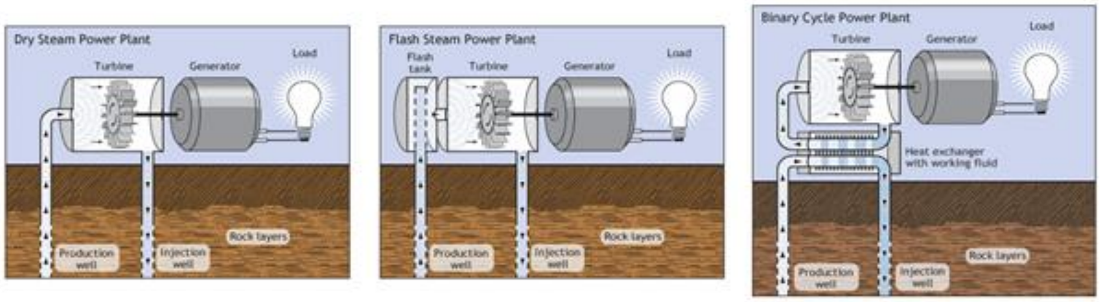
There are three basic designs for geothermal power plants, all of which pull hot water and steam from the ground, use it, and then return it as warm water to prolong the life of the heat source. In the simplest design, known as dry steam, the steam goes directly through the turbine, then into a condenser where the steam is condensed into water. In the second approach, very hot water is depressurised or 'flashed' into steam, which can then be used to drive the turbine. In the third approach, called a binary cycle system, the hot water is passed through a heat exchanger, where it heats a second liquid, such as isobutene, in a closed loop. Isobutane boils at a lower temperature than water, so it is more easily converted into steam to run the turbine.[4] These three systems are shown in Figure 3.4.

The choice as to which design to use is determined by the resource. If the water comes out of the well as steam, it can be used directly, as in the first design. If it is hot water of a high enough temperature, a flash system can be used; otherwise it must go through a heat exchanger. Since there are more hot water resources than pure steam or high-temperature water sources, there is more growth potential in the binary cycle, heat exchanger design.

[4] Union of Concerned Scientist, *Renewable Energy Technologies.*http://www.ucsusa.org/clean_energy/our-energy-choices/renewable-energy/how-geothermal-energy-works.html?_ga=1.45989348.1118731882.1401506087#.VWkcHEYYOP4

Figure 3.4: Three Basic Designs for Geothermal Power Plants:

Dry Steam, Flash Steam, and Binary Cycle



Source of image: US Department of Energy, Office of Energy Efficiency & Renewable Energy. http://energy.gov/eere/geothermal/electricity-generation

3.3.2. Selection of available technology

The option to utilise appropriate RE technology in a remote area is dependent on what the energy will be used for. The utilisation for heat is simpler, compared to the utilisation for electricity. RE for heat generation has been implemented in remote areas a long time ago, both in small scale (household level) and bigger scale. Biomass, solar, and low enthalpy geothermal energies were used to produce heat in remote areas. For a more efficient and sustained RE use, a screening process to select the most appropriate technology is important. Table 3.2 provides a comparison of RE technologies that may be selected as the most suitable type for heat generation in a remote area. The table shows that solar, biomass direct combustion, and biogas energy technologies are good candidates. Solar technology has weakness in terms of cost due to the still expensive solar panels. Biomass direct combustion also shows it still has an environmental problem due to some particulate emissions, such as COx and NOx that are emitted from biomass combustion especially at small or household scale. The biogas energy satisfies all criteria and seems to be the best option for heat generation in remote areas.

Table 3.2: RE–Heat Generation Technology Comparison

Requirement/ Criteria	Technology option							
	Solar	Biomass				Wind	Hydro	Low enthalpy Geothermal
		Direct Combustion	Gasification	Liquid Fuel	Biogas Fuel			
Low capacity	√	√	X	√	√	√	√	√
Fast start-up/ transient time to produce heat	√	√	X	√	√	√	√	√
Operate in modular system	√	√	√	√	√	√	X	X
Simple pre-treatment to produce heat	√	√	X	X	√	X	X	X
Simple on maintenance	√	√	X	X	√	X	X	X
Impact to environment	√	X	√	√	√	√	√	√
Low cost heat production	X	√	X	X	√	X	X	X

Source: Authors.

Table 3.3 provides a comparison of RE technologies as guide in selecting the most suitable type for a remote area demand profile. The table shows that biogas and wind energy technologies satisfy all criteria and seem to be the best options for power (electricity) generation in remote and sparsely populated areas. If electricity production cost for solar energy can be reduced, solar energy technology also has a high potential for electricity generation in remote and sparsely populated areas.

Table 3.3: RE–Electricity Generation Technology Comparison

Requirement/ Criteria	Technology option							
	Solar	Biomass				Wind	Hydro	Geothermal
		Direct Combustion	Gasification	Liquid Fuel	Biogas Fuel			
Low capacity (< 500 kVA)	√	X	√	√	√	√	√	X
Fast start-up/ transient time	√	X	X	√	√	√	√	√
Operate in modular system	√	X	√	√	√	√	X	X
Simple pre-treatment to produce fuel	√	√	X	X	√	√	√	√
Simple on maintenance	√	√	X	X	√	√	√	X
Impact to environment	√	X	√	√	√	√	√	√
Low electricity production cost	X	√	X	X	√	√	√	X

Source: Authors.

3.3.3. Summary

Considering the heat and electricity demand profile, not all available RE technologies are appropriate for meeting the energy demand in remote and sparsely populated areas. The biogas, solar, and biomass direct combustion technologies have high potential to provide heat in remote areas, although only the biogas technology satisfies all criteria. Solar heat technology has good potential, but it needs more effort to reduce heat production cost. Improvement in technology is also needed to reduce the environmental impact of direct biomass combustion for heat generation.

Electricity demand profile in remote areas is characterised by small capacity with high peak-to-base load ratio. This condition suits some technologies. The following screening criteria were used to select the most appropriate technology option:

1. Low capacity (< 500 kVA)
2. Fast transient time to reach optimum capacity/output
3. Capability to be installed and to operate on a modular basis
4. Simple pre-treatment and maintenance to produce electricity
5. Better environmental impact

6. Low electricity production cost

Considering the existing technologies, the biogas and wind (if the sources are available) energy technologies satisfy all criteria and seem to be the best option for power (electricity) generation in remote and sparsely populated areas. Solar technology is also a good option for electricity generation in remote and sparsely populated areas if it could reduce its production cost.

3.4. Environmental Indicators

RE sources are generally assumed to be environmentally benign by default. Although RE sources tend to have environmental benefits because many of them—such as solar, wind, and others—do not have emissions during operation, still they are not without environmental burdens, especially when looked at in a lifecycle perspective. For example, solar PVs do not have any emissions during their operation when they are actually producing electricity using sunlight. However, they use energy-intensive materials, which are responsible for emissions (particularly, greenhouse gas emissions [GHG]) during their production. Also, there are environmental burdens associated with disposing them at the end of life as toxic materials (lead, cadmium) may be released or rare materials (indium, gallium) may be lost to the environment. Recycling materials at the end of life may avoid the above damages, but they will be at the expense of releasing emissions and using resources during the processing. So, when considering GHG emissions of solar PVs, it is not enough to consider emissions only from the operation/electricity generation phase, but the upstream (materials extraction and production) and downstream (end of life) phases must also be considered.

The commonly accepted advantages and disadvantages of various RE sources are listed in Table 3.4. These will help in identifying the criteria that should be considered in evaluating the environmental sustainability of RE systems.

Based on the possible advantages and disadvantages, the following criteria appear prominently:

1. Life cycle GHG emissions,
2. Air pollutant emissions during operation,
3. Water pollution,
4. Energy return on investment / Renewability (ratio of RE output to fossil energy input),
5. Reliability of power supply,

6. Physical footprint / land use,
7. Agricultural practices, and
8. Noise, aesthetics, bird kills, fish population, etc.

As can be noted, some of the criteria can be defined quantitatively and rigorously (e.g. life cycle GHG emissions) whereas others are qualitative and quite subjective (e.g. aesthetics). Based on the importance and ease of application, the following criteria were shortlisted for the evaluation of RE systems:

- Life cycle greenhouse gas emissions
- Renewability
- Land use

Table 3.4: Advantages and Disadvantages of Renewable Energy Sources

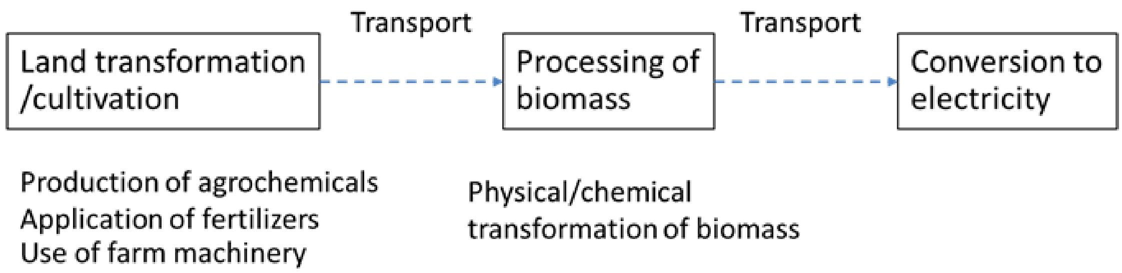
Renewable energy source	Environmental implications
Solar	Advantages: • Low life cycle GHG emissions as compared to fossil fuels • No air pollutant emissions during operation • No noise pollution • Low maintenance requirements Disadvantages: • Need batteries or other techniques for storage of electricity • Combination with other devices (e.g. diesel engine) to ensure stable power supply • Physical footprint
Wind	Advantages: • Low life cycle GHG emissions as compared to fossil fuels • No air pollutant emissions during operation Disadvantages: • Noise • Aesthetics • Fluctuating power supply • Bird kills
Biomass	Advantages: • Low life cycle GHG emissions as compared to fossil fuels in some circumstances (avoid land use change in high carbon stock areas, appropriate fertilization, etc.) • Reduces indoor air pollutant emissions during cooking (advanced biomass use) • Avoids odour (from manure, municipal solid waste) • Afforestation • Low sulphur dioxide emissions Disadvantages: • Bad practices can overturn GHG advantages (land use change, etc.) • Open burning (can lead to local air pollution problems) • Physical footprint
Small hydropower (run-of-river)	Advantages: • Low life cycle GHG emissions as compared to fossil fuels • No air pollutant emissions during operation Disadvantages: • Fluctuating power supply • Could affect fish population if not properly designed
Geothermal	Advantages: • Low life cycle GHG emissions as compared to fossil fuels • No air pollutant emissions during operation Disadvantages: • Sometimes toxic gases may be released from below the earth's surface

Source: Authors.

3.4.1. Life cycle of GHG emissions

This is a well-established and tested indicator that has been used throughout the world. It entails the calculation of the GHG emissions occurring over the entire life cycle of any system, including raw material extraction, material manufacture, operation and maintenance of the system, and end-of-life disposal. Emissions transportation are included in all intermediate stages. The detailed method of calculation for biomass utilisation is outlined in ERIA (2008). For biomass power generation, the GHG emissions must be considered from direct and indirect activities associated with agricultural production and processing along with conversion of the biomass to useful energy/electricity, as shown in Table 3.5 (Sadamichi et al., 2012; Gheewala, 2011).

Figure 3.5: Life Cycle Diagram of Biomass to Electricity (generic)



Source: Authors.

As shown in Figure 3.5, GHG emissions result not only from conversion of biomass to electricity, but also from upstream activities such as (i) conversion of land to agriculture, (ii) use of machinery during cultivation (and harvesting), (iii) production of agrochemicals such as fertilizers and pesticides, (iv) application of nitrogen fertilizers, (v) transformation/processing of biomass (e.g. shredding), and (vi) intermediate transportation. The GHG emissions from all the above stages have to be summed up when evaluating the life cycle GHG emissions of power production from biomass.

A generic equation for calculating life cycle GHG emissions from biomass systems is as follows (Sadamichi et al., 2012):

$$LCGHG = \sum_{i,j} \left(GHG_{i,j} \times GWP_i \right)$$

Where,

i : is a greenhouse gas, e.g. carbon dioxide, methane and nitrous oxide.

j : is a stage consisting of the life cycle of biomass utilisation for energy, e.g. feedstock cultivation, feedstock collection, and biomass energy production.

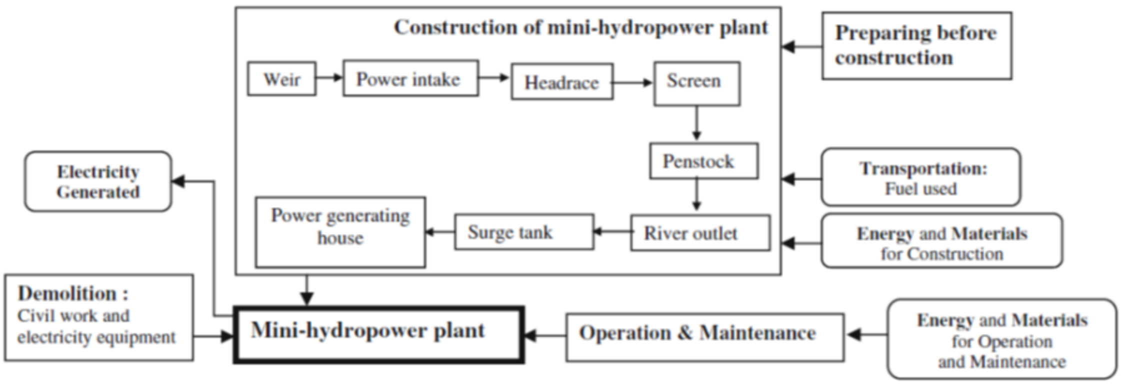
$LCGHG$: Life Cycle GHG emissions [$kgCO_{2eq}$].

$GHG_{i,j}$: Quantity of a GHG 'i' in a stage 'j' [$kgCO_{2eq}$]

GWP_i : Global Warming Potential for a greenhouse gas 'i'

Similarly, for other RE sources, life cycle GHG emissions have to be calculated by summing up the GHG emissions from the entire life cycle. An example of electricity generation by mini hydropower plant is illustrated in Figure 3.6.

Figure 3.6: **Life Cycle Diagram of Mini Hydropower Plant**



Source: Suwanit and Gheewala (2011).

Figure 3.6 shows the life cycle diagram of a typical mini hydropower plant. It includes the construction of several components such as weir, power intake, headrace, penstock, and others, which can have significant contribution to the life cycle GHG emissions. As many of the important components (e.g. turbines, etc.) are imported and need to be transported in hilly terrain, the GHG emissions from fuel consumption can also be significant. The results of the analysis indicate why it is not enough to consider only GHG emissions from the operation of the mini-hydropower plant; these are quite nominal, contributing less than 10 percent of the total life cycle GHG emissions (Suwanit and Gheewala, 2011). About 60 percent of the GHG emissions are from the construction of the mini-hydropower plant and about 30 percent of the emissions are from transportation.

3.4.2. Renewability

Renewability is defined as the ratio of the total energy output to the total fossil energy input (Gheewala, 2013). This important indicator reflects the amount of RE gained from the investment of a single unit of non-RE; a higher value indicates a larger benefit. Values less than ‘1’ should, in principle, be unacceptable since they indicate that there are virtually no savings in non-RE resources.

A simple example for calculating renewability is shown in Table 3.5 for the case of cassava ethanol in Thailand (Silalertruksa and Gheewala, 2009). From Table 3.5, it can be seen that the fossil energy input for the production of 1,000 litres [L] of cassava ethanol is 15,401 megajoules (MJ). The energy content of 1,000 L of ethanol is 21,200 MJ; thus, the renewability of cassava ethanol is 21,200/15,401 = 1.38.

Table 3.5: Energy Inputs for Production of 1,000 L Cassava-Based Ethanol

	Unit	Total energy	Fossil energy
1. Cassava farming/processing			
1a. Cassava farming			
NPK fertilizers	MJ	1,779	1,693
Herbicide	MJ	645	612
Diesel (farm machinery)	MJ	315	315
Labour	MJ	375	-
1b. Cassava processing			
Diesel (chip processing)	MJ	761	761
2. Transport			
Fresh cassava	MJ	880	880
3. Ethanol conversion			
Coal (steam production)	MJ	8,104	8,104
Energy recovered from biogas used for steam production	MJ	1,760	-
Electricity	MJ	3,130	3,036
TOTAL ENERGY INPUTS	MJ	17,749	15,401

Source: Authors

3.4.3. Land use

The physical footprint or land occupation of an RE system is the land area physically occupied by the infrastructure of the power production facility. As many RE facilities (e.g. solar, mini hydropower plant, etc.) may require substantial space or land area, this indicator represents the land requirement in terms of the product of occupying area and year, namely square metre (m^2) •year or hectare (ha)•year, for every unit of electricity generated. For example, if a mini hydropower plant occupies an area of 10 ha and over, its entire lifetime of 50 years produces 10,000 kWh electricity, then its land use would be 500 m^2•year/kWh.

The above three indicators are all qualitative and can be rigorously calculated using the well-established methods. Other indicators—such as air pollutant emissions during operation, water pollution, particulate emissions from biomass power plants, and aesthetics—can be discussed qualitatively. As the main indicator chosen for representing air emissions has been GHG based on the priorities observed from many of the case studies considered, other emissions need also to be highlighted at least qualitatively as many RE systems have the advantage of no emissions during operation, which can be quite important from the perspective of local air pollution. Hence, air pollutant emissions associated with, for example, diesel engines, are avoided when producing electricity from solar, wind, and others as noted in Table 3.4. Similarly, emissions to water, as well as odour, are avoided when manure or municipal solid waste is used for biogas production. The emission of particulate matter from the use of biomass for heat and power production can be quite significant; however, these can be substantially controlled by proper particulate control equipment. All the above are quite location- and context-specific; thus, they need to be addressed on a case-to-case basis.

3.5. Economic Indicators

3.5.1. Assessment of economic perspective

A popular tool in assessing the economic perspective of a project, including public projects, is the cost–benefit analysis (CBA). CBA calculates the expected balance of benefits and costs, including an account of foregone alternatives (opportunity costs) and the status quo. If the CBA analysis is accurate, changing the status quo by implementing the alternative with the lowest cost–benefit ratio can improve Pareto efficiency.[5]

Assessing the best energy mix from the economic perspective also has to apply the CBA framework. However, instead of focusing on both cost and benefit sides as a standard CBA, the assessment for the best energy mix can be focused on cost only. The optimisation criterion would be minimising the levelised cost. This is also a creditable methodology in

[5] Pareto efficiency means that there is no alternative that can make anyone better off without making the others worse off.

the literature. While CBA is the most popular cost analysis, there are three other kinds of cost analysis— cost-effectiveness analysis, cost-minimisation analysis, and cost-utility analysis (Palmer et al., 2009). It also makes sense intuitively. Given the fixed start and end points of the best energy mix analysis, cost-effectiveness analysis or cost-minimisation analysis would be sufficient, without considering the benefits side.

In the previous ERIA report about sustainability assessment methodology (ERIA, 2013), the economic aspect of sustainability assessment is represented by Total Value Added (TVA), which is defined as below:

$$\begin{aligned} \mathrm{TVA} &= \text{output value} - \text{costs of intermediates} \\ &= \sum \text{price} \times \text{outputquality} - \text{costs of intermediates} \end{aligned}$$

Where output value is simply the product of price and quantity (this applies to both main product and by-products); and intermediates include goods and services, other than fixed assets, used as inputs into the production process of biomass that are produced elsewhere in the economy or are imported.

The TVA is applicable to the development of biomass energy where the final outputs are diversified fuels (bioethanol, biodiesel, etc.) and, thus, benefits should be calculated. In the best energy mix case, since the final output is electricity and it remains constant across various cases, the benefits are identical across various options. Thus, these are not necessary to be explicitly calculated. Instead, the only focus is on the 'costs of intermediates' item, which are the levelised costs of electricity (LCOE).

Overall, the primary indicator could be LCOE, while internal rate of return (IRR) and capital investment requirement could be used as sub-indicators. Minimising the LCOE would be the primary economic indicator. IRR is employed to check the commercial attractiveness of the project, while capital investment requirement will check whether the project is feasible from a financing perspective.

3.5.2. Major indicator to assess the best energy mix

i) Levelised costs of electricity

To make the results comparable, the total life cycle costs of electricity should be normalised as cost per unit of electricity output, or LCOE. LCOE is an economic assessment of the average total cost to build and operate a power-generating project over its lifetime divided by the total power output of the project over that lifetime. It is also the cost at which electricity must be generated in order to break-even over the lifetime of the project. It is often used as a proxy for the generation costs.

LCOE is calculated as the net present value of all costs over the lifetime of the asset, divided by the total electricity output of the project.

As used by NREL (Short et al., 1995), the formula[6] is presented below:

$$\mathrm{LCOE} = \frac{\sum_{t=0}^{n} \frac{I_t + O\&M_t + F_t + OC_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

Where I_t, $O\&M_t, F_t$, and OC_t represent investment, operations and maintenance costs, fuels costs and other costs in the year t; E_t represents electricity produced in the year t; r is a discount rate; and n is the project's life time.

The life cycle costs include, but not limited to capital costs (equipment costs and financial costs), operation and maintenance costs, and fuel costs. Costs of land and other inputs could also be a significant part. Typically, the LCOE is calculated over the design lifetime of a project and given in the units of currency per kWh.

ii) Investors' concerns: IRR and capital investment

In addition to the cost minimisation, the investors' interest should be closely watched out as an economic cost minimisation does not necessary deliver accounting profits that are acceptable by investors. Therefore, other financial indicators that are matters of concern for private investors, such as IRR and capital investment requirement, should be used as sub-indicators for the assessment of the best energy mix.

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[6] This equation appears to show that the energy term in the denominator is discounted. This is not the case but is a result of the algebraic solution of the equation.

The IRR is a popular measure of investment performance. It is the rate of return that makes the net present value (NPV) of all future cash flows from a particular investment equal to zero. It can also be interpreted as the discount rate at which the present value of all future cash flow is equal to the initial investment or, in other words, the rate at which an investment breaks even. In more specific terms, the IRR of an investment is the discount rate at which the NPV of costs (negative cash flows) of the investment equals the NPV of the benefits (positive cash flows) of the investment. Basically, an investment is acceptable if its IRR is greater than the benchmark. The higher a project's IRR, the more desirable it is to undertake the project. This benchmark rate is often considered to be the opportunity cost of capital of the investment (the risk-adjusted cost of capital of alternative investments).

The IRR can be solved by setting the NPV equation equal to zero (0) and solving for the IRR.

$$\mathrm{NPV} = \sum_{t=1}^{n} \frac{CF_t}{(1+IRR)^t} = 0$$

Where CF_t represents cash flow at a period t (investment is a negative cash flow) and n is total number of period (usually the life of the project and in year, but could be in month) that have cash flow.

A frequent way of using IRR is to compare various plans of investment. Assuming all projects require the same amount of up-front investment, the project with the highest IRR would be considered the best and is undertaken first.

The IRR, however, would not report the scale of initial investment, but rather looks at return/investment ratio, or the efficiency. Another constraint of investment decision is the availability of capital investment to the firm. The scale of investment, however, could be significant for a rural community where access to capital is limited. Therefore, the capital investment is another sub-indictor for assessment of the best energy mix. To achieve a given target, indicating a certain amount of electricity to be generated, and giving an acceptable IRR, the lower the capital investment the better.

3.5.3. Different perspectives of cash flow between government and investors

Calculation of cash should be distinguished between the government and the private sector. The government's cash flow, or economic benefits, could include not only the value of electricity itself, but also other benefits beyond the project itself, such as revenue from the new industries, or business brought up by electrification, such as revenues generated from, for example, preserved food products and homemade or handmade products. Access to electricity will enable local households to do home-based weaving business, which generates economic benefits that can be counted as a positive 'cash flow' from the government's perspective. From more broad and theoretical perspectives, the cash flow of a project may incorporate non-market values, such as public willingness to pay compensation or willingness to accept compensation for the welfare change resulting from the project.

From investors' perspective, the benefits are different from the government. Those benefits beyond the project, and the non-market value, would not be captured by the project investors. Therefore, the investors' 'cash flow' would be different from the government. In the best energy mix case, what investors often can get is the selling prices of electricity, regardless of subsidised or inflated tariff.

The government, however, can alter the investor's IRR through financial and fiscal policies, such as tax exemption, subsidy, and others. In the case of RE development in rural areas, for benefits to extend beyond the project itself, the government often sets supporting policies, including financial incentives (soft loans, grants, loan guarantees, etc.) and fiscal incentives (tax exemptions, tax concession) (IRENA, 2012). With such policies in place, the investors' benefits (positive cash flow) will be increased, so does the IRR. These kinds of policy interventions are justifiable by the theory of market failure due to such factors as externalities, public goods, infant industry, and uncertainty (Rajagopal and Zilberman, 2007).

Government support, if not properly designed, could post challenges to selecting the best energy mix. Perhaps the largest barrier to achieving the best energy mix is fossil fuel subsidies, which distort the market behaviour. Therefore, if policy instruments are to be used, their applicability should be carefully assessed. Nevertheless, such assessment is not easy given the multiple, complicated, and diverse factors involved in policy development.

3.6. Social Indicators

Identifying of the best and sustainable energy mix for any country needs to take into account several factors, including technological, socioeconomic, environmental, and institutional aspects. Considering the energy availability, access, and affordability in off-grid areas and isolated communities, RE can play a prominent role in the EAS region. However, proportion of various forms of RE in the energy mix may be country specific and will depend on resource availability, the community's paying capacity and willingness to pay, involvement of community in managing the facilities, and the government's policies on the promotion of REs.

3.6.1. Social considerations

In general, social considerations that may affect the choice of an energy mix are (i) community participation, (ii) employment generation for local people, (iii) improvement in the quality of life of community members, (iv) reduction in their health hazards, (v) reduction in drudgery of women and their empowerment, and others. However, there are no fix social criteria and they may differ from country to country and will depend upon the level of social development in the country. For example, in the EAS region, the criteria for countries like Japan and Singapore may be different from those for India and Thailand. In India, 65percent of the total rural energy demand is still met by fuelwood, an inefficient source of energy, and around 100 days per household are wasted in the collection of fuelwood. Cooking and heating with fuelwood lead to several health problems to household members, particularly women and children, due to their exposure to indoor air pollution. Thus, under such circumstances, the best mix could be developed based on the criteria that provide clean energy, reduce health hazards, and improve the quality of life of the rural and urban poor households.

One of the most common problems of energy planning is how to choose from amongst various alternative energy sources and technologies. An added complexity is how to choose the best mix of available renewable and conventional energy sources to be promoted in a given locality.

A report on the energy indicators for sustainable development takes into account two major social parameters—equity and health/safety. Equity is subdivided further into accessibility, affordability, and disparities. The energy indicator for accessibility is the share of household without commercial energy or dependence on traditional forms of energy. Affordability is indicated by the share of household income spent on fuel and electricity and disparity is indicated by household energy use for each income group and corresponding fuel mix. Health and safety indicators are represented by the accidental fatalities per unit of energy produced by a particular fuel chain (IAEA, 2005).

The availability of energy services has impact on poverty, employment opportunities, education, community development and culture, demographic transition, indoor pollution, and health (UNDESA, 2007). Thus, social indicators are used to measure the impact of energy systems on human well-being. In choosing the best mix at the community level, the social indicators to be considered are social capital, access to modern energy, and employment generation as described in the following paragraphs.

3.6.2. Access to modern energy

Energy poverty is an enormous challenge in many developing countries. As energy plays a critical role in being the engine for growth and social development, it is important to ensure access to affordable, reliable, sustainable, and modern energy resources for all as proposed in the Sustainable Development Goal Seven.[7]

The current definition of modern energy access used by the International Energy Agency, the United Nations, and the World Bank uses a threshold of 500 kWh per year per urban household and half of this rate for rural households, assuming five persons per household. This translates into an international definition of modern energy access at 50–100 kWh per person per year, which is unacceptably modest. To put it in context, the use of a single 60-watt light bulb four hours per day equates to about 90 kWh per year (i.e. 60watts * 4hours * 365days) (Bazilian and Pielke, Jr., 2013). There are ongoing discussions to increase the level of goal to achieve energy access compatible with a decent standard of living. Nonetheless, the measurement of expanding access to modern energy services remains the same.

The total amount and percentage of increased access to modern energy services gained through renewable and conventional energy sources are measured in terms of (i)

[7]The Rio+20 outcome document, *The Future We Want*, among other things, sets out a mandate to develop a set of sustainable development goals (SDGs) coherent with and integrated into the United Nation's development agenda beyond 2015.
Refer to this link for more information: https://sustainabledevelopment.un.org/sdgsproposal

energy, and (ii) number of households and businesses.

Providing modern energy services for all means having to enhance household access to electricity and clean cooking facilities (e.g. fuels and stoves that do not cause indoor pollution). A change in the access to different forms of modern energy (liquid fuels, gaseous fuels, solid fuels, electricity, etc.) for various services (heating, cooling, commercial activities, etc.) can be measured in megajoules per year. This allows comparison of different forms of energy services. Likewise, each form of the energy may be measured in an appropriate unit of volume or mass per year, such as

- liquid fuels : litres/year or MJ/year
- gaseous fuels : cubic metres/year or MJ/year
- solid fuels : tonnes/year or MJ/year
- heating and cooling: MJ/year
- electricity :
  - MWh/year or MJ/year (for electricity used)
  - MW/year (if only electricity generation capacity to which new access is deemed to have been gained can be measured)
  - hours/year (for the time either for which electricity is used or for which there is access to a functioning electricity supply)

3.6.3. Social capital

One way in which energy access can affect local communities and groups of people is through increasing social capital. Social capital facilitates cooperation because people have the confidence to invest in collective activities, knowing that others will also do so (Pretty, 2003). It has been demonstrated in many places all over the world how social capital increased after their access to modern forms of energy. As energy drives economic development and, with enhanced social capital, the share of electricity consumption in the productive sector also increases. Local enterprises are set up; schools, medical facilities, and other government offices operate for longer hours; farmers get access to post-harvest technology; people get more and latest information through different forms of media; and many others benefits. Similarly, focusing on building up social capital as a complementary measure might be important in reducing carbon dioxide (CO2) emission impacts of economic development, for example, by implementing RE projects (Ibrahim and Law, 2014).

These are the good effects of social capital that attracts the interest of many politicians and policymakers.

Social capital consists of four major components—social trust, norms, social networks, and social structure (Lee et al., 2011). To measure social capital, Table 3.6 may serve as a guide. These examples of social capital indicators were taken from Lee et al. (2011) and the UK ESDS (2007). These indicators can be modified to reflect their appropriateness to the selected community to which it will be applied to assess the increase of social capital due to the provision of electricity in the community.

Table 3.6: An Example of Social Capital Indicators

Component of Social Capital	Lowest-level of Indicators	Example of Variable	Definition
Social trust	Generalized trust	Trust in people	Share of respondents who answered that most people can be trusted.
		Fairness	Share of respondents who answered that people try to be fair in dealing with others.
		Safety	Share of respondents who answered that feel safe walking in the area at any time.
	Public trust	Confidence in public institutions	Share of respondents who answered that they have confidence in (1) government, (2) parliament, (3) police, (4) justice system, (5) armed forces, (6) civil services and (7) political parties.
		Confidence in legal institutions	Average share of respondents who answered that they have confidence in government, parliament, police and justice system.
		Legal structure and security of property rights	Extent to which legal system protects property rights in the following areas: judicial independence, integrity of the legal system, legal enforcement of contracts.
		Confidence in social institutions	Share of respondents who answered that they have confidence in (1) church, (2) press, (3) labour union, (4) local companies.
		Well-informed	Share of respondents who answered that feel well-informed about local affairs.
Norms	Civic attitude		Share of respondents who answered that each of the following activities is not justified: (1) claiming government benefits falsely, (2) avoiding a fare on public transport, (3) accepting a bribe, (4) cheating on taxes.
	Social support	Support	Share of respondents who answered that had at least three sources of support for different scenarios (Need help when ill in bed; Need to borrow money)
		Reciprocity with neighbors	Share of respondents who answered that have done or receive a favor for or from a neighbor.
	Social behavior	Public corruption	Extent to which corruption is perceived to exist among public officials and politicians. (with higher scores indicating less corruption)
		Rule of law	Extent to which people have confidence in and abide by the rules of the society.
Social networks	Religious organization		Share of respondents who participate in the following civic activities: (1) religion, (2) art, music, educational organizations, (3) sports and recreation.
	Interest groups		Share of respondents who participate in the following civic activities: (1) labour unions, (2) political party, (3) professional organization.

Table 3.6 (cont.): **An Example of Social Capital Indicators**

Social structure	Culture	Informal sociability	Share of respondents who spend time with the following group at least once a month: (1) friends, (2) colleagues, (3) people at religious organizations, (4) people at sports club.
		Enjoyment of living in the area	Share of respondents who answered that would say this is an area enjoying living in.
	Civic engagement	Political rights	Extent to which people are allowed to participate freely and effectively in choosing their leaders or in voting directly on legislation.
		Opportunity of involvement	Share of respondents who answered that we can influence decisions that affect the area
	Social conflict	Income inequality	Gini coefficiesnts.
		Democracy	A formal institution designed to reach consensus among different types of voters
		Government effectiveness	The ability of local government to find agreements among different interest groups.

Note: Different groups may utilise social capital in different ways when acquiring information about the energy access. Nevertheless, previous studies suggest that whilst there is a potential to develop social capital around the provision of environmental goods or energy access, the institutional role of the state is fundamental.
Source: Lee et al. (2011) and the UK ESDS (2007)

3.6.4. Employment generation

Rural electrification programs and energy projects have most often political and development objectives such as employment generation. Monitoring of economic progress and welfare gains as consequences of the project is important.

Net job creation[8] as a result of provision of renewable and conventional energy is disaggregated as (i) skilled/unskilled, and (ii) indefinite temporary/permanent.

The total number of jobs should adhere to recognised labour standards consistent with the principles enumerated in the International Labour Organization (ILO) Declaration on Fundamental Principles and Rights at Work, in relation to comparable sector. The measurement will be in terms of number and as percentage of (working age) population, or number per MJ, or MW and percentage.

[8]Similar to GBEP (2011)'s 12th indicator 'Jobs in the bioenergy sector' under social pillar.