MSc Program
Renewable Energy in Central and Eastern Europe

Solar Mini-grid, Energy Solution to Remote Islands in Nigeria: Powering the Ancestral Home of the Itsekiri People

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
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15 October 2016, Vienna

Affidavit

I, **Alex Kofi Eruwa**, hereby declare:

1. that I am the sole author of the present Master Thesis, “Solar Mini-grid, Energy Solution to Remote Islands in Nigeria: Powering the Ancestral Home of the Itsekiri People, 110 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and

2. that I have not prior to this date submitted this Master Thesis as an examination paper in any form in Austria or abroad.

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Abstract

The electricity situation in Nigeria is examined with focus on the plight of Ode Itsekiri, the ancestral homeland of the Itsekiris. At the moment Ode Itsekiri is marginally powered by an over-sized 300 kW diesel plant, in contrast to a relatively little load demand by the community. This generator is operational only when sufficient diesel is acquired. The community mandatorily subjects anyone wishing to bury a relative in the community to provide 50 litres of diesel per corpse. This is due to the fact that the community cannot afford the cost of running the large diesel generator, which requires about 200 litres of fuel for a round of operation of five hours per day for about three days. In attempting to solve the above electrification problem, a solution proffering the integration of solar energy which is abundant in the area is investigated. This thesis therefore, explores three scenarios of power generation using the HOMER software for simulations of the least cost energy solution for the community. In the ranking of these three scenarios, installing a 100 kW solar plant with a 20 KW diesel generator backup provides the best economic cost of electricity at approximately US$ 0.64/kWh, an environmental friendly option, longer hours of electrical load for some productive uses and a meaningful life. Next is a 200 kW autonomous solar plant with cost of energy at US$ 0.76/kWh and no carbon dioxide emission. Finally, operating the existing 300 kW plant remains the least solution to the electrification of Ode Itsekiri, as this presently runs at US$ 4.80/kWh and at US$ 21.64/kWh for the extended electrical loads examined, and least environmentally friendly with high carbon dioxide emission.

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List of Abbreviations

BOS	Balance of Systems
AC	Alternating Current
CAPEX	Capital Expenditure
CBN	Central Bank of Nigeria
DC	Direct Current
DCF	Discounted Cash Flow
DESOPADEC	Delta State Oil Producing Areas Development Commission
DISCO	Distribution Company
ECN	Energy Commission of Nigeria
FIT	Feed-in Tariff
FOB	Free on Board
GEF	Global Environment Facility
GENCO	Generating Company
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
GNI	Gross National Income
HOMER	Hybrid Optimization Model for Electric Renewables
ICSHP	International Centre on Small Hydro Power
KPMG	KPMG Advisory Services, Member of the KPMG Network
kWh	Kilo Watt Hours of Electrical Energy
kWp	Kilo Watts Power
LCOE	Levelized Cost of Electricity
Mtoe	Million Tons of Oil Equivalent
MW	Mega Watts
MYTO	Multi Year Tariff Order
₦	Naira – Nigeria Currency
NBET	Nigerian Bulk Electricity Trading
NDDC	Niger Delta Development Commission
NEPA	National Electric Power Authority
NERC	Nigerian Electricity Regulatory Commission
NESC	Nigerian Electricity Supply Company
NIPP	National Integrated Power Project
NMA	Nigerian Meteorological Agency
NNPC	Nigerian National Petroleum Corporation
NPC	Net Present Cost
O&M	Operation & Maintenance
OPEC	Organization of Petroleum Exporting Countries
OPEX	Operating Expenditure
PCAF	Power Consumer Assistance Fund
PHCN	Power Holding Company of Nigeria
P-N	Positive (+) and Negative (-)
PPA	Power Purchase Agreement
PV	Photovoltaic
RE	Renewable Energy
REA	Rural Electrification Agency

REB	Rural Electrification Board
REF	Rural Electrification Fund
SPWA	Strategic Program for West Africa
TCN	Transmission Company of Nigeria
UNIDO	United Nations Industrial Development Organization
W	Watt
WLGA	Warri Local Government Area

CHAPTER 1: INTRODUCTION

In the opening text of the topic electricity in the principles of physics, new impression copy Nelkon (2010) states that "*in the modern age, the science of electricity holds one of the key positions*", this is true in the sense that human existence is directly linked to the services that can be obtained from the use of electricity such as for cooking, heating, refrigeration of food, pumping water, illumination, TV viewing, powering of mammogram machines and other equipment in health services too numerous to mention. The availability of electricity and the convenience of its usage is sometimes taken for granted by people in regions that have it in abundance, but some people in developing countries especially in the rural/remote areas such as Ode Itsekiri will give everything to have maybe five regular hours of power supply daily rather than waiting for corpses for burial or the benevolence of prominent Itsekiri sons and daughters to donate diesel to power their 300 kW generator.

The state of availability of electricity in a country is amongst the indicators that define its level of prosperity because this can signify the energy generation ability, and that consumed per capital in the country. The absence of electricity in an area affects the living standard of its inhabitants be it a village, a local government area, a state or the country as a whole, which Simonyan and Fasina (2013) sum up concisely that "*Energy is crucial to the wellness of humans and to a country's economic development*", and this clearly illustrates why the rural and remote areas and including not easily accessible islands in Nigeria wallow in abject poverty.

The World Bank analytical classification of the world's economies use the gross national income (GNI) per capital in the computation of the state of development of countries, which is directly linked to the domestic economy of a country (The World Bank website). However, by extrapolation the economy of any country can be interconnected to the level of business that it engages in with other countries or nations through the goods and services it can trade in and the balance of trade. Therefore, manufacturing, productivity, mining, and other economic indicators play key roles in the economy of countries, but electricity is the basis of turning the wheels of the industries that create the wealth, and this can make a country either a high income or a low income nation.

The importance of energy in the form of electricity thus makes it one of the measurements used to classify nations into different echelons of development, no wonder those countries with sufficient electrical power are considered developed while those with insufficient are rated as either developing or underdeveloped, because lack of electricity hinders the growth of a people and the economy of a region or country.

Development indicators such as electricity production, sources and access by The World Bank (2014) data show that Nigeria like some other developing countries is still lacking behind in generation and supply of electricity, such that by 2012 only 55.6% of the Nigerian population had access to electricity, and mainly from natural gas (thermal plants) at 81.6% and hydropower 18.4%. Also, electricity generation and transmission in Nigeria has all along been centralized in a government agency, and some of these plants over the years have become under maintained and therefore are operating below the initially installed capacities. Table 1 below shows the grid connected power generation in Nigeria from 2007 to 2014 and the corresponding per capital electricity for each year.

Table 1 Grid-Connected Power Generation

Year	Average generation availability (MW)	Maximum peak generation (MW)	Maximum daily energy generated (MWh)	Total energy generated (MWh)	Total energy sent out (MWh)	Per capita energy supply (kWh)
2007	3,781.3	3,599.6	77,322.3	22,519,330.5	21,546,192.2	155.3
2008	3,917.8	3,595.9	86,564.9	18,058,894.9	17,545,382.5	120.4
2009	4,401.8	3,710.0	82,652.3	18,904,588.9	18,342,034.7	122.0
2010	4,030.5	4,333.0	85,457.5	24,556,331.5	23,939,898.9	153.5
2011	4,435.8	4,089.3	90,315.3	27,521,772.5	26,766,992.0	165.8
2012	5,251.6	4,517.6	97,781.0	29,240,239.2	28,699,300.8	176.4
2013	5,150.6	4,458.2	98,619.0	29,537,539.4	28,837,199.8	181.4
2014	6,158.4	4,395.2	98,893.8	29,697,360.1	29,013,501.0	167.6

Source: Deutsche Gesellschaft für Internationale Zusammenarbeit (2015)

With an increasing population also comes higher demand for usage of electricity. However, Nigeria with a population of about 173.6 million[1] still grapples with a total installed capacity of about 6,158.4 MW out of which the average available capacity hovers around 4,395.2 MW in 2014 as indicated in Table 1, while the country's

[1] The World Bank Nigeria, http://data.worldbank.org/country/nigeria, viewed 5 March 2016

Power Ministry website[2] live update shows that the highest peak power available capacity was 5,074.7 MW[3] and this occurred on 2nd February 2016.

Discussing further Table 1 on the other side of this page, the fluctuations in generation capacity is mostly due to frequent shortage of oil and natural gas for the thermal plants as a result of vandalizing of pipe lines in the creeks, and Udofia and Joel (2012) attributes these occurrences to stealing of crude oil by oil thieves, and gas line sabotage by militant youths trying to draw the attention of the Federal Government to lack of infrastructural development in their communities while claiming to fight for justice and a bigger share of the oil revenue.

While The Economist, June 25th 2016 edition attributes these power generation fluctuations to the preference of indigenous gas companies marketing natural gas offshore to earn higher profit/foreign currency, instead of selling to the local power plants at government regulated price which adds to the thermal plants down time. In addition, other contributing factors include frequent down time in the Nigerian dams due to poor water management at the hydro dams, equipment breakdowns resulting from improper maintenance and grid constraints in general.

On energy consumption the IEA (2015) energy statistics indicates an electricity consumption of just 141 kWh/capital or 0.141 MWh/capital for Nigeria, the largest economy in Africa compared to 4,328 kWh/capital (4.3 MWh/capital) for South Africa. This shows that Nigeria is underpowered, with the implication that the remote areas such as islands and villages will be worse hit with low or completely lack of electricity.

The electricity situation has caused manufacturing companies that cannot operate private diesel generators to close shop in most parts of the country, GIZ (2015) comments that averagely in Nigeria businesses suffer down time due to power outages for about 197 hours per month. The relatively newly appointed Nigerian Minister for Power (about seven months in office) [4]Mr. Fashola out of frustration while addressing journalists on the state of affairs in his ministry commented inter alia "(…) *between 1950 and 2013 what did we achieve in power? Pointing out that in all that time only*

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[2] Power Statistics (2016), Federal Ministry of Power: http://www.power.gov.ng/Viewed 26 July 2016
[3] Power Statistics (2016), Federal Ministry of Power http://www.power.gov.ng/ viewed 9 March 2016
[4] Power Supply, http://www.vanguardngr.com/2016/06/power-supply-dont-shut-dont-downsize-fashola-tells-industrialists/ viewed 25 June 2016

4,000 MW capacity was available", this confirms that there is power shortage in the country if this is what is meant to serve the large population both in the urban and rural/inaccessible settlements that are seldom considered in the power discussions in the country.

In reviewing electricity generation and distribution to end-users, [5]The Global Alliance for Clean Cook Stoves comments that about "*15.3 million households in Nigeria are not connected to the grid, and even those connected electricity availability remains unreliable, with the rural areas suffering the most of the electricity deprivation*." The agency, therefore, suggests that Nigeria should increase the sourcing of electricity through investing in low carbon means of electricity generation.

Presently the economy and private life of the country is being run on improvised individual noisy, and highly polluting diesel generators which produce high CO_2 emissions, So_x, Co, NO_x and PMs emissions, while (Simonyan and Fasina, 2013 cited by Akinbami, 2001) conclude that these emissions have unfortunately resulted in the deaths of several Nigerians because of health issues such as carbon monoxide inhalation and many gasoline accidents.

In retrospect, the problem with the energy sector in Nigeria can be indirectly traced to the period of the establishment of the first state utility, the Nigerian Electricity Supply Company (NESC) in 1929 by the Nigerian government, with KPMG (2013) arguing that the then electricity company (NESC) operated as a monopoly from inception. This means that the state utility has since managed the provision of electricity in the entire country under different names such as the Electricity Corporation of Nigeria, National Electric Power Authority and finally the Power Holding Company of Nigeria until about 2013[6] when the Federal Government of Nigeria achieved a major milestone in privatising the power generation and distribution sectors in the country.

With this scenario of the erratic state of electricity in Nigeria, no one would wonder much how the already described low generation state of electricity in Nigeria will affect the villages, rural areas and other remote islands whose terrain and location

[5] 15.3m Nigerian households lack access to grid electricity (2012), http://www.premiumtimesng.com/news/111301-15-3m-nigerian-households-lack-access-to-grid-electricity-group.html viewed 5 June 2016

[6] Execution of transaction and industry agreements (2013), http://www.nigeriaelectricityprivatisation.com/ viewed 5 June 2016

seldom make connection to the grid a difficult task, and also the cost implications of investing in such grid extensions.

Figure 1 below shows a computer simulation of the required installed power capacity of Nigeria starting with historical data from 2005 through 2008 and a projection into the future of the needed power installation necessary to be put in place in achieving three different scenarios of industrial state of growth by the end of 2030. On examination of each of these scenarios based on the average power generation availability figures on Table 1 (page 2), this is still a far cry from the minimum requirements of 50,000 MW on the x-axis of the figure. The power generation availability which at best in 2014 was a lowly 6,158.4 MW, with an annual energy of about 29,013,501 kWh sent into the national grid during the same year. This shows that much work still needs to be done in achieving the power requirement in any of the scenarios by 2030.

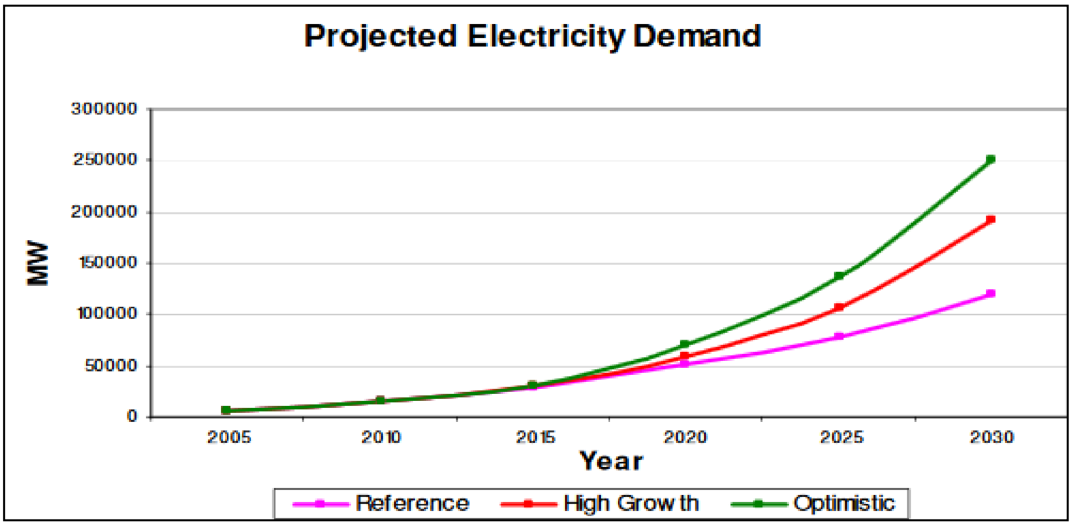

Figure 1 Projected Electricity Demand. Source: Prof Abubakar S. Sambo (2009)

With better provision of electricity to remote areas, these inhabitants can attempt to live normal life. The location of a community should not define or confine their destiny to perpetual darkness and poverty considering that Fechner (2015) states that about a third of the world population is without electricity, and suggests that stand alone photovoltaic systems might play an important role in developing countries for the provision of energy to power water pumps, health and other services including information systems.

This means that the conventional approach to electrification through primarily fossil and large scale hydro power plants and transmission through large grid connections to distant areas or regions in a country might need to be jettisoned, so that the natural endowments of each location over the globe can be harnessed. In different areas of the world some potential sources are available that can be utilised for power generation in the form of sustainable renewables, and some parts of the world have the sun shining all year round, which can be put into good use. In line with the need to diversify the source of energy, [7]the Executive Secretary of the French-Based REN21, Christine Lins argues that Nigeria may not achieve its objectives of providing electricity for 75 per cent of its population by 2020 if the massive potentials in renewable energy are not tapped.

Electricity supply situation in the country is not all about the anguish, there is presently an ongoing privatization policy change to make electricity more available. A nationwide monthly polls data result conducted by NOIPOlls from January 2013 to August 2015 on how respondents feel about power supply in their domain as shown in Figure 2 overleaf illustrates. The response shows some positive account of an average improvement of electricity by about 37.9% of respondents in the country over the reporting period, while for the month of August 2015 it shows a 60% improvement, 20% not improved and 20% non-responding.

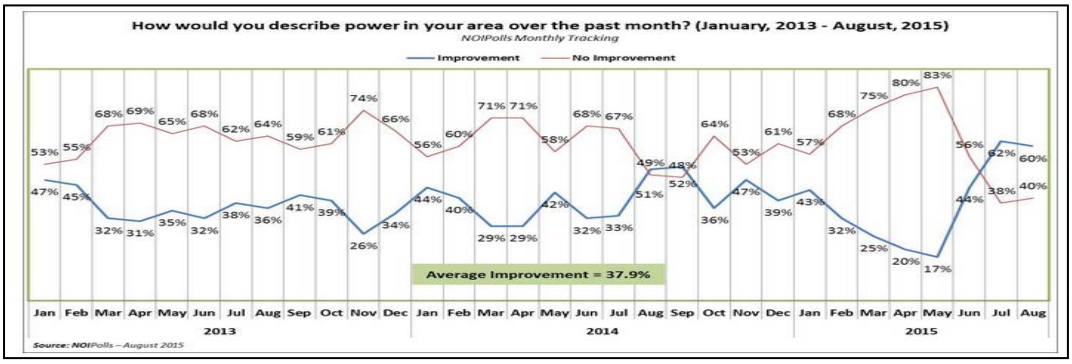

Figure 2 Electricity Response Appraisal by Sampled Households. Source[8]

[7] Nigeria's huge renewable energy potential remains untapped (2016),http://guardian.ng/energy/nigerias-huge-renewable-energy-potential-remains-untapped/ viewed 9 June 2016

[8] Polls: NOIPolls monthly (2016), http://www.noi-polls.com/root/index.php?pid=16&ptid=10&cat_id=2&parentid=2&timeline_id=81viewed 24June 2016

The period of supply of electricity measured in the survey as evident from the time duration was after the commencement of the privatisation process of the power sector in the country, and it is important to emphasise that the survey was carried out in the urban areas because the rural areas do not participate in such polls since they don't have access to electricity and also no knowledge of such polls.

1.1 Objective of the Study

The Objective of this study includes the following:

1. To carry out a research on whether the present diesel generator powered mini-grid being marginally operated for about (5-6) hours per day when diesel is available can be improved upon to be effectively used in delivering a meaningful and sustainable electricity in Ode Itsekiri (Big Warri) the chosen project area, or should it be replaced by an autonomous solar photovoltaic plant, or a hybrid system composed of a solar array system with a sized diesel plant. The final decision will be based on a least cost solution to the community which presently lacks regular electricity supply and is not connected to the national grid.

Therefore, this thesis will examine the following scenarios:

i. Operation of the existing diesel generator at the present state;

ii. Installation of a photovoltaic based system with battery storage;

iii. Installation of a photovoltaic system with batteries and a backup with a diesel generator.

2. Cost implication of each system above, and the resulting cost of electricity to enable the least cost option to be advised for implementation.

3. What is the effect of the (i) existing diesel system presently installed and operating as the main means of electrification on CO_2 emission in the community in comparison with that of (ii), a PV system alone or (iii) the existing generator or an optimal generator as a backup to a PV installation as a means of mitigating against the sustenance of the environment.

4. The method of sourcing for funds in implementing the proposed project decision in Ode Itsekiri, based on a review on how the existing diesel electrification system in the area was funded, and operated over the years. To review the outcome of the results obtained from the analysis and draw an inference that can act as a guide for the implementation of similar projects in other islands all around the Niger Delta region of the country and other villages not yet connected to the transmission grid.

1.2 The Literature on Solar Off-grid Systems

The World Bank (2008) report on sustainable rural electrification off-grid projects suggests, "*from solar photovoltaic to small generators and micro hydropower (…), off-grid or stand-alone service provision has emerged as a viable alternative for increasing electricity access, especially in remote and dispersed communities.*"

Samsø was initially an island originally grid connected based on fossil fuels, and Saastamoinen (2009) comments on the Samsø, Denmark - renewable energy island programme as the islanders decided to convert to 100% renewable over a period of 10 years, after Samsø won Denmark's Renewable Energy Island contest in 1997. Stakeholders involved in the project included the Danish Government, the local municipality, renewable energy personnel and the citizens of Samsø.

The inhabitants of Samsø were initially educated on the cost implications, payback time and most the favourable technologies based on available resources (strong wind power, biomass and solar) on the island by the experts of the founded Samsø Energy Company set up to implement the project. The project was achieved 2 years ahead of the planned target showing that islands can be powered in isolation to a transmission grid, however, in this project a larger portion of the renewable energy was wind power but with biomass and solar contributing their fair proportions.

(Akpan, U et al., 2013) examined the irradiation data of the north eastern part of Nigeria and suggested that due to the high solar irradiation level in this region and the poor state of electricity, a better access to power can be addressed with off-grid electrification systems primarily by using solar photovoltaic panels in the rural communities that are not connected to the national grid, they argued further that the study did not consider the option of a PV/diesel system due to the low income level of the population of the area compared to the high recurring cost of diesel in the country which will make an hybrid system ineffective.

In realising the essence of renewable energy, the Nigeria Federal Ministry of Power is increasing efforts to diversify the energy mix "*in view of the present monopolistic type of fuelling and imbalance in the location of the existing power stations. The use of renewable energy is encouraged to provide alternative sources of power generation especially in the rural areas*[9]". The Ministry has therefore completed some solar pilot projects in Ogun and Cross River states of the country. In this context the term rural area also applies to the proposed project site in Ode Itsekiri that is a remote island area in the country that is cut off from the main land by a geographical barrier the River Warri and making it presently uneconomical to erect a grid across the river or lay electrical cables underwater.

(Chaurey and Kandpal, 2010) in reviewing and analysing decentralized rural electrification argue that most governments in developing countries are saddled with providing electricity in rural areas due to factors related to growing discrepancy between demand and supply and the cost required to maintain the electricity network in general, such that basic energy needs of rural areas can best be met with renewable energy while emphasising that "*Photovoltaic (PV) technology is one of the first among several renewable energy technologies that was adopted globally as well as in India for meeting basic electricity needs of rural areas that are not connected to the grid".* The main barriers limiting the use of this technology remains the challenge of the cost of the system and proper dissemination of the use of photovoltaic as meeting this need for electrification in rural and remote areas.

Considering the herculean task involved and the cost implications of extension of the grid to rugged remote lands and islands in tackling the consequence of subsequently energy poverty, Dornan (2014) states that the traditional approaches to rural electrification which prioritise grid extensions are not suited to the small states of the Pacific Islands and argues further in favour of off-grid systems generally in remote areas and the deployment of renewable technologies for remote areas and similar islands.

[9] Renewable and rural power access, http://www.power.gov.ng/index.php/department/electrical-and-inspectorate-services viewed 5 June 2016

In an effort at investing in the rural population and the remote areas of South Africa that have long lacked electricity, the government in 2002 reviewed the old energy policy that put the rural areas out of the reach of electricity during the apartheid years, and tried to provide off-grid solar home system electricity, a form of stand-alone system in such communities in South Africa. Notwithstanding some of the hiccups associated with projects of this nature, this programme has been well used in supporting the electrification of these communities.

Additionally, the South African government support these non-grid electrified homes under the electricity basic scheme in the country (Azimoh, et al, 2015) with about 48 ZAR per month as subsidies for payment of electricity charge to lower the energy burden. Further assessment of the electrification programme by Azimoh, et al (2015) shows that this intervention has had positive effect on the livelihood and social impact of some of the communities, such as better access to information and entertainment especially the communities without any immediate hope of connection to the grid due to their remoteness from the grid.

The use of off-grids in Indonesia appears to be one of the viable options in solving the electrification problems in rural areas of the country due to the fragmented terrain, because connecting the major electricity grid and other isolated grids to these areas would be too costly. [10]Therefore, in Indonesia the Agency for Assessment and Application of Technology, and the Bavarian Ministry for Economic Affairs, Transport and Technology Germany have implemented a photovoltaic pilot project in the Java Province, which integrates some agricultural activities namely fishing, chicken farming, banana plantation and solar boat systems.

The PV system has found applications in some countries such as Bangladesh and Blunck (2008) examines the use of PV for productive uses in rural settings, and reviewed the application in the form of stand-alone Solar Home Systems (SHS) in rural areas of Bangladesh which is the most prevalent method of the use of photovoltaic in the country. The work highlighted the shortcomings of SHSs due to its limited economic impact in productive uses, and argues that since centralized PV mini-grids can provide basic household illumination and power for productive uses in

[10] Application of photovoltaic systems for increasing villagers' income (2001), http://www.sciencedirect.com/science/article/pii/S0960148100000239 viewed on 8 June 2016

small machinery through larger electric load generation, therefore, consideration should be given to PV mini- grids.

While Kabir and Uddin (2015) in analysing the policy of Bangladesh on the prospects of renewable energy in rural areas of the country, due to the gradual reduction of the country's natural energy resources opined that the government is now examining the use of RE for energizing off-grids in rural and remote areas with solar energy having the highest potential since the country is well endowed with sun light. This argument brings supports the popular correlation that if countries close to the north pole like Canada and to some extent Norway use solar energy, it therefore, shows that it is daylight and not really only sunshine that power solar panels, and as such Bangladesh, Nigeria and other countries blessed with good sunshine should be able to harness this potential.

The Rural Electrification Agency[11] (REA) of Nigeria in a memo dated 6 August 2014 argues that based on the prevailing circumstances for each rural community, the options for rural electrification will be either through extension of the grid by the Transmission Company of Nigeria for those that can be connected, while remote settlements will be served by mini-grids which is claimed to be more cost effective than the grid extension.

The Rural Agency in justifying its modus operandi states inter alia "*in some particular cases where the level of demand and population density is relatively high, mini-girds (with either fossil fuel or renewable resource-powered generation technology) may be the most technically and economically viable approach to providing rural electricity.*" The caveat here is that in most of the communities already operating diesel-generating sets, the cost of operation is mostly too high for the communities to cope with, thereby resulting in the oversized plants lying idle for most periods as described in sub-chapter 1.3.

The GEF 4 project under the Strategic Programme for West Africa (SPWA) on Energy Access, is implementing the 60 kW PV-Gasoil Kaur hybrid mini-grid project

[11]New national rural electrification implementation strategy and plan (2014), http://www.power.gov.ng/National%20Council%20on%20Power/Rural%20electrification%20agency.pdf viewed 1 June 2016

component owned by the Gambia Government. [12] The project involves the application of PV to generate electricity during the daytime, while gasoil is applied at night. This will directly cut down on the volume of gasoil used when the sun is shining and the PV portion is generating electricity for use.

The Government of Ghana in meeting its target for the universal access to electricity by 2020 is anticipating the extension of grids to areas not presently connected to the grid. However, there is a limitation when it comes to grid connection to more than [13]200 islands in the Volta river lakesides due to the rugged topography. Ghana is empowered with RE resources basically biomass, solar and wind, while technical and economic feasibility of solar PV mini-grids has been conducted for a 50 kWp solar plant for Alorpkem village of about 1000 inhabitants using a cost estimate per kilowatt-peak (kWp) of about US$ 9,830, therefore installation and commission of such a system is estimated at US$ 491,500 for an annual output of about 70,000 kWh.

Further computation by the report using tariffs of 1.3 US$/kWh for households and 1.4 US$/kWh for commercial entities gives a revenue of US$ 60,928/year, an internal rate of return of 0.9% and a break-even in 15 years. The government plans to replicate this plant in other islands of the country if the pilot project is successful.

(Buragohain, 2012) examines the impact of solar energy in rural development in India and lack of access to electricity in about 25,000 villages in rural and remote areas, and the deprivation of basic human needs like water and food, and argues that off-grid schemes like the solar home lighting system used in the rural electrification of the studied areas assisted in the enhancement of rural societies such as a reduction in money spent on kerosene, and the women had longer hours to carry out the house chores while the positive effect on the children to read at night was emphasized.

The IRENA and the Abu Dhabi Fund for Development (IRENA ADFD) promoting renewable energy for rural electrification programme is assisting the government of

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[12] Promoting renewable energy based mini grids for productive uses in rural areas in the Gambia (2012), http://www.ecreee.org/sites/default/files/event-att/gambia_-promoting_renewable_energy-based_mini_grids_for_productive_uses.pdf viewed 8 June 2016

[13] Ghana renewables readiness assessment (2015), http://www.irena.org/DocumentDownloads/Publications/IRENA_RRA_Ghana_Nov_2015.pdf viewed 10 June 2016

Senegal through concessional loan to provide electricity in [14]rural electrification programme for about 100 villages that are in remote areas of the country, and this assistance will be through the use of solar PV mini-grids. Through this initiative, approximately 80,000 people who have been in darkness will be able to enjoy the services of electricity and the application of this electricity in the villages for medical facilities and in schools.

In most of the studied rural electrification projects, the use of PV mini-grids in these rural areas has a positive impact on the health of the village dwellers due to the replacement of kerosene lanterns (which are hazardous to health) for illumination in the households at night, people will be able to extend their evening time together and the children can use electricity in doing their homework, thereby improving the wellbeing of man.

In line with the Kenya Government vision 2030 which is aimed at providing electricity access to 100% of its citizens by the year 2030, the government has realized that this vision can be best attained through implementation of solar hybrid mini-grids in the rural areas without connection to the national grid, an example is the solar mini-grid power project in [15]Talek town in the Narok County, where the inhabitants have reported a remarkable improvement not only in the use for household utilization but also in other economic and commercial activities in the town.

The literature on mini-grids sometimes incorporates the hybridisation of renewables such as PV, wind and biomass systems with diesel in some cases when necessary. This is because the technology of diesel generator is matured and well proven, so there are some existing mini-grids being powered solely with diesel generators like in the chosen project site for this thesis see page 14, but there is a growing school of thought that there are potentials in replacing some of the diesel component with PV systems in areas with good solar irradiance. The Frankfurt School in collaboration with UNEP[16] suggest that the exorbitant cost of diesel in most cases makes the operation of solely diesel run plant uneconomical and as such the amount saved by

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[14] 3rd cycle Senegal (2016), http://adfd.irena.org/contentimages/Senegal%20summary.pdf viewed 12 June 2016

[15] Enabling access to electricity in rural Kenya with mini-grids (2016), https://www.youtube.com/watch?v=SkuOWcgH_0I. viewed 12 June 2016

[16] Renewable energy in hybrid mini-grids and isolated grids: Economic benefits (2015), viewed 12 June http://fs-unep-centre.org/sites/default/files/publications/hybridgrids-economicbenefits.pdf2016

reducing the consumption in grids is a significant argument for investing in hybrid systems.

In general, solar is best perceived compared to the other renewable sources of energy such as hydro and wind, [17] this is evident from surveys and studies in Switzerland which point to the fact that the public find it easier to relate to the beneficial attributes of the sun like using it in heating water in some areas, drying cloths and do not perceive a visible drawback on the landscape like hydro and wind.

With these benefits of solar PV arrays, a connection to mini-grid is a likely option to electrification of rural areas in off-grids. It is also important to highlight some of the barriers that have limited the use in some circumstances and has made the option less attractive to the diesel generator connected grids. The high capital cost of PV plants is a factor to consider, which Zhai and Williams (2011) argue that notwithstanding the gains of the gradual reduction of cost of solar PV in most parts of the developed world, developing countries still have little market for solar and not much penetration of the technology so the cost can be a mitigating factor.

Another drawback to the use of centralized solar plants is the issue of space with Oghogho et al (2014) commenting on the large expanse of land required for the installation of a solar generator in comparison to a shed for the mounting of a diesel generating set, and also on the efficiency of PV panels although gradually increasing with research, more work still needs to be done for their reliability to be fully accepted in the markets of the developing countries.

1.3 Brief History and Overview of the Project Area

The area chosen for this thesis is Ode Itsekiri also known as Big Warri (see Figure 3) is an island in Delta State of Nigeria occupied by the Itsekiris, a riverine people who are predominantly fishermen, hunters, farmers in cassava, plantain, cocoyam and forestry.

[17] How Does the Public View Renewable Energy Technologies (2014), http://www.leonardo-energy.org/blog/how-does-public-view-renewable-energy-technologies viewed 15 June 2016

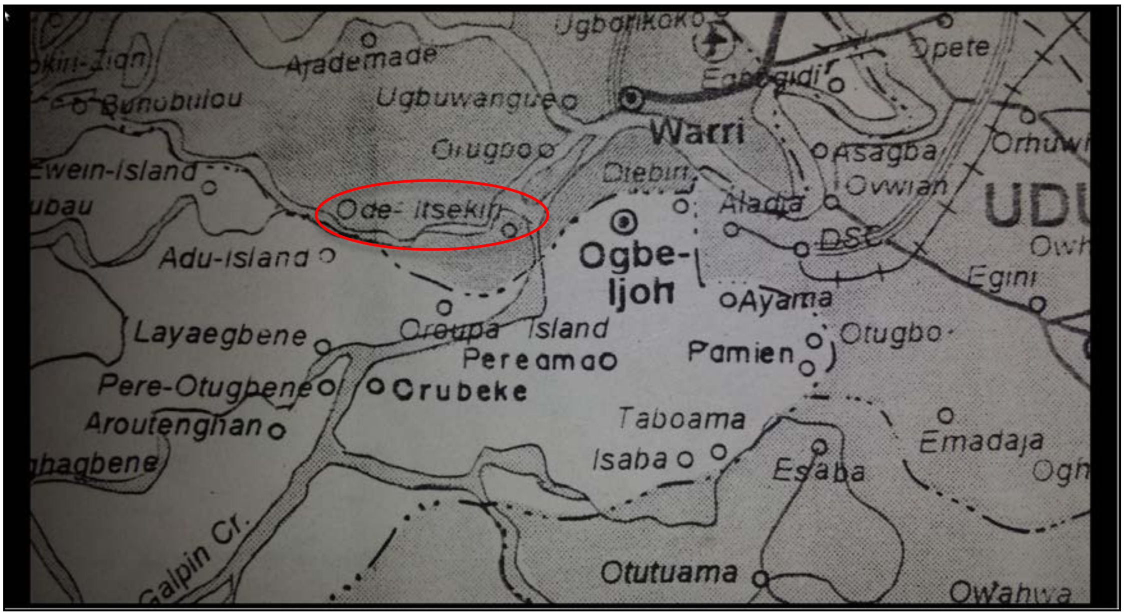

Figure 3 Extract from Map Showing Ode Itsekiri and Adjoining Towns. Source: The Shell Petroleum Development Company of Nigeria Limited

Ode Itsekiri as highlighted in Figure 3 above is surrounded by towns with solid land grounds such as Aladja, Ovwian, Ogbe-Ijoh and Ugbuwangue in Warri metropolis, and other islands namely Orugbo, (Odogene, Aja-Igba, Inorine and Usele). The distance from Ugbuwangue the loading anchorage to Ode Itsekiri based on coordinates computation by Zenith Survey, Warri is approximately 5.55km.

The community recorded a population of about 5,372 in 1988 which was a projection of the 1963 conducted national population, and it is about eight kilometres in circumference[18] and rich in flora and fauna due to the large expanse of mangrove forest.

The area is also home to canes, a grass like flexible plant with woody stock, which the villagers harvest and trade in with the nearby communities and towns; canes are used for weaving household goods like baskets, furniture and roofing materials.

The main motivation for selecting this topic and the community is because the area has the potential of being a great tourist destination due to its historic importance, cultural values and also being the ancestral home and traditional headquarters of the Itsekiri people since the then old Warri Kingdom (WLGA, 1988). The kingdom was later named as Warri Division, and then split into three local government areas

[18] Warri local government area guide: A tourist guide (1988)

namely: Warri South, Warri North and Warri South West Local Government Areas which are represented in red in Figure 4 below with a tourist potential if well developed (Ayomike, 2008). The Itsekiri region is surrounded by the Urhobo and Ijaw people in the hinterland and in the westerly by the Atlantic Ocean.

Figure 4 Itsekiri People and Ethnic Local Government Areas[19]

The River Warri in the Niger Delta area of the country separates the island from the main land of Warri city. The name Big Warri should not therefore be confused with the city of Warri which is the headquarters of Warri South Local Government Area. These are two different locations but just some distance apart. By contrast the word "Big" must signify the importance of the land to the Itsekiris the inhabitants of this relatively underdeveloped island which qualifies as a rural community, where electricity is distributed by a mini-grid because it is not connected to the national grid, and hereafter can be referred to as a village compared to the main metropolitan city called Warri.

Ode Itsekiri is located in the crude oil rich region of Nigeria, because most of the oil installations are in the three Warri Local Government areas and some other surrounding communities of the Niger Delta.

[19] Itsekiri archives-information Nigeria, https://www.google.at/search?q=itsekiri&client=firefox-b&tbm=isch&imgil=MbHN2RaE1qY9SM%253A%253BwZ-mr4IicX-VbM%253Bhttp%25253A%25252F%25252Fkwekudee- viewed 8 June tripdownmemorylane.blogspot.com%25252F2014%25252F03%25252Fitsekiri-people-unique-riverine-and.html&source=iu&pf=m&fir=MbHN2RaE1qY9SM%253A%252CwZ-mr4IicX-VbM%252C_&usg= viewed 8 June 2016

Figure 5 Ode Itsekiri Jetty at the Entrance to the Community. Own Source

The sale of crude oil is the main source of revenue to the Nigerian economy, while the inhabitants of the area claim that the crude is piped from the region and refined to develop the hinterlands leaving the people of Ode Itsekiri and its environs in abject poverty, resulting in lack of basic amenities, electrification and good schools in these communities, for instance according to the inhabitants, the health centre in the community functions once a week because the health personnel do not live in the village but rather come in from the city due to lack of amenities like regular electricity.

The lack of infrastructure and social development in the community has contributed to the death in the art of craft in silver works and a sharp decline in blacksmithing[20], such that in some of the other rural communities around Big Warri this deprivation results in lots of violent agitations from the inhabitants which in some cases lead to destruction of the gas pipe lines carrying gas through the swamp, piracy and other adverse conditions which are natural reactions if a people are confined to lack of basic amenities such as access to electricity and water.

While Ijala town is the burial ground of Itsekiri monarchs who pass away (Moore, 2013), Big Warri is accorded the final resting place of an Itsekiri native. Notwithstanding where he or she dies in the world, the corpse is supposed to be

[20] Itsekiri people, Encyclopaedia Britannica, https://www.britannica.com/topic/Itsekiri viewed 8 June 2016

conveyed back to Ode Itsekiri for burial. These burials also happen to be an important source of diesel for the operation of the diesel generating set in the village as will be discussed further in chapter 3.

1.4 Structure of Work

This thesis is written in five chapters with sub chapters to describe in more detail the overall section. Chapter one begins with a broad overview of the past, of the present state of electricity in Nigeria and the implications of the use of primary conventional fossil fuel and large-scale hydro for electricity generation in the country, an objective guide for what is considered in the later part of this thesis because fossil fuel usage has mitigated against the use of renewable energy resources. A review of the literature on renewable energy and access to electricity on islands, remote and rural areas globally and then a brief introduction of the project site based on a visit to the area to access the actual status of the place and conduct direct meetings (see Appendix A) with some of the inhabitants to obtain first-hand information that have been sparsely documented due to the remoteness and precisely the lack of electricity to put the community and the activities in the area on the world map.

Chapter two examines the energy sector of Nigeria, the recent energy policy changes and the legal framework backing these changes. This chapter also describe in detail generation, grid and off-grid transmission of electricity and distribution networks in the country, which are necessary to fully understand the thesis. Discussed also are the currently available forms of renewable energy potentials in the country and the usage of these potentials for electricity generation.

Chapter three takes a general appraisal of the electricity system at the proposed project area Ode Itsekiri and also a brief review of photovoltaic technology and the relevant components of a PV plant. Also in this chapter the proposed three scenarios through which installation of electrification systems will be investigated based on the existing generator, an autonomous solar plant and a solar plant with a backup generator, with simulation works conducted using the HOMER software with sets of loads computed from household devices obtained from interviews conducted in the community and extended or additional hours of electrification to provide for productive uses and better life for the people.

Chapter four discusses in detail the simulation results obtained under the three scenarios using the HOMER software for the entire project and the thesis has a conclusion in chapter 5 discussing the method a sustainable renewable energy project like that being proposed for Ode Itsekiri can be implemented and funded, considering that renewable energy projects may be front loaded capital intensive investment, and then finally the summary section that gives a general review of the entire thesis.

CHAPTER 2: A REVIEW OF THE ENERGY SECTOR IN NIGERIA

In this thesis the term energy sector is used to describe the entirety of activities that are related to the production and supply of energy in Nigeria, this review is important in order to understand how and why electricity is generated in the country the way it is presently done. As mentioned in page 2 under Chapter 1, power is largely generated through the use of thermal plants and a small percentage from hydro, therefore, a review of energy production and consumption pattern will be dealt with under this chapter.

2.1 Types of Energy Resources in Nigeria and Potentials

Figure 6 gives a pictorial summary of the sources of energy available in Nigeria from hydropower potential, nuclear, crude oil, natural gas, coal, wind, biomass to solar power, which shows that there are adequate fossil and alternative sources of energy for electricity generation if well harnessed.

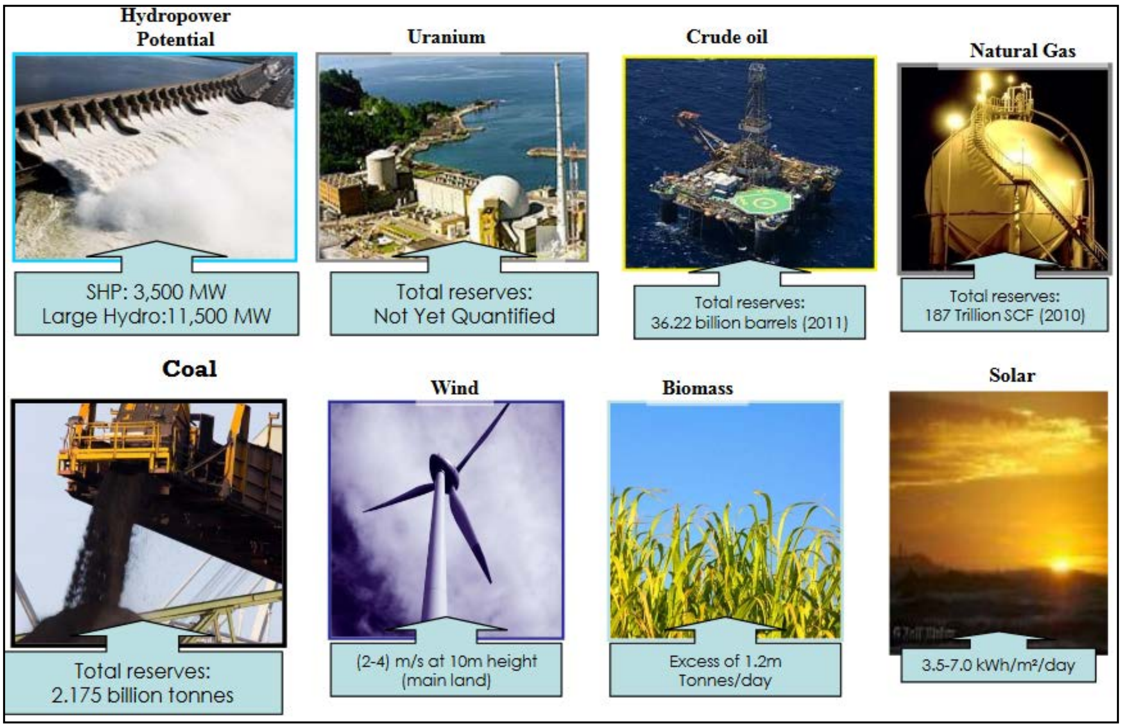

Figure 6 An Overview of Nigeria's Energy Resources Base: Source: Chukwu and Kwajaffa (2013)

The figure further shows that there is a high impending renewables that have not been taped in Nigeria such as a good irradiation solar of 3.5 – 7 kWh/m^2/day, a potential of about 1.2 million tonnes/day of biomass and an average wind speed of 2-4 m/s at heights 10 m and hydropower potentials. Each of these energy resources is discussed further below in this subchapter.

The energy consumption pattern also shown in Table 2 depicts a breakdown of primary energy consumption of approximately 82 Mtoe in 2013 for Nigeria with no mention of renewables since this is not significant, biomass on the table has always been used in the rudimentarily and inefficient form of firewood in open fires and charcoal production which causes deforestation, atmospheric pollution and associated health hazards (Sambo, 2006).

Table 2 Total Primary Energy Consumption in Nigeria (2013). Source: ECN (2014)

Energy Form	Consumption in (toe)	Percentage (%)
Hydropower	588,384.97	0.72
Fuelwood[a]	54,539,027.42	66.58
Petroleum Products	18,258,605.52	22.29
Coal	28,132.48	0.03
Natural Gas	8,502,790.95	10.38
Total	**81,916,941.34**	**100**

Hydropower

The available documented hydropower potential sites in Nigeria for small hydropower plants (SHP) is about 3,500 MW, while approximately 64.2 MW presently exploited (ECN, 2012), while[21] in Nigeria SHPs are within a capacity of 10 MW, mini hydropower plants are those capacities up to 1 MW and micro are those with capacity of 500 kW. Under the GEF 4 project "*scale up small hydropower development in selected countries to contribute to inclusive and sustainable industrial development*", UNIDO and the ICSHP, China in collaboration with the Energy Commission of Nigeria are carrying out further studies on additional hydro sites potentials for energy generation in the country based on the numerous rivers in the Nigeria.

[21] World small hydropower development report (2013), http://www.smallhydroworld.org/fileadmin/user_upload/pdf/Africa_Western/WSHPDR_2013_Nigeria.pdf

SHPs can be developed to power rural areas closest to a potential site, and if generating capacity is equal to or above 1 MW and close to the grid it can be connected. In Nigeria power generation that can be grid connected and qualify for the FIT has to be in the magnitude of 1 MW or above but not greater than 30 MW at a particular site[22]. However, Big Warri and environs do not have any hydrological data to consider hydropower as a means of power generation for the time being.

Nigeria generates electricity mainly from large scale hydropower plants from, Zarma (2006) comments that these are "*three (3) large hydro power stations, Shiroro, Jebba and Kainji*", and in addition other large power plants are under construction, the 4,000 MW Mambilla power project, 40 MW Kashimbila hydropower station in Taraba state[23], the Zungeru 700 MW power plant that was put on hold due to legal issues but has now resumed construction and the Gurara dam which is projected with a generation capacity of 30 MW first stage and 300 MW in the second phase to provide hydro-electric power which will feed the national grid[24]. Some other large-scale hydro plants are at the feasibility stage.

Nuclear

Nigeria does not presently have a nuclear plant in operation and the reserve of nuclear material such as Uranium is not well documented and Umoren and Ebiwonjumi, (2013) further comment that Nigeria is presently in the second phase of the development of infrastructure for nuclear power programme through competitive bidding, and the IAEA website report on the International Conference on Research Reactors: Safe Management and Effective Utilization (2008) states that the country presently has a research reactor built solely for teaching purposes and production of short-lived radioisotopes, the Nigeria Miniature Neutron Source Reactor known as the Research Rector-1 is powered by enriched Uranium-aluminium alloy extrusion clad with aluminium.

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[22] ESI Africa website: https://www.esi-africa.com/info/about-esi-africa-2/ 3 July 2016
[23] Kashimbila hydropower station Taraba (2014), http://www.blackborderbuild.com/industry--services/kashimbila-hydropower-station-taraba
[24] Gurara dam & water transfer project, http://www.tractebel-engie.com/references/gurara-dam-and-water-transfer-project-2/viewed 4 July 2016

Crude Oil

Nigeria is the leading oil producing country in Africa[25] and a member of the OPEC. The country has at present a proven crude oil reserve of 37,070 million barrels and from the records of the Federal Ministry of Power and Steel this constitutes the world's sixth largest reserve, and a production capacity of about 1,807,000 barrels per day (OPEC, 2015). Crude oil is a major source of revenue for Nigeria.

Natural Gas

Nigeria has a proven natural gas reserve of 5,111 billion cubic metres and marketed production of about 43,842 million cubic metres per year (OPEC, 2015). The high value of availability and relatively easy access to this product from underneath the ground in the country makes it a major energy driver and led to Nigeria depending primarily on fossil for her power production using turbines and gas generators, thus making most of the thermal power plants being located in the vicinity of the gas plants. Ode Itsekiri is in the waters and is surrounded by a network of natural gas plants from the Escravos gas project a joint venture operated by the NNPC and Chevron Corporation[26].

Coal

Nigeria has large coal deposits made-up of sub-bituminous (49%), bituminous (39%) and lignite (12%) coals occurring in about 22 fields spread round 13 states of the country (ECN, 2003). The use of coal in Nigeria in the 1950s was primarily for driving locomotives, but with the discovery of crude oil in 1958 most of the trains converted to the use of diesel engines and the production of coal fell from 905,000 tons to about 52,700 tonnes in 1983 (ECN, 2003) and further to about 14,300 tons in 2001 and presently contributes just approximately 0.03% of the primary energy consumption as contained in Table 2.

[25] Nigeria to triple natural gas output for power supply (2014), http://www.bloomberg.com/news/articles/2014-09-15/nigeria-must-boost-gas-output-for-power-supply-minister 5 July 2016

[26] NNPC & Chevron sign agreements on escravos gas project (2011), https://www.chevron.com/stories/nnpc-and-chevron-sign-agreementson-escravos-gas-project viewed 10 June 2016

Coal is not primarily used in power generation in Nigeria, but due to the low sulphur content of the mined coal it has presently found some markets in Italy and the UK, while the use in other industries such as steel making and paint manufacturing is being examined (ECN, 2003). None of these coal deposits or mines in Nigeria is located in Big Warri or within its environs.

Wind

The use of wind energy in power generation is generally site specific, and before installing a wind turbine the wind potential (full load hours/year) and the speed in meter per second (m/s) of the location has to be measured over a period not usually less than a year in average (Neubauer, 2015). There have been some on-shore wind mappings in the past for some areas in Nigeria with results of favourable wind conditions such as the work by Lahmeyer (2004) where areas and cities like Jos Plateau, Gembu, Kano, Funtua, Maiduguri, Enugu and Lagos recorded speeds of about 5 m/s compared to the average range of 1.4 – 3.0 m/s in the southern areas and 4.0 – 5.12 m/s in the extreme north (Idris et al, 2012).

However, the viability of the Nigeria implementing on-shore wind power systems does not look certain because of lack of very detailed wind mapping and constant wind flow, therefore, GIZ (2015) argues that the country should consider off-shore wind measurements which will be more profitable than on-shore wind power plants. Again Ode Itsekiri, the envisaged project area and environs do not have any detailed wind mapping so as to consider wind as a means of power generation at this time. With the availability of daily weather data for example the current temperature is [27]23°C and a prognosis high of 28°C as at 10.32 am today 10 July 2016 which is readily available online in conjunction with more accurate weather and irradiation data from the metrological centres in the country, and this also makes the use of solar likely practicable for the proposed project site.

Biomass

Nigeria is endowed with different types of biomass fuels that can be used for electricity generation from a landmass of approximately 910,770 sq. km, made up of

[27] AccuWeather (2016), http://www.accuweather.com/en/ng/ode-itsekiri/927396/current-weather/927396. Viewed 10 July 2016

forest area of approximately 172,340 sq. km and agricultural land area of 79.1% (World Bank, 2012). This makes the country enriched with vast agricultural products and forest woods. After the processing of some agricultural products, these leave behind large residues such as rice husk, cashew shells, corncobs, stalk and leaves, palm kernel shells, cassava stems, leaves and peelings, waste woods and sawdust just to mention a few. These biomass residues are mostly not used for economic production. In 2004 alone Nigeria consumed an estimated 60.851 million m^3 of wood as fuel (FAO, 2007), while in most cases these waste residues generated constitute environmental problems since they are dumped along river channels, side roads and at best in the forest.

Nigeria also generate a large amount of forest residues, consisting of logging residues (tops, branches) and process residues (off-cuts, sawdust) from wood industries, and demolition wood that constitute a large potential. "*Typical residue yield from a tropical sawmill for export is between 15% and 20% of the total biomass (full tree, or 30% to 45% of the actual biomass (example logs) delivered to sawmill*------ "(Simonyan and Fasina, 2013), the wastes generated are very enormous and the wood processing units lack the facilities for their utilisation (Adeyoju and Bada, 2010), these biomass wastes can be potential fuel for electricity generation.

The proposed project site has a lush green forest and biodiversity of fauna and flora, agricultural trees, bamboos, crops and fibre plants (Warri Local Government Area, 1988). The forest areas have to some extent been preserved except for the increasing habitation by humans resulting in deforestation. The forest woods cannot be used for generating electricity because of the negative effect on the environment, presently there are no studies of the area on agricultural products occurring on renewable basis or biodegradable municipal solid waste, there are no local industries processing timber or generating much agricultural waste produce. There are no substantial waste materials for energy production and therefore, does not favour a biomass plant which leaves room for the natural sun light that is in abundance in the area.

Solar

Figure 7 shows that Nigeria is in the region of solar radiation which is quite about 1,600 kWh/m^2 value in the least region to values above 2,200 kW/m^2, and has two climatic seasons; the dry season (November-March), and the raining season April-

October (Adeyemo, 2013), and that during both seasons the sun still shines across the country.

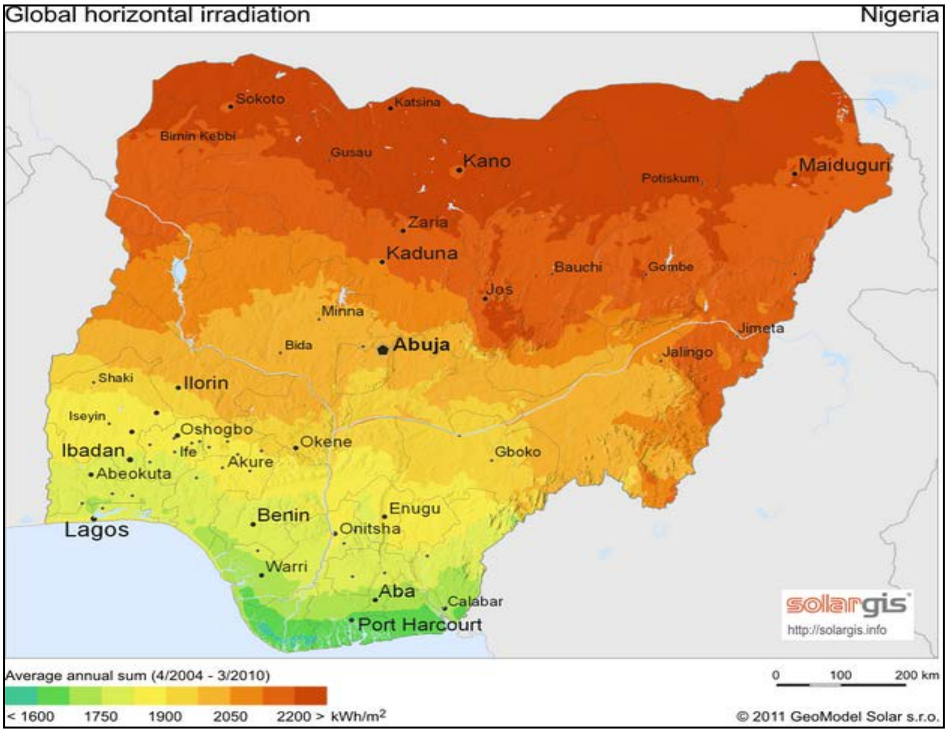

Figure 7 Average Annual Sun in Nigeria. Source: Solaris[28]

The oil and natural gas richness of Nigeria has made the use of alternative energy sources marginally low, solar energy is abundant in the country at approximately 4-7.5 hrs of average sunshine per day (IRENA, 2012), whereby Bala (2014) comments that the country is endowed with solar intensities between 4 kWh/m^2 and 6.5 kWh/m^2 per day from the southern coast to the far north which means that Nigeria on the average has almost 1.6 times of more solar intensity as that of Germany (900 kWm^2 – 1200 kWm^2)[29], while the northern part of the country on the other hand is of the same rating with Spain and these are amongst some of the countries in Europe using a large component of solar in their electricity mix.

Though Germany is obviously less sunny compared to Nigeria, but it has clearly achieved in 2014 the production of about [30]50.6% of its electricity need from solar on

[28] www.google.at/search?q=solargis+map+nigeria&client=firefox-b&tbm
[29] Same source as 28

[30]Germany gets 50 percent of its electricity from solar for the first time (2014), http://theweek.com/speedreads/451299/germany-gets-50-percent-electricity-from-solar-first-time viewed 7 July 2016

the 9th of June, which approximates to 23.1 GW of electricity per hour, and plans to produce 35% of the entire electricity needs from renewables by 2020 and 100% by 2050.

A further study of energy sources in Germany in 2015 shows a mix of renewables in the energy source up to about 30% amounting to 195.7 TWh, with solar contributing 38.4 TWh, see details in Figure 8 below.

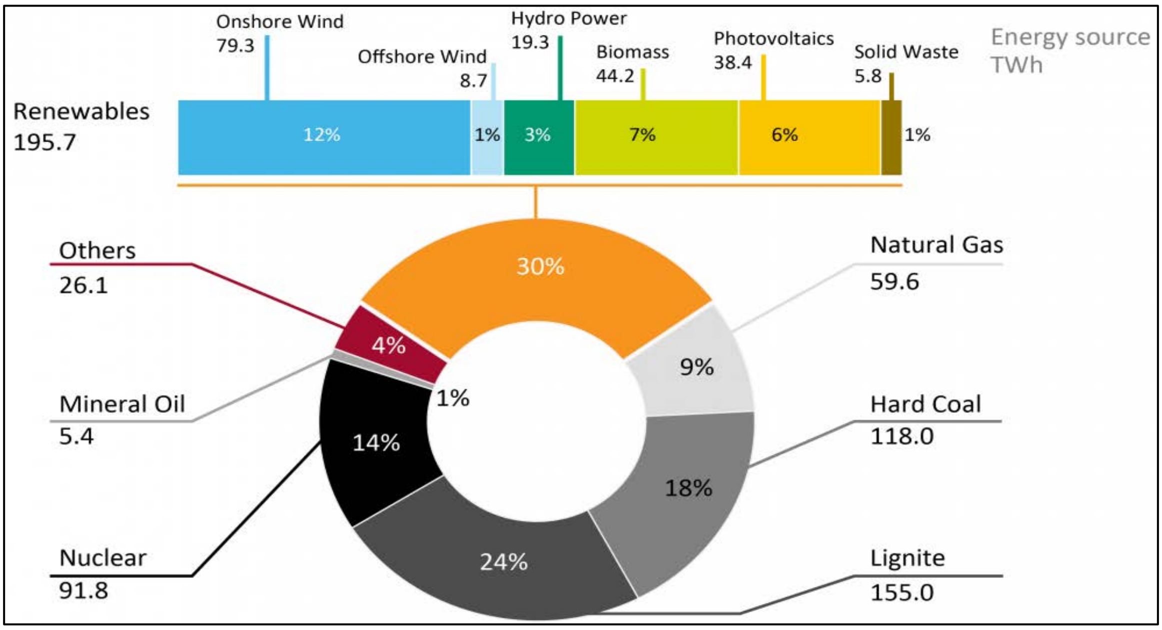

Figure 8 The Share of Energy Sources in Gross German Power Production in 2015[31]

In comparison to Nigeria with a more favourable solar intensity, Table 2 on page 21 shows that the total energy consumption in 2013 does not include any proportion of electricity contribution from solar, while in the case of Germany, input from solar has been on the increase, this value was about 29.7 TWh[32] (2013), 32.4 TWh by November 2014[33] and an impressive figure of 38.4 TWh in 2015 of electricity production from solar into the energy mix of the country.

This feat by Germany shows the underutilization of the sun as a means of generation of electricity by Nigeria, but there is now a greater awareness by the Federal

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[31] Clean energy wire, https://www.cleanenergywire.org/factsheets/germanys-energy-consumption-and-power-mix-charts. Viewed 19 October 2016

[32] Electricity production from solar and wind in Germany in 2013, https://www.ise.fraunhofer.de/en/downloads-englisch/pdf-files-englisch/news/electricity-production-from-solar-and-wind-in-germany-in-2013.pdf. Viewed 19 October 2016

[33] Electricity production from solar and wind in Germany in 2014, https://www.ise.fraunhofer.de/en/downloads-englisch/pdf-files-englisch/data-nivc-/electricity-production-from-solar-and-wind-in-germany-2014.pdf. Viewed 19 October 2016

Government on the use of solar energy and developing the technology within the country for the ease of application, while Bala (2014) comments that this can be used as a complementary energy resource in both the rural and urban areas in conjunction with fossil fuel in a reasonable proportion.

While also accessing the energy resources potential, the Nigerian Minister of Power[34], Works and Housing, Babatunde Fashola, stated that his ministry is working with other stakeholders to "*deliver an energy mix that will boost power productivity by positioning solar power plants in the far North, hydro power plants in the North and North-Central, coal plants in the North Central and South East and gas plants in the South-West and South-South*".

The Nigerian Bulk Electricity Trading (NBET) an agency of the government set up as a bulk purchaser of electricity from generating companies and thereafter sells to distribution companies who in turn sell to electricity customers, is about to sign power purchase agreements with solar power providers for some sixteen (16)[35] projects with a total of 1,300 MW capacities being planned to be added to the national grid, these projects are just awaiting the signing of bankable PPAs between the project promoters and NBET, this is a good attempt at installation in the megawatt range.

Notwithstanding the low numbers of solar implemented projects, Nigeria has tried to use solar for water pumping purpose, street lighting and in some relatively bigger applications such as the [36]75 MW solar plant in Katsina to be implemented under a 20 year PPA, and will sell power at a fixed rate of US$ 11.5¢/kWh (NERC, 2012) under the MYTO wholesale and retail prices contain a Feed-in tariff (FIT) for electricity generation from renewable energy systems above 1 MW. These tariffs (see Appendix B) undergo minor review biannually and a major review every five years.

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[34] Construction work on Zungeru power plant in Nigeria resumes (2016), http://constructionreviewonline.com/2016/05/construction-work-on-zungeru-power-plant-in-nigeria-resumes viewed 4 July 2016

[35] Construction work on Zungeru power plant in Nigeria resumes (2016), Federal Ministry of Power Website

[36] http://independentnig.com/2015/04/25/much-unbundling-nepa/# viewed 19 July 2016

2.2 Nigeria Electricity Policy and Rural Electrification

2.2.1 An Overview of the Electricity Policy

Prior to the policy on privatisation of electricity, and the eventual implementation in 2013[37]of the sale exercise of the generation and distribution subsectors in Nigeria, private investment in electricity generation and distribution was not encouraged, Omojola and Oladeji (2012) comment that this resulted in the concentration of power generation, transmission and distribution solely under the Federal Government electricity company, the National Electricity Power Authority (NEPA), with the use of mainly fossil fuel and large hydropower plants. The monopoly by NEPA could not meet the increasing demand for electricity resulting in a sharp decline in power generation compared to an increasing population and industrial activities.

Privatization of the electricity sector meant the withdrawal of the government from the day to day running of the sector and thus liberalising the operation to allow market forces come in to play and with the intension that this exercise will create more active players in electricity generation and distribution in the country and subsequently greater supply to meet the growing demand (GIZ, 2015).

To facilitate the sale of NEPA the Federal Government initially restructured it into different companies then legally held it as a state powerholding entity named PHCN, thereafter four former NEPA thermal plants were sold off while two hydro plants are under concession to a private management Detail, (2012), making the six new private generating companies (GENCOs) in the country. Other government owned newly built National Integrated Power Projects (NIPP) thermal plants were also after restructuring sold like NEPA. While the power distribution sector was split into eleven distribution companies (DISCOs) and also sold, with government still maintains the transmission grid and administrative regulation of the power sector in the country (GIZ, 2015).

The electricity supply crisis in the country became evidently prominent from around 2009, however, this was from a cumulative large disparity between supply and demand of electricity beginning from 2001, which necessitated the Federal Executive Council (FEC) to issue the National Electricity Power Policy (NEPP) in 2001, GIZ

[37] Execution of transaction and industry agreements (2013), http://www.nigeriaelectricityprivatisation.com/ viewed 19 July 2016

(2015). This was the first step on the path to the privatization and liberalization of the electric sector in the country; this was followed four years later with the enactment of the Electric Power Sector Reform Act 2005 that subsequently changed power ownership from government-owned electricity company to include private players.

Some regulations that constitute the legal framework forming the basis of the privatization of electricity and policies, with special emphasis on renewable energy and rural electrification in the country are briefly discussed below:

2.2.1.1 National Energy Policy (NEP) 2003

This policy recognises the importance of various sources of energy and the need of integration of alternative forms of energy into the nation's energy mix. The NEP (2003) document lists the different types of renewables, on pages 17 and 18, and the objectives of the use of solar energy and the strategies of achieving the application in energy generation are well enumerated. The document emphasises that improving access to electricity in remote areas would be best served by the deployment of off-grids for rural electrification.

2.2.1.2 Electric Power Sector Reform Act 2005

This Act enacted by the National Assembly of the Federal Republic of Nigeria on 11th March 2005 forms the basis of the power reform and partly reads as follows: "*An Act*[38] *provided for the formation of companies to take over the functions, assets, liabilities and staff of the national electricity power authority; to develop competitive electricity markets, to establish the Nigerian electricity commission; to provide for the licencing and regulation of the generation, transmission, distribution and supply of electricity; (...) determination of tariffs; and to provide for related matters.*"

(Sambo 2009) comments that this act prepared the stage for the establishment of the Nigerian Electricity Regulatory Commission and Rural Electrification Agency with the later setting the mandate to increase electricity access to the rural areas and also assist with the financing of renewable energy projects and the Power Consumer

[38] Federal Republic of Nigeria Official Gazette (2005), http://www.power.gov.ng/download/Electric%20Power%20Sector%20Reform%20Act%202005.pdf viewed 13 July 2016

Assistance Fund (PCAF) to subsidise less privileged consumers as contained under Part VIII of the Act.

2.2.1.3 Renewable Electricity Policy Guidelines (REPG) 2006

This document states the views of the Federal Government policy on the possibility of electricity derivation from renewable energy sources (FMPS, 2006)[39] with a clear vision of a sustainable development and an increase of renewable energy to the national grid. The document identifies that renewable energy is the key to a rapid expansion of access to electricity supply in the country.

REPG also identifies the major barriers to renewables in Nigeria as, non-consistent incentive policy of centralized conventional sources of electricity, financing and investment barriers based on the fact that renewable energy projects have high initial investment costs, lack of technological knowhow of renewable energy systems in the country, public awareness and low standards of locally produced and some imported equipment resulting in lack of confidence in renewables as well as lack of maintenance and frequent collapse of installed systems (see Appendix C).

2.2.1.4 Renewable Energy Master Plan (REMP) 2012

The REMP policy is intended to optimize the use of the various energy resources for sustainable development in Nigeria, which is an articulated road map for increasing the role of renewable energy. The Energy Commission of Nigeria and the United Nations Development Programme drafted this document in 2005 with an update in 2012, and it envisages that renewable energy would account for 10% of Nigeria's total energy consumption by 2025.

2.2.1.5 Draft Rural Electrification Strategy and Plan (RESP) 2015

The RESP document prepared by the Federal Ministry of Power is in a draft form, GIZ (2015) presents an extract from this document as "*The primary objective of the Nigeria Rural Electrification Policy and by extension this Rural Electrification Strategy and Implementation Plan is to expand access to electricity as rapidly as can be afforded in a cost effective manner…*" This shows that the approach to rural

[39] Renewable electricity policy guidelines (2006), http://iceednigeria.org/backup/workspace/uploads/dec.-2006.pdf viewed 10 July 2016

electrification when it eventually gets enacted into law is to be used for both grid extension and off-grid methods depending on which approach will be more cost effective for rural electrification programmes.

2.2.2 Rural Electrification

Rural electrification and access to electricity in remote areas and islands is under the portfolio of the Rural Electrification Agency and is affiliated to the Federal Ministry of Power, and other active stakeholders include the Nigerian Electricity Regulatory Commission (NERC), the Energy Commission of Nigeria (ECN), the Federal Ministry of Environment, the Federal Ministry of Science and Technology and other entities.

The amount of work that is involved in providing electricity to rural areas in Nigeria is so intensive because these areas have long been neglected, such that Ohaire (2015) argues that the challenge is also compounded by lack of clear electrification plans for such areas. [40]The Rural Electrification Agency of Nigeria in 2014 estimated that only 26% of rural households had access to electricity which it states is similar to the figure obtained earlier in 1981 when the Nigerian Rural Electrification Programme started, while Odi (2016) comments that about 70 million Nigerians living in rural areas have no electricity actually supports the level of electricity availability in rural areas.

With the above observation on the state of electricity shows that the market in rural electrification will be very lucrative in the future for private investors because there are many sites for implementation, and the use of renewable energy resources will be of great potential in achieving this objective. [41]The earlier discussed RESP encourages public-private partnership, and that the initiative for rural electrification projects should come from the communities and operators while a market based approach is envisaged. The Rural Electrification Agency therefore, provides the central coordination of the rural electrification activities.

Due to the economic conditions in rural areas, the inhabitants usually have limited source of income and investment in electricity generation projects by the locals may

[40]New national rural electrification implementation strategy and plan (2014), http://www.power.gov.ng/National%20Council%20on%20Power/Rural%20electrification%20agency.pdf viewed 10 July 2016
[41] Expert Interview with Sunday Goube, operator of the plant in May and July 2016

be very difficult, and also payment for electricity has to be substantially better subsidized than the case of the grid electricity customers country-wide who consume less than 50 kWh/month (GIZ, 2015) and have a fixed lifeline tariff of ₦ 4.00 (US$ 0.025)/kW.

Without support from the government or international organizations and financial institutions the implementation of off-grid systems in rural areas like the proposed integration of a solar PV mini-grid or any other renewable technology in Ode Itsekiri will not be easily attained, therefore the Rural Electrification Fund (REF) as a support mechanism and price incentives proposed in EPRA (2015) will be a good support for renewable energy projects in rural and remote areas.

The REF to be implemented by the Rural Electrification Agency will according to section 88 of the EPRA (2015) receive funds from monies such as fees, donations, charges from electricity licensees, fines or penalties obtained by NERC, contributions from state governments, local and the Federal Government.

When this electrification funding comes into effect GIZ (2015) comments that it will partly support total project cost and, because the intension is as an incentive to lower the cost of installation of renewable energy systems in rural areas for project development from requesting communities and other interested groups that want to invest in rural areas.

2.3 Methods of Electricity Generation in Nigeria

In articulating a long term plan, the Nigerian Government developed the vision 20: 2020 transformation blueprint which intends to place Nigeria amongst the top 20 economies of the world (ECN, 2014) by the year 2020, the document spells out economic growth and development strategies for achieving the objectives between 2009 and 2020, with a minimum of 35,000 MW installed generation capacity planned for by the year 2020 to achieve this feat. Efforts are being put in place to achieve the above target and this will be discussed further under subparagraph 2.2.

The next section will be used to describe the various methods of electricity generation, which The Detail (2012) in its publication titled “Power generation options in Nigeria” identifies four (4) different techniques that are used for providing electricity through the national grid system, and by private individuals and companies for self-consumption.

a. Captive generation

These are electricity self-generating plants not exceeding 1 MW Omoboriowo (2012) in Nigeria, that are either operated by individuals to produce electricity for individual use at home such as for refrigerating foods, watching TV, pumping water or providing comfort of illumination and others. While some companies in order to be able to remain in the business of production of goods and services are compelled due to the erratic power supply to install in their premises a diesel or petroleum generating set or an inverter.

This group of power generators do not need a permit to operate these self-generating plants. In this type of generation, owners of captive generating sets cannot distribute excess electricity outside the vicinity of generation if produced, which is their homes or companies (GIZ, 2015), this mode of power generation also fits under the off-grid system.

b. On-grid generation

The on-grid is the generation of electricity that is sent directly into the national grid of the country. Prior to the privatisation of the power sector, this type of generation was primarily by the government controlled power plants that led to the limited supply of electricity by the grid. [42]Presently, on-grid generation in the country requires a legal license to operate and is now open to private investors to participate in. This allows both fossil fuel and renewable energy sources but for capacities up to or greater than 1 MW. Table 3 shows some of the plants that feed the grid in Nigeria which are mainly gas and large-scale hydro plants.

[42] Nigerian power plants (2015), http://www.nercng.org/index.php/about-us viewed 9 July 2016

Table 3 Existing Nigerian Power Plants as at 2015. Source: Nigeria Energy Regulatory Commission

Name	Fuel Type	Year Completed	Installed Capacity (MW)	Available Capacity (MW)	Actual Generation Capacity (MW) as at May 2015
AES	Gas	2001	270	267	0
AFAM IV-V	Gas	1982	580	98	0
AFAM VI	Gas	2009	980	559	523
ALAOJI NIPP	Gas	2015	335	127	110
DELTA	Gas	1990	740	453	300
EGBIN	Gas	1985	1320	931	502
GEREGU	Gas	2007	414	282	138
GEREGU NIPP	Gas	2012	434	424	90
IBOM POWER	Gas	2009	142	115	92
IHOVBOR NIPP	Gas	2012	450	327	225
JEBBA	Hydro	1986	570	427	255
KAINJI	Hydro	1968	760	180	181
OKPAI	Gas	2005	480	424	391
OLORUNSOGO	Gas	2007	335	244	232
OLORUNSOGO NIPP	Gas	2012	675	356	87
OMOKU	Gas	2005	150	0	0
OMOTOSHO	Gas	2005	335	242	178
OMOTOSHO NIPP	Gas	2012	450	318	90
RIVERS IPP	Gas	2009	136	166	0
SAPELE	Gas	1978	900	145	81
SAPELE NIPP	Gas	2012	450	205	116
SHIRORO	Hydro	1989	600	480	350
ODUKPANI	Gas	2013	561	70	0
Total			**12,067**	**6,840**	**3,941**

On Table 3 above, from the names of the thermal plants, it is evident that because the fossil fuel is primarily located in the southern part of the country, almost all the thermal power plants are also in this area and electricity generated is then transmitted round the country with the attendant losses along the transmission grid to the hinterland and the far northern parts of the country (see Figure 7 the map of Nigeria). The on-going discussion is that in order to increase electricity generation in the country, each region should use the source of electricity that it is endowed with and this will predominantly incorporate renewables in the form of solar and wind systems in the north with higher solar irradiance.

c. Off-grid generation

Mini-grid seldom referred to as micro-grid or isolated grid is a form of off-grid system with electricity generation serving a group of consumers[43]. However, GVEP (2011) defines mini-grid as distribution networks <3MW power system supplying electricity in a small locality (rural areas, industrial clusters or residential estates)[44], the system may consist of a single technology (conventional or renewable) or hybrid of technologies of power sources (diesel and renewable). Mini-grids in Nigeria fall into the category mostly with diesel plants, and are a subset of off-grid plants in the country.

Off-grids also include standalone private generators as discussed under captive plants since these systems cannot transmit current to the grid but only to the homes, offices or companies where they are installed. This section will focus on the off-grid arrangement in rural areas as autonomous systems whereby a network of electricity cables are wired around the houses in some of the remote villages and islands that are far from the national grids.

In Nigeria some of the state government Rural Electrification Boards see the approach of development of mini-grids in remote and rural areas as a more economic and logistical approach of providing electricity to these areas, and most of the existing off-grids in the rural areas in Nigeria have diesel based power plants as the electricity generators as a means of promoting rural electrification in the country.

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[43] Mini-grid policy toolkit (2014), http://www.ruralelec.org/grid-electricity-systems. Viewed 10 July 2016

[44] Opportunities for off-grid solutions in the Nigerian power sector (2016), http://www.financialnigeria.com/opportunities-for-off-grid-solutions-in-the-nigerian-power-sector-sustainable-293.html viewed 10 July 2016

Although the above system of electrification is not a perfect arrangement but it assists the communities in having some access to electricity otherwise they will be in total darkness. A better arrangement would be providing electricity for productive uses, which would cover the daytime and night time activities of the communities.

An improvement to these grids that can be provided by the Rural Electrification Boards in these remote and isolated areas in Nigeria by retrofitting these electrification systems with other locally available renewable energy technologies such as hydro power, solar PV, biomass, tidal wave or geothermal in communities that already have installed electricity distribution grids.

There are different models for managing the operation of mini-grids with the rural electrification in most areas in Nigeria and the proposed project site, grid installation and diesel generators were provided by the government agency REB and handed over to the communities, who became the owners of the system and took responsibility for management services, operation and maintenance.

Presently the idea of collecting tariff by the communities electrified by the REB is a nouveau idea because the mini-grid and diesel plants were provided by the government and the communities do not pay for electricity and in most cases this leads to the demise of the projects when the diesel generators break down until a replacement can be made which in some cases takes time.

The above approach of free electricity is gradually being jettisoned after the deregulation of the electricity market now that the power sector has been privatised and the [45]REA opines that an appropriate tariff should be charged which will be "*responsive and supportive*" of the average customer and at the same time should be "*reflective of costs of setting up generating system*", expansion and upgrade, and a reasonable return on investment for private investors or utility based operator if they are to operate it instead of the community.

d. Embedded generation

The NERC (2014) defines embedded generation as generated electricity that is directly connected to a local distribution electricity network of either 33kV, 11 kV or

[45] Rural electrification Agency in the emerging deregulated electricity markethttp://rea.gov.ng/sites/default/files/REA%20IN%20THE%20EMERGING%20DEREGULATED%20ELECTRICITY%20MARKET.pdf viewed 20 July 2016

0.415 kV and not to the national grid (GIZ, 2015). Therefore, the electricity generated has to be sold or used in the area it is generated because the generated electricity is directly dispatched to a distribution company that distributes within the licensed area, or straight to end users, which has the advantage of minimizing losses due to the shorter distribution network. Embedded generation are for capacities greater than 1 MW and require a licence to operate but excess electricity cannot be sent to the national grid (Detail, 2015).

2.4 Transmission of Electricity in Nigeria

Transmission lines used in Nigeria are conductor intertwined wires made of aluminium or reinforced with steel or carbon composites like glass fibre and carbon, and used to transport electricity[46]. This transmission of electricity enables large amount of electricity produced at a power plant to be moved over a long distance and takes place at high voltage of about 132 kV or a higher voltage[47] due to losses experienced during transportation. Figure 9 below is a schematic illustration of how power generation, through transmission labelled in red colour and then through distribution lines labelled in orange to the final consumer.

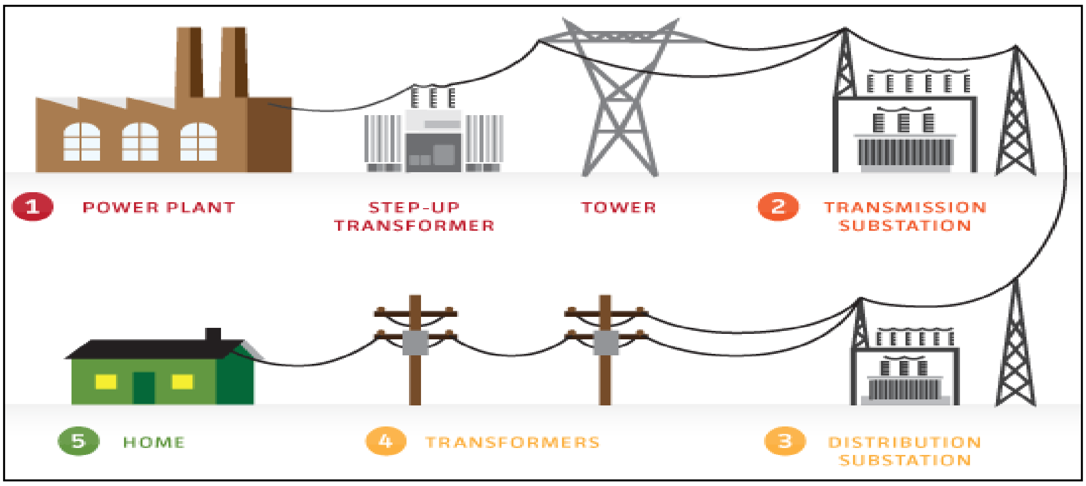

Figure 9 Route of Electricity from Generation to End-Users. Source: Nigeria Electricity System Operator[48]

[46] Overhead power line, https://www.google.at/?client=firefox-b#q=what+are+transmission+lines+made+of&gfe_rd=cr viewed 18 July 2016
[47] Transmission of electricity http://tspnigeria.com/learn/transmission-of-electricity/ viewed June 30 2016
[48] How electricity gets to you, http://www.nsong.org/Pages/ContentPageLink1.aspx viewed on 20 July 2016

During the privatisation of the power sector, the transmission segment was not privatised by the Federal Government of Nigeria because of the cost that would be involved in grid management and new extensions for a private investor, and as a result this sector is operated on behalf of the government by Manitoba Hydro International a private entity named the Transmission Company (TCN) of Nigeria and is responsible for transmission service, system and market operation of the grid.

The transmission system in Nigeria is made up of high voltage levels of 330 kV connecting 32 substations, and 132 kV connecting 105 substations[49]. The grid as of 2010 was approximately 5,523 km of 330 kV and 6,801 km of 132 kV, GIZ (2015) and it is still undergoing extension and grid strengthening.

2.5 Distribution of Electricity in Nigeria

Following the privatisation of the power sector in Nigeria, the distribution of electricity was transferred to eleven (11) distribution companies[50] that solicited and won the tender for distribution, which listed in alphabetical order are; Abuja, Benin, Enugu, Ibadan, Ikeja, Jos, Kaduna, Kano, Port Harcourt and Yola distribution companies. The distribution networks in the country are the low voltage which is 11 kV and the high voltage 33 kV, and generally copper wires are used in medium-voltage distribution and low-voltage connections to customers (GIZ, 2015).

Presently to get electricity to the end consumer in the country, the Nigerian Bulk Electricity Trading Plc which is a limited liability company but owned by the government buys off the electricity generated by the power generating companies by contracts established through power purchase agreements, and the electricity is in turn sold to the distribution companies who supply electricity directly to the customers within their zone of operation (GIZ, 2015).

[49] http://www.nsong.org/ viewed on 20 July 216
[50] Nigeria electricity privatisation project, http://www.nigeriaelectricityprivatisation.com/?page_id=2viewed on 30 July 2016

CHAPTER 3: APPRAISAL OF ELECTRIFICATION AT ODE ITSEKIRI VILLAGE

The Power Ministry of Nigeria under the "Operation Light Up Rural Nigeria" which is a power transformation agenda of the country aims at using solar and other renewable energy "*…which will be cost effective in those areas where electricity cannot be supplied, especially in the rural, riverine and areas remote…*[51]*.*" This section will therefore examine the present state of electricity in Big Warri and the possibility of adapting solar alone, in a mix with other technologies, an attempt at providing more regular or longer hours of electricity in comparison to the present state of approximately 5 hours of electricity whenever the diesel plant and diesel fuel are available.

3.1. The Research Environment

Ode Itsekiri lies along (Latitude: 5 30' 00" and Longitude: 5 43' 00") is surrounded by River Warri, which empties into the Atlantic Ocean. This area is not connected to the national grid. The people in this village have been deprived of good life since they virtually do not have the chance to enjoy basic amenities when desired.

Ode Itsekiri operates a large 300 kW diesel generator which pollutes the environment, but this community has the potential of either a small hydropower or solar sources of RE. The latter is considered in this write up while discussions on the hydro potential will require further research and flow rate measurement of the rivers in the area for future dissertation work. According to the interviews conducted in the community and at the generator house (see Appendix A) the technicians informed that the diesel generator break down frequently thereby leading to long periods of darkness in the communities and this does not make for effective regular use of the system, resulting in the frequent use of lanterns and candles during breakdowns and when there is no diesel to power the generator. The other surrounding islands are also non-electrified villages that remain isolated without any form of electricity grid.

[51] Update on major projects and programme implementation in the power sector (2014) website:http://www.power.gov.ng/Recent%20Events/Up%20Date%20on%20Major%20Projects%20and%20Programme%20Implementation%20in%20the%20Power%20Sector.pdf viewed 20 July 2016

Figure 10 shows that this community has had a minimum of four generators over the years, with each serving some period of time, actual data do not exist but from expert interviews with the generator operators (see Appendix A) each of these generators have a life span of about four to five years considering that they have never been run continuously due to lack of diesel supply.

Presently three generators are cannibalized and litter the generator room and at this rate diesel generating sets might become a sort of consumable due to the need to purchase new ones when each becomes faulty. The present generator in service was donated to the community by NDDC, a Federal Government of Nigeria agency set up to specially cater for the sustainable development of the Niger Delta[52] area of the country where the Nigerian oil wealth is generated.

Figure 10 Generator House Showing Some Defective Generators. Own Source

Maintenance of the generator is also a problem, because technicians have to be sourced from the hinterland to come from across the river and carry out routine maintenance, equipment breakdown and repairs when necessary because the community does not have such technicians.

Another negative aspect of the diesel generating plant in the community is the fuelling pattern of the generator which adds a comic dimension to the electrification of Ode Itsekiri, whereby fuelling can be at the mercy of prominent Itsekiri sons and daughters from the city, who decide to donate some drums of diesel to the village to operate the generator when he or she is on a visit to the village.

[52] Niger Delta Development Commission, http://www.nddc.gov.ng/newsandevents.html

Otherwise, the major source of diesel for operating the existing generator is through the levy imposed on families that bring in corpses for burial in Ode Itsekiri. [53]According to the technical and community members interviewed (see appendix A), before burial ceremonies, the family of a deceased is mandated to provide a minimum of fifty litres of diesel fuel for the running of the generator, more so, the generator is operated only when a cumulative amount of about 200 litres is collected which creates an electricity gap when such quantity of diesel is not available or no corpse to bury, and the villagers cannot bear the cost and luxury of regularly buying 200 litres[54] which is consumed over a maximum three day period at a scheduled approximately five (5) hours of operation from about 7pm to 12 midnight, which means that the villagers are without light for most part of the day and subsequently in the year.

In other words, if there is no death, operation of the generator goes on waiting for a corpse or donation of fuel by a Good Samaritan. However, once in a while especially when there is a special activity in the community such as the coronation of The Olu of Warri a paramount king in the country, DESOPADEC a state government agency set up to cater for the needs of oil producing communities in the state provides diesel supply to Ode Itsekiri for operation of the generator for the period of such ceremonies, also a very short intervention since this is not a regular activity.

This pattern of fuelling the diesel generating set in the community shows that it is only operational periodically when diesel can be sourced and not in a routine operation that will enhance the generator for productive use, or in the health centre for vaccine preservation, for daytime laboratory experiments in community schools, operation of fans in the hot daytime and other devices (see Appendix D). Due to this non regular supply of light in the community there is a solar pump station for safely pumping water (see Figure 13).

Ode Itsekiri is in the vicinity of Warri city, and the 2014 direct irradiance (DNI) data, Source: Nigerian Meteorological Agency (NMA) for the area under review is available in MJ/m^2 and converted to kW/m^2 as shown in Table 4 is the monthly radiation for Warri with a computed daily average value of about 4.8 kWh/m^2 while

[53] Expert Interview with Sunday Goube, operator of the plant in May and July 2016
[54] Expert Interview with Sunday Goube, operator of the plant in May and July 2016

daily irradiance of Nigeria range from 3.5 to 7.0 kWh/m^2/day (Chukwu and Kwajaffa, 2013). Table 5 shows the monthly average for the year 2014 which will be used in chapter 3 for simulation, see Figure 29.

Table 4 Monthly Solar Radiation for Warri Area, 2014. Source: NMA

Month	Total Solar Radiation		Month	Total Solar Radiation	
	MJ/m^2/month	kWh/m^2/month		MJ/m^2/month	kWh/m^2/month
January	588.1	163.4	July	435.2	120.9
February	513.1	142.5	August	451.6	125.4
March	593.4	164.8	September	481.4	133.7
April	560.1	155.6	October	552.9	153.6
May	531.9	147.8	November	539.8	149.4
June	460.5	128.0	December	576.9	160.3
Total	6,284.90 MJ/m^2/a = 1,745.81 kWh/m^2/a				

Table 5 Computed Daily Solar per Month Radiation for Warri Area (2014): Own Source

Month	Daily Average (kWh/m^2/day)	Month	Daily Average (kWh/m^2/day)
January	5.277	July	3.900
February	4.914	August	4.045
March	5.316	September	4.180
April	5.187	October	4.955
May	4.768	November	4.980
June	4.267	December	5.171

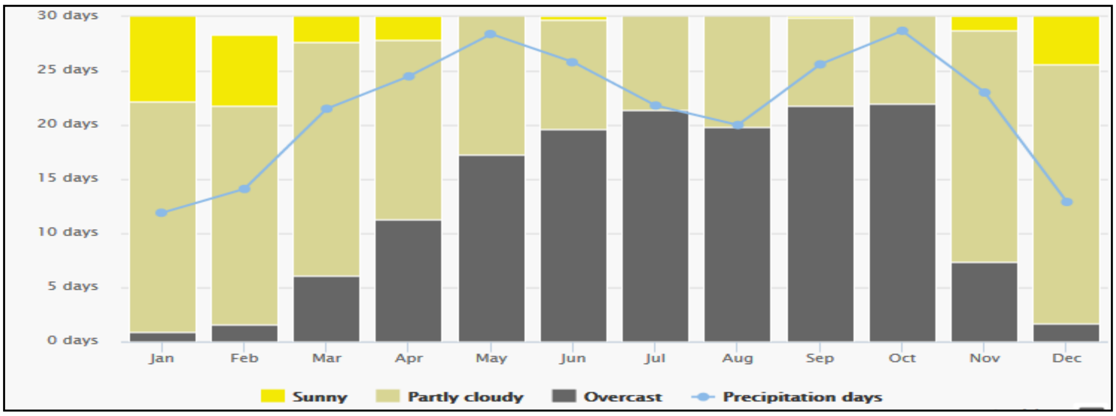

Figure 11 Monthly Number of Sunny, Partly Cloudy, Overcast and Precipitation in Warri Environ. Source: Meteoblue Weather[55]

[55]Climate Warri, https://www.meteoblue.com/en/weather/forecast/modelclimate/warri_nigeria_2319134 viewed 12June 2016

Figure 11 on the previous page shows the pattern of daily and sunny solar days in the area which is good and shows why the use of PV system is not new to the community, while Figures 12 below and 13 overleaf show the use of solar powered street lights and solar water pumping station already in Ode Itsekiri community but no solar system for household illumination which is part of the focus of this thesis.

NDDC and DESOPADEC in the past provided the community with the solar street lights that comes up in the night to electrify the major streets and solar water pump, this means that the incorporation of a solar array to illuminate the household, schools and refrigerate vaccines in the health centre will be an appropriate step to provide basic electricity, thereby powering Big Warri for additional hours and also a backup if necessary to the solar water pump if it goes faulty.

Figure 12 Solar Powered Street Light. Own Source

The solar street lighting and water pump creates a lot of convenience for the villagers interviewed notwithstanding that these lights work only at night pointing out that this provides security from attacks by wild animals from the virgin forest surrounding the community, and security can be further improved with more household lighting in the community.

Figure 13 Solar Powered Water Pumping Station. Own Source

Neither is the waiting for a transmission electricity grid connection, which might never be realized in these remote communities nor is the continuous usage of a large capacity diesel generators that is not a sustainable approach to electricity in this village meeting the functional needs of the inhabitants.

Presently in Big Warri there exists a mini-grid connecting the households to a diesel generating set, this grid can also be used to transmit the electricity from a solar plant in Big Warri or an hybrid system whichever is deemed more economical. Therefore, a more pragmatic approach will be to examine and evaluate the effect of renewables in the form of a solar mini-grid as autonomous, solar-diesel hybrid or only the diesel plant.

3.2 Description of Existing Electrification Facility in Big Warri

The configuration of the electricity network installation in Big Warri is basic and consists of the grid and a generator house tucked away at one corner of the community and operated by two operators that run the service on a voluntary basis when enough diesel fuel is collected which is then used to resume operation for the number of days it can last. The operation of the electrification system is a community based electricity management approach whereby the community handles the maintenance and economic aspects[56].

[56] Expert Interview with Sunday Goube, operator of the plant in May and July 2016

3.2.1 The Generating Diesel Set

The presently operational generator in Ode Itsekiri as depicted in Figure 14 below has a power rating of 300 kW and Perkin powered see nameplate in (Appendix E), and as mentioned earlier is operated whenever there is a cumulative collection of about 200 litres of diesel to put it on and this serves for approximately three days (3) x (5) hours each making a total of 15 hours of operation till the next operation usage.

The installation of the diesel plant must have been due to the perceived cheapness because of the lower immediate investment cost, Root (1997) compared diesel systems to renewable energy systems, and argues that the former has lower up-front capital expenditure (CAPEX) investment, while the associated life time maintenance and operation costs (OPEX) are mostly not of interest in arriving at implementation of conventional fuel mini-grid plants.

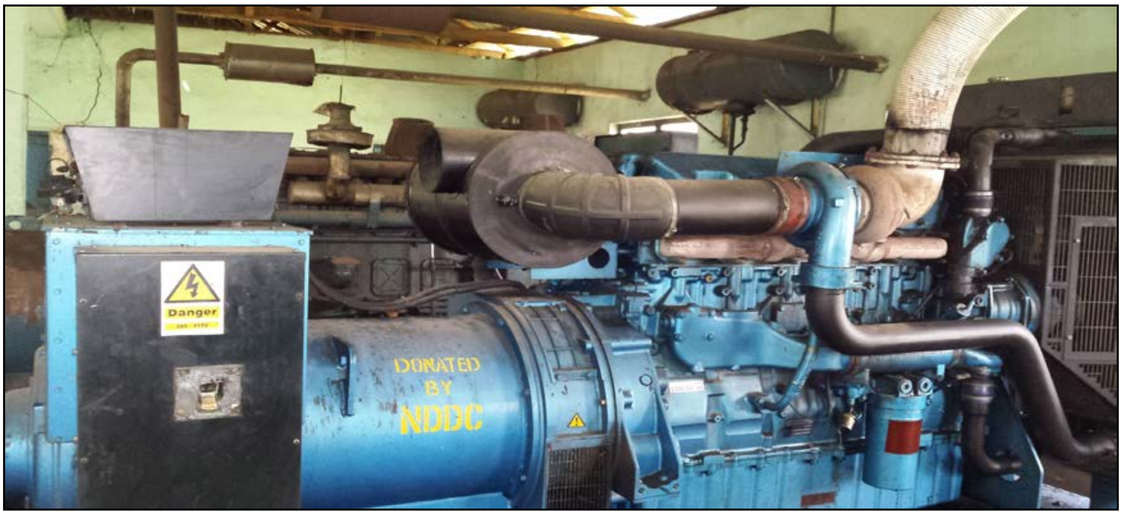

Figure 14 The Presently Functional Generator in Big Warri. Own Source

3.2.2 The Electricity Grid

The existing mini-grid and generator house in Big Warri was built by the Rural Electrification Board of Bendel State Government, and commissioned in 1977[57]. The network cable is a mixture of types 60mm x 1 AAC and 70mm x 1 AAC conductors which are wired around the village, using 28ft ≈ 8.5m poles, 95mm x 4 up risers and a few electrical stays wire. Figure 15 shows an electric pole in the network. In the community extensions of lines to newly built houses are carried out when necessary,

[57] Expert Interview with Engr. Bright Okpopo. Consultant Mosbright Nig., Ent., Benin-City

and this might be the reason for a large 300 kW generator in anticipation of expansion, but this is not a technically sound reasoning because the generator might be faulty before these new load demand and operating at a high cost in anticipation.

Since the mini-grid was a government initiated project and not a private investment, permit for generation was an internal procedure. An investor company would have to comply with the regulations for an independent electricity distribution network for isolated rural or urban networks required to operate a mini-grid or off-grid system (GIZ, 2015), the concept of private investment in electricity business in rural areas or islands is not common in Nigeria because most of the rural dwellers still believe in free electricity usage because majority of these inhabitants are economically unproductive[58].

The Big Warri electricity grid is presently tied to a diesel set, and the grid will be suitable for distribution of electricity also from a renewable energy source such as a solar generating plant alone or in a hybrid mode with the present conventional resource.

Figure 15 Electric Pole with Distribution Cables. Source: (Okpokpo, 2016)

With a solar plant even without a battery storage there will at least be more regular provision of day time electricity for relaxation in the community; electricity for watching TV and people having current knowledge of national and world affairs,

[58] A brief note on the condition of rural areas in Nigeria (2012), http://www.vanguardngr.com/2012/01/a-brief-note-on-the-condition-of-rural-areas-in-nigeria/viwed 20 July 2016

charging their mobile phones, refrigeration of vaccines in the health centre, and public places such as schools having electricity to perform science experiments in the day-time when the schools are in session. More light can also improve the access of electricity to other business enterprises for productive uses and better living standard.

3.3 Description of Photovoltaic Technology

Photovoltaic describes the conversion of the energy from sun rays to direct current (DC) upon striking a semi-conductor (Nelkon, 2010). This phenomenon is due to voltage potential difference created when electrons are set free as sunrays impinge on semiconductors, and when the resulting electrons and electron holes assemble at P-N junctions. (Fechner, 2015) states that electricity is then transmitted when conductors are connected to the poles of the modules, with no moving parts involved in this energy transformation and therefore, not subjected to wear and tear like machines with mechanical motions. The French scientist Alexandre-Edmond Becquerel[59] first discovered this photo-electric-effect in 1839.

There are various semi-conducting materials such as cadmium telluride, cadmium selenide, gallium arsenide, indium arsenide and silicon with potential conductivities and efficiencies suitable for different types of systems. Gallium arsenide cells are used in space programmes (Szweda, 2015), while amorphous silicon in wristwatches and solar cells, and crystalline silicon are mostly for PV electricity systems. In most of these cells the laboratory efficiencies tend to be higher than what is obtained commercially (Lasnier and Ang, 1990). Some of the major components of a PV power plant are discussed below:

3.3.1 Solar Modules

PV installations commonly used in electricity generation are typically made from silicon. Modules are made from wafers, and cells that are first etched, undergo dopant diffusion, fired and then assembled, then encased in a layer of ethylene vinyl acetate

[59] Photoelectric effect-solar basics, http://www.renewable-energy-concepts.com/solarenergy/solar-basics.html. Viewed 20 July 216

(EVA), and sandwiched into a module as above that are basically used in electricity generation[60].

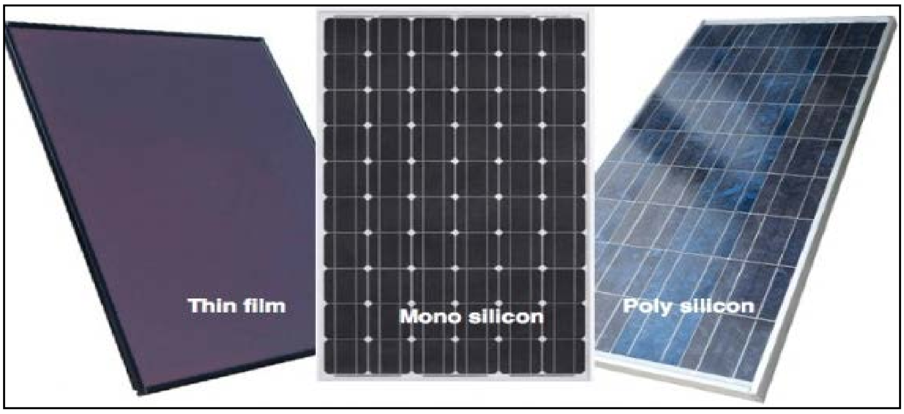

Figure 16 Thin Film, Monocrystalline and Polycrystalline Panels[61]

Some types of cells manufactured from silicon that are commonly used for power generation applications are shown in Figure 16 above. The efficiency of a module is important in a plant design because it is a measure of how the cells of the module converts solar rays into electricity, Fechner (2015) defines the power efficiency of a module as shown in equation 1) below:

$$\eta = \frac{P_m}{E*A_c} \quad \text{--1)}$$

Where P_m = maximum power point, E = input light (W/m^2), A_c = surface area of cell (m^2), assuming 1 kW = $8m^2$.

A monocrystalline cell has approximately research and commercial module efficiencies of 24% and 18% respectively, and polycrystalline silicon, with a research efficiency of 18% and commercial modules up to 15%. Although the polycrystalline have a lower efficiency, they are, however, relatively cheaper due to the less expensive method of production,

Both the mono and poly crystalline types of solar silicon are referred to as the first generation solar cells based on the basic materials used for their production and

[60] Solar PV module assembly process (2013), https://www.youtube.com/watch?v=varpdTceX0s.viewed 20 July 2016
[61] https://www.google.at/search?q=polycrystalline+pv+module&client=firefox-b&tbm=isch&tbo=u&source=univ&sa=X&ved=0ahUKEwiW7Zjo2pHOAhXlLcAKHXPqCw4Q7AkISA&biw=1920&bih=946 viewed 20 July 2016

commercial maturity of technology (IRENA, 2012). For commercial applications in electricity generation the monocrystalline and polycrystalline can be used for the proposed project in Nigeria, however, due to the price advantage and relatively high efficiency the polycrystalline will be recommended for the project in Big Warri.

Thin film cells mostly manufactured from amorphous silicon (a-Si) are second generation solar system with a research efficiency of about 12% and typical production efficiency of 8% and they look as a potential future technology in solar system, while the concentrated cells use lenses and curved mirrors in focusing light onto multi-junction cells which makes this system still relatively expensive and are referred to as third generation and mostly in the pre-commercial stage (Fechner, 2015).

Setting up a PV plant will also involve the balance of system (BOS) which is composed of the mounting structures, battery racks, inverter, battery or other forms of storage, electrical cable, transformer and converter. The cost of BOS components in the PV plant project includes also services such as site preparation, design of system and wiring (IRENA, 2012).

3.3.2 Charge Controller

A charge controller is a useful component in a PV power system. The controller basically protects the battery bank by regulating the voltage and current from the solar panel[62]. This is done through the controller blocking reverse current, and when the battery is full to capacity it prevents it from further accepting current that will cause damage to the battery by raising the voltage very high leading to boiling of the battery.

3.3.3 Inverters

[63]When the rays of the sun falls on a solar panel, DC electric current is generated, but this form of electricity is not very compactable with most types of household devices, therefore, inverters are electronic system that can convert DC current to 50 Hz AC current which is the form that is most compatible with many home appliances such as

[62] http://www.solar-electric.com/solar-charge-controller-basics.html/ viewed 20 July 2016
[63] What are the different types of inverters (2016), http://www.solarpowerworldonline.com/2016/05/different-types-solar-inverters/, Viewed 20 July 2016

TV, radio, electric grinders, in the schools and for laboratory equipment and medical centres.

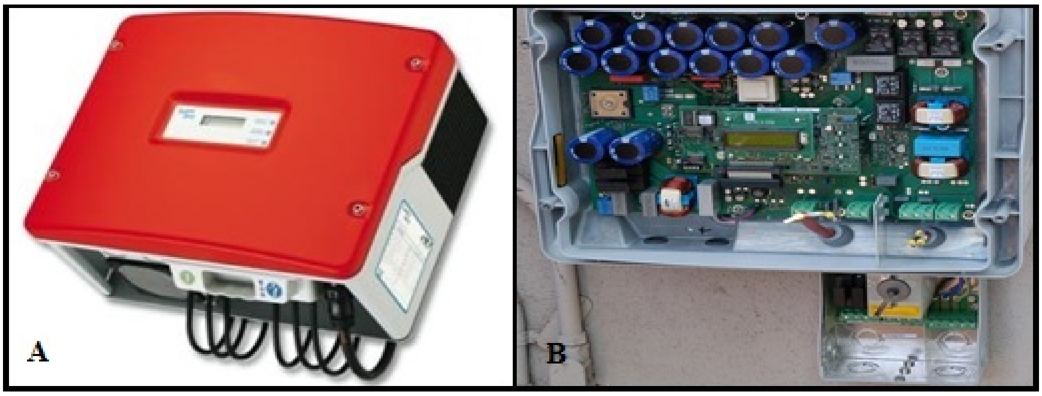

Figure 17 An Inverter (A). Internal View of a Solar Inverter **(**B**)**[64]

3.3.4 Battery

Battery storage is important for decentralized off-grid PV systems because there are times that the sun will not shine brightly. Therefore, electricity generated in bright weather when there is not much immediate demand can be stored until such a time when it is needed for instance, in the night when the sun has set or during other daytimes when there is much cloud cover over the sky. (IEA, 2014) comments that in most off-grid PV systems where a storage system is required, the deep discharge lead-acid type battery are most reliable, an example of this product is shown in Figure 18.

Figure 18 Tudor Lead Acid Deep Cycle Battery[65]

[64] https://en.wikipedia.org/wiki/Power_inverter viewed 20 July 2016
[65] Source: Trama TechnoAmbiental (2010)

Deep discharge lead-acid batteries are relatively cheaper compared to the lithium-ion (LiO), nickel-cadmium (NiCd) and nickel-metal hydride (NiMH) batteries which are although more expensive, but have the benefit of not easily getting over charged during storage of electricity and discharge during usage[66]. Batteries when properly used, regularly maintained and protected by a functional charge controller can last several years. (Fechner, 2015) recommends a maintenance schedule of regularly checking, cleaning of terminals and in case of flooded batteries topping with electrolyte about every six months and operation at a temperature range of -20 °C to 40 °C to increase battery life span.

3.4 Approach to Installation of Systems

It is important to describe clearly the approach to data collation for this thesis and the constraints encountered. In most African countries and Nigeria in particular Chukwu and Kwajaffa, (2013) argue that data are not easy to come by unlike in Europe and America where data are published and most research works had been accomplished and uploaded online. Therefore, in this thesis, data and information had to be sourced out physically at the project area by the author to personally obtain them. This is the only way a study of Ode Itsekiri can be put in a library for future referencing by other interested persons.

In designing a plant for Big Warri and, for effectiveness a detailed geotechnical testing of the soil of the area will be carried out, and the modules would be ground mounted to enable good ventilation, and properly aligned in the direction of the wind flow that will allow for sufficient cooling of the panels, and regulate the temperature of the modules. This is necessary due to the fact that c-Si modules are relatively more sensitive to high temperature in contrast to thin film panels, but with relatively lower efficiency.

Due to the cost implication of tracking the optimal position of the sun, no tracker will be used in this installation. Shadowing effect can be avoided by installing the polycrystalline module solar plant in an area far from objects like trees and, since there are no high-rise buildings in the village shadowing from such obstacles will not be a problem. The inclination of the panels affects output of solar modules (Fechner,

[66] What is the best type of battery for solar storage (2015), http://www.solarpowerworldonline.com/2015/08/what-is-the-best-type-of-battery-for-solar-storage/

2015), based on the location of Ode Itsekiri, simulation using a solar calculator suggests that the panels of the plant will be best angled 84° to the vertical[67] according to the time of the year with the best radiance.

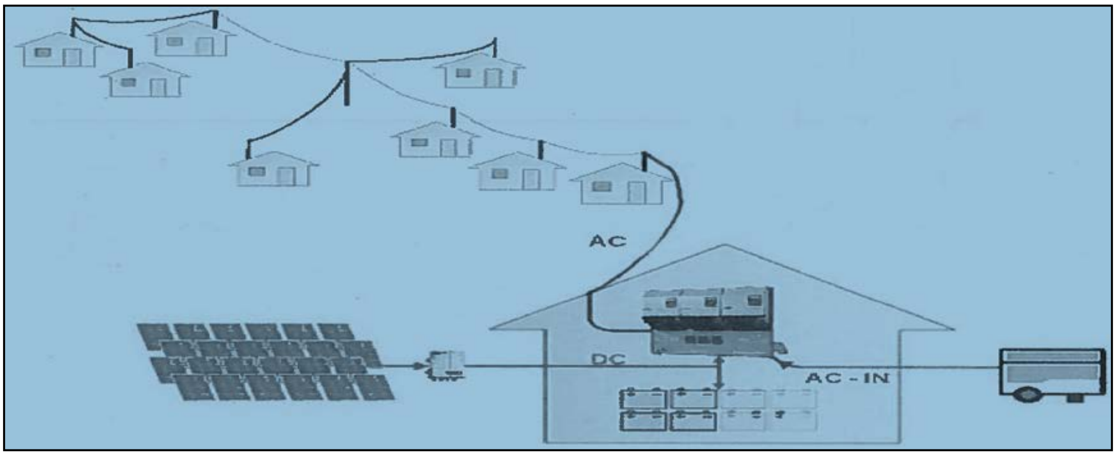

Figure 19 Solar Mini-Grid and Diesel Plant[68]

For Warri vicinity, this period will be March with daily average of 5.316 kWh/m^2 (see Table 5) to get the best performance out of the system, this can also be an advantage for cleansing the surface when it rains, which means that the modules can be guaranteed proper cleanliness throughout the year in Big Warri especially from the month of March to November when rainfall is very significant (see Figure 11).

Figure 20 An Autonomous Solar Mini-Grid[69]

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[67]Solar electricity handbook (2016), http://solarelectricityhandbook.com/solar-angle-calculator.html

[68] https://www.google.at/search?q=solar+mini+grid+system+design&client=firefox-b&tbm=isch&tbo=u&source=univ&sa=X&ved=0ahUKEwjXjoer247OAhXH6xoKHXO8B24QsAQIKA&biw=1680&bih=889#imgrc=ovFRFl4-iswmFM%3A viewed 25 July 2016

In a solar plant or a solar hybrid design, the solar component allows for the provision in future expansion of electricity generation capacity, which is another advantage of the modular property of a solar system, more modules and additional storage batteries can be incorporated when required either to the solar arrays or on roof tops and connected to the mini grid network.

The operation of a solar system is less cumbersome compared to the operation of a diesel plant and also maintenance of a solar plant does not require much knowledge of electrical engineering, while Haney and Burstein (2013) comment that qualification skills for handling a PV system can be earned on the job through training by equipment manufacturers. What will also be required is the education of the community to observe some basic rules on the usage of household equipment applications to make the plant last long.

Nigeria subsidies electricity nation-wide for consumers because the amount they pay is not reflective of the actual cost of electricity, while a sustenance tariff of ₦4.00 (US$ 0.025)/kW has been set for the low income people who usually consume less than 50 kWh/month (GIZ, 2015). This form of assistance from the government will come into play also in big Warri, where the installation of the solar plant or hybrid system which ever is more economical will be paid for by the collaboration of the oil companies, the Federal and State Governments, and the Rural Electrification Fund.

However, when the plant is fully operational, a management committee can be set up to run the system and collect a reasonable tariff with some subsidy from the government. The tariff collected over the years can assist in the replacement of defective polycrystalline modules after the guarantee period if necessary, replacement of batteries after their life span and a token payment of stipends to the management team.

3.4.1 Dimensioning of the Electrification System for the Community

A visit to the project area shows that most of the inhabitants have just the basic house hold devices as pictured in Appendix D, and most people interviewed would prefer cool ambience during the hot daytime with more use of electric fans in the daytime and at night time, watch TV, operate barbing and hair salons, be able to charge their

[69] Sunny Island https://www.youtube.com/watch?v=NqafKFHyzJk viewed 25 July 2016

phones and light up their houses during the day when the weather is cloudy outside and definitely at night time and the schools will have electricity for the laboratory works and the health centre refrigerators.

Loads to be considered are only AC at a voltage 220-240 V and frequency of about 50Hz, since DC appliances were not found in any of the households interviewed (see Appendix D). Also, there will be the need for more energy saving devices such as electric bulbs, which should be encouraged, and the inhabitants educated on proper usage of the common facility installed in the community.

Therefore, to enable planning and dimensioning of a system in the Big Warri for this thesis, a simple interview format (see Appendix F) was designed and administered through direct interview with inhabitants to get a representative sample of the devices in the homes so as to determine an appropriate community load demand. A total of about 250 homes were accessible during the visit and feedbacks retrieved were collated (see Figures 21). Care had to be taken in using this data gathering method because in general people tend not to be responsive to outsiders just coming into their communities, and a questionnaire approach might not be successful because of suspicion of the purpose and the level of literacy in the community.

Based on the device samples obtained in the homes, a daily electricity load demand structure using an excel energy sheet is extrapolated as shown in Figures 21, 22 and 23 for about four hundred households counted in the scattered formation in the village, the graphical depictions of the excel energy file applied for obtaining the load characteristics for the residential and private/public facilities are in Appendix G.

HOURLY LOAD [W]	00h	01h	02h	03h	04h	05h	06h	07h	08h	09h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h
Energy saving bulb (10W)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2000	2000	2000	2000	2000
Incandescent bulb (40W)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10000	10000	10000	10000	10000
Incandescent bulb (60W)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15000	15000	15000	15000	15000
Fluorescent bllb (36W)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7200	7200	7200	7200	7200
Music system (10W)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2000	2000	2000	2000	2000
Radio/Phone chargers (10W)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	500	500	500	500	500
TV (65W)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9750	9750	9750	9750	9750
Table fan (68W)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6800	6800	6800	6800	6800
Ceiling fan (68W)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10200	10200	10200	10200	10200
Fridge (100W)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2000	2000	2000	2000	2000
TOTAL [W]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	65450	65450	65450	65450	65450
Number of users	1																							
TOTAL USERS [kW]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	65.45	65.45	65.45	65.45	65.45
Demand factor	0.67																							
TOTAL DEMAND hh [kW]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	43.85	43.85	43.85	43.85	43.85

Figure 21 Residential Load Characteristics in Ode Itsekiri Based on Five Hours of Electricity Generation. Own Source

Figure 21 shows the obtained energy load from the devices in the residence and for the generator running for only five hours and in the night, while Figure 22 shows the energy load for the few public/private premises in the community running at the same number of hours. Using this method of device grouping, the entire village was taken as a unit instead of taking a house and multiplying the load obtained by the total number of houses in the community. The term Public/Private Premises is the same as Commercial in the Figures 23 and 26.

HOURLY LOAD [W]	00h	01h	02h	03h	04h	05h	06h	07h	08h	09h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h
TOTAL COMMERCIAL DEMAND kW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.8	0.8	0.8	0.8	0.8
SCHOOLs- Lab & HM office @ 40W	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	160	160	160	160	160
ENTERT. @ 1 fridge	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	100	100	100	100
STORES 2 @ 2 fridge	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	200	200	200	200	200
HEALTH Centre fridge	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	100	100	100	100
HAIR SALOON 2 40W bulbs others	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	120	120	120	120	120
BARBING SALOON	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	100	100	100	100
CHURCH: security bulbs @ 40W	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	20	20	20	20

Figure 22 Public/Private Premises Load Characteristic in Ode Itsekiri Based on Five Hours of Electricity Generation. Own Source

The figure below is a summation of Figures 21 and 22, which shows the total energy demand (kWh) as **223.26 kWh/day**.

Row Labels	-00h	-01h	-02h	-03h	-04h	-05h	-06h	-07h	-08h	-09h	-10h	-11h	-12h	-13h	-14h	-15h	-16h	-17h	-18h	-19h	-20h	-21h	-22h	-23h	
TOTAL DEMAND COMMERCIAL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.8	0.8	0.8	0.8	0.8	4
TOTAL DEMAND RESIDENTIAL [kW]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	43.9	43.9	43.9	43.9	43.9	219.258
TOTAL DEMAND INSTUTIONAL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
																				44.7	44.7	44.7	44.7	44.7	223.26

Figure 23 Total Load Characteristic in Ode Itsekiri Based on Five Hours of Electricity Generation. Own Source

Another set of load characteristic is contained in the Figures 24, 25 and 26 with more availability of electricity for the daytime and also at night time, see Appendix H for the graphical representation of the electrical load structure. This set of data will be used for the simulation of the existing 300 kW generator, an autonomous PV solar plant and a combination of PV solar and diesel in a hybrid system.

The essence of this second load structure is to provide more electricity duration for more productive activities and relaxation in the daytime, making use of the sun during the day as reflected by some of the community members interacted with during the visits.

HOURLY LOAD [W]	00h	01h	02h	03h	04h	05h	06h	07h	08h	09h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h
Energy Savig Bulb (10W)						9000	9000													9000	9000	9000	9000	9000
Music System (10W)								2000		2000			2000		2000		2000			2000		2000		
Radio/Phone Charger (10W)							500		500		500		500		500	500					500			
TV (65W)									9750		9750	9750		9750	9750		9750		9750		9750	9750		
Table Fan (68)										6800		6800		6800	6800	6800		6800		6800		6800		
Ceiling Fan (68W)											10200		10200		10200	10200	10200		10200		10200		10200	10200
Refrigerator (100W)	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
TOTAL [W]	2000	2000	2000	2000	2000	11000	11500	4000	12250	10800	22450	18550	14700	18550	31250	19500	23950	8800	21950	19800	31450	29550	21200	21200
Number of users	1																							
TOTAL USERS [kW]	2	2	2	2	2	11	11.5	4	12.25	10.8	22.45	18.55	14.7	18.55	31.25	19.5	23.95	8.8	21.95	19.8	31.45	29.55	21.2	21.2
Demand factor	0.67																							
TOTAL DEMAND hh [kW	1.34	1.34	1.34	1.34	1.34	7.37	7.705	2.68	1.7	7.236	14.78	12.17	9.81	12.33	16.34	6.16	16.05	5.896	14.71	13.27	21.07	19.8	14.2	14.2

Figure 24 Residential Load Characteristic in Ode Itsekiri Based on Extended Hours of Electricity. Own Source

HOURLY LOAD [W]	00h	01h	02h	03h	04h	05h	06h	07h	08h	09h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h
TOTAL COMMERCIAL DEMAND (kW)		0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.54	0.72	0.76	0.77	0.72	0.72	0.72	0.72	0.62	0.62	0.62	0.8	0.8	0.58	0.58	0.49
SCHOOLs- Lab & HM office		0	0	0	0	0	0	0	100	100	100	100	100	100	100	100	0	0	0	160	160	160	160	160
ENTERT. @ 1 fridge + bulbs		100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	10
STORES 2 @ 2 fridge		200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200
HEALTH Centre fridge		100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
HAIR SALOON 2 40W bulbs others		0	0	0	0	0	0	0	0	120	120	129	120	120	120	120	120	120	120	120	120	0	0	0
BARBING SALOON		0	0	0	0	0	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100	0	0	0
CHURCH: security activities bulbs @ 20W		0	0	0	0	0	0	0	40	0	40	40	0	0	0	0	0	0	0	20	20	20	20	20

Figure 25 Public/Private Premises Load Characteristic in Ode Itsekiri Based on Extended Hours of Electricity Generation. Own Source

Row Labels	-00h	-01h	-02h	-03h	-04h	-05h	-06h	-07h	-08h	-09h	-10h	-11h	-12h	-13h	-14h	-15h	-16h	-17h	-18h	-19h	-20h	-21h	-22h	-23h	
TOTAL DEMAND COMMERCIAL	0	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.72	0.76	0.769	0.72	0.72	0.72	0.72	0.62	0.62	0.62	0.8	0.8	0.58	0.58	0.49	*13.44*
TOTAL DEMAND RESIDENTIAL [kW]	1.34	1.34	1.34	1.34	1.34	7.37	7.71	2.68	1.7	7.24	14.78	12.17	9.81	12.33	16.34	6.13	16.05	5.9	14.71	13.27	21.07	19.8	14.2	14.2	*224.1435*
TOTAL DEMAND INSTITUTIONAL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*0*
	1.34	*1.74*	*1.74*	*1.74*	*1.74*	*7.77*	*8.11*	*3.08*	*2.1*	*7.96*	*15.54*	*12.87*	*10.53*	*13.05*	*17.06*	*6.85*	*16.67*	*6.52*	*15.33*	*14.07*	*21.87*	*20.38*	*14.78*	*14.69*	*237.58*

Figure 26 Total Load Characteristic in Ode Itsekiri Based on Extended Hours of Electricity Generation. Own Source

The summation of the loads in Figures 24 and 25 the total energy load (kWh) is given in Figure 26 as **237.58 kWh/day.**

The next sub-sections will be used to compute the most favourable method to power Ode Itsekiri based on the three scenarios already specified under subchapter 1.1.

3.4.2 Scenario 1: Operating the Diesel Generating System

The electricity currently produced by the diesel generating set goes through a switch box (see Appendix E) and then into the mini-grid. For the computation of the economic cost, and the least cost of energy, prices for generators were sourced and the offered price for a brand new generator similar to that in Ode Itsekiri was obtained from Jubailibros Engineering Ltd, Nigeria and adjusted, see Table 6.

Table 6 Breakdown Cost of an Equivalent 300 kW Generator. Own Source

Description	Model	Price in (₦)	[70]Price in (US$)	[71]Price in (€)
MP350kVA Set	2206A-E13TAG2	16,665,000	53,932.00	48,165.00
Transportation		500,000.00	1,634.00	1,156.00
Installation/ commissioning		300,000.00	980.00	867.00
Total			56,546.00	50,188.00

From the table above therefore, the approximate average cost of generator per kW = US$ 188/kW

Cost of diesel per litre = ₦150

Transportation cost of diesel to Ode Itsekiri = ₦50/litre

Total cost of diesel is ₦200/l = 0.65 US$/l

Cost of routine changing of generator oil: 1,000 hours of operation

Generator oil tank capacity 40 litres

Cost of engine oil = ₦150/litre

Total cost of engine oil O&M is ₦ 200/l = 0.65 US$/l

[70] CBN exchange rate as of 15 August 2016 https://www.cbn.gov.ng/rates/ExchRateByCurrency.asp
[71] CBN exchange rate: ₦306/$, ₦346/€

Applying the HOMER Pro software and using the above data and the electrical load on Tables 6 and 7 for simulation (A) to derive values of parameters such as the Cost of Energy (CoE) in kW/h, Net Present Cost (NPC) and Emission data in this section with the 300 kW generating plant as it is presently installed in Ode Itsekiri.

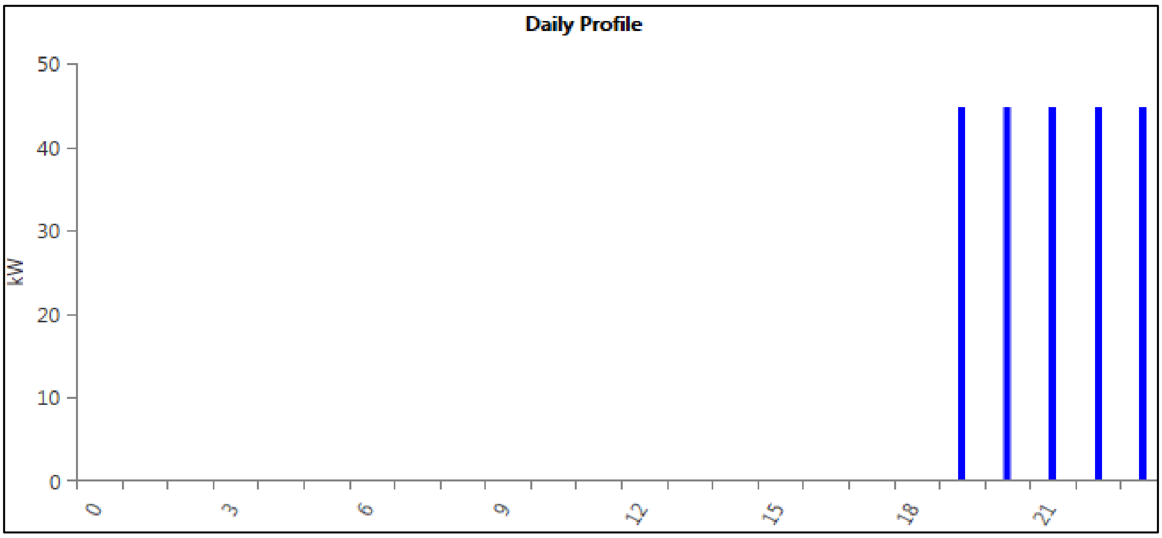

Figure 27 Load Characteristic Based on Five Hours of Electricity Generation. Source: Homer Pro Software

Table 7 Homer Simulation (A) Result for 300 kW Generator Based on Five Hours of Electricity Generation. Own Source

Generator Capacity	**300 kW Diesel Generator**
Initial Capital	US$ 56,400.--
Operating Cost	US$ 387,349.--
Cost of Energy	US$ 4.80/kWh
Fuel Cost	US$ 26,691.--
NPC	US$ 5,060,000.--
O & M Cost	US$ 355,875
Operation Hours	1,825 hours
CO_2 Emission	108,132.67 kg/yr

Using the data on Figure 26 to obtain simulation (B) in HOMER for extended hours of electricity see daily profile load in Figure 28.

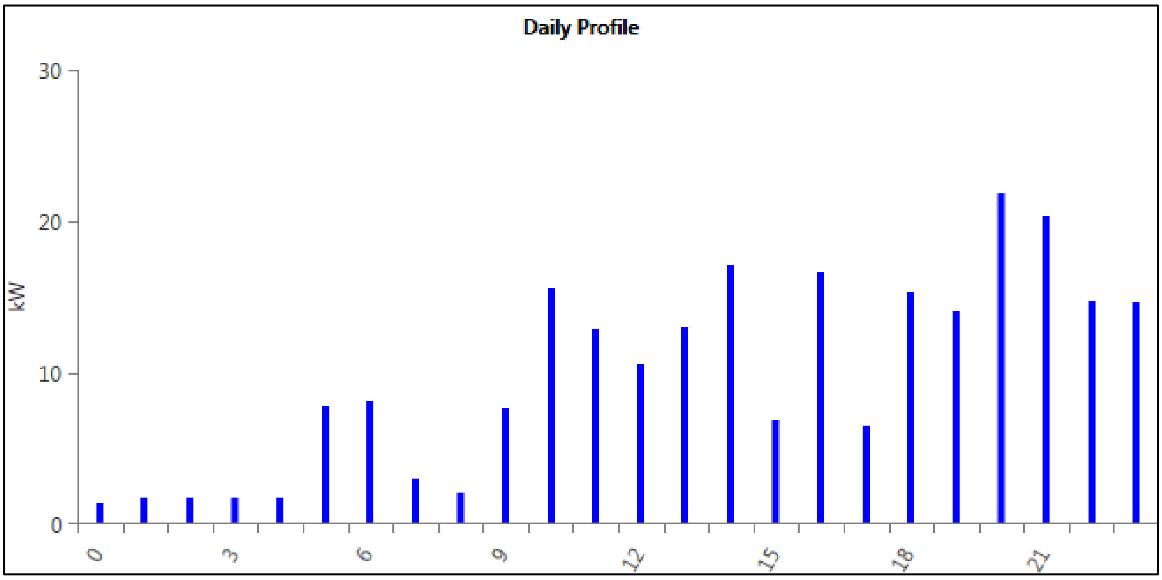

Figure 28 Load Characteristic Based on Extended Hours of Electricity Generation. Source: Homer Software

The simulations data below will be used in comparing the next two simulations that will be carried out in subsections 3.4.3 and 3.4.4 for these scenarios and results discussed.

Table 8 Homer Simulation (B) Result for 300 kW Generator Based on Extended Hours of Electricity Generation. Own Source

Generator Capacity	**300 kW Diesel Generator**
Initial Capital	US$ 56,400.--
Operating Cost	US$ 1,870,000.--
Cost of Energy	US$ 21.64/kWh
Fuel Cost	US$ 128,115.--
NPC	US$ 24,200,000.--
O & M Cost	US$ 1,708,200.--
Operation Hours	8,760 hours
CO_2 Emission	519,029.18 kg/yr

3.4.3 Scenario 2: Autonomous PV Solar System

This scenario can be viewed as a direct replacement of the diesel plant with a solar plant with a battery storage assembly. The load demand as shown in the Figures 24, 25 and 26 indicates more availability of electricity duration due to the usage of the day time sunlight. With this assumption of the same load, it will allow for a proper comparison of cost of electricity and comparing apple with apple as regards the least cost option of electricity generation path.

The modular nature of solar plants make future increase in energy demand to be met by the redesigning of the system through increasing the number of modules and other BoS that would need to be scaled up. However, under this scenario this will not be necessary for consideration because the snapshot is of the present existing capacity in comparison with the existing generator.

For price of components, attempts were made at comparing data from the literature with those from offers received from tenders, and other actual implemented project costs in Africa and other developing regions. (IRENA, 2012) comments that accurate data on global PV module price and solar systems is difficult because of the difference in cost structures of different manufactures, location of markets and module efficiency, therefore, argues that there are a wide range of prices.

The literature reviewed and some actual implemented projects by some renowned developers show a gradual reduction in price of solar powered projects. In an overview of PV technologies statistics, IRENA (2012) comments that PV price is on the decline and the current PV module cost < US$ 1.4/W as at 2012. While discussing the total installed costs for solar PV systems, IRENA (2015) comments that "*in Africa, the total installed costs for utility-scale projects in 2013 and 2014 spanned the range of US$ 1,820 to US$ 4,880/kW,(...)*", which when compared to other regions like Europe within the same time frame, was in the range "*US$ 1,300 to US$ 3,750/kW*." Messrs. Sunlabob, Lao PDR[72] a reputable company with experience in project implementation in Asia and Africa presents data of module cost of US$ 1,360/kW including BOS and installation cost for projects implementation in Africa, lead acid battery US$ 168/kW, converter US$ 752/kW. Online quotation by Messrs.

[72] www.sunlabob.com

Yuyao Ollin Photovoltaic Technology Co., Ltd., China photovoltaic manufacturers (see Appendix K) specification data, provides a cost range of US$ 0.38 – 0.46/W for a 230 W polycrystalline module, with a transportation cost of US$ 0.56/W, FOB INCOTERMS ® 2010.

While IRENA (2012) states a cost and performance value for residential c-Si PV module as at 2010, 1.02 – 1.24 US$/W, installed cost 3.5 – 5.8 US$/W and a levelized cost of electricity US$ 0.36 – 0.71/kWh at efficiency.

Following from above and the falling price trend of PV modules, the cost estimates for the components of a solar plant are based on prices gotten from the market, quote for a 230W polycrystalline Atesa PV module is at US$ 0.7/W, with an efficiency of 14.1% (see Appendix K), and applying a transport value 0.56/W FOB INCOTERMS® 2010, insurance cost of [73]US$ 0.60 per US$ 100 of wattage of equipment (module) amounting approximately to US$ 0.004/W. Due to the remoteness of Ode Itsekiri and lacking in large retail outlets for equipment and machineries, therefore, applying 70% per cost of module for the BOS equal to US$ 0.5/W per instalment (IRENA, 2012). Therefore, installation cost approximates to 1.76 US$/W or 1,760 US$/kW at the site for the module. Assuming a replacement cost of 1,700 US$/kW because some of the BOS components will still be usable at the time of replacement of the modules during their life span.

This simulation in Ode Itsekiri will require a large battery storage, therefore the price of RES OPzS deep cycle battery at 200[74] Euro/kWh (222 US$/kWh)[75] and replacement cost of 230 US$/kWh approximately 4% cost inflation, converter and sunny Island inverter 45448-US type 5,750W at US$ 4,760 (US$ 0.8/W) suitable for off grid systems, datasheets for each product is attached in Appendix K. The simulation result for an autonomous solar plant is shown in Table 9.

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[73] Cargo Insurance Guidelines, http://www.priorityworldwide.com/resources/cargo_insurance_guidelines.asp. Viewed 6 October 2016

[74] Data by Trama TechnoAmbiental, www.tta.com.es

[75] Online converter, https://www.google.at/search?q=conversion+from+euro+to+US$&ie=utf-8&oe=utf-8&client=firefox-b&gfe_rd=cr&ei=S5T8V6LXHKGT8Qf47p6ADA viewed 11 October 2016.

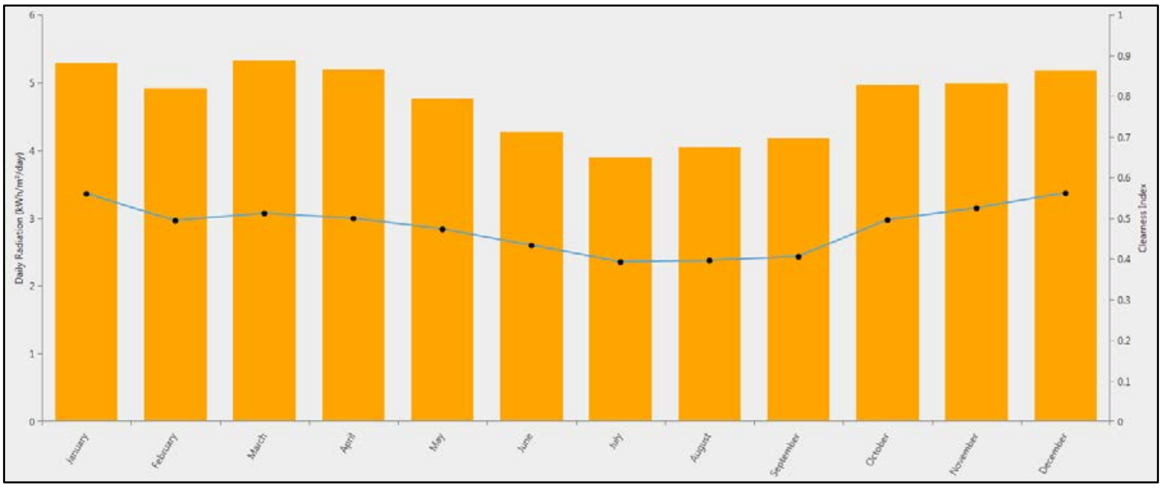

Figure 29 Monthly Average Solar Global Horizontal Irradiance for Warri by Homer Pro Software. Source of Data: NMA **(**2014**)**

Table 9 Homer Simulation (C) Result for a Solar Autonomous Plant Based on Extended Hours of Electricity Generation. Own Source

Generator Capacity	200 kW Solar PV Plant
Initial Capital	US$ 551,830
Operating Cost	US$ 23,230
Cost of Energy	US$ 0.76/kWh
Fuel Cost	0
Net Present Cost (NPC)	US$ 852,133
Capital Cost	US$ 352,000
Renewable Fraction	100%
CO_2 Emission	0

3.4.4 Scenario 3: PV Solar and Diesel Generator System

This section examines the use of solar energy with an appropriately sized generator to generate electricity to meet the load using the data in Figure 26 as already described. This load profile is supposed to make more availability of electricity time in Ode Itsekiri due to the usage of day time sunlight and with a generator as a backup. Below is the HOMER simulation for this scenario:

Table 10 Homer Simulation (D) Result for a Solar Plant Based on Extended Hours of Electricity Generation and a Backup Generator. Own Source

Generator Capacity	**100 kW PV & 20 kW Diesel Generator**
Initial Capital	US$ 347,760
Operating Cost	US$ 28,329
Cost of Energy	US$ 0.64/kWh
Fuel Cost	US$ 1,248
Net Present Cost (NPC)	US$ 713,981
Capital Cost	US$ 200,00
Renewable Fraction	92%
CO_2 Emission	5,055.82 kg/yr

CHAPTER 4: DISCUSSION OF RESULTS

The subsequent three subchapters below present the simulation results for each of the scenario simulated in the previous paragraph. The process involved the simulations of the present electric load status in Ode Itsekiri with the existing 300 kW generator, while the others involved scenarios with the extended hours of electricity to simulate, (i) the existing 300 kW generating set, (ii) an autonomous solar system and (iii) a solar/diesel system as analysed in chapter 3.

4.1 Scenario 1: Operating the Diesel Generating System

Under this scenario, two simulations were carried out and labelled simulations (A and B) respectively. In simulation (A) the load demand was for a period of five hours per day, which is basically in the evenings as is the case with the existing 300 kW diesel generator in the community when fuel is available. The result obtained shows a cost of energy generation (COE) or levelized cost of energy (LCOE) of US$ 4.80/kWh. For an investor, this is the minimum cost that electricity is to be sold to break-even based on discounted cast flow (IRENA (2012). Thus simulation (A), with though a low initial capital cost of US$ 56,400, and a fuel cost of US$ 26,691, but a high operating cost of US$ 387,349.-- is presently a problem for the community that cannot afford to fuel its generator unless a corpse arrives to be buried thereby making it a piece of decorative piece in the generator house.

The second simulation labelled (B) is a load based on an attempt at improving the electricity generation in Ode Itsekiri through more daytime hours of electrification, and thereby enhancing operations of refrigeration systems to assist in health care, productive uses in the barbing/hair salons and recreation activities, schools and entertainment. The result under simulation (B) shows that with the existing 300 kW generator, increasing the operating hours drastically increases both the COE to US$ 21.64/kWh and operating cost to US$ 1,870,000.--, although the initial capital cost remains unchanged at US$ 56,400 as in simulation (A). The simulations and HOMER optimization charts shown in Appendix I illustrate that the electricity generation under this scenario using a 300 kW generating set is very expensive with a high COE and therefore not a feasible project, which was also evident during the visits to Ode

Itsekiri which coincidentally did not have diesel supply to run the generator because there were no burial ceremonies during the visiting periods.

With the implementation of the 300 kW generator in simulation (B) in Ode Itsekiri, merely analysing the initial capital cost looks good, but a detailed analysis of all cost items considered over the years shows high operation and maintenance cost and fuel cost of US$ 1,708,200 and US$ 128,115 respectively. This entails a high volume of diesel of 191,000 litres for 8,760 hours of operation, and a large energy production of 657,000 kWh, whereas the daily demand load is 237.58 kWh (see Figure 26) amounting to an annual energy demand of approximately 86,717 kWh with an excess output of about 570,411 kWh/yr (86.8%) which is such a large excess energy production as shown in Figure 30 below.

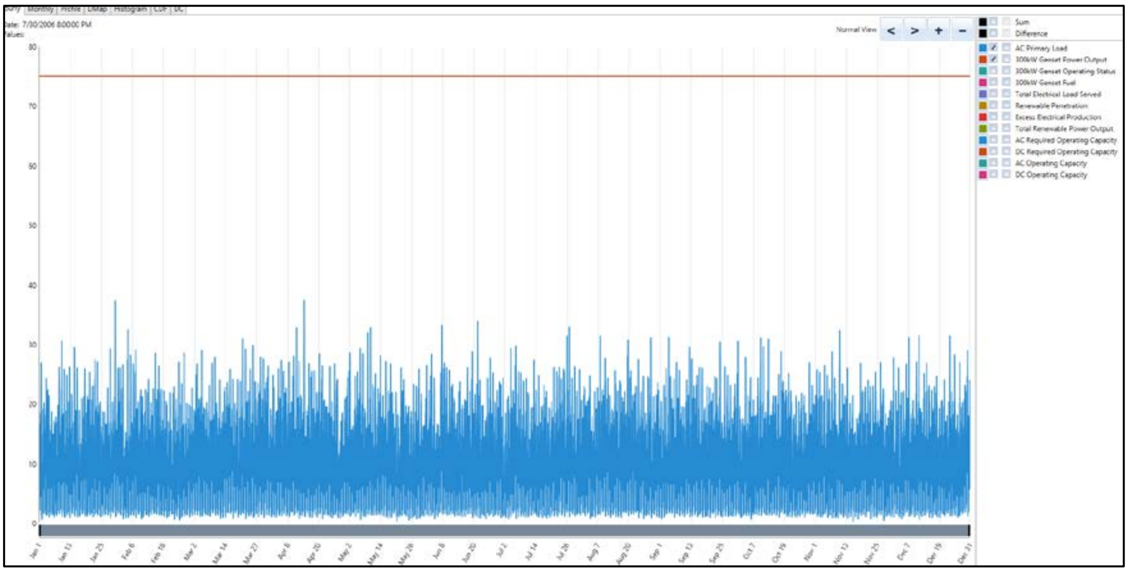

Figure 30 AC Load to 300 kW Generator Output. Source: HOMER Software

While the figure above shows the case with the 300 kW generator, the red line in the figure is the generator output in contrast to the load demand in blue, this shows that the 300 kW generator installed to run the way it is presently being operated in Ode Itsekiri or with an extended hours of load is not one bit optimal, since the generator produces electric current that far exceeds the local load demand and a waste of diesel fuel.

The results of both simulations (A and B) under scenario 1 also reveal the negative impact of the 300 kW generator on the environment in relation to pollution. Carbon dioxide (CO_2) emissions are 108,132.67 kg/yr and 519,029.18 kg/yr respectively for simulations (A) and (B), and this may partly be the reason why steel items and a sign board within the vicinity of the generator house is so badly rusted and is hardly legible as a result of the effect of acid rain[76] due to the emission from the generator (see Appendix J).

4.2 Scenario 2: Autonomous PV Solar System

Under the autonomous solar plant simulation labelled C, the result shows an investment with low cost of energy of US$ 0.76/kWh and operating cost of US$ 23,230 which are by far lower than the costs of the 300 kW diesel generator from simulation B under scenario 1, however, simulation (C) has a relatively high initial capital cost of US$ 551,830 as explained on page 46.

The initial capital cost of installing the 300 kW generator at (US$ 56,400), as noted above looks very good at a first glance, but if other cost elements such as running cost are taken into consideration this paints a very different picture. A detailed analysis shows a high operation and maintenance costs and fuel cost of US$ 1,708,200 and US$ 128,115 respectively for the 300 kW generator. In comparison, the ratio of the initial capital costs of simulations (B) and (C) is 1:9, however, the operating cost ratio is the other way round 74:1. This shows that over the life span of both systems establishing an autonomous 200 kW solar plant is a cheaper and better solution than the 300 kW generator. There is no fuel cost with the autonomous system, which is actually a cost element that Ode Itsekiri community cannot afford except when there is goodwill from a wealthy individual visiting the ancestral home or the arrival of corpse.

Figure 10 shows 4 generators in the generator house, out of which three have already been cannibalised, and just for comparison using approximately the initial capital cost in the earlier simulation gives a total cost of US$ 225,600 (4 X US$ 56,400). There is no available data on the total number of defective generators so far, but this computed amount is already almost the half of the initial cost for scenario (C) without any other cost considered. We can also analyse the fuel cost for five years and that gives 4 X US$ 128,115 = US$ 512,460 and adding (US$ 109,200) the cost of the second replacement of a generator occurring at the 5th year of the diesel generating system as

[76] What is acid rain (USA Environmental Protection Agency), https://www.epa.gov/acidrain/what-acid-rain viewed 20 September 2016

contained in the cash flow diagram in (Appendix I), combining these cost (US$ 612,660) is far above the initial cost for simulation (C) in just five years of operation of the 300 kW generator simulation (B). This same type of computation can also be carried out for maintenance costs and confirms that in the long run operating a diesel plant is much more expensive.

While a solar module may have a product warranty of about 10 years[77], but performance warranty of 25 years are common. Arersa grupo, Spain, the company whose modules is shown in (Appendix K) warrants replacement if annual degradation is above 0.68% or/and a photonic degradation of 3% over a period of 25 years unless the modules are subjected to misuse by the buyer[78]. The company also, warrants a power output between 97% at purchase and approximately 80% at the 25th year. This confirms that the solar plant has a longer life span compared to the 300 kW generator.

However, the downside of the simulation of the autonomous plant is in the months where the solar radiation is relatively low, such as in July, August and September and in Ode Itsekiri a little percentage of about 0.1% electric load would not be met, which can be solved by proper education of the community on how to use the plant vis-à-vis their household appliances, this is not a problem for the 300 kW generator (see Appendix K) that meets the load demand. This occurrence of the unmet load will be further discussed in the next subparagraph under scenario 3 by comparing the result of a system comprising a solar and a well sized diesel plant.

Another advantage of a solar PV system is that it requires minimum maintenance such that the villagers can be taught how to handle the equipment during the period of installation and commissioning of a photovoltaic generator plant. Additionally, the beauty of a solar plant unlike the diesel plant is that it does not need to be sited far away from the community because of combustible fuels, pollutants and noise that emanate from large diesel generating sets. A solar plant can be flexible in energy generation and therefore can be expanded to meet increasing demand, and the inhabitants can have a more regular access to electricity, which will eventually

[77] 25 year warranty. http://coffssolarenergy.com.au/25-year-warranty/.Viewed 20 October 2016
[78] Atersa limited warranty. http://www.atersa.com/img//en_Garant%C3%ADas%20M%C3%B3dulos%20Nov13.pdf.Viewed 20 October 2016

transcend to a better life than just the generator that is randomly available making planning for human existence difficult.

4.3 Scenario 3: PV Solar and Diesel Generator System

In this scenario a further attempt at finding a solution to the irregular electricity situation in Ode Itsekiri is examined by simulating the same load data in Figure 26 with the HOMER software in sourcing for an optimal solar plant capacity and an appropriate sized diesel engine. There is also an attempt at meeting the 0.1 % unmet load already observed in scenario 2 above with the autonomous solar plant. For ease of reference simulation scenario 3 is labelled as (D), and the simulation result is shown on Table 10, while the HOMER optimization results are shown in Appendix I.

The plant architecture obtained from this simulation shows that a 100 kW capacity solar plant with a hybrid 20 kW capacity rated generator would adequately replace the 300 kW generator with some extra hours of access to electricity in Ode Itsekiri. Simulation (D) presents the most favourable levelized cost of electricity of US$ 0.64/kWh, this is the lowest compared to those obtained from the other previous simulations (A, B and C). The net present cost under scenario (D) is US$ 713,981, while for the 200 kW solar plant it is US$ 852,133 and that for the 300 kW diesel generator plant is US$ 24,200,000. Simulation (D) is also the most optimal of all the simulations because it presents the lowest net present cost of all costs over the life time of this plant HOMER Pro[79], followed by simulation (C) while simulation B is the least favourable option due to the high cost of energy.

The initial cost of capital for the 100 kW solar plant is US$ 347,760 and looking at the ratio with the 300 kW diesel generator plant and the 200 kW solar that is (B:C:D) gives a ratio 1:10:6 while the ratio of the operating costs of scenarios B, C and D is approximately 80:1:1.2 which shows that the running cost of the 300 kW diesel plant is about 80 times more expensive than both the 100 kW solar plant-20 kW diesel hybrid plant and 200 kW solar plant.

In simulation (D) the fuel cost is just US$ 1,248 and this is an operation for about 602 hours in a year with about 1,920 litres of diesel for the hybrid plant comprising a smaller 20 kW generator, whereas for the 300 kW the fuel cost is US$ 128,115 in a

[79] Homer Pro introductory training, http://homerenergy.com/homer_pro_training_video.html.

ratio of C:D (102:1). This shows that approximately 102 times the cost of fuel to run the 20 kW generator will be used by the 300 kW generator which is about 191,100 litres as shown on the chart. The problem of Ode Itsekiri is the availability of diesel fuel which simulation (D) has drastically reduced. Should this component (diesel) supply still be taken care of with the burial of corpses (50 litres per corpse), this translate to approximately 25 corpses per year to have some productive electricity, compared to the case of the 300 kW generator where 3,822 corpses have to be buried per year or over 8,760 hours of operation. This shows a lot of improvement in installing this system in scenario 3. The proposed method of funding of the sustainable chosen project will be discussed under chapter 5.

It is also important to examine the alternating current load for the 20 kW generator plant output as shown below.

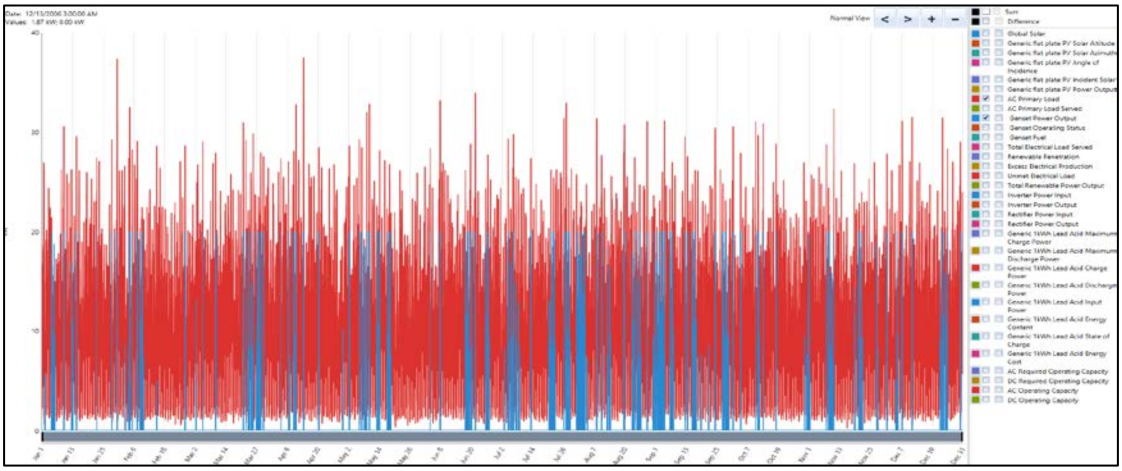

Figure 31 AC Load to 100 kW Solar and 20 kW Generator Output. Source: HOMER Software

Figure 31 shows the load demand as simulated compared to the portion in blue colour being met by the 20 kW generator. The generator produces 7,178 kWh/year which shows that the system is well sized to optimally meet a part of the total load demand in red, while 139,485 kWh/year is produced by the solar component to meet the community load demand at different times in the day and the storage system at night time as contained in Appendix I. In scenario 3, the unmet electric load by the 200 kW autonomous plant in the months of July, August and September and to some extent in November are now better met under simulation (D) (see Appendix I).

Although, the 200 kW autonomous solar plant produces some excess electricity, it would require additional battery storage to meet the load demand at night time and would likely make the system more expensive and less attractive. In both scenarios 2 and 3 some electricity is produced in the daytime by the solar modules that is not used by the community, but these excesses are very minimal compared to that by the 300 kW generator see diagrams in Appendix I.

While in some countries like in the United States of America electricity generation still produce the highest pollution in comparison to other industries because fossil fuels still play a major part in the form of natural gas, coal and oil[80]. The importance of making an investment decision in electricity power generation should also consider the impact of the chosen technology on the environment and health (IAEA, 1999). The simulation results show that scenario 2 is the most environmentally friendly system with 100% renewable and zero emission. In comparison to the other scenarios, scenario 3 comes second with a CO_2 emission of approximately 5,056 kg/yr against the high value of 108,133 kg/yr presently being emitted into the community from the 300 kW generator, which will increase drastically to 519,029 kg/yr should Ode Itsekiri have a little more hours of electricity supply to meet some of its additional load demands.

Based on the above, if environmental aspect is strictly the prime motive in making the implementation decision of a new system for Ode Itsekiri and also the advantage of eliminating the inconvenience of buying diesel fuel for the generator, then the autonomous plant would be considered as the first choice.

However, in line with the objective of this thesis, scenario 3 with the 100 kW solar and 20 kW back-up generator is the first choice for the replacement of the existing 300 kW generator because being the least cost option it will provide a reliable electric service to Ode Itsekiri "*minimize life-cycle system costs and adverse environmental effects"*[81] The choice of scenario 3 is followed by the autonomous solar plant which is scenario 2.

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[80] Electricity generation and pollution, http://www.science.smith.edu/~jcardell/Courses/EGR325/Readings/ElecPollution_EnvDef.pdf. Viewed 21 October 2016.

[81] Least cost option law & legal definition, http://definitions.uslegal.com/l/least-cost-option/.Viewed 22 October 2016

CHAPTER 5: CONCLUSION

5.1 Funding Mechanism for the Proposed Project

Project funding can be a bone of contention when competing interests for money is considered. The electrification of Big Warri was carried out by the Electrification Board of the Bendel State Government of Nigeria in 1977[82] at a time when the knowledge of photovoltaics for electricity generation was still a relatively new technology because Fechner (2015) comments that *terrestrial* use of solar electricity began about 1980 and Austria actually started using solar in 1987, therefore, the thought of using a solar mini-grid or hybrid system for electrification in Ode Itsekiri would not have been foreseeable, but this should not be the case in the 21st century as the technology now matures into a typical electrification technology worldwide[83].

In Nigeria, the so called Oil Producing Communities are assigned a 13% oil derivation fund[84] from the national budget. This special fund is meant to develop those communities from whom crude oil is extracted, because in most cases these regions are remote and therefore these special funds are set aside and made available for the development of these areas. The actual oil revenue portion for 2015 in the Nigerian budget was ₦2,745.68 billion (US$ 1.4 billion) at an exchange rates of ₦190/1 US$ (Federal Republic of Nigeria, 2016). Funding can therefore be sourced from such funds for financing this laudable project as described under scenario 3 that looks the most plausible solution to the electricity problem in Ode Itsekiri, and the same funding method can be carried out for the other hamlets in the region of Ode Itsekiri to receive electricity.

As inscribed on the existing generator in Ode Itsekiri (see Figure 14), the generator was donated by the Niger Delta Development Commission one of the agencies set up for the sustainable development of the Niger Delta region, this commission can also partly fund the 100 kW hybrid plant in collaboration with the Global Environment facility (GEF) whose mandate states inter alia "*GEF support is provided to government agencies, civil society organizations, private sector companies, research*

[82] Expert Interview with Engr. Bright Okpopo. Consultant Mosbright Nig., Ent., Benin-City
[83] Technology Roadmap (2010), https://www.iea.org/publications/freepublications/publication/pv_roadmap.pdf. Viewed 6 October 2016
[84] Information Nigeria, https://www.informationng.com/tag/13-derivation. Viewed 6 October 2016

institutions, among the broad diversity of potential partners, to implement projects and programs in recipient countries" GEF in fulfilling its mandate has worked with the United Nations Industrial Development Organization in implementing many similar projects in Africa, Asia and Latin America. Ode Itsekiri also has the advantage because it has the potential of a tourist destination due to the lush flora and fauna in this region.

Another future source of funding may be through the Rural Electrification Fund (REF) which is yet to be operational, GIZ (2015) comments that this is a support funding mechanism by the Federal Government of Nigeria, whereby through this scheme an interested community will be responsible for part funding the proposed project for the electrification project for the area, which will be appraised and if approved the REF will co-fund the project in conjunction with the state government where the community is located and with the community itself applying for funding for a project.

The community can therefore, also source for funding from the REF while getting its own counterpart funding that is mandatory in a REF aided assistance from the bodies already discussed above, while the state government and REF put in their portions in implementing the project in the ratio 20% by the community or investor, 50% by the state and 20% by the REF (GIZ, 2015).

The African Development Bank as part of its sustainable development objectives, goal number 7 reads [85]*"Ensure access to affordable, reliable, sustainable and modern energy for all"* and this is exemplified in soft loans or grants given out for the funding of sustainable projects; example is the Menengai geothermal development project in Kenya. The Federal Government of Nigeria can therefore apply for soft loan on behalf of Delta State Government to be used in the execution of projects of this nature in the entire creeks and remote areas of the state because the African Development Bank being a multilateral development financial institution can provide long term soft loans to the Federal Government at low interest rates in contrast to the national banks in the country whose emphasis is on short term loans and at high interest rates.

[85]ADB, Mission & Strategy, http://www.afdb.org/en/about-us/mission-strategy/Viewed 7 October 2016

5.2 Summary

The state of electrification in Ode Itsekiri makes an interesting study due to the fact that the community has a large capacity generating set, and a well laid out mini-grid network but it still languishes in darkness. This thesis examined the continuous use of a 300 kW generator in Ode Itsekiri and the cost implication of the existing system to the community if they were able to operate as it is and with additional hours of light, as well as the environmental implication of running this 300 kW generator. Also, the motivation in the first instance for this topic was to critically analyse this issue and proffer a plausible option to the existing situation.

From the obtained results after extending the hours of electricity in the community, a hybrid 100 kW solar and 20 kW diesel generator provided about US$ 0.64/kWh which although not that low, but reasonable in comparison to the generator's operational cost of about US$ 4.80/kWh for the five hours of electricity usage when diesel is available, or the extended hours simulated for each of the scenarios with an astronomical cost of energy US$ 21.64/kWh for the 300 kW generator and the highest CO_2 emission. The thesis also reveals that investing upfront in a sustainable energy system though higher in initial capital cost, is cheaper than a less initial investment cost in the long run on the 300 kW generator plant due to a lower operational cost of the renewable energy plant with a 92% of renewable energy component system.

There was no simulation carried out based on solar for the present five hours of operation because this does not add any value to the electrification in the community, therefore, the extended hours was necessary to have longer hours of electricity in the community and this is in the daytime. This also provides for having a basis of comparison for the various scenarios. This extended hours also allowed for the use of the solar energy. Although the optimal simulation contains a diesel generator in an hybrid system, but comparing this simulation to the results obtained under scenario 1, this is a smaller generator of 20 kW and the fuel cost is also very low at US$ 1,920 in contrast to the present operational fuel cost of US$ 26,691 and US$ 197,100 for the extended hours for the 300 kW generator.

The optimized system obtained under scenario 3 has a solar plant component that does not need any fuel for operation, less maintenance required because this will involve routine cleaning of the solar panels and the little generator will be less cumbersome to maintain compared to the larger 300 kW generator.

For the installation of this energy sustainable plant under scenario 3, the implementation of the plant is assumed to be feasible if either the state or federal government handles the project, just as the mini-grid and the faulty generators in the generator house in the community that have always been provided by either the state or a government agency. After the installation and handover of such a system to the community, a management community can be set up to run the plant with a reasonable electricity tariff paid by the community based on the number of points of electricity usage per house in the community. In addition, the state government will have to subsidise the cost of electricity computed under scenario 3 to make for a reasonable electricity charge for the community, subsidies to low income citizens in the country was explained in detail on page 54. The tariff collected over the period in the community can thus be used for replacement of faulty components and the batteries when the batteries eventually reach the end of the useful life.

The situation in Ode Itsekiri as discussed in this thesis is a mirror reflection of the power situation in most of the riverine areas, islands and remote communities in Nigeria. The country's electricity situation as described in chapter one shows that it suffers from acute power shortage. This thesis also discussed the ongoing reform in the energy sector which started about 2013 based on the Electric Power Sector Reform Act (2005) that triggered the privatization of the power sector, through selling off the generation and distribution sectors but still retains the transmission of electricity due to the cost implications that will be borne by the private sector investors in extending the national grid in the country, however, the Federal Government is finally now considering privatising the operation and management of the grid to private investors[86].

The main objective at the onset of this work was to challenge the continuous use of a large 300 kW capacity diesel generator in Ode Itsekiri and review the cost implication of using this capacity of generator to power a community for just about five hours each day for about a maximum of three nights for the consumption of 200 litres, and

[86] FG to Decentralise, Concession Transmission Grid (2016), http://www.thisdaylive.com/index.php/2016/05/06/power-fg-to-decentralise-concession-transmission-grid/.Viewed 10 October 2016

the environmental consequence in comparison to other electricity generation techniques. While it is assumed that the community has a power plant, but hardly with electricity.

The carbon emission by each system in each scenario shows that the autonomous system which is also relatively low in cost of energy has an emission of zero, while the 300 kW emits in a year approximately 103 times that of the 100 kW solar hybrid diesel plant if the extended number of hours are put into operation. Ode Itsekiri can do away with this inefficient method of electricity generation.

In conclusion, this thesis has been able to establish that the continuous use of a 300 kW generator as it is now operated in Ode Itsekiri is not cost effective, and also extending the operation with more hours especially into the day time to enable for more productive uses of electricity makes the operating cost so prohibitive that an optimal approach would be to consider the implementation of a solar 100 kW solar installation with a 20 kW generator plant back-up.

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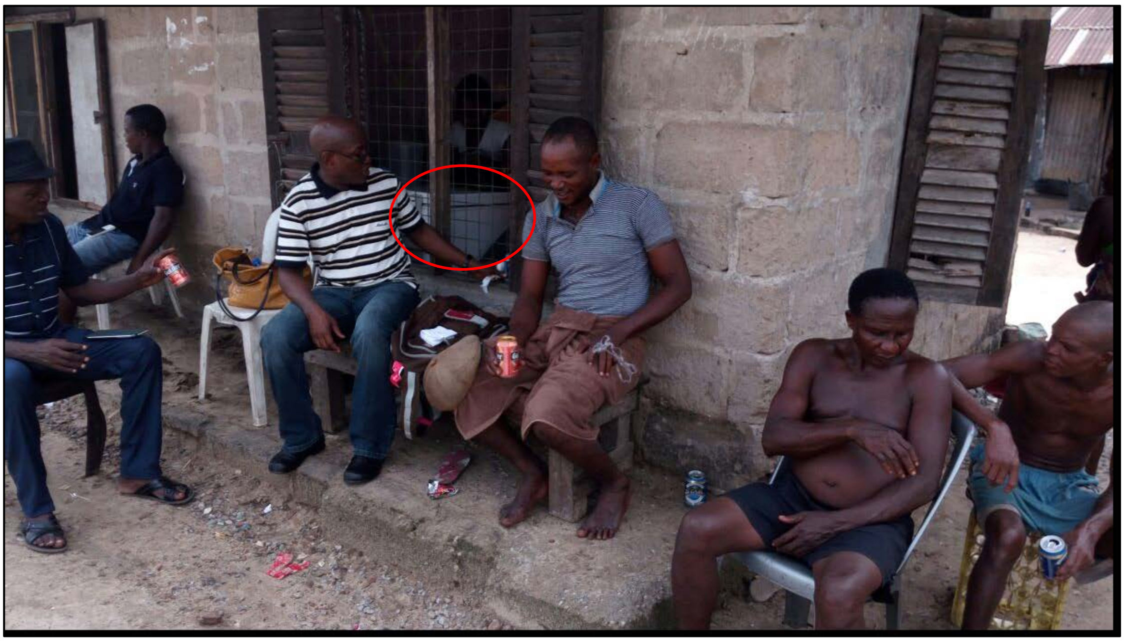
List of Appendices

Appendix A

Briefings by the Operators of the Diesel Generating Set in Big Warri. Own Source



More briefings by members of the community under a lighter mood with warm unrefrigerated drinks because no electricity, however, see highlighted refrigerator inside the house.

Appendix B

Feed-in Tariff for Renewable Energy Systems (Extract) as at 2012. Source: NERC (2012)
Wholesale Feed-in Tariff for Small Hydro Plant

	2012	2013	2014	2015	2016
Wholesale contract prices (₦/MWh)	23,561	25,433	27,456	29,643	32,006

Wholesale Feed-in Tariff for Solar Power Plant

	2012	2013	2014	2015	2016
Wholesale contract prices (₦/MWh)	67,917	73,300	79,116	85,401	92,192

Wholesale Feed-in Tariff for Biomass Power Plant

	2012	2013	2014	2015	2016
Wholesale contract prices (₦/MWh)	27,426	29,623	32,000	34,572	37,357

Amended Feed-in Tariff for 2016 Base Year. Source: NERC (2015)

Year	Description	Unit	Solar	Wind	SHP	Biomass
2016	Capital Cost	(₦/MWh)	35,370.05	24,791.55	30,887.43	22,400.51
Naira	O&M	(₦/MWh)	29.49	302.73	55.92	8,541.11
	Total	**(₦/MWh)**	**35,399.54**	**25,094.28**	**30,943.35**	**30,941.62**
2016	Capital Cost	(US$/MWh)	176.85	123.96	154.44	112.00
US$	O&M	(US$/MWh)	0.15	1.51	0.28	42.71
	Total	**(US$/MWh)**	**177.00**	**125.47**	**154.72**	**154.71**

(₦/MWh) connotes: Nigeria Naira/Megawatt and (US$/MWh) connotes: Dollar/Megawatt

Appendix C

Faulty Solar Street Lights in Big Warri. Own Source

Appendix D

Some of the devices in the homes

10 W Energy Saver Bulb

65 W Colour Television

10 W Video Disc Player

68 W Ceiling Fan

68 W Table Fan

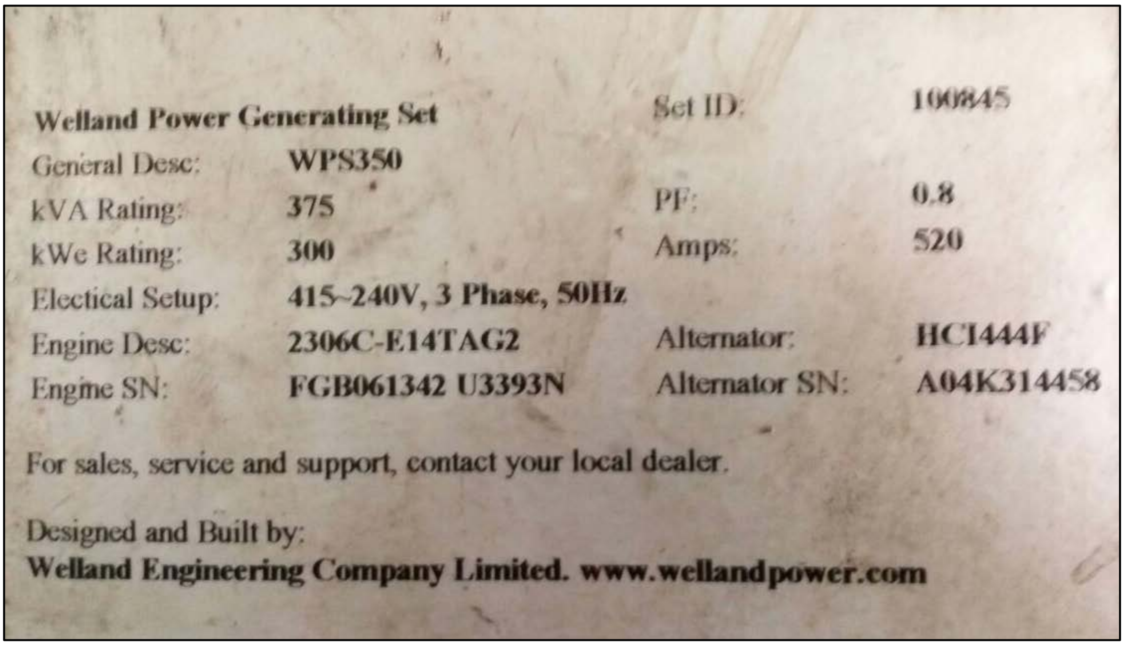
40W & 60 W Incandescent Bulbs

36 W Fluorescent Lamp

100 W Refrigerator

Appendix E

Generator Characteristics



Switch Box

Appendix F

INTERVIEW QUESTIONS

Name of family: ………………………………….

Number of occupants:……………………………..

a. How often do you have light?

b. Are you satisfied with the frequency of having light? YES ☐ or NO ☐

c. If NO, why?...

Types of electric devices and number of each in your house:

1. Electric saving bulb………………………….

2. Incandescent bulb 40W………………………

3. Incandescent bulb 60W………………………

5. Fluorescent lamp…………………………….

6. Music system………………………………..

7. Radio………………………………………...

8. Telephone charger…………………………..

9. TV……………………………………………

10. Table fan……………………………………

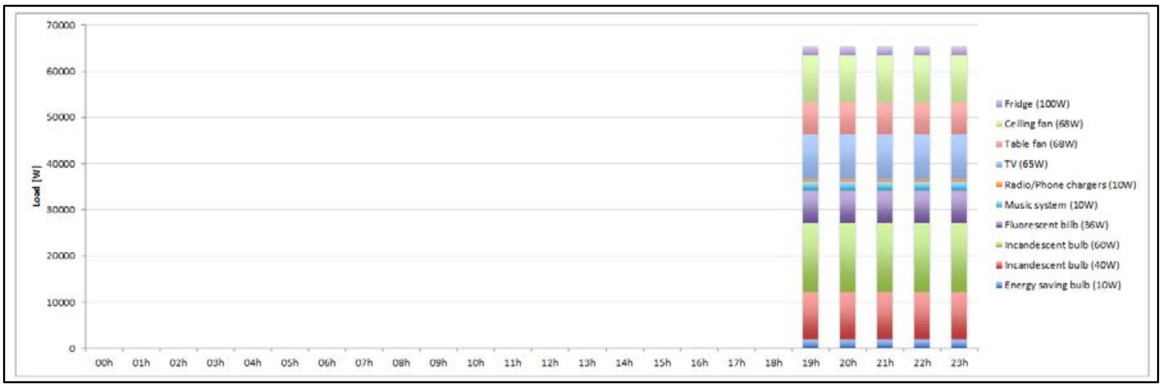
11. Ceiling fan…………………………………

12. Refrigerator……………………………….

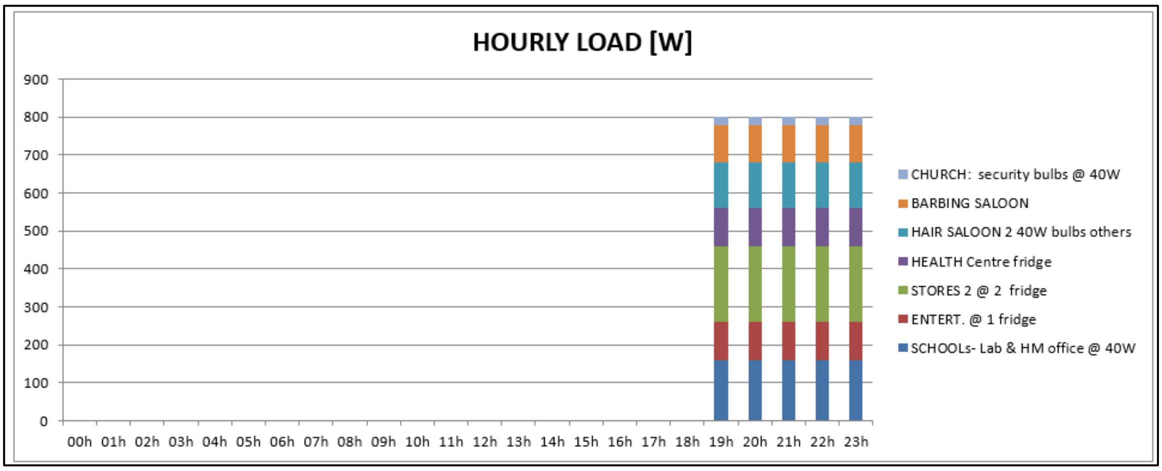
13. Other gadgets …………………………….

Appendix G

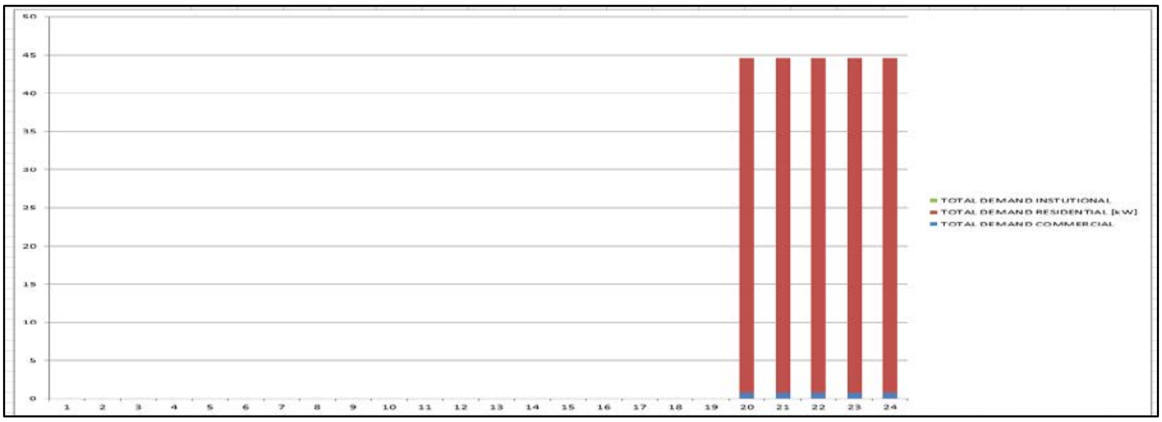
A. Residential Load Based on Five Hours of Electricity Generation



B. Private/Public Premises Based on Five Hours of Electricity Generation

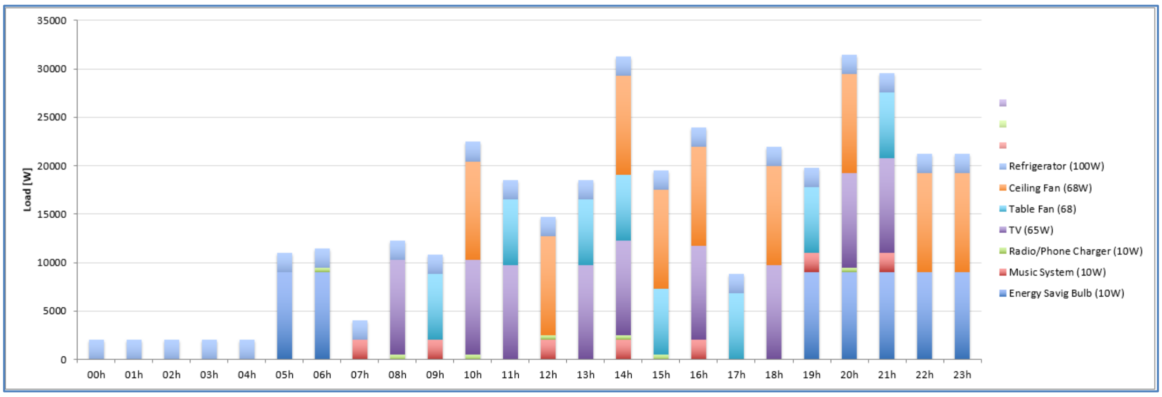


Sum of A and B Above

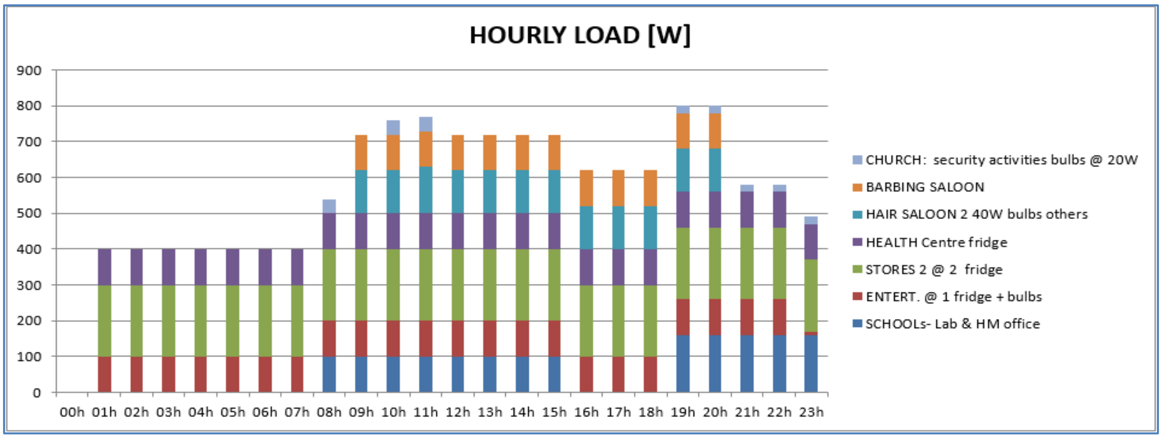


Appendix H

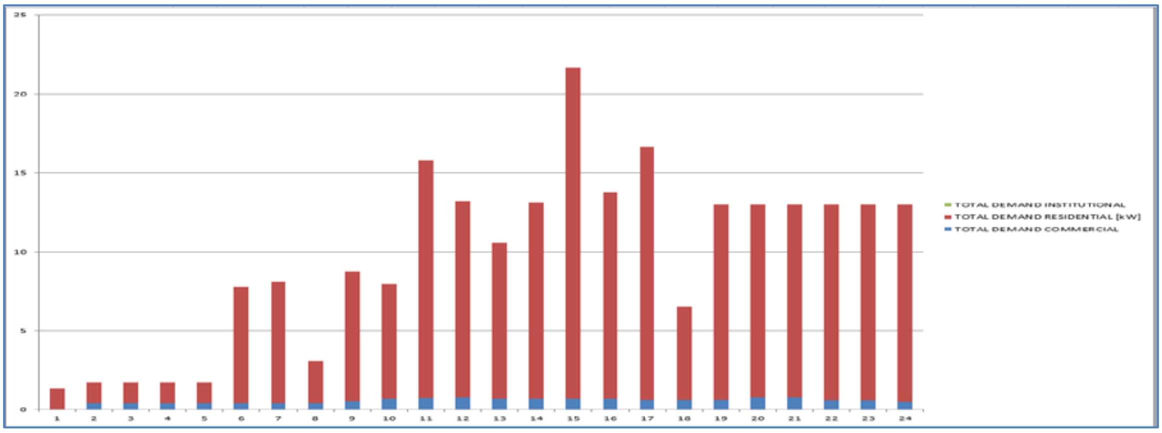
A. Residential Load Based on Extended Hours of Electricity Generation



B. Private/Public Premises Based on Extended Hours of Electricity Generation



C. Sum of A and B Above



Appendix I

Simulation A 300 kW Diesel plant

Export... Optimization Cases: Left Double Click on a particular system to see its detailed Simulation Results.

Architecture			Cost				System	Gen					
	Gen (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)	Hours	Production (kWh)	Fuel (L)	O&M Cost ($)	Fuel Cost ($)	
	300	CC	$4.80	$5.06M	$387,349	$56,400	0.0	1,825	136,877	41,063	355,875	26,691	

Simulation B 300 kW Diesel plant extended hours

Export... Optimization Cases: Left Double Click on a

Architecture			Cost				System	Gen500				
	Gen500 (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)	Hours	Production (kWh)	Fuel (L)	O&M Cost ($)	Fuel Cost ($)
	300	CC	$21.64	$24.2M	$1.87M	$56,400	0.0	8,760	657,000	197,100	1,708,200	128,115

Simulation C Autonomous solar plant

Architecture					Cost				System	PV	
	PV (kW)	1kWh LA	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)	Capital Cost ($)	Production (kWh)
	200	900	40.0	CC	$0.762	$852,133	$23,230	$551,830	100	352,000	278,970

particular system to see its detailed Simulation Results.

1kWh LA		Converter	
Autonomy (hr)	Annual Throughput (kWh)	Rectifier Mean Output (kW)	Inverter Mean Output (kW)
55	55,919	0	10

Appendix I

Simulation D Solar plant with diesel back-up

Export...

Optimization Cases: Left Double Click on a particular system t

Architecture					Cost				System	Gen		
PV (kW)	Gen (kW)	1kWh LA	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)	Hours	Production (kWh)	Fuel (L)
100	20.0	450	30.0	LF	$0.638	$713,981	$28,329	$347,760	92	602	7,178	1,920

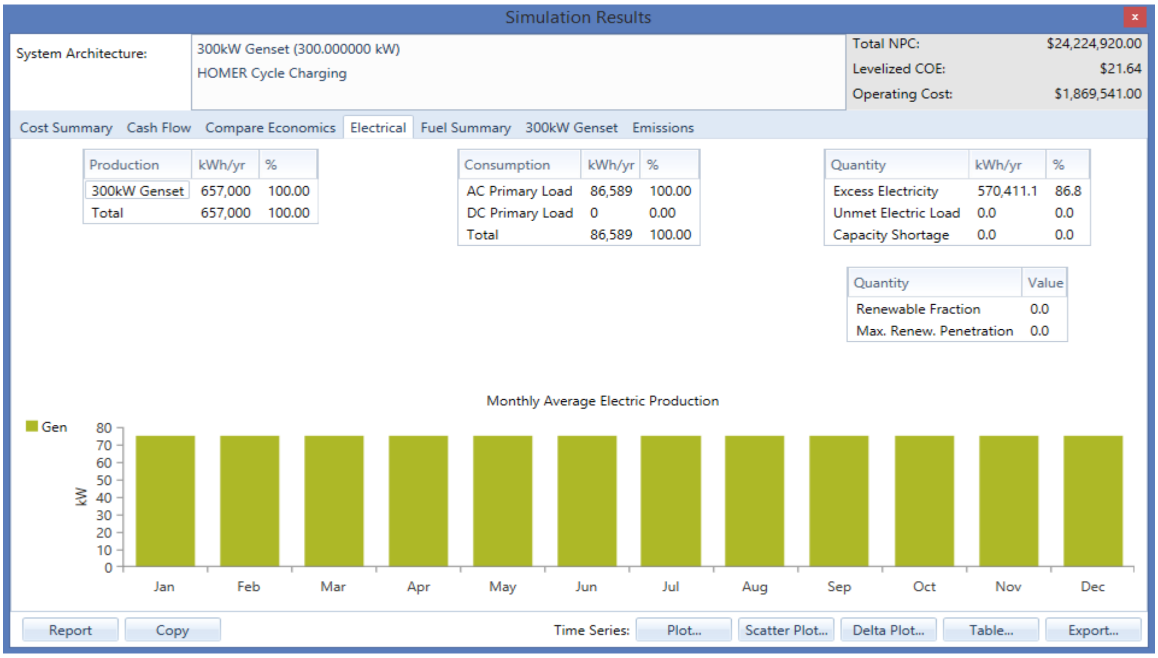
o see its detailed Simulation Results.

Categorized

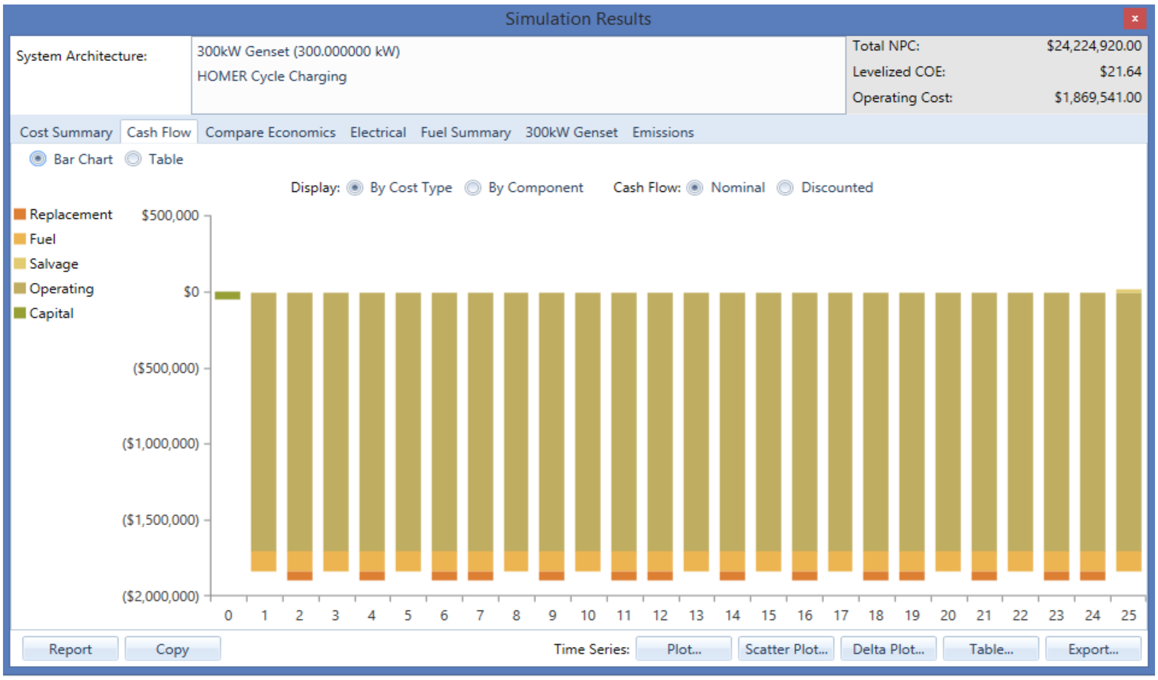
		PV		1kWh LA		Converter	
O&M Cost ($)	Fuel Cost ($)	Capital Cost ($)	Production (kWh)	Autonomy (hr)	Annual Throughput (kWh)	Rectifier Mean Output (kW)	Inverter Mean Output (kW)
7,826	1,248	200,000	139,485	27	50,769	0.03	9

Appendix I

Electrical performance for the 300 kW generator with the extended load

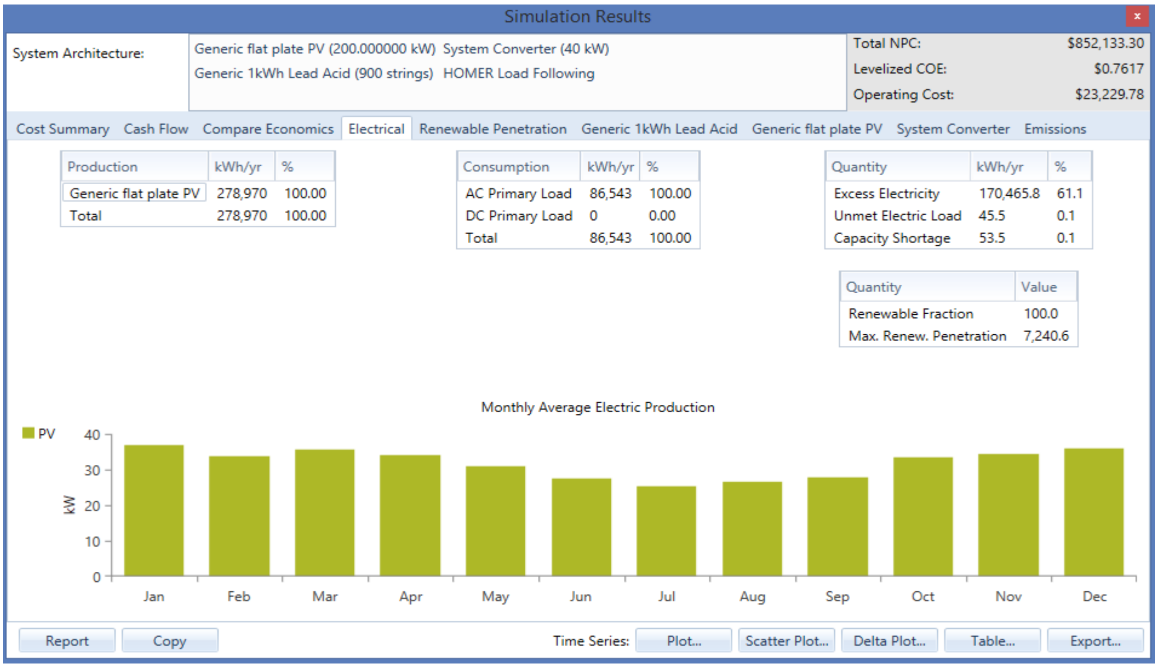


Cash flow for the 300 kW generator with the extended load

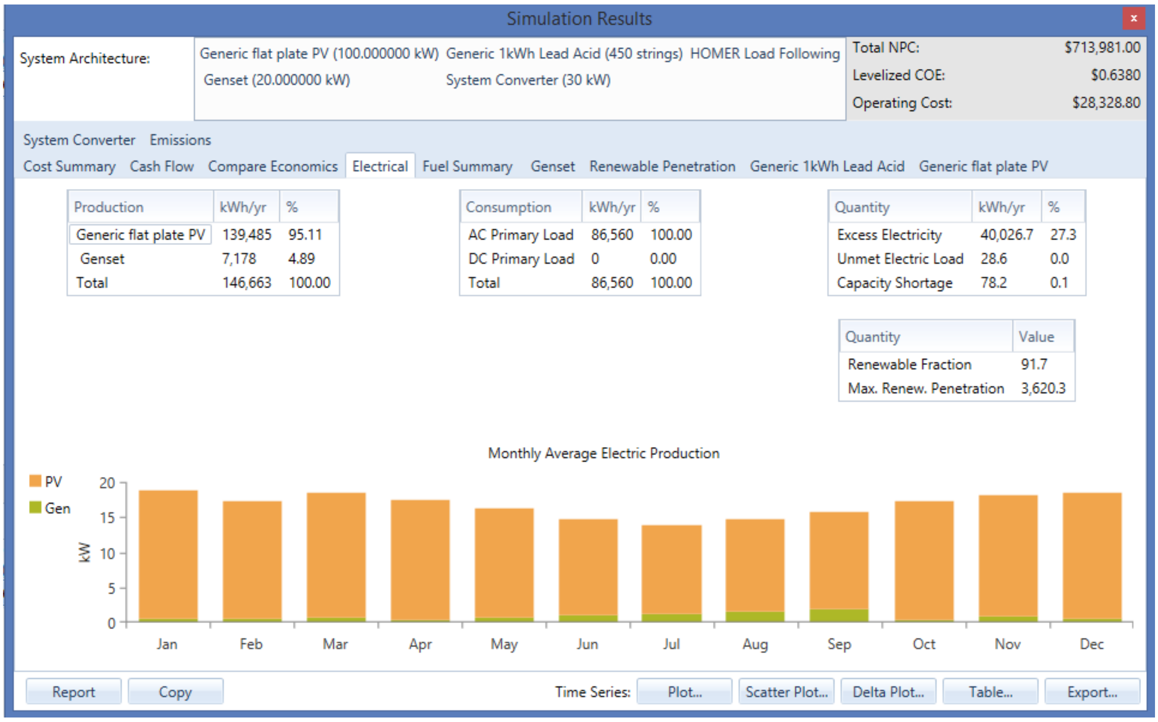


Appendix I

Electrical performance for the 200 kW autonomous plant with the extended load



Electrical performance for the 100 kW solar, 20 kW diesel plant with the extended load



Appendix J

Rusted Rural Electrification Sign Post by the Generator House

Appendix K

Specifications

25 years warranty
Class-A Grade quality
EL test of each panel
Produced under automatic machines which bought from Germany

Supply Ability & Trade Terms

Port	Ningbo/Shanghai
Terms of Payment	TT,30% deposit in advance, the balance upon the BL copy
Trade Terms	EXW, FOB, CIF,
MOQ	Small quantity for trail order allowed
Production ability	1000000 watts/month
Production Lead Time	1-4 weeks

OL200-60P ----OL250-60P SOLAR PANEL DATASHEET

Model type	OL250-60P	OL240-60P	OL230-60P	OL220-60P	OL210-60P	OL200-60P
Peak power(Pmax)	250W	240W	230W	220W	210W	200W
Tolerance	±3%					
cell type	Poly Crystalline Silicon， 156mm×156mm					
Number of cells	60 cells in series					
Weighe	21kg					
Dimensions	1650×992×50mm (65.01×39.06×1.97 inch)					
Maximu power voltage (Vmp)	30.39V	30.18V	29.82V	29.34V	28.70V	28.50V
Maximu power current (Imp)	8.23A	7.96A	7.72A	7.50A	7.32A	7.02A
Open circuit voltage (Voc)	36.97V	36.72V	36.10V	36.56V	36.48V	36.24V
Short circuitcurrent (Isc)	9.29A	8.99A	8.73A	8.48A	8.28A	7.94A
cell effciency	17.60%	16.50%	16.00%	15.25%	14.50%	13.75%
module efficiency	15.27%	14.66%	14.05%	13.44%	12.83%	12.22%
Maximu system voltage	DC 1000V（TUV）/600V(UL)					
Temp.Coeff.of Isc(TK Isc)	0.045%/℃					
Temp.Coeff.of Voc(TK Voc)	-0.34%/℃					
Temp.Coeff.of Pmax(TK Pmax)	-0.47%/℃					
Normal Operting Cell Temperatu	45±2℃					
Glass Thickness	3.2 mm					
Static Loading	≤5400Pa					
Cable cross section size	4m㎡					
Application Class	Class A					

Appendix K

Product Details | Company Profile | Transaction History

ADD: No.12, Yuci North Road,Yuyao,Zhejiang,China	Website: www.ollinsolar.com
Contact: Grubby Hong(Salesmanager)	E-mail: hongzefeng839@gmail.com
TEL: +86-0574-62566175 FAX: +86-0574-62566176	Cell Phone: +86-13685849641 Post Code: 315400

Quotation Sheet

Product's Basin information :		
Product: Solar panel	Model Type: OL-250-60P	Photo:
Certification:CE ROHS	Power: 250W	
Weight: 21KGS	Cell Type:Poly(6*10)156*156MM	
Dimension: (m)	1650*990*40MM	
Long: 1.65		
Wide: 0.99		
Height: 0.04		
Cube: 0.06534		
Maximu power voltage(Vmp): 30.39V		
Maximu power current(Imp): 8.23A		
Open circuit voltage(Voc): 36.97V		
Short circuit voltage(Isc): 9.29A		
Maximu system voltage: DC 1000V		
Tolerance: ±3%		
Normal Operting Cell Temperature: 45±2℃		Note: the picture is just for reference only
Front Glass:3.2mm high transmission,low iron,tempered glass		
Output cables:2.5mm2 length 90mm,MC4 connector		
junction box:IP65 rated		
MOQ: 10000W		
Price: FOB(ningbo) 0.56$/W		Valid: JULY 30,2014
Payment:TT (30% in advance)，balance before shipment after inspection		
Delivery: 20 days after receipt of deposit		
Warranty: 2 years，5 years power not change, 90% power for 10 years, 80% power for 25 years		

Appendix K

→ www.atersa.com

atersa
grupo elecnor

A-xxxP GSE (xxx = potencia nominal)

Características eléctricas

Potencia Máxima (Pmax)	230 W	235 W	240 W	245 W	250 W	255 W	260 W
Tensión Máxima Potencia (Vmp)	29.49 V	29.72 V	29.95 V	30.23	30.58 V	30.90 V	31.23 V
Corriente Máxima Potencia (Imp)	7.81 A	7.91 A	8.02 A	8.11	8.18 A	8.26 A	8.34 A
Tensión de Circuito Abierto (Voc)	36.58 V	36.76 V	37.03 V	37.28	37.61 V	37.85 V	38.12 V
Corriente en Cortocircuito (Isc)	8.36 A	8.45 A	8.54 A	8.64	8.71 A	8.82 A	8.91 A
Eficiencia del Módulo (%)	14.11	14.42	14.73	15.03	15.34	15.65	15.95
Tolerancia de Potencia (W)				0/+5			
Máxima Serie de Fusibles (A)				15			
Máxima Tensión del Sistema				DC 1000 V (IEC) / DC 600 V (UL)			
Temperatura de Funcionamiento Normal de la Célula (ºC)				46±2			

Características eléctricas medidas en Condiciones de Test Standard (STC), definidas como: Irradiación de 1000 w/m², espectro AM 1.5 y temperatura de 25 ºC.
Tolerancias medida STC: ±3% (Pmp); ±10% (Isc, Voc, Imp, Vmp).

Especificaciones mecánicas

Dimensiones (± 2.0 mm.)	1638x995x40 mm.
Peso	18.7 kg
Máx. carga estática, frontal (nieve y viento)	5400 Pa
Máx. carga estática, posterior (viento)	2400 Pa

Materiales de construcción

Cubierta frontal (material/tipo/espesor)	Cristal templado/grado PV/3.2 mm
Células (cantidad/tipo/dimensiones)	60 células (6x10)/Policristalina/156 x 156 mm
Marco (material/color)	Aleación de aluminio anodizado/plata
Caja de conexiones (protección/nº diodos)	IP65/3 diodos
Cable (longitud/sección) / Connector	1000 mm./4 mm²/Compatible MC4

- **Optimice sus instalaciones.**
- **Alta eficiencia** del módulo y potencia de salida estable, basado en una tecnología de proceso innovadora.
- **Funcionamiento eléctrico excepcional** en condiciones de alta temperatura o baja irradiación.
- Facilidad de instalación gracias a un **diseño de ingeniería innovador.**
- **Riguroso control de calidad** que cumple con los más altos estándares internacionales.
- **Garantía, 10 años** contra defectos de fabricación y **25 años** en rendimiento.

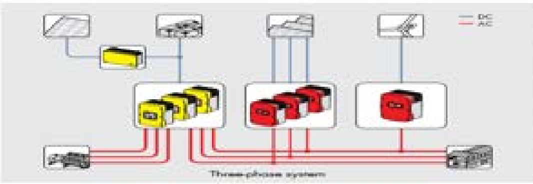
Appendix K

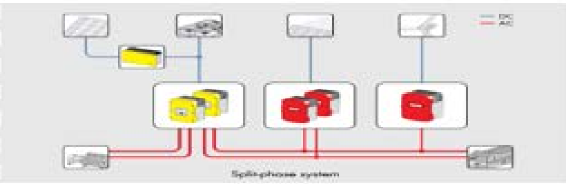
SMA

SUNNY ISLAND 4548-US / 6048-US

Technical data	Sunny Island 4548-US	Sunny Island 6048-US
AC output (loads)		
Rated grid voltage / AC voltage range	120 V/105 V – 132 V	120 V/105 V – 132 V
Rated frequency / frequency range (adjustable)	60 Hz/55 Hz ... 65 Hz	60 Hz/55 Hz ... 65 Hz
AC power (at 25 °C / at 40 °C) for 3 hours	5000 W/4000 W	6000 W/5000 W
Rated power (@ U_{nom}, f_{nom} / 25 °C / @ cos φ = 1)	4500 W	5750 W
AC power at 25 °C for 30 min / 1 min / 3 s	5300 W / 8400 W / 11000 W	7000 W / 8400 W / 11000 W
Rated current / max. output current (peak)	37.5 A/180 A for approx. 60 ms	48 A/180 A for approx. 60 ms
Total harmonic factor output voltage / power factor with rated power	3 % / -1 ... +1	3 % / -1 ... +1
AC input (PV array or grid)		
Rated input voltage / AC input voltage range	120 V/80 V – 150 V	120 V/80 V – 150 V
Rated input frequency / allowable input frequency range	60 Hz/54 Hz ... 66 Hz	60 Hz/54 Hz ... 66 Hz
Max. AC input current / adjustable	56 A/0 A ... 56 A	56 A/0 A ... 56 A
Max. AC input power	6.7 kW	6.7 kW
Battery DC input		
Rated input voltage / DC voltage range	48 V/41 V – 63 V	48 V/41 V – 63 V
Max. battery charging current / DC rated charging current	100 A / 85 A	130 A / 110 A
Battery type / battery capacity range	Lead, NiCd/100 Ah ... 10000 Ah	Lead, NiCd/100 Ah ... 10000 Ah
Charge control	IUoU charge procedure with automatic full charge and equalization charge	IUoU charge procedure with automatic full charge and equalization charge
Efficiency / self-consumption		
Max. efficiency / CEC efficiency	96 % / 94.5 %	96 % / 94 %
Self-consumption without load / standby	25 W/4 W	25 W/4 W
Protective devices		
DC reverse polarity protection / DC fuse	● / ●	● / ●
AC short-circuit / AC overload	● / ●	● / ●
Overtemperature / battery deep discharge	● / ●	● / ●
General data		
Dimensions (W / H / D)	467 / 612 / 235 mm (18.4 / 24.1 / 9.3 inch)	467 / 612 / 235 mm (18.4 / 24.1 / 9.3 inch)
Weight	63 kg / 139 lb	63 kg / 139 lb
Operating temperature range	-25 °C ... +60 °C / -13 °F ... +122 °F	-25 °C ... +60 °C / -13 °F ... +122 °F
Features / function		
Operation and display / multi-function relay	Internal / 2	Internal / 2
Degree of protection (according to IEC 60529)	indoors (NEMA 1)	indoors (NEMA 1)
Three-phase systems / parallel connection	● / ●	● / ●
Integrated bypass / multicluster operation	– / ●	– / ●
State of charge calculation / full charge / equalization charge	● / ● / ●	● / ● / ●
Integrated soft start / generator support	● / ●	● / ●
Battery temperature sensor / data cable	● / ●	● / ●
Warranty	5 years	5 years
Certificates and approvals	www.SMA-Solar.com	www.SMA-Solar.com
Accessories		
Battery cable / battery fuse	○ / ○	○ / ○
Interface (RS 485 / Multicluster PB)	○ / ○	○ / ○
Extended generator start "GenMan"	○	○
Load-shedding protection / battery current measurement	○ / ○	○ / ○

● Standard feature ○ Optional feature – Not available





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Appendix K

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RES OPzS OVERVIEW

Vented Tubular Plate Batteries for Renewable Energy Applications

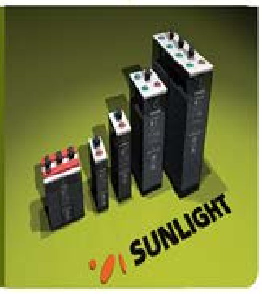
RES OPzS is a **premium range**, developed for applications **requiring regular deep cycling.** It is a **low maintenance** energy storage solution that offers significant benefits in terms of cost per cycle, combined with the highest level of **reliability** and **performance** even for remote installations where long discharges occur and excellent recharging properties are essential.

Optimum design, exclusive use of high quality materials, robust construction and state of the art manufacturing processes make RES OPzS batteries an **ideal solution for demanding Renewable Energy Storage applications.**

APPLICATIONS

Indicative Battery-Based Power Supply Systems

- **Telecom Networks**
  Autonomous remote communication hubs such as cellular base stations, repeaters and VSATs.
- **Mini-Grids**
  Electricity to isolated off-grid areas or regions with unstable power supply
- **Residential Installations**
  Off-grid or smart grid connected power systems electrifying homes, hotels, hospitals, schools or factories
- **Traffic systems**
  Signaling and lighting to roads, railways, airports and marines



CERTIFIED QUALITY

- Compliant with IEC 61427 requirements for photovoltaic energy systems
- Fully compliant with IEC 60896-11 requirements for vented lead-acid batteries
- Full conformity to DIN 40736-1 specifications for OPzS cells and DIN 40737-3 for OPzS blocks
- Compliant with the safety requirements of EN 50272-2 for stationary batteries
- Manufactured at SUNLIGHT's European production facilities, certified with ISO 9001, ISO 14001, BS OHSAS 18001

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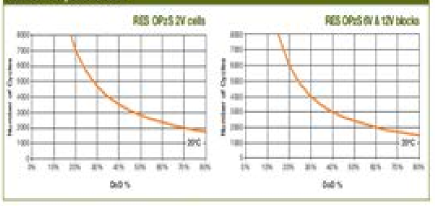
QUALITY FEATURES & PRODUCT BENEFITS

Long cycle life
Tubular positive plates, unique sliding pole design and special alloys composition offer a 60% DoD cycle life of 2300 cycles for 2V cells and 2000 cycles for 6V & 12V blocks.

Number of Cycles vs. DoD



Outstanding performance and reliability
Products of optimum design made from high quality raw materials in European state-of-the-art production facilities and cumulative experience on advanced submarine battery manufacturing, ensure reliability in applications demanding high performance.

Minimum maintenance
Low maintenance design with reduced topping up needs. Transparent container for easy visual electrolyte level monitoring.

Space optimization
Racks designed for optimal space utilization, quick installation and easy battery maintenance.

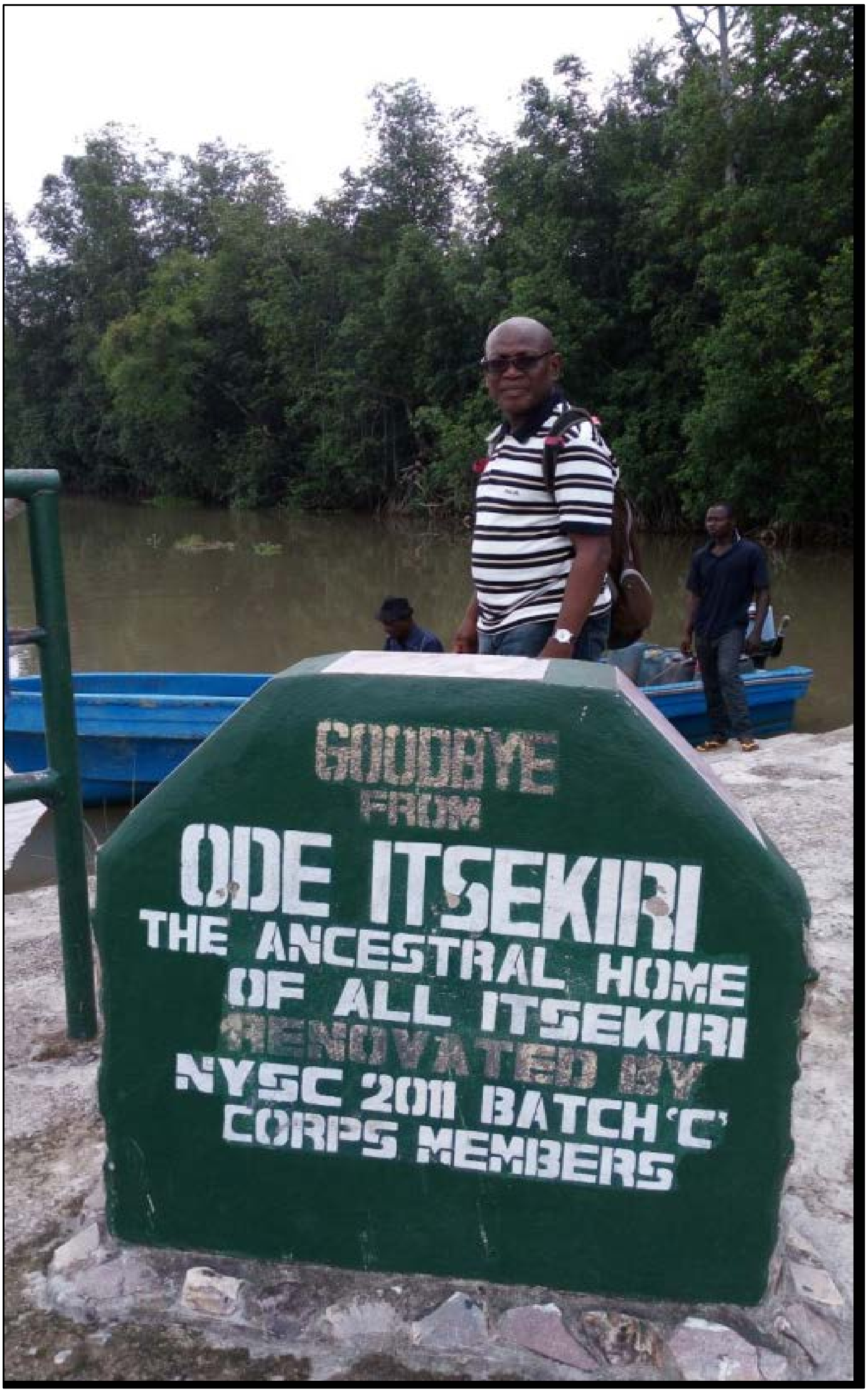
Operational safety
Extensive compliance testing performed under European and Global norms and verified by independent 3rd party certification agencies.

Complete battery solution
Complete and ready to install systems, filled and charged or dry charged form with all the necessary accessories. Extensive range of adding value products and services.

Flexibility
Design and production of customized products and services, high volume orders handling capability, fast delivery.

Peace-of-mind
24x7 experienced pre-sales and after sales support through SUNLIGHT Global Partners Network.

Optimum Total Cost of Ownership (TCO)
Low cost per cycle. Lifetime value maximized especially at hybrid systems where using batteries can greatly reduce the Genset daily run time resulting on fuel savings and less CO_2 emission.



Departing Ode Itsekiri