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# Solar Energy

## A Sustainable Solution to Rural Electricity Problems in Nigeria

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Abstract

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Lack of access to electricity is one of the major impediments to growth and development of rural economies in developing countries. Currently around 1.5 billion people worldwide live without access to electricity, and this number is not likely to go down without a concerted effort. Energy and electricity in particular is critical to achieving virtually all the Millennium development goals. Electricity can be used to support important development like access to education, improved health, communication and women empowerment. The main objective of this thesis is to find a sustainable way of bringing electricity to the rural communities in Nigeria.

The World Bank and other development organizations such as Alliance for Rural Electrification (ARE) have made access to modern energy, most especially electricity, one of their priority themes. These organizations have implemented hundreds of rural electrification projects around the world. I was recently involved in a similar UNDP funded project in Nigeria. The reports and lessons learned from these projects can provide insight on vital issues that must be considered in order to plan sustainable and replicable rural electrification projects for Nigeria’s rural communities.

It was concluded that grid extension to the poor, scattered, rural population is not economically justifiable at the moment. The least-cost method of getting electricity supply to the rural areas in the country is through off-grid electrification. The best technology option to be used for rural off-grid electrification is either a village mini-grid or different energy home systems, depending on several factors. Such factors are the type of loads, population concentration, resources and equipment availability, and income level. It is also important to consider the financial and organizational issues involved as they are critical to the success and long term sustainability of rural electrification programs.



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| Key words | solar energy, Nigeria, rural electrification, photovoltaic (PV) off-grid, mini-grid |

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**Contents**

# 1 Introduction

## 1.1 Background

Nigeria is a country blessed with abundant energy resources that could be used to generate electricity, but its people live in total darkness. About 60 percent of Nigeria's population has no access to electricity, and 90 percent of them live in rural areas.

Electricity helps to satisfy the basic needs of people, and is also an important catalyst for rural development. For rural Nigerians, lighting is the most expensive energy need and the second most important, after cooking. Majority of the rural inhabitants light their homes with kerosene lamps and sometimes with firewood. Kerosene lamps provide poor lighting and are expensive, inefficient, highly polluting and dangerous. Carbon monoxide (CO), sulphur oxide (SOx), nitrogen oxide (NOx), and carbon dioxide ($CO_2$) are gases emitted by kerosene lamps and firewood. These gases are detrimental to health and cause chronic respiratory problems. Electrification of rural communities is therefore essential to prevent these and other problems.

Obstacles such as dispersed population, difficult terrains, geographical remoteness, low commercial energy consumption and limited income of consumers make extension of electricity network to rural areas economically inefficient for both public and private organizations. It is necessary to seek other ways of providing electricity to these rural communities. Off-grid electrification using solar photovoltaic (PV) or a hybrid combination of PV with other locally available energy sources offers the best solution of bringing electricity to rural Nigerians.

### 1.2 Objectives of the work

The aim of the work was to find answers to these three fundamental rural electrification questions.

I. How do we provide sustainable electricity services to the Nigeria's rural population, most of which have no purchasing power to pay for the services?
II. What is the best available technology that offers the least-cost, clean and reliable electricity to off-grid communities?
III. How do we regulate and finance the infrastructure to provide these services?

### 1.3 Methodology

The work presented in this thesis consisted of theoretical analysis studies and documented personal experiences. I was part of a team involved in an electrification project in a rural community in Nigeria, hence the interest in the research topic. During the project, I had the opportunity to interview the beneficiaries of the electrification project as well as many inhabitants of the community to understand their problem of lack of access to electricity.

## 2 Electricity in Nigeria

### 2.1 Historical overview

Electricity production in Nigeria began in 1896, fifteen years after its introduction in England. In 1929, the Nigeria Electricity Supply Company (NESCO) was established and commenced operations in the same year as an electric utility company with the construction of a 2MW hydroelectric power station at Kurra Falls near Jos. NESCO, a private company was originally set up for the main purpose of supplying electricity to the Tin mines. It later extended its services to the people of Jos and the surrounding towns [1; 2].

The Electricity Corporation of Nigeria (ECN) was created by the government in 1951 to oversee the electricity sector of the country. ECN built several small generating plants to serve administrative centers and industrial areas nationally [1]. In 1962, the Niger Dam Authority (NDA) was established by an act of parliament with the mandate to develop the economic potential of River Niger. As part of its mandate, the NDA constructed Kainji Dam and an associated hydroelectric power plant (with a generating capacity of 960MW) which began operations in 1968. The electricity produced by NDA was sold to ECN for distribution and sales at utility voltages [1].

However, ECN and NDA were merged in the early 1970s to form the National Electric Power Authority (NEPA). NEPA was authorized to develop and maintain an efficient and economical system of electricity supply throughout the federation. At the inception of NEPA in 1973, only five of the then 19 states were connected to the national grid. Today, all the state capitals (36 states) and major cities in Nigeria are being served by the grid, although haphazardly. NEPA, until the late 1990s was solely responsible for generation, transmission, distribution, and sales of electricity in Nigeria [1].

The government ended the monopoly status of NEPA in 1998, paving way for the active participation of private investors in the country's electricity sector. In March 2005, the federal legislature passed the Electric Power Sector Reform (EPSR) Act. The Act lead to the unbundling of NEPA into 18 successor companies (comprising of 6 generation companies, 1 transmission company and 11 distribution companies) with PHCN serving as the initial holding company, and entry of Independent Power Producers (IPP) . The Act also established National Electricity Regulatory Commission (NERC) as a regulator of the sector [1].

The decade preceding the unbundling of NEPA, i.e. the early to late 1990s was the worst decade in the country's electricity sector. Despite the surge in electricity demand, no new generation capacity was added; the transmission and distribution infrastructures were not properly maintained leading to frequent power outages. The whole power sector was practically neglected, leading to perhaps the lowest point in the 100 year history of electric sector in the country.

## 2.2 Current State of Electricity in Nigeria

Despite the vast energy riches of Nigeria, its citizens hardly enjoy 24 hours of electricity. The majority of Nigerians (about 60 percent) do not have access to electricity [3]. The failure of the national electrification in the country for the past decades is attributed to corruption, poor maintenance and sheer neglect. The country's power supply has been stagnant for more than 30 years. There has not been any significant investment in the sector despite the surge in demand [3; 4]. The Nigerian government in the 1980s and 1990s failed to anticipate national needs. For example, the last major electric installation in Nigeria was in 1990 when the Shiroro power plant (600 MW) was commissioned. Since then no new units have been added and none of the existing ones have been rehabilitated, leaving them in a state of disrepair [1].

In 2008, according to the state power company, power production dropped on one occasion to as low as 800 MW. Current production is about 3,000 MW, according to the government [5]. An official involved in the power sector reform talks with the government reported that, ''there were three days when no power at all was generated and nobody at the government power agency noticed." [5]. The few Nigerians that can afford costly diesel generators, operate them because of daily blackouts.

According to the panel of experts appointed by the late President Umaru Yar'Adua, Nigeria needs 85 billion USD of investment in its power infrastructure for its citizens to enjoy electricity 24 hours a day [6]. The panel's chairman, Rilwanu Lukman stated that electricity generation is not the only problem, but also the transmission grid is in a very poor condition. He explained there were not enough engineers in the country to work in power stations or maintain the electricity grid.

The manufacturing sector in the country has crumbled due to the poor electricity state. Lack of adequate supply of electricity was cited by many multinational companies (Dunlop Plc, Michelin, Volkswagen Plc, PZ etc.) as the major reason they closed down their operations in Nigeria [7; 8]. The few manufacturing companies left in the country have no choice but to produce their own electricity, running their operations with expensive diesel generators, adding considerably to their operating and capital costs [8].

### 2.3 Nigeria's Electricity Infrastructure

The bulk of electricity generation in Nigeria comes from thermal power plants (77 percent), with about two-thirds of thermal power derived from natural gas and the rest from oil. The only other source of power generation in the country is hydroelectricity [9]. Figure 1 illustrates electricity generated by type in Nigeria in 2009.

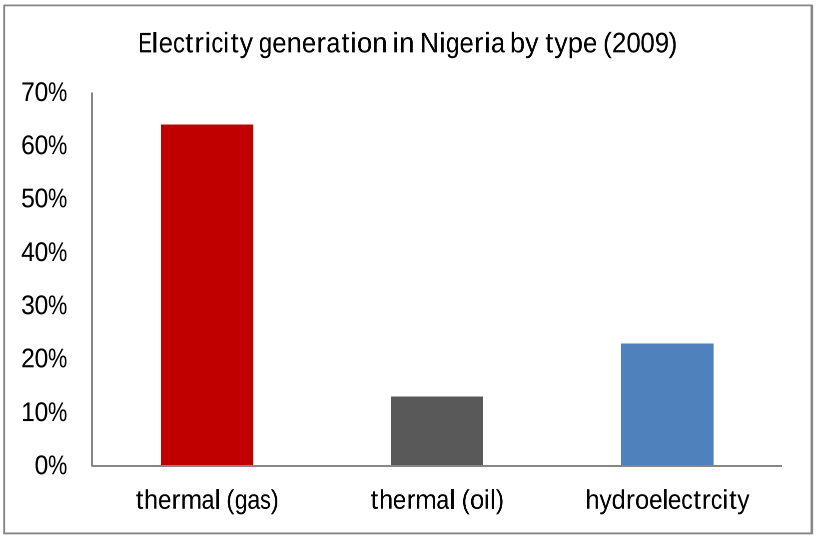


*Figure 1. Total installed electricity net generation in Nigeria by type. Adapted from U.S. EIA [9]*

The national electricity grid presently consists of nine generating stations with a total installed generating capacity of 5906 MW. This makes Nigeria's per capita electricity consumption one of the lowest in the world, and far lower than many other African countries. In August 2010, the peak electricity generated by PHCN was 3804 MW. This put Nigeria's per capita electricity consumption to about 7% of Brazil's and 3% of South Africa's with grid-based generating capacities of 100 GW and 40 GW respectively. However, it was estimated that self generation of electricity from diesel and petrol generators in the country is about 6000 MW. This is more than twice the average output from the national grid in 2009 [10].

There have been many documented reasons for the poor performance of the electricity sector in the country. Aside corruption, another important factor affecting the electricity sector is the distortion in the investment pattern, which has focused more on generation at the expense of transmission and distribution facilities [11].

Electricity transmission is a major problem in Nigeria. The centralized grid system is based on the large scale power generation, and a significant amount of power is lost in transmission [3]. An average of 900 MW of power was reportedly lost annually in transmission from 1970 to 2008 (see appendix 1) [11]. This is a very high amount compared to an average of 60 to 70 MW lost in some developed countries. The government realizes the need for more investment in decentralized power production, but still prioritizes infrastructure for centralized generation.

With the ongoing privatization of the power sector, the government's projection is to reach the target of 40 GW of generated electricity by 2020. This target seems highly optimistic and unrealistic, not only because of the amount of money (14 billion USD) needed annually to be invested in the sector for the next 10 years to reach this target but also because of the inability of the government to frame the necessary policies needed to attract private investors.

# 3 Energy Potential of Nigeria

Nigeria is a country blessed with a vast amount of energy resources that can be used t o generate electricity such as coal, oil, natural gas, hydro and other renewable sources.

## 3.1 Coal

Coal was first discovered in Nigeria in 1909, and its mining began in 1916 [12]. Over 900, 000 tonnes of coal was produced in the late 1950s with a contribution of over 70 percent to commercial energy consumption in the country. Nigeria's coal reserve was estimated at over 2.5 billion tonnes [3; 12]. Production of coal started falling after the discovery of crude oil in1959. The market of coal was affected by the move to diesel and gas-powered engine by organizations that were previously major coal consumers. In 2001 coal accounted for just 0.2 percent of Nigeria's total energy mix [3; 12].

Nigeria's coal can be utilized for power generation. The government has recently placed a high priority on reviving the coal mining industry in order to expand power generation. The government's goal is to privatize the sector and allow private companies to develop the large coal reserves and construct coal-fired generating plants [13].

Nigeria's coal is of sub-bituminous grade, with low sulphur and ash content. These characteristics make this coal ideal for coal-fired power plants [12; 13]. Besides power production, there is also potential domestic demand for coal briquettes to replace wood for cooking and heating so as to curb the country's deforestation rate. Also, Nigeria can export its coal due to its low sulphur content, a quality desired by many international customers [13].

## 3.2 Oil

Nigeria is the largest oil producer in Africa, and the 12th largest in the world. It has the 12th largest proven reserves of world oil [9]. Nigeria has been a member of the Organization of Petroleum Exporting Countries (OPEC) since 1971. As at the end of

2001, Nigeria was estimated to have an estimated 37.2 billion barrels of proven oil reserves [9].

Oil production in Nigeria peaked in 2005 at 2.63 million barrels per day (bbl/d). However, violence and agitation for better resource control in the Niger Delta, its main oil producing region, forced many oil companies to withdraw staff and shut-in production [9; 12]. Lack of transparency of oil revenues, tension over revenue distribution, and environmental damages from oil spill have created a fragile situation in the oil rich Niger Delta area. In 2012, crude oil production averaged 2.15 million barrels per day, up from 2.13 million barrels per day in 2011 [9; 12].

Nigeria consumed around 286,000 bbl/d of petroleum, of which about 180,000 bbl/d was gasoline in 2011 [9]. According to oil and gas journal [9], the country has four refineries (Port Harcourt I and II, Warri, and Kaduna) with a combined capacity of 445,000 bbl/d. However, none of these refineries have ever been fully operational due to poor maintenance, operational failure, and sabotage on crude pipelines feeding them. The operational capacity of the refineries was just 24 percent in 2011. In 2009 and some part of 2010, Nigeria imported more than 85 percent of its fuel needs due to low refinery runs [9].

### 3.3 Natural gas

Nigeria has the ninth largest natural gas reserve in the world, and the largest in Africa. The total reserve at the end of 2011 was over 180 trillion cubic feet (Tfc), which are substantially larger than its oil reserve in energy terms [3; 9; 12]. Despite the large gas reserve, gas production is low because the country has limited infrastructure to develop the sector.

Most of Nigeria's natural gas is exported as Liquefied Natural Gas (LNG). Nigeria is the fifth LNG exporter in the world and the largest in the Atlantic Basin [9]. Domestic consumption account for a small part and other portions are exported regionally via West African Gas Pipeline. Domestic consumption of natural gas is mainly for power generation which account for more than 60 percent of the country's electricity generation. Household use of natural gas is negligible in the country [9; 12].

Nigeria is the second largest gas flarer behind Russia [3; 9]. Natural gas that is often associated with oil production is mostly flared due to lack of infrastructure to convert it to useful energy for domestic and industrial purposes [9]. In 2008, Reuters reported that Nigeria was exporting 3 billion cubic feet of gas per day (in the form LNG), while flaring about 2.5 billion cubic feet per day, and delivering just 0.5 billion cubic feet per day to the domestic power sector [3]. With so much flaring, Nigeria is missing out on significant revenue, while valuable resources that could be used for power generation are being wasted.

## 3.4 Renewable energy

Nigeria is endowed with abundant renewable energy resources. The most significant ones among them are solar energy, wind and small hydropower. These resources if properly utilized, can provide off-grid communities access to electricity, as well as add significantly to the national grid.

### 3.4.1 Solar energy

There is a huge potential for solar powered energy service provision in Nigeria especially in the rural communities. Solar photovoltaic (PV) can power, for example, households, water pumps, health clinics, small to medium enterprises, information and communication technologies (ICTs).

**Solar Radiation in Nigeria**

Nigeria lies between latitude $4^0$ and $14^0$ North of the equator. This is entirely within the tropical zone, a region with the highest solar radiation in the world. Nigeria receives an average solar radiation of about 7.0KWh/m$^2$/day in the northern part and 3.5KWh/m$^2$/day in the south [14] (see appendix 2). The annual estimate of potential solar energy in Nigeria with 5% conversion efficiency is $5.0 \times 10^{14}$ KJ of useful energy. This is an equivalent of about 260 million barrels of oil produced annually and $4.2 \times 10^5$ GWh of electricity production [14]. This is more than enough to satisfy the electricity need of the entire country and also make Nigeria a major electricity exporter.

### 3.4.2 Wind energy

Nigeria has significant onshore and offshore exploitable wind energy reserves [3]. A study conducted by the Energy Commission of Nigeria (ECN) on the wind energy potential of some cities show that annual wind speed, at 10m height ranges from 2.32 m/s in the south to 3.89 m/s in the north [15].

### 3.4.3 Small Hydropower (SHP)

Large scale hydropower is a major source of electricity in Nigeria and accounts for about 29 percent of the total electricity power supply [15]. However, small hydropower potential is underutilized. The recent studies carried out in twelve states and four different river basins show there are over 278 unexploited SHP sites with a total capacity of 734 MW [3; 15]. The study claimed that SHP potential exists in almost all parts of Nigeria with an estimated capacity of 3,500 MW.

# 4 Energy Condition in Rural Nigeria

## 4.1 Rural People

Rural Nigeria, like every other rural area in Sub-Sahara Africa and other developing nations, is dominated by the poor. Nigeria, with population of about 170 million is the seventh most populous country in the world [16]. The country has seen a very rapid urbanization in the recent decades but still has a large percentage (about 58%) of her population residing in rural areas [16]. Agriculture is the mainstay of Nigerian economy besides petroleum. Nigerian National Bureau of Statistics [16] reported that Agriculture contributed 40 percent to the nation's GDP in the last quarter of the year 2011.

The Agriculture sector employs about two-thirds of the country's labor force and provides almost 90 percent of the rural population a means of livelihood. More than 85 percent of Nigeria's food is produced by small scale farmers that cultivate small plots of land. These farmers largely depend on rainfall rather than irrigation systems thereby, susceptible to climate change and other environmental hazards. Survey [17] shows that

44 and 72 percent of male and female farmers cultivate less than one hectare of land per household, respectively.
Like many other rural communities in the world, women play significant roles in rural economic activities. They play a major role in production, processing and marketing of agricultural produce. Households headed solely by women are the most poor within rural communities. Men have higher status in the cultural set up of rural communities; thus, they have better access to schooling and training. There has been an increase in rural urban migration where men move to the cities in search of better employment thereby making households that are headed by women to increase.

The rural dwellers of Nigeria are mostly farmers and low-income earners. According to a research conducted by Babatude [18], the average annual income of a typical rural household in Nigeria is NGN 30,245 (an equivalent of 225 USD). The majority of rural residents of Nigeria live in poverty despite the fact that the bulk of the country's wealth is derived from agriculture, and crude oil which are in abundant quantity in rural communities [16].

Rural infrastructure in Nigeria has been neglected for a long time. The government's investment in health, education, energy and water supply has been mainly focused on the cities. As a result, the rural population has limited access to services such as schools, health centers, safe drinking water and electricity.

About 40 percent of Nigerian households have access to electricity [3]. The other 60 percent of the country's population, or over 80 million people, out of which majority reside in rural and semi rural areas have little or no access to grid electricity. Most of these unconnected rural people reside in isolated communities far from the national electricity network. These off-grid communities are usually small and dispersed, consisting of low income households that are economically unattractive to utility companies. They are over-looked by the government electrification programs that prioritize the urban cities full of industries and economically attractive customers.

### 4.2 Energy Consumption in Rural Nigeria

Energy encompasses light, heat, mechanical power and electricity from a combination of fuels. These fuels can range from fossil sources such as coal, gas, kerosene to renewable sources such as solar, wind, hydro and biomass.

The most energy need of rural inhabitants is cooking, and to some extent lighting. Sixty-seven percent of the population prepares their food on wood-fire. This is not only practiced in rural areas but also in some urban cities. This is largely due to the lack of affordable alternatives, and partly to the belief among some people that food cooked on wood stove tastes better [3]. Wood fuel cooking is inefficient and is believed to be responsible for about 79, 000 deaths annually from indoor air pollution [3; 19].

The Energy Commission of Nigeria reports that majority (over sixty percent) of the rural population relies on fuel-wood as their main source of energy. Sambo A.S. [20] observes that Nigerians consume more than 50 million metric tonnes of fuel-wood annually. Though it cannot be ascertained the exact amount used for domestic purposes as rural dwellers routinely cut down primary forest in their immediate surroundings to source fuel.

Biomass combustion, as shown in figure 2 represents the largest share of the total Nigeria energy consumption in 2008. The lack of access to electricity of rural populace has left them no option other than to rely on biomass for their energy needs. Most end users of energy in rural Nigeria rely on fire wood to prepare the foods and heat their homes [20]. The rural areas are generally inaccessible due to absence of good road networks. This makes access to modern energy such as electricity and other petroleum products difficult. Petroleum products such as kerosene and diesel are purchased in the rural areas at prices over 100 percent in excess of their official pump prices. Rural Nigerians therefore relies, almost entirely on fire wood to meet their daily heat energy and lighting need [20].

Presently, the rural households can only enjoy a limited number of hours of illumination based on kerosene lamps and in rare cases, diesel generators. They pay a huge percentage of their income to enjoy these few hours of light that the majority of them cannot afford [3]. Kerosene lamps provide poor lighting and are expensive, inefficient, very polluting and dangerous. Small generators (of about 800 Watts) are not uncommon in some rural communities, especially to shop owners that want to keep their shop opened at night. But generator is not an option for most rural Nigerians as it carries high fuel cost and requires maintenance. They are not environmentally benign as they produce polluting fumes and noise and generate excess unused power [20].

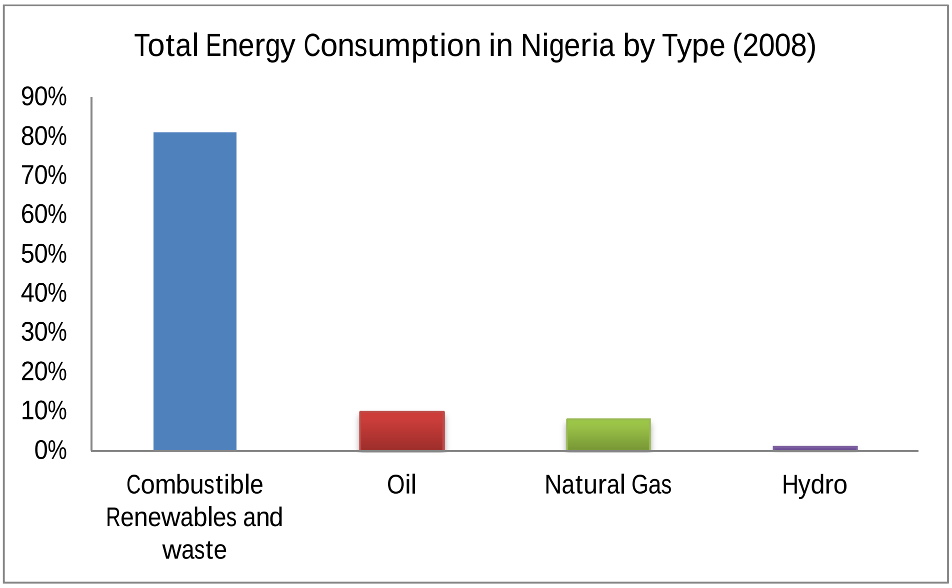


*Figure 2. Nigeria energy consumption in 2010. Adapted from U.S. EIA [9]*

The lack of modern energy services in the rural areas has lead the populace to depend largely on biomass which not only are highly inefficient and environmental unfriendly but also cause health problems especially for women and children that are typically involved in domestic duties in Africa [3; 20].

### 4.3 Energy and Rural Development

Development is a socio-economic-technological process with the objective of raising the standard of living of the people. For this process to be successful, there is a need for adequate supply of energy to facilitate the growth in every sector of the economy. It is essential to consider the sustainability of the development and plan it in a manner that does not endanger the environment [20].

Nigeria derives the bulk of her wealth (e.g. crude oil, agriculture) from the villages in rural communities. Unfortunately, these villages have to depend on firewood, animal dung and fossil fuels such as diesel and kerosene as their source of energy supply. There is little hope for improvement in the standard of living of these rural inhabitants without the support of modern energy technology. The wide range of energy services, such as cooking, water pumping, water heating, lighting and refrigeration, can bring about development, which in turn can facilitate sustainable livelihoods, improve health and education and significantly reduce poverty in rural communities [3; 20].

It is widely believed [22-24] that electricity, a form of energy is required for basic developmental services such as pipe born water, health care, communications and quality education. And electricity increases other social activities as well as reduces poverty as a result of jobs creation and increase in small businesses (e.g. restaurants, barbershops, small grocery stores and bars). The lack of electricity in Nigerian villages has limited their activities socially, economically and educationally. Sambo A.S. [20] explained that the absence of modern energy has left the rural Nigerians socially backward and their economic potential untapped.

Providing energy services to the bottom of the pyramid people have been a challenge to the government of the developing countries. Rural areas are mostly populated with the very poor, and their inability to pay for energy services makes it difficult for energy companies to extend their services to them. This problem is likely to be exacerbated when the Federal Government of Nigeria (FGoN) concludes its plan to privatize the country's electricity industry. Without proper policies, that will mandate the potential private companies to supply rural people electricity or proper incentives to attract these companies to rural areas. It is difficult to see the rural households with their low purchasing power and remote locations attracting private investors in the power industry.

The World Bank studies on off-grid rural electrification projects further buttresses the point on the effects of privatizing electricity generation and distribution sector on the low populated, sparsely distributed rural households living in off-grid areas [22]. According to the study, there was an influx of private energy utility companies into the energy sector of developing countries in the 1990s which compound the energy problems of the rural areas. The private utilities companies were set out to maximize their profits and had concessions contract that limited their service to the households that were located near the grid. Utilities had little or no incentives to connect households that were located beyond this limit because unit connection costs are higher and rural customers are generally poor and can only be charged below the marginal cost of service.

For similar situation to be avoided in Nigeria, there is a need better policies formulated to guide the eventual private utility companies that will invest in the country's energy sector on rural electrification and the need to connect the majority of Nigerians that are not currently on grid.

For the rural people to contribute meaningfully to the socio-cultural and economic development of Nigeria there is a need for rural development programs, such as modern energy, to be a priority of the three tiers of the government in the country.

### 4.4 Finding Solution to Nigeria Rural Energy Problems

Constant electricity supply will go a long way in alleviating poverty in Nigeria, most especially in the rural areas. The effect of electricity is not limited to poverty alleviation: elevated standard of living; increased social awareness; better education and communication will also be achieved with the penetration of electricity into rural communities. Rural residents' access to electricity will also help the country in meeting some of her Millennium Development Goals.

The centralized supply of power generated by conventional method using fossil fuel is proving to be uneconomic as well as unmanageable as far as supply to rural areas, especially remote places far away from the grid are concerned [21]. With the decentralized approach based on supply of power produced with renewable energy resources available locally being recognized as a viable means of  supplying power to rural and remote areas, it is time Nigeria followed suit and found a lasting solution to her rural energy crisis.

Sambo [20] suggests that the logical solution to rural energy poverty of Nigeria is for the government to harness the abundant renewable energy potentials in the country. The types of distributed energy generation adopted now depend on the local energy resources of each rural community as well as their most energy need and energy demand. The Federal Government through the Energy Commission of Nigeria (ECN) has funded some pilot solar (PV) electrification projects around the country. This was to demonstrate the PV viability and to generate public awareness for their applications.

In addition, there has been other government attempts to find a permanent solution to the rural energy problem. Among them is the Renewable Energy Master Plan (REMP) that was drafted in 2006 to increase the share of renewable energy in the country's energy mix. REMP focus on mapping out ways by which national development can be achieved by exploiting the renewable energy resources of the country. It was meant to provide the framework for raising the standard of living, especially of the rural people among others [24]. The plan, if properly implemented would go a long way in solving rural energy problems.

# 5 Use of Electricity in Rural Communities

Electricity in rural communities can be used for residential, industrial, agricultural (usually for irrigation), and commercial purposes. However, the most common use for electricity in rural communities is domestic. According to the World Bank, the rural electrification projects financed by the organization were majorly focused on residential end users [25].

## 5.1 Energy Ladder

Energy ladder is a process where households shift from low-efficiency fuels to high-efficiency ones, as their income per capita increases. Biomass fuels such as dung and fuelwood are at the bottom of the energy ladder while electricity is at the top. Due to their generally poor income, the majority of rural households are at the bottom of the energy ladder. Studies have shown that the poor are the least able to take advantage of moving up the energy ladder from biofuels to electricity because of the connection charge barrier [25; 26]. In some cases over 80 percent rural households did not connect to the grid, a decade after their communities have been electrified [25]. This is to the rural's poor detriment as more efficient fuel like electricity is cheaper per unit of energy consumed [25].

The green house gases (GHGs) emission of Sub-Saharan African countries are minimal compared to many industrialized nations, yet one of the objectives of rural electrification in the region is to cut down on emissions by promoting more efficient alternative fuels. It then becomes essential for the success of the rural electrification programs to help rural households move up the energy ladder. More efficient fuels pollute less, and for basic fuels, the transformation of matter into energy takes place in or near the home, so the pollution is more concentrated and closer to the user. Therefore, moving up the energy ladder has positive environmental as well as health effects.

## 5.2 Domestic Use of Electricity

Energy ladder is present in the use of electricity for domestic purposes. It progresses from lighting, through television, to other small appliances and then to refrigeration, cooking, and finally to air conditioning.

Lighting is the most common domestic use of electricity in rural communities. It helps the women save day-light time by shifting some of their domestic chores to the night. The children benefit from the brighter light to study. Electricity provides more and better lighting at lower cost than the alternatives, candles and kerosene lamps, for most households [10; 25].

Television and radio are the second most common domestic use for electricity. The World Bank surmised in one of its reports on benefits of RE that nearly half of the electrified homes in rural areas have a television [25]. About the same amount of households have radios, but it was suggested that ownership of radios is not due to grid connection because they can be easily powered by batteries. However, grid electricity is cheaper than battery power; thus, electrified homes listen for longer hours. It is also stated in the same study that not owning a television does not restrict people from viewing one in rural communities. People, especially teenagers, go to friends' and relatives' houses to watch television.

Cooking as a domestic use of electricity is not popular in rural areas. Less than one percent of rural homes use electricity for cooking [25; 27]. The only exception was in Asian countries where rice cookers are a regular purchase for electrified homes. Table 1 below shows the type of fuel commonly used for cooking by rural people in some African countries.

*Table 1. Percentage of fuels used for cooking in rural households in selected African countries [21].*

| Country | Firewood | Gas, Kerosene | Charcoal | Electricity | Other |
|---|---|---|---|---|---|
| Central African Republic | 100 | 0 | 0 | 0 | 0 |
| Guinea | 99 | 0 | 1 | 0 | 0 |
| Guinea Gambia | 97 | 1 | 1 | 0 | 0 |
| Mali | 97 | 0 | 0 | 0 | 2 |
| Tanzania | 96 | 0 | 3 | 0 | 0 |
| Madagascar | 94 | 0 | 5 | 0 | 0 |
| Uganda | 94 | 2 | 4 | 0 | 0 |
| Kenya | 93 | 2 | 4 | 0 | 0 |
| Ghana | 92 | 1 | 7 | 0,1 | 0,2 |
| Burkina faso | 91 | 1 | 1 | 0 | 7 |
| Niger | 90 | 1 | 0 | 0 | 9 |
| Cote d’ivoire | 89 | 1 | 2 | 0 | 8 |
| Zambia | 89 | 0 | 9 | 1 | 1 |
| Botswana | 85,73 | 14,1 | 0 | 0,03 | 0 |
| Senegal | 84 | 2 | 12 | 0 | 2 |
| South africa | 49 | 23 | 5 | 21 | 2 |
| Djibouti | 44 | 48 | 5 | 1 | 2 |

There are many reasons attributed to why electricity is not used for cooking in rural communities. One reason is cost; many poor homes cannot afford the initial connection cost and the ones that do connect are conscious of the rapidly running wheel of electricity meter whenever an electric cooker is turned on. Another reason is tradition: some rural people believe that food cooked over wood or charcoal tastes better [25; 27]. Refrigerator ownership is reported to be low, with less than one in five electrified homes. Perhaps this is due to the low income of rural inhabitants [25].

## 5.3 Communal Use of Electricity

### 5.3.1 Health centers

Rural health centers can benefit from electricity in two ways: they can open for longer hours and can acquire the necessary electrical equipments. The World Bank analysis of health center survey data for two countries, Bangladesh and Kenya found that health centers with electricity open for an average of one hour longer each day [25].

Electrical equipment such as fan for adequate ventilation, electrical medical equipments for minor surgeries are needed in the rural community health centers. They also need refrigerators, which are most easily and cheaply operated be electricity, to store vaccines in the appropriate temperature. This helps bring down the cost of immunization, thus making it more attainable for the rural people.

### 5.3.2 Water pumping

There is lack of adequate water supply in many rural communities. I witnessed this when I was involved in a rural electrification project in Odighi community, Edo State, Nigeria (see Appendix 3). The people of the community travel over a kilometer to fetch water from a stream. The people often rely on rain water for their water consumption and have developed various methods of collecting and storing rain water. But rain water is not always available throughout the year.

Water pumping is a typical example of productive, as well as communal use of electricity that is essential for the well being of rural communities. The pump is usually located far away from the grid and is driven by either windmill – rural best practice for many decades – or by a diesel or PV generator. Water pumping is a specifically suited application for PV in Nigeria because of abundant supply of sunshine throughout the year.

# 6 Rural Electrification and Rural Development

The prevailing ideas of development economics in the mid-1900s considered rural electrification as a way of attaining rural development [28]. But the last two decades have seen a total reversal of the idea. The earlier perception that rural electrification drives rural development has been shelved. It is now believed that under certain circumstances the development phase may lead rather than follow rural electrification [28].

In America and other developed nations, investment in public infrastructures (roads, railways, electricity) in rural areas created employment opportunities for the locals, thereby triggered development [28]. What happened in America at the time was massive production of electricity with the belief that consumption of electricity will increase with availability of cheap electricity supply. The same method was attempted in Africa, but important constraining factors such as dispersed rural population, low purchasing power, and limited potential for load growth were overlooked. Also rural areas were located far away in difficult geographical terrains, thereby discouraging electricity providers due to high operational, maintenance, and administrative costs. Because of these constraints, the projections that demand for electricity will follow supply of power to rural areas in Africa did not occur [28].

In the view of recent developments in the last two decades, the relationship between rural electrification and rural development was re-evaluated. The conclusion was that rural electrification was a necessary but not sufficient condition to bring about rural development [28]. In a 1995 review of the World Bank's rural electrification projects in Asia and other developing economies [28], the Bank's operations evaluation department concluded that there is no evidence to support the claim that rural electrification can induce industrial growth in low-income economies. It stated that rural electrification has not, by itself triggered industrial growth or regional development. The study found that the demand for electricity for productive uses did not grow where other requirement for sustained development were absent. The study concluded that rural electrification is economically justified only when there is enough demand to guarantee reasonable rate of return on investment [28; 29].

The World Bank's position has since changed based on recent evolvement of rural electrification. The Bank, in the light of recent studies now justifies, economically, investment in rural electrification. The economic justification of RE was based on the assertion that there is possibility for return on investment in rural electrification in the long run [28; 29].

### 6.1 Rural Electrification and Millennium Development Goals (MDGs)

Another perspective is to try to understand the value of rural electrification in contribution towards rural development and poverty alleviation. A good example of this is the contribution of rural electrification towards achieving Millennium development goals. MDGs are United Nations' frameworks that consist of eight different international development goals that are to be achieved by the year 2015 [30].

The objective of MDGs is to end world poverty by promoting access to universal primary education; promoting gender equity; reducing child mortality rate; improving maternal health and ensuring environmental sustainability among others. The role of energy in achieving some of these goals cannot be over emphasized.

Application of energy can be used to support the important development like access to education, health, communication and women empowerment [25; 26; 31; 32]. Empirical evidence based on some studies [25] show that households are likely to earn higher income if provided with both education and electricity in relative to if they were only provided education without electricity. Access to electricity is correlated with significant educational achievement according to a World Bank's socio-economic studies [25]. With other important factors being equal, children from electrified homes are educationally ahead for about two years compared to their counterpart from non-electrified homes. Rural children from electrified homes are able to dedicate a significant amount of their evening time to studying rather than carrying out domestic chores like their counterparts from non-electrified homes [25].

Improved health is another important MDG that will greatly benefit from access to electricity. Access to electricity enables rural women watch television where they gain crucial knowledge related to health and family planning [25]. Access to electricity makes domestic chore of women easier, thus freeing up some of their time to run other important errands such as visiting clinics. Furthermore, access to electricity can enable rural people gain access to modern technology such as internet and wireless devices to fight pandemics such as malaria and HIV/AIDS that are common in Africa [25]. Access to electricity also helps to attract and retain professionals like doctors, nurses, and teachers that would have otherwise preferred to live in the cities [25; 26]. It enables the professionals working in rural areas to enjoy services like communication and entertainment from television. They also believe that their tasks will not be hindered in any way due to absence of electricity.

Poverty alleviation, the main goal of MDGs can benefit immensely from rural electrification. Jobs creation can help reduce poverty and induce rural development. Access to electricity help create jobs by increasing the numbers, incomes, and productions of small scale enterprises (SMEs) in rural communities [23; 28]. The production and increase in activities of SMEs also drive the demand for electricity up, thereby helping in recouping the operating costs, and increasing the return on investment of rural electrification.

The relationships between rural electrification and rural development have been discussed thus far. It has been established that access to electricity in itself does not single handedly bring about social and economic progress to rural areas. However, it is an essential element that drives rural development.

# 7 Benefits of Rural Electrification

## 7.1 Health Benefits

### 7.1.1 Indoor air quality

Animal dung, fuel-wood, and crop residue are examples of traditional fuels that expose women and children to indoor air pollution [25]. The exposure can have consequent effects on health such as respiratory infections, low birth rate, infant mortality and pulmonary tuberculosis [25]. Women and children are most affected because of their domestic roles in rural settings. The World Bank's studies revealed that exposure to indoor cooking using traditional means increased the risk of premature death by a factor of about two to five [25]. Close to two million people, over half of them children younger than five, died annually as a result of diseases caused by indoor air pollution [25]. There is also a fire risk associated with using these traditional fuels to cook. In addition, women and to some extent children, spend about 8 hours a day on fuel collection, time that could be used for other productive exercises.

Indoor air pollution is not only a result of using traditional fuels to cook but also a result of using kerosene lamps for lighting. Kerosene lamps emit small particlesthat cause health hazard.

Candles are widely used in rural Nigeria, especially among students. They rely on its illumination to study at night. According to a 1999 Australian study, the lead used in candle wicks results in air lead concentrations at levels exceeding the established safety standard [25].  Burning a candle in an enclosed room for some hours, results in lead concentrations sufficient to harm the mental development of children and cause fetal damage [25]. Many developed countries have banned the use of lead in wicks after the study, but these bans do not extend to candles shipped to developing countries like Nigeria.

Theoretically, rural electrification can help solve these health issues by promoting better health through reduced air pollution and reducing the time burden on women and children of fuel collection. But due to the fact that electricity is not largely used by rural inhabitants for cooking, these problems have been little realized in practice. However, improvement can be realized by replacing kerosene lamps and candles with electric lamps, thereby reducing indoor air pollution.

### 7.1.2 Knowledge and fertility reduction

Increase in population is one of the problems that hinder the development of Nigeria [34]. The annual population growth of Nigeria is 2.55 percent and the total fertility rate stands at 5.38 children born per woman (2012 estimate.) [35]. The population is estimated to increase to over 250 million people by 2050 from its current 170 million if the current growth rate is not curbed [36].

To help check the growth in the population, it is vital to promote and disseminate the appropriate knowledge necessary to facilitate fertility reduction both in urban and rural Nigeria. Lack of family planning knowledge is endemic in rural Nigeria as a result of lack of information. Rural electrification can help solve this problem by exposing the rural populace to the media for necessary information. Access to television is one of the impacts of rural electrification, which as a result leads to more access to knowledge and information. Figure 3 below further illustrates how rural electrification impact on women's health and knowledge.

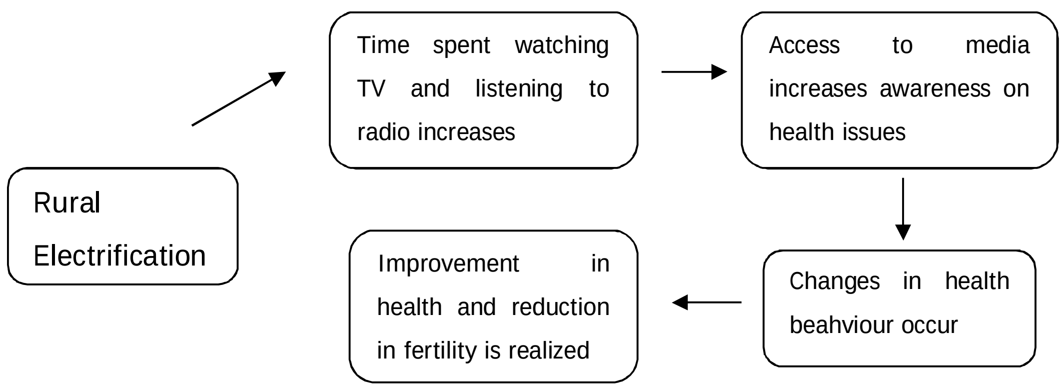


*Figure 3. Impact of rural electrification on family planning (adapted from [25]).*

### 7.2 Social Benefits

The goal of rural electrification programs in developing countries is limited not only to providing alternative to conventional energies but also to raising the standard of living of the rural people, thereby improving their quality of life

Rural electrification can impact greatly on the time use of rural inhabitants. Electric lighting enables people to undertake a range of activities in the evenings, both at home and outside of their homes. Children utilize the extra hours available in the evening as a result of bright lighting to study and do school assignments. Mothers are able to extend the domestic chores that are usually rushed in the day time to the evenings. Adults have more time for entertainment, socializing, and participating in community activities [25].

Public facilities such as schools and community buildings can be used for activities that go beyond daytime. Electricity for television and radio gives people access to mass media for entertainment and information. Communications to the outside world through internet and mobile telephones is made possible with electricity [25].

In addition, rural electrification may facilitate access to safe drinking water with the use of electric pump. Electricity is important for the local and small health centers in rural communities for the preservation of vaccines. Security in the rural and remote area is enhanced with the aid of street lighting [32]. Access to electricity in rural areas can stimulate the penetration of refrigerators, hence improving preservation of food.

Electrification has increased gender equity and awareness among rural women [31]. Installation of TV in homes has made women to be more aware of political events going on in the world. This has boosted their confidence to speak up to defend themselves and take on more leadership roles in the community, opportunities that wouldn’t be otherwise available to them due to the cultural set up of rural communities. Men are held above women and automatically assume leadership positions, even in the areas where the decisions made affect women’s lives [31; 32].

Electricity saves time for women from their domestic chores, which means they have time to participate more in events that affect their lives. In addition, freeing up time for women creates opportunities to engage in small businesses or other income generating activities. Women with income are economically empowered and have a better status within the household [37].

According to Nigeria Bureau of Statistics, rural women have a higher illiteracy level than men [16]. Women are also believed to be more inclined to attend literacy classes [37]. Provision of electricity provides educational opportunities (see education benefits). A higher level of literacy will empower women to be more active in decisions making, to take part in political discussions, assist and encourage their wards with their school homework, understand medical prescriptions and handle money with more confidence [37].

Another social benefit of rural electrification is in rural-urban migration. With the availability of amenities such as electricity in rural communities, people are less inclined to migrate to urban cities [38]. The rural people benefit from the influx of professionals into their communities as a result of availability of electricity and other energy services.

### 7.3 Education Benefits

Education benefits through electrifying rural communities can be realized by improving the quality of schools with the provision of computers and other electricity dependent equipments; attracting and retaining teachers; provision of night classes and distant learning opportunities; increasing time allocated to study at home by students, and access to educational programs on television.

Households with school age children in rural Tunisia cited education as the number one benefit of electricity when polled years after completion of electrification in their area [32]. They stated that the recent electrification in their community has lead to improvement in school performance of their wards.

Avoiding eye problems from using candles and kerosene lamps to study was also another benefit attributed to the electrification of their village. School and public streets were also electrified which have directly increased the number of girls enrolled in school [32]. Families enrolled their female children to school as public lighting has reduced the risks of traveling to school. The schools benefit from electrification as students were asked prior to electrification to bring their own candles to school especially during the dark hours of winter. All these aforementioned reasons were believed to have contributed to about 65 percent increase in graduation rate in these rural communities [32].

Children in electrified communities attained higher education levels than those without electricity. Although other factors may account for this, for example education level of parents and school facilities, there are many studies that claim that rural electrification has a direct impact on rural education [25; 27].

Furthermore, rural electrification ensures that schools in rural communities are able to attract and retain quality teachers. Teachers in rural schools are often absent from school, and many of them do not want to live in rural areas because of lack of basic amenities like electricity. It was claimed in a report by Asian Development Bank [27] that availability of electricity makes rural positions more attractive to teachers. This greatly improves the quality of teaching in rural school, thereby encouraging students to stay on longer to attain higher education.

### 7.4 Economic Benefits

The use of electricity for productive economic purposes in rural and remote areas is limited. Nonetheless, there has been a modest impact of electricity on agricultural development, small scale and home businesses, which in turn has lead to economic growth of rural areas.

There are several studies with varied conclusions on the impacts of rural electrification on agricultural development. Mason [cited in 26], after investigating some World Bank projects in developing world, concluded that rural electrification had some impact on agricultural development in a few countries where irrigation is a common practice, but very little in others. She also concluded that there was a modest growth of new businesses as result of rural electrification impact on industrial and commercial development.

Schramm [cited in 26], in his study argues the opposite of Mason’s claim. He believed that electrification by itself has never been a catalyst for economic development. He implied that the impact of electrification on agricultural growth is often overestimated. He also stated that there is little evidence that electricity by itself results in new agro-industries, commercial or small scale industrial activities. Munasinghe [cited in 26], corroborates Schramm when he stated that overestimating productivity growth in the industrial and commercial sectors when evaluating electrification programs happen regularly. He believes that rural electrification encourages growth in the overall commercial activities but it is difficult to clarify the exact direction it takes. He also reported that RE of rural areas in the third world countries promotes agricultural development best when other infrastructures like electric pumps and financial services are in place.

Other studies like that of Hourcade et al. [cited in 26] reported that the best way to stimulate economic growth is to select the rural areas that are ready for sustained growth for electrification. It was argued that the more developed an area, the greater the impact of electricity on the local economy. The conclusion was that rural electrification is a ‘‘selective catalyst’’ in the sense that regions already well equipped with infrastructures such as transportation, water systems benefit from rural electrification while less developed areas cannot.

All of the aforementioned authors based their studies on the projects completed in the 1980s and earlier decades. The rural electrification programs implemented in the recent years suggested that there are positive economic results.

Davies et al. [cited in 25] examined the impact of electrification on a small rural community, six years after electrification. The results were based on comparative analysis as a base line study was conducted prior to electrification. The conclusion was that electrification indeed triggered local economy development. New businesses and employment opportunities were created. About ten percent of the relevant annual salaries were estimated to be as a result of electrification.

Vogel [cited in 26] argues that many rural electrification programs seem unappealing for profit oriented projects such as power plants and factories which are based on the returns that can be generated internally. He therefore believes economic and financial analyses of rural electrification projects should focus on least cost approach instead of an economic cost-benefit analysis, which usually relies on uncertain data in rural areas. He argues further that rural electrification should be regarded as part of infrastructural project that is meant to aid rural development. It does not belong to profit-oriented projects but to the category of public infrastructure. He suggested that rural electrification projects should be justified not on their individual profitability but on their contribution to achieving positive developmental impacts and to satisfy basic social need in general.

Vogel is of the opinion that rural electrification should not be seen in isolation from the overall development level. He believes that a rural electrification program should not only be based on the wishes of rural people to benefit from the comfort of services requiring electricity supply. But rather be justified in connection with factors such as:

- Identified activities of economic potential which could not, or fully appreciated without electricity access.
- The willingness of the community and their political representatives to reallocate surplus and funds to develop rural areas.
- The ability to cope with the organization and financial requirements by the institutions implementing, and benefiting from the programs.

He concluded that with the above reasons, rural electrification is unlikely to be just a heavy burden on fragile economies without having a significant impact on regional and national development. Instead it could bring about positive changes such as diversifying the economy, creating employment, improving general living conditions, and reducing urban-rural disparities.

### 7.4.1 Reduction in energy costs

Electricity consumers are likely to enjoy a reduction in energy costs for their existing appliances [38]. The purchase of batteries for running radio and the costs of generators in some households to operate their television will not be necessary as these appliances can be fed with electricity through a socket. The cost of grid electricity is much less than the energy costs of services driven by its alternatives [38].

### 7.4.2 Employment opportunities

Rural electrification is likely to stimulate direct employment opportunities by the implementing utility and their subcontractors for installation of power cables, grid infrastructure, operation and maintenance, as well as services such as marketing and administration. SHS encourages home businesses in areas where grid electricity is too expensive or absent [25; 38]

### 7.4.3 Micro home enterprises

Electrification may provide opportunity for small business activities that help offset the costs of electrification [25]. Examples of these are abundant in World Bank assisted projects in some African countries. In Ghana, a woman of an electrified household prepares snacks to be sold to people who come to her house to watch television in the evening. Another example of this is in South Africa where electrified households sell cold beverages and rent out refrigerator space [25]. Electricity also allows shop owners open to customers long after daylight as can be seen in Figure 4 below.

*Figure 4. A rural village shop at dusk, lit by solar lamps. Source: World Bank Photo Library [25]*

### 7.5 Safety

Electricity, besides bringing comfort and convenience, also makes live safer and easier in rural communities. Electric lights offer protection against animal and human predators, especially in the remote and far away villages. Some villagers reported that snakes left their home after electricity was installed [27]. Crime has also reduced in some areas, especially at night after the installation of many street lights [32].

In Bhutan, some rural electrification beneficiaries stated that electricity assists them to protect their harvests from wild animals [27]. According to some of them, crop loss due to pests is as high as forty percent. Before electrification, and a few weeks before harvesting, villagers would stay up all night protecting their crops by chasing away wild animals from their fields to avoid their crops from being consumed or damaged. With electricity, electric lines can be extended out to illuminate the field and scare away the unwanted pests.

In addition, rural electrification has lead to reduction in fire risks and occurrence. It is not uncommon for little children to accidentally drink kerosene in the absence of bright light. Villagers also mentioned some instances where children have tumbled on kerosene lamps and burned themselves or caused house fires. These accidents are reported to have reduced after electrification [27].

### 7.6 Environmental Benefits

Environmental benefits of rural electrification can be fully appreciated when both the grid and off-grid connections are examined. The grid connections mainly involve transmission and distribution [25]. Therefore, unlike power generation projects, it has limited direct environmental impact. Grid rural electrification is believed to promote increase in energy consumption which leads to increase in $CO_2$ emissions [25]. However, the emissions are partially offset by the other traditional fuels displaced.

The off-grid energy supply mainly relies on renewable energy technology (RET), and the most common is solar home systems (SHSs). Installation of RET generation capacity displaces the existing non-renewable energy sources such as kerosene, thus creating an environmental benefit. The most important environmental benefit of off-grid electrification is reduced $CO_2$ emissions [25]. However, estimating these emissions is difficult due to absence of baseline for the displaced fuels and the rate of reduction over time.

Black carbon is an air pollutant that can be reduced by rural electrification. Also known as soot, it is a harmful air pollutant that contributes to climate change. Scientists believed that it is second only to $CO_2$ in the amount of heat it traps in the atmosphere. Black carbon belongs to a class of air pollutants known as particulate matter. Particulate matter consists of small particles of dust, soot and wood smoke particles that have become suspended in the air. One of the sources of black carbon is the incomplete combustion of wood.

Another environmental benefit of RE is in the replacement of dry cell batteries used to power radio and television prior to electrification. In a survey carried out in rural Bhutan, averages of six batteries were used in a month [27]. Add these up and the numbers of exhausted batteries pile up in a year. The exhausted batteries are disposed of in the forests, rivers, or nearby streams, thereby contaminating the environment.

### 7.7 Deforestation

It has been argued that electrification of rural villages is directly proportional to less deforestation as a result of reduction in wood fuel use [27]. However, there is insufficient data on the impact of rural electrification on wood fuel use. Many people in the rural homes continue to cook on wood stoves years after electrification. The exception is perhaps in Asia where rice cooker is an important part of every household [27]. It is suggested that the reluctance of rural people to abandon wood stove cooking to electric cooker may be due to cultural rather than economic reason. A socioeconomic study in Namibia found little impact of rural electrification on deforestation [27].

The study found a correlation between electrification and reduction in consumption and demand for other energy sources. In addition, it stated that only few households made a total switch to electric cooking and the majority of the electrified households still preferred wood fuel to other energy sources for cooking. The study also went further to state that fuelwood sourcing is not a major cause of deforestation in most communal rural areas [37].

# 8 Rural Electrification Options

Reliable electricity supply is a basic necessity for improving people's lives in rural communities; for better health care and education, as well as for local economy's growth. Therefore, it is essential to find ways of bringing electricity to the rural populace. Three different technical options of bringing electricity to rural areas are discussed in the following sections.

## 8.1 Grid Extension

The first option is simply to extend the national electricity grid. However, rural communities in Nigeria are often sparsely populated and located in remote areas. They are far away from the existing national electricity grid, making grid extensions too expensive for the government and utility companies [23; 39]. Another factor is that the size of the demand determines the cost per KWh of expanding the grid [39]. Rural areas are usually small in size and their use of energy limited. In places where there is no electricity whatsoever, the potential demand needs to be precisely calculated. Due to the associated costs, grid extension to an isolated village is only feasible at a certain distance and as long as the village has enough demand to reach 'critical mass' [23; 39]. In villages where there is not enough demand potential, the most cost effective option is off-grid electrification [23]. Advantages such as reliability, cheaper costs (in the long run), and economies of scale are associated to grid connection compared to off-grid options [39]. However, it is important to note these issues:

- The electricity provided by PHCN in Nigeria lacks the security of supply and quality of the developed countries. In most parts of the country, consumers do not have access to uninterrupted supply of electricity, and cases of total blackouts or brownouts are common. Also grid extension increases demand, and if there is no subsequent increase in generation capacity – as it is often the case in Nigeria where there has been total neglect of electricity sector – adding new consumers will only exacerbate the situation and further reduce the quality of service.

- Grid extension is often used as a tool to gain political advantages. Grid extension electrifies more users and faster than off-grid electrification. Therefore, politicians tend to prioritize the extension to semi-urban areas with more population so as to maximize their political support [39]. It is not uncommon for politicians to go to rural villages in Nigeria, especially before election promising them infrastructure development just to get their votes.

Once it is established that grid extension is not economically justified for connecting an un-served community, the next step is to decide which off-grid technology or technologies is suitable. Figure 5 below illustrate the technology path way to finding the best solution of bringing electricity to the un-served rural communities.

### 8.2 Energy Home Systems (EHS)

The second option of bringing electricity to rural communities is through different energy home systems. Using any of the home systems approach will depend largely on the proximity of the households to each other, and the types of load required. A small power system can be built for a village. But the viability of such projects relies on the distribution grid cost among other things [39]. In a village where the population is sparsely distributed, covering a large area will require higher connection cost, due to longer distribution lines. In cases like these, stand-alone systems are the better alternatives. Solar home systems (SHS), small wind systems, or small hydro systems are the best solution to provide energy to isolated households [23; 33; 39].

The power generated in these stand-alone systems is installed close to the load; hence no transmission or distribution costs [39]. However, due to the lack of economies of scales the total cost of energy is higher with these systems. In order to keep the prices affordable the components are minimized and capacities low, just enough to provide power for domestic uses (lighting, TV, cooling, communications), productive uses (water pumping, sewing machines, mills) and public uses (schools, health and maternity clinics, street lights etc) [33; 39].

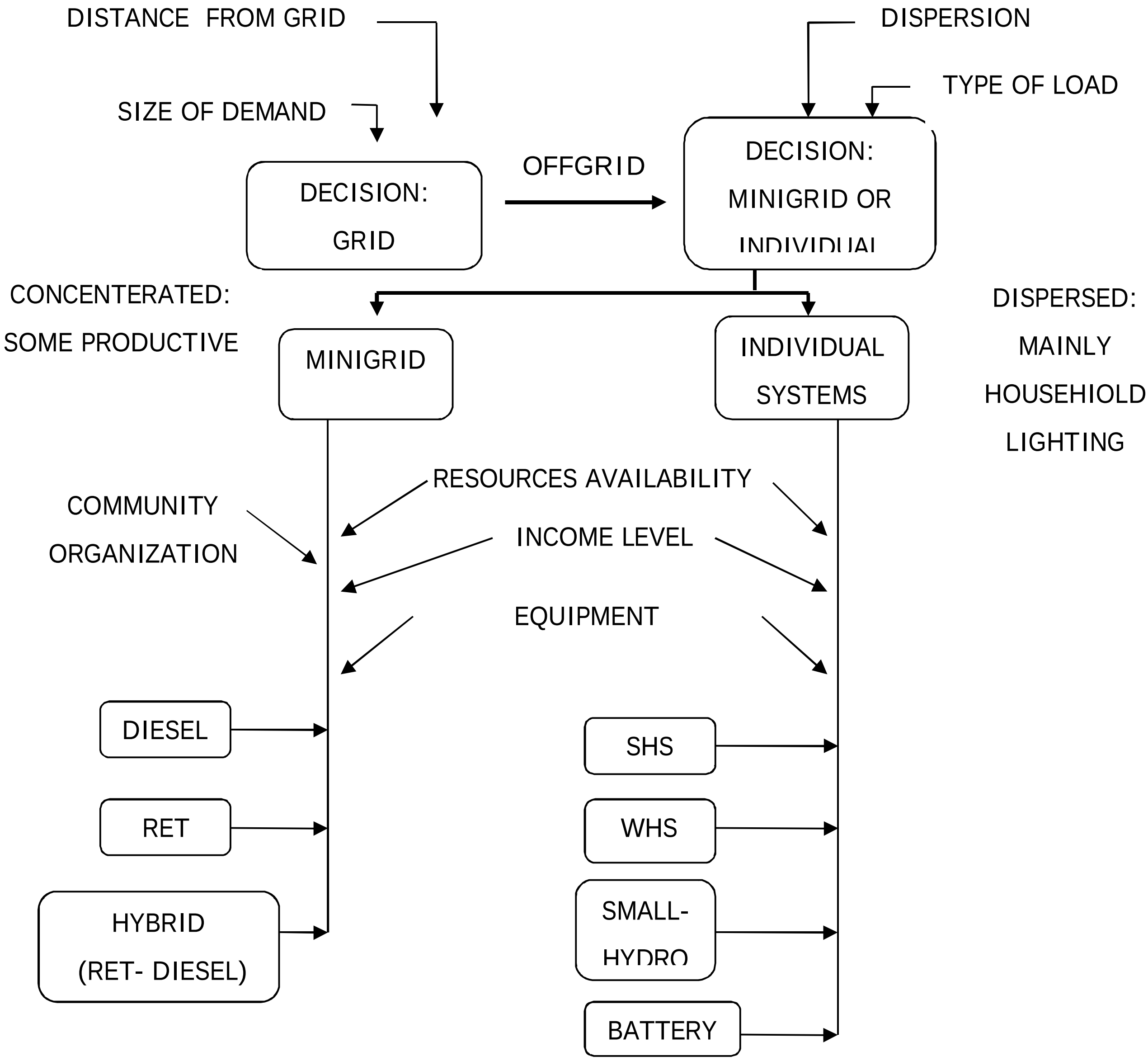


*Figure 5. Technology options for off-grid rural electrification. Adapted from World Bank [39]*

## 8.3 Mini-Grid

The third and last option is the mini-grid system, where centralized electricity can be generated and distributed at the village local level. Mini-grids can provide for both domestic appliances and local businesses, thereby enabling rural communities to create jobs and other productive services [23; 39]. Customers far away from existing grid, as is the case in many rural villages, can be served using mini-grids. This method is encouraged in villages that are fairly densely populated to avoid costly distribution wiring. The distribution system is similar whether served by a diesel generator, renewable energy source, hybrid systems, or a central grid [33]. Due to this similarity, mini-grids have the advantage of being upgraded through grid connection later in the future [33].

The energy resources used to generate electricity will depend largely on the village load profile, local renewable energy resources, and fuel transportation costs [33; 39]. In recent years, calculations of life-cycle costs show that hybrid mini-grids powered by the combination of renewable energy and diesel generator are usually the most competitive technical solution [39]. However, it is proving difficult to translate the great potential of hybrid systems into real success stories. Deploying hybrid mini-grid system is believed to be difficult, not for technical reasons but for financial and organizational reasons [39].

## 8.4 Hybrid Mini-Grid Power Systems

Hybrid power systems combine multiple power generation or storage technologies to create an electricity generation system that optimizes the characteristics of the individual generation sources [40]. A typical example is the PV hybrid systems that combine photovoltaic generation of electricity with energy storage (rechargeable battery) and use a (diesel) engine generator, commonly referred to as genset as a back-up.

Hybrid power system is a cost effective way of bringing electricity to the rural communities [39]. It can provide high quality and reliable electricity for lighting, communications, as well as motive power, among other services. It can operate autonomously with no connection to the national grid and provide almost the same quality of services as the national grid [39; 40]. It is also possible, technologically, to design a mini-grid to interconnect with the national grid and operate under normal conditions as part of the national grid with disconnection occurring when required (e.g. when there is a blackout) [39]. In countries like Nigeria, where the national grid only provides electricity for a few hours a day and is totally unreliable, the rural communities served by mini-grid could enjoy better electricity than their urban counterparts [39; 40].

Using a single technology and a generation source for mini-grid is less efficient and more costly than using different technologies with different energy sources [39]. It is believed that the combination of the renewable energy sources with a genset is the least cost solution of bringing electricity to the rural communities [39]. Choosing which renewable sources to deploy depends on the availability of the resource in the community at a specified time. Deploying different renewable sources can complement each other to accommodate seasonal fluctuations. For example, solar PV complements wind turbines when there is less wind or during dry season when there is less water flow for hydro [39].

### 8.5 Mini-Grid Technology Comparison

It is very important to consider different technologies before deciding on the best system suitable for a particular community. When assessing the suitability of a system, the two most important factors to consider are the cost structure of the system and the quality of service [39]. Renewable energy technologies and diesel generators have different cost structures. Diesel generators power systems have a low initial capital cost but a high operating, maintenance and fuel costs. In contrast, RETs have a high initial capital cost but low operating and maintenance costs [39; 40].

The other important factor is quality of service. Diesel generators provide energy on demand as long as there is adequate fuel. This means that they can adequately meet the energy demand of the rural communities as at when needed. Unlike the RETs that are subjected to daily and seasonal fluctuations.

### 8.5.1 Diesel Generators

Systems running entirely on diesel generators have the advantage of being dispatchable on demand, i.e. can deliver electricity whenever needed [39]. Though, the ability to run the diesel generator does not always match the availability of fuel to run it. Nearly all rural communities in Nigeria lack good road network which makes the fuel to run the generator(s) powering twelve households or more for many hours a day difficult to come by [15]. It is important to also factor in local environmental conditions. Diesel generators are noisy, produce green house gases and other air pollution. They also have a direct health impact on the users when sited close to the house [39].

### 8.5.2 Renewable Energy

Many batteries with large capacities are required for power systems running entirely on renewable energy so as to have electricity available at all times and as at when demanded [39]. In order for the power systems to provide reliable quality of service, there is need for bigger generation capacity than diesel generator or hybrid power systems in order to produce excess electricity to store [39]. Batteries’ lifetime is reduced as they are constantly subjected to high stress. This inevitably increases the costs compared to the other power systems. Without a diesel generator back up, any significant deviation from the expected daily load profile or unusual bad weather conditions can potentially collapse the system or necessitate load shedding [39].

### 8.5.3 Hybrid Power Systems

Hybrid power systems usually utilize renewable energy to generate about 75 to 99 percent of the total electricity supply [39; 40]. It is reported that in some cases that diesel generators were installed for back- up but hardly ever used due to the good performance of the renewable energy system [39]. The diesel generators in these systems are only used as back-up to assist in periods of high load or when the renewable power is low. The large share of renewable energy in the systems makes it almost independent, thereby lowering the energy price on the long run [39]. Furthermore, the battery back-up size is lower and suffers less stress compared to the 100 percent renewable power system, which in turn prolong the battery lifetime and significantly reducing replacement costs [39; 40].

Hybrid system, in most cases is the least-cost and long-term solution in bringing the best energy services to the rural areas among the three alternatives [39]. Furthermore, it is important to consider the types of renewable energy technologies to be utilized in the hybrid system.

- Solar photovoltaic (PV) is suitable for almost any location in the world, most especially Nigeria with a high solar insolation (see Appendix 2). It is easy to install, maintain and scale up whenever the need arise. However, the initial capital cost is higher compared to other renewable technologies.
- Small or micro-hydro is the cheapest technology, but also the most location dependent. It requires a river with a certain flow rate and volume conditions. [39]
- Small wind turbine is also very site specific. Wind conditions vary significantly from site to site, therefore wind speed must be carefully studied before any system is installed.

## 8.6 Village mini-grid

Village mini-grids provide electricity to off-grid rural settlements, offering an improvement from batteries, solar home systems, and small diesel generators [40]. These systems are small and only supply a limited amount of power to meet basic domestic and productive needs. Single-phase, low voltage AC wiring is commonly used for this type of system to cover a small village with few households [40]. Figure 6 below shows a village mini grid in rural Indonesia.

The main challenge of rural electrification is designing a system that is affordable and sustainable over a long period for the people at the bottom of the economic pyramid. It is important to consider the social-economic and environmental conditions of each community in whatever technology deployed

*Figure 6. A mini-grid in a rural community comprising 24 KWp PV, 20KWh battery and 125 KVA genset. Photo adapted from Transenergie [40].*

### 8.7 Solar Home System (SHS)

This is suitable for a community where there are many isolated households to avoid costly distribution wires. A solar home system, as Figure 7 depicts typically includes a photovoltaic (PV) module, a battery, a charge controller, wiring, fluorescent DC (direct current) lights or LED lamps (for better efficiency), and outlets for other DC appliances [41]. A regular SHS can operate many lights, a small television, a radio, as well as a fan [33]. It can eliminate, or at least reduce the need for kerosene and candle. It can provide increased convenient and safety; improved indoor air quality; a better quality of light for reading; and generally elevate the standard of living of rural inhabitants [33; 41].

The size of the system determines the number of lights or TVs that can be used and for how long. For example, a 35 Wp SHS provides enough power for four hours of lighting from four 7W lamps every evening, and many hours of television (black and white) viewing. [33]. It has been estimated that more than half a million SHS is installed in rural areas of developing countries [33].

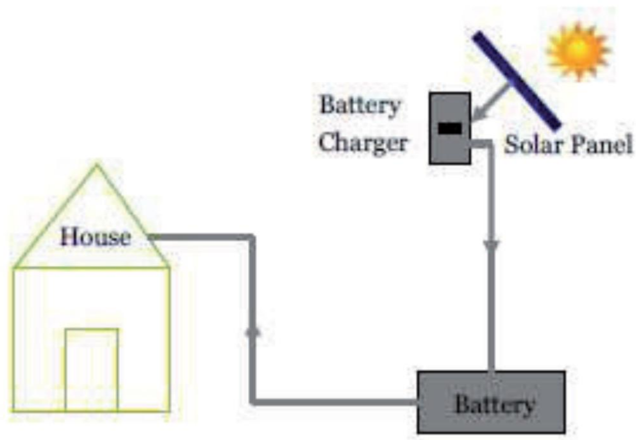


*Figure 7. A solar home system [41].*

# 9 Financing and Regulating Rural Electrification in Nigeria

Financing and operational issues are critical to the sustainability of rural electrification. For example, operations and maintenance, tariffs and subsidies, roles of private investors, and capacity building and training within the community are fundamental to the development of rural electrification programs [39]. The financial and organizational models to be followed in bringing electricity to rural communities should be marked out as early as the planning stage of RE projects.

With the ongoing privatization of electricity sector in Nigeria, it is of paramount importance that all the tree tiers of government try to entice private investors into rural communities. Left to private electricity providers, they would want to serve those that are able to pay for their services in the urban cities and neglect the rural people that are not economically attractive to them. Figure 8 below depicts different mechanisms by which rural electrification can be promoted.

There are many available models that can be used when implementing rural electrification programs. Some models that have been successfully implemented and can be replicated in Nigeria are examined in the case studies below. The NIPP model that was passed, not long ago, in Nigeria is also discussed.

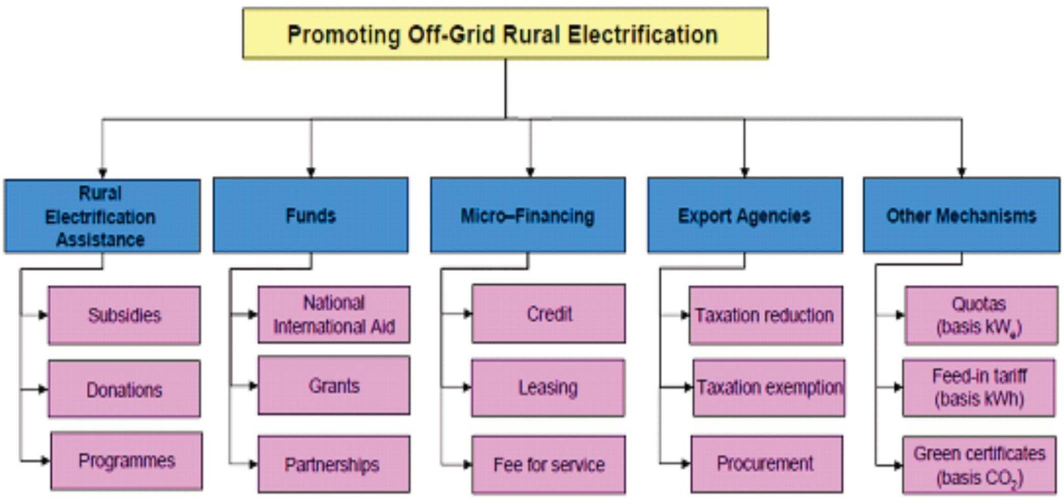


*Figure 8. Instruments to support rural electrification [39]*

**Case Study I: Concessionary Agreement Model – Public-Private Partnership (PPP)**

**The Argentina PAEPRA Program**

When Argentina started to privatize and reform its power sector in 1995, off-grid electricity to rural areas was integrated into the plan from the beginning [42]. The Argentina government divided provincial electricity service into two separate markets: the grid connected customers that are concentrated in the urban areas, and the off-grid customers that are located in dispersed rural settlements [42]. Through private rural energy service concessions, the PAEPRA (Programa de Abastecimiento Electrico de la Poblacion Rural Dispersa de Argentina) program aims to supply electricity to 300,000 households and 6,000 public facilities, e.g. schools and hospitals in rural communities [42].

Under the program, the provincial government set tariffs for particular types of electricity services. Companies are then invited to bid for a 15-year monopoly concession contract. The contract binds the concessionaire to service all households and public facilities within the province at tariffs set by the provincial government [42]. However, concessionaires hold the right to disconnect any customers that refuse to pay in a timely manner. The concessions receive subsidies from provincial government and the companies that compete do so on the basis of how little subsidy they are willing to accept [42].

Concessionaires are eligible to re-bid for their businesses every 15 years up to a total of 45 years, competitively against other eligible companies. The 15-year period was seen as a compromise between the need for a short period for the quasi-monopoly and a long period for the annuity calculations of the concession, hence the need for subsidy [42]. After the 15-year period elapses, the government can modify the concession rules to account for new technological developments or may even decide to abandon the concession system and open the market to competition [42].

This model is favored over others, such as competitive market with private dealers because of the following potential advantages [42].

- creates a market that is big enough for commercially sustainable business by granting exclusive rights over a large geographical area
- attracts bigger, and better organized private investors
- allows easier administration and regulation
- ensures long period of service to the consumer, i.e. the 15-year contract life of the concession
- reduces unit costs of equipment (through volume discounts), operation and maintenance (through economies of scale), and per-unit overhead costs
- brings better chance of covering a large number of customers in a few years

**Case Study II: International Aid/Grant – Public-Private Partnership (PPP)**

i. Two years after establishing the PAEPRA program, the Argentina government requested financial assistance from the World Bank and Global Environment Facility (GEF) to help implement the program in several regions [42]. The World Bank/GEF tagged the project ‘Renewable Energy in the Rural Market’. The project aims to electricity up to 66,000 households with individual SHS ranging from 50Wp to 400Wp in size, 1,100 public facilities with solar PV systems, and 3,500 households with village power systems using small hydro or different combination of hybrid systems. Concessions are free to choose which technology to apply but GEF grants only apply to installations of solar home systems [42].

ii. The concessionary agreement model was adopted by the World Bank/GEF in its 'Decentralized Rural Energy' projects in Benin and Togo, two West African countries [42]. The two projects are similar to each other. Monopoly concessions will be granted to two financially viable installation and service companies for 15 years. Like Argentina in case study 1 above, each concession will have exclusive rights to service a specific geographical area and will be responsible for installing and maintaining systems and collecting fees from the customers [42]. Each project aims to install 5,000 SHS (a combination of 20Wp and 50Wp systems totaling 125kWp) through these concessions over a 5-year period. According to the World Bank [42], concession model was adopted for the projects because the market survey showed customers preferred sale of service to sale of equipment; the approach helps establish local private infrastructure, among other reasons.

iii. The Netherlands sponsored a PV-based rural electrification using a rural cooperative (Cooperativa Rural de Electrificacion) in the department of Santa Cruz in Bolivia [42]. The project subsidized the installation of one thousand PV systems. The project also looked for ways to expand using the private sector, monthly fees-for-service, soft loans to end-users from municipal government, and payment of import duties for system components by the departmental government [42].

The UNDP/GEF project in Bolivia named, 'Renewable Energy Based Rural electrification Under the Popular Participation Law' tries to build on earlier experience in the country and pilot institutional models [42].

The 1994 Bolivia Popular Participation Law channels twenty percent of government revenues to municipalities, which can be used for rural renewable energy electrification [42]. The project will help to select rural electrification companies to procure, install and maintain the renewable energy systems. It will identify the best ways of utilizing public funds through the popular participation law. The communities will be given the opportunities to select among the institutional options such as NGO provision, direct private contract, municipally based options and mixed public-private corporations [42].

The project targets a mixed public-private *‘local electricity company’* contracting with users for provision of services. Flat monthly fees would be charged for SHS, while kWh tariffs would apply to mini-hydro systems [42]. The local electricity company would contract for maintenance and system support, and would receive subsidies from the government. The project plan identified 25 community-based projects where renewable energy would be economically viable. Nine of these projects are mini-hydro and 16 are SHS, serving 1,200 and 4,600 households respectively [42].

**Case Study III: Business Model – Public-Private Partnership (PPP)**

A typical example of PPP business model was in Goyola, a remote village in Guinea, West Africa where a private electricity supplier launched its services in 2009 [43]. The whole village has signed up for the service, and all of them pay their electricity bills on time. What made this particular service unique was its payment model. The villagers pay for electricity with the produce they grow, instead of cash which is hard to come by. It was simply tagged ‘rice for light’ [43].

A villager, Mme Péléora Koivogui, praised the innovative payment method, which takes into account the socio-economic realities of rural communities where cash is scarce [43]. She said the payment method is easier for them because they can pay directly with rice, palm or coffee instead of worrying on how to find money. ‘‘Now, our children can study at night and watch films or TV locally and we have cold water and drinks’’, she said [43].

Goyola is a community rich in agriculture, producing rice, maize, peanuts, coffee, bananas, and palm oil, at different times of the year. But marketing their produce is a difficult task; thereby the cash flow into the village is limited. This makes the residents reluctant in committing themselves to any services that require regular monetary payment. The private electricity operator, La Société Électricité Nakoloma De Goyola (ENDG) then came up with an innovative payment method that suits both the operator and the villagers. The villagers did not hesitate to sign up when they were told that both the connection charge and the tariff obligations could be met by payment in-kind, at market value. ENDG usually store the produce for three months before selling it in off season at the closest market. [43]

The Goyola's public-private partnership model for scaling up rural access was the winner in a call for paper innovative solutions to Africa's electrification challenges organized by the World Bank's African Electrification Initiative (AEI). The World Bank supports government's efforts to build PPPs through enabling policy and regulatory frameworks, capacity building and knowledge sharing. [43]

**Case Study IV: Business Partnerships - National Integrated Power Project NIPP**

Legislation passed in the year 2000 that supports independent power production, permits Nigerian states to build their own decentralized power plants, known as Independent Power Projects (IPPs) [3; 10]. IPP can be partnerships between the private sector and federal, state or local government. Some states in Niger Delta, the oil producing region in Nigeria, have partnered with international oil companies (IOCs) to develop and repair some power plants [3].

**The Egi Electrification Program**

This is an IPP and community development project carried out in partnership between Total and Nigerian National Petroleum Company (NNPC) [3]. The aim is to provide electricity to every community of Egi District, Rivers State, in the Niger Delta region. The associated gas from the nearby Obagi field is used to power a 13 MW power station. The electricity generated is distributed through a local transmission network. The project renovated, expanded, and activated the electricity network in communities already connected to the grid. It also includes a new transmission to connect the un-served communities to the grid [3].

IPPs provide an opportunity for the domestic use of flared gas, and also help companies meet their gas flare reduction goals. Gas powered IPPs benefit from generous tax incentives from the government and may also be eligible for carbon credits [3]. The current IPP approach prioritizes large-scale projects and on-the-grid communities. The challenge is to support more small-scale, off-grid community-based approach [3].

The IPPs in the southern part of Nigeria are most likely to use gas, since they are located close to oil wells, West African Gas Pipeline, and other gas supply infrastructure serving Lagos [3]. The IPP model could also benefit the people in the northern part and the Middle Belt region if applied to smaller-scale RETs [3]. A good example of this is the biomass based IPP, a joint venture between United Nations Industrial Development Organization (UNIDO) and Ebonyi State [3]. They signed a memorandum of understanding to construct a 5 MW power plant fuelled by locally sourced waste rice husks. Power generated from the plant will benefit local rice millers, farmers, small industries and local residents [3].

# 10 Discussion

It is important to take into account the socio-economic situation of rural villages when planning a village power system. There are many financial and funding instruments that can be deployed as discussed in the previous chapter. The NGO/grant model was used for the Odighi rural electrification project, where solar home systems were installed for 40 households (see Appendix 3). The project was a social one; there was little or no consideration for economical or productive use of electricity.

Planning a power system for the same or similar village would require the knowledge of potential productive use of electricity, as this will significantly improve the prospect for long-term sustainability of the project. It then becomes necessary to do an energy survey of the community. It is important to generate awareness in the society, of the advantages of off-grid power system. In the case of Odighi community, the villagers have been exposed to solar home systems, so they are partially aware of the benefits of off-grid energy systems.  The next stage would be to identify, and classify potential productive, commercial, communal and residential use of electricity in the village.

The model adopted in bringing electricity to rural communities will depend on the target area. For example, if the target area is domestic, it is important to identify the market segments. Typically, 2 to 3 percent of the inhabitants can afford cash payment for the service. With microcredit, the customer base can reach up to 20 to 25 percent. Micro leasing and longer-term fee-for-service arrangements may expand the market to about 45 to 60 percent. The rest of the inhabitants are at the bottom of the economic pyramid. These are the poorest of the poor, which may require fully subsidized social programs. For profit oriented private investors, the people at the top of the economic pyramid in rural communities is a market that is worth looking into.

The most common use of electricity in rural communities is domestic. The survey carried out after the completion of Odighi project showed that villagers prefer bigger and more powerful systems that can power all their electronic appliances. The system installed for them was just for lighting purpose. The survey also indicated that many villagers are willing to pay for electricity service if such service is available.

The conclusion from the survey was that private-sector led microenterprises for domestic electricity provision could be successful in Nigerian villages. The survey was limited to Odighi community; therefore further studies are needed in other communities in order to ascertain this claim.

## 11 Conclusion

Providing sustainable electricity services to the rural population has remained a challenge to the Nigerian government. Despite its vast oil and natural gas reserves and different renewable energy resources that can be used for domestic electricity generation, less than ten percent of rural people have access to electricity. Over 70 million people living in rural villages rely on firewood as their main source of energy.

Off-grid electrification offers the best solution to bringing electricity to the remote areas of the country. It is clean, sustainable and at present, the most economically viable method available to the rural populace. Solar PV or a hybrid combination of solar PV and any other locally available renewable energy resources can be used for off-grid rural electrification. Solar home systems can be used to generate electricity for domestic purposes, especially in isolated households and in cases where the load requirement is low. A PV based hybrid mini-grid system where centralized electricity can be generated and distributed at the village local level is a preferred option in communities that have high load demand potential. Mini-grids can provide electricity for domestic appliances and local businesses.

Majority of the rural people cannot afford the upfront cost of PV; therefore it is necessary to set up credit facilities and other financial mechanisms that would enable them attain their dream of having electricity in their homes. With the ongoing privatization of the power sector, the government should come up with policies that will mandate the private companies to extend their services to the rural areas. The state and local governments that are closer to the people should provide subsidies or other incentives for private companies in order to lure them to rural communities.

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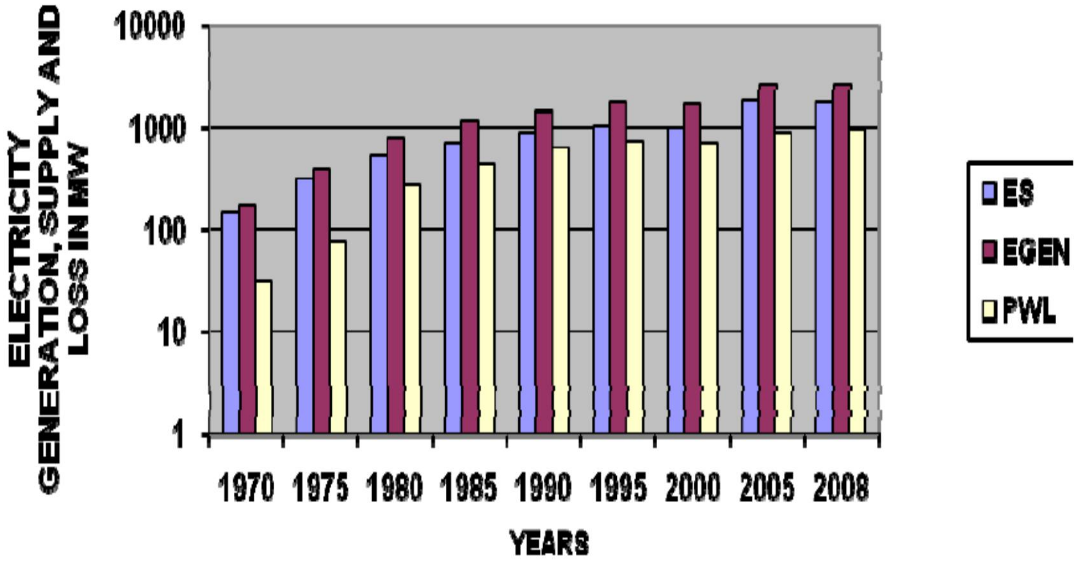
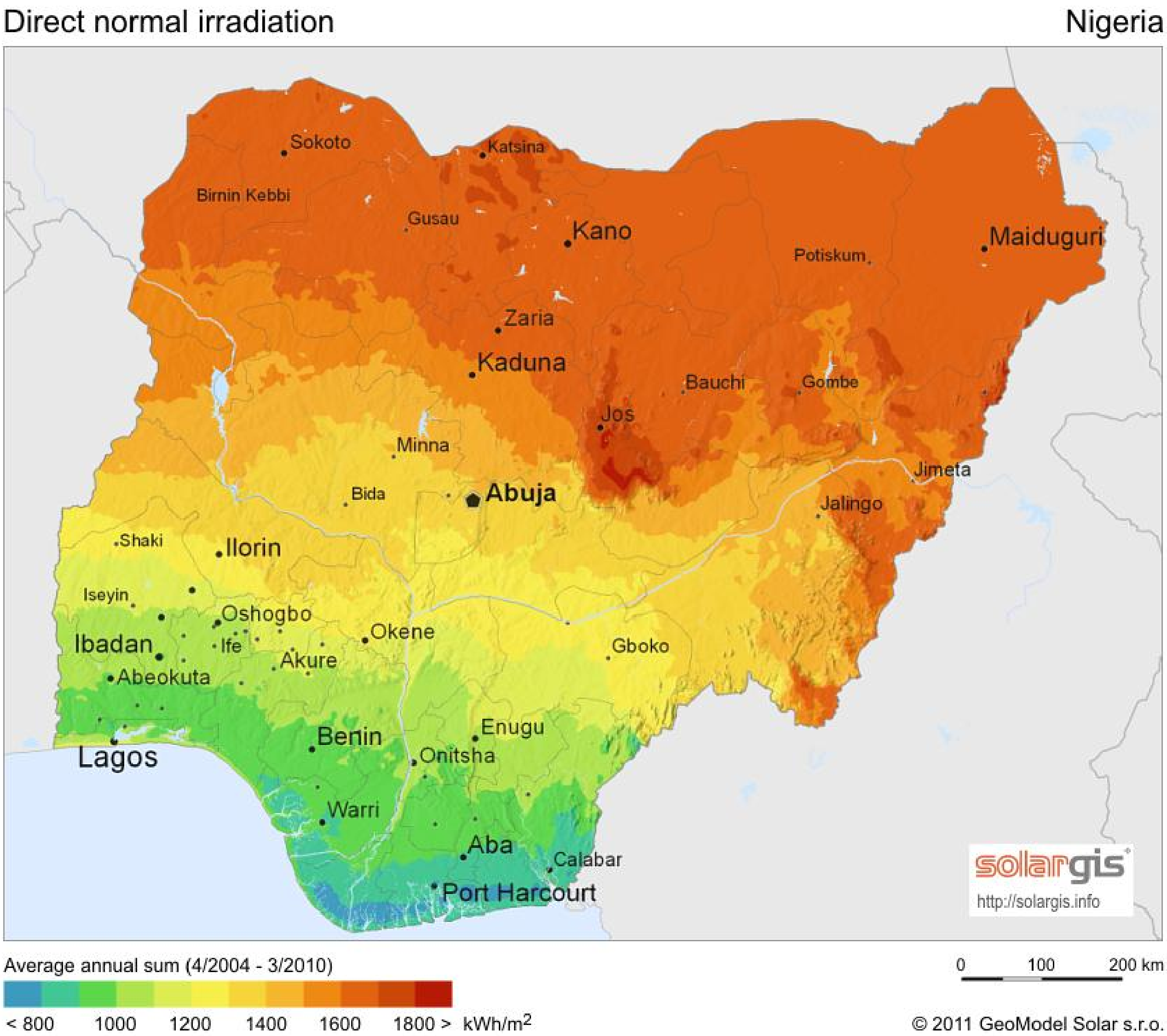
Appendix 1. Electricity generation, supply and power loss in mega watts in Nigeria



# Appendix 2. Average annual solar radiation in Nigeria




Solar radiation in Nigeria [image on the internet]. 2013 [cited 2013 April 25]. Available from: solargis.com

Appendix 3. My experience in a rural electrification project in Nigeria

**Odighi Rural Electrification Project**

I was part of a team that took part in the rural electrification project of Odighi community in Edo State, Nigeria. The project was funded by UNDP/GEF, endorsed by the European Commission's Sustainable Energy Europe Campaign as an official partner. It was executed by Community Research and Development Centre (CREDC), an NGO based in Benin City, Nigeria.

The project titled, *''Access to Electricity in Odighi Community using Photovoltaic''* was part of the PREEEN (Promoting Renewable Energy and Energy Efficiency in Nigeria) project. The PREEEN project is a concept of CREDC that was designed to address the environmental and social-economic challenges posed by the crises in the electricity sector of Nigeria. The main goal of the PREEEN project is to increase Nigerians' access to electricity and modern energy services using renewable energy, as well as to promote energy efficiency.

The main objective of Odighi's project was to provide lighting to some households in the community using Photovoltaics. The other objectives were to build capacity in the community to install and maintain power systems as well as to create awareness in Edo State on the potential of renewable energy technologies to address the current energy crisis in Nigeria. Forty households, in two phases were provided with lighting and about twenty youths were trained on solar system.

Odighi is a rural community in Ovia North East Local Government Area of Edo-State, Southern Nigeria. The community is populated with more than 2000 people. The major occupation of the people of the community is farming; mainly cocoa and cassava farming. As at the time of visit, the community did not have access to electricity because they were yet to be connected to the national grid.

Electrification of Odighi was done in three phases: inception workshop (visiting the community, informing them about the proposed project to be executed and seeking the approval from the community elders), training workshop for some youths of the community and the installation of solar systems for 40 households.

The project started off by visiting the elders of Odighi community, informing them of the proposed project. The concept of renewable energy in general, and solar system in particular were explained to them. They were made to understand the benefits of the project; 40 households in the community would have access to electricity in the form of lighting at no cost whatsoever. Also the interested community youths would be trained on the concept of solar system and the maintenance of solar home system. The community elders were happy, enthusiastic, and welcomed us to their village.

The elders were later visited and reminded before the commencement of the project. The beneficiary households were educated on the working principle of the solar system and how to efficiently use them for optimum performance. They were also advised to call on the trained youths if they encounter any difficulties in the future. The systems were installed by the CREDC team, together with the trained community youths.

**The Solar System Pack**

The solar pack that was used was a plug and play system (By Schneider Electric In-Diya™). It consists of:

1) LED Lamp
2) Backup unit (Battery)
3) Solar Panel
4) Cable and Screws

The capacity of the battery: 12V × 5Ah = 60Wh

The annual average peak of solar insolation in Nigeria is 4 hrs per day. The rated power of the solar panel to be used is 10W.

10W × 4hrs = 40Wh, the max energy generated by the panel to be stored in the battery.

The SHS can provide lighting for 8 hrs per day during maximum solar intensity. They were advised to use it for 3 hours per day during rainy season when there is less sunshine.

The first phase of the project lasted for six days, between the 7th and 12th September 2011. The households' roof tops of the beneficiaries were inspected to determine the *South Pole* to which each of the solar panels would be oriented to ensure maximum year round energy production. The first installation was done at the community head's house. Some of the panels were installed on the roof of the houses while some were mounted on vertically erected solid poles. Some roofs are too slanted for the correct angle of inclination while some are just not strong enough.

The community people that had their installation done previously were happy and excited to see us on the second day of installation. They were surprised by the brightness of the lamp. The head of the community described the solar lamp *'as bright as sun'*. The members of the community that were skeptical about the whole exercise were also impressed. The villagers that were not shortlisted to benefit were not happy. They lamented at their inability to afford one for themselves. The cost of the solar system is about NGN 23000 (about 150 USD), too expensive for the majority of the community to purchase.

The initial skepticism of the villagers, as we later learnt stemmed from earlier disappointments from government officials and other organizations that have failed repeatedly to keep their promise to the community.

**NB**: It should be noted that the choice of households that benefitted from the project was determined by the elders of the community, mostly based on hierarchy**.** There was an incident where the list of names of beneficiaries did not include the oldest man in the village. The list was redrawn and man's name included.

**Solar Energy Opportunity in Odighi Community**

**Electricity for pumping water**

There is scarcity of water in the village. They rely heavily on rain for their water consumption, as can been seen by the various methods by which they collect and store rain water in the whole community. As at the time of visit (12.9.2011), there was no functional well or any water sources in the whole community except for a stream, about 2 km away. The people of the community go to this stream to wash their laundries and also fetch water for cooking and drinking purposes.

I interviewed Pa James, a village elderly man. According to him, their previous source of water is an artificial well (borehole) of about 200 meters depth. There was a pump in the well, powered by a diesel generator that pumps water for storage and for consumption of the village. Unfortunately this particular well dried up. Though a similar well is being planned, it will be a long time before the villagers have access to water as the well of about 200 meters depth will be dug manually.

The water table in the community is far below the ground, about 800 feet (approximately 245 meters) under, according to the last geological survey conducted by the state government. The water scarcity is not limited to Odighi village. It is a common occurrence among rural dwellers, they rely on rivers and streams for their water supply.

Solar PV can be used to power the pump for the well. The villagers will stop relying on diesel generator. Diesel fuel in many rural areas is very expensive, because it is sold by black marketers at almost double the price. Solar system will also save the villagers the cost of maintenance.

**Solar electricity for commercial purpose**

During the installation process, I encountered a woman that was fascinated with solar system and asked if it could be possible to power her grocery store (a small shop) with solar system. She said bright light will let her stay opened till night, thereby bring more customers. She also said her customers prefer cold drinks and there is no electricity to power her refrigerator.

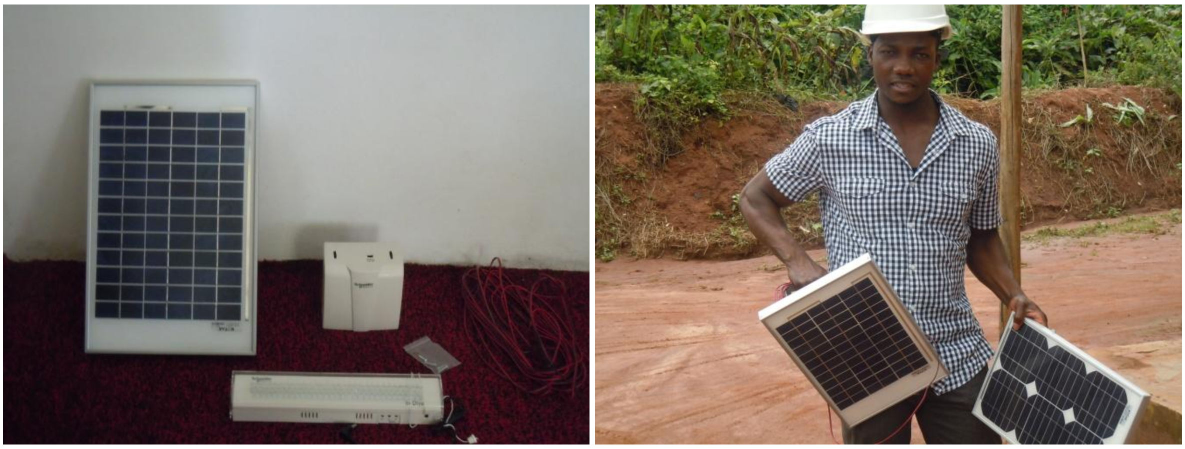
I told her it will be more expensive than the ones we are providing their village as she would need a more powerful solar system to power the refrigerator in her shop. As at the time, the woman relies solely on diesel generator to power the refrigerator for about an hour or two on weekends. She lamented about the scarcity of diesel fuel and how much she had to pay to get it as she buys from black market.

This further shows how the ordinary lives of the villagers could be transformed with some access to electricity and how willingly they are to accept renewable energy technology to solve their energy problems.

Some lessons learned:

- The elders of rural communities appreciate and welcome organizations that are willing to help and better the lives of their people
- Majority of the rural people cannot afford the upfront cost of solar PV but are willing to pay on installment or monthly fee if such service is available.
- Some of them would prefer sale of service to sale of equipment.
- The people are willing to adopt renewable energy to solve their energy problems.
- There is lack of awareness of RET and off-grid electricity in rural communities. Their knowledge is limited to grid electricity and diesel generator.

**The electrification project in pictures**



1. The author holding the solar pack used for the project

2. The author and CREDC staffs meeting with village elders

3. A typical village kitchen; cooking with firewood

4. Explaining PV system to the villagers

5. Installation

6. First installation at the village head’s house

7. Digging a new well for the community

9. Methods of collecting and storing rain water for later consumption