OVERVIEW OF OFF-GRID RURAL ELECTRIFICATION PROGRAMME IN NIGERIA

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Abstract: It is evident that out of the 1.3 billion people worldwide that lack access to electric energy are rural dwellers. Furthermore, the majority of them are living in rural areas of developing countries which are often remote, dispersed populated, and categorized by pitiable infrastructure and services. Given this, the rising contemplation concerning the target of worldwide access to energy has stressed the role of rural electrification and off-grid hybrid power generation system. To this effect, the present work focuses on the overview of rural electrification programs in Nigeria and offers a general framework. The Mini-grid Value Chain for the effective implementation of mini-grid projects was developed. Furthermore, to overcome the issue of affordability of cost of energy in rural areas of the country and to promote sustainability of the off-grid electrification projects, an Improved Local Electrification Committee Model (ILEC) was developed. The main aim of this is to guarantee the reliability of the power supply network to the off-grid rural areas and also to overcome the major demerit of the overall high initial capital cost that is associated with the establishment of mini-grid projects for off-grid rural electrification.

Keywords: Renewable energy, Mini-grid, Value chain, Rural electrification, Rural area, Solar photovoltaic

List of abbreviations
NEP - Nigeria Electrification Project
REA - Rural Electrification Agency
NEPP - National Electric Power Policy
EPSRA - Electric Power Sector Reform
RESIP - Rural Electrification Strategy and Implementation Plan
NERC - Nigerian Electricity Regulatory Commission
REPG - Policy Guidelines on Renewable Electricity
AfDB - African Development Bank
RETF - Renewable Electricity Trust Fund
AMDA - Africa Mini-Grid Developers Association
BOI - Bank of Industry Nigeria
UNDP - United Nations Development Program
HRES - Hybrid Renewable Energy System
NEPO - National Energy Policy
NEPA - National Electric Power Authority
PHCN - Power Holding Company of Nigeria
DisCos - Electricity Distribution Companies
GenCos - Electricity Generating Companies
TCN - Electricity Transmission Company
NDPHC - Niger Delta Power Holding Company
NIPP - National Integrated Power Projects
NBET - Nigerian Bulk Electricity Trading
PPA - Power Purchase Agreements
OAGF - Office of the Account General of the Federation
AG - Associated Gas
NNPC - Nigerian National Petroleum Corporation

1. INTRODUCTION

The effects of global warming and climatic change have motivated both developed and developing countries to show interest in using available renewable energy resources to generate clean electricity. Countries like Sweden, Iceland, Germany, and the United Kingdom among others, are already investing in renewable energy sources for electricity generation. The Government of Nigeria has set for itself the intention to be among one of the 20 largest economies and doubling the percentage of renewable energy in the country's overall energy mix by 2030; [1] despite the numerous challenges that are associated with climate change, growing population, and low access to grid electrical energy. Moreover, the reserves of fossil fuels in the country in addition to environmental degradation associated with these resources cannot sustain the development in the future [2]. Renewable energy sources are comparatively stochastic and dependent on climatic conditions [3]. For instance, the available potential of hydropower is always equal to or near the installed capacity during the rainy season when the flow rate is high and goes below the average during the dry season when the flow rate is low. Likewise, solar energy is usually available in the daytime (with expected high insolation in the dry season and low insolation in the rainy season), other alternative sources of energy or battery are required at night for the continuity of the electrical energy supply.

To achieve the government of Nigeria's vision, renewable energy has been identified as one of the mechanisms to guarantee the supply of environmentally friendly and reliable electrical energy in rural areas by establishing small decentralized units based on a variety of available resources. This type of system that is based on renewable energy resources can be utilized as a hybrid renewable energy system (HRES), or as a micro-grid which is the integration of renewable energy resources or renewable resources with fossil fuels to provide electric power which can meet the present and future electrical energy needs of an area in a sustainable manner. A system that employs two or more locally available renewable energy resources (geothermal, small hydro, solar, biogas, wind, biomass, etc.) to generate electricity is known as Hybrid Renewable Energy System (HRES) [4-7]. HRES, can be grouped into two main types which are: stand-alone and grid-connected type [8]. A grid-connected HRES is usually connected to electricity grids to sell excess energy when the generated energy is more than the load demand or purchase energy when the load demand is more than the generated energy at a predetermined price. The stand-alone HRES is suitable to supply the electrical energy requirements of off-grid rural areas as against the extension of the electric grid which may be costly in some cases based on the topographical nature of the area.

Therefore, standalone HRES is gaining popularity for the electrification of rural areas. For the electrification of remote areas, using renewable sources the HRES can be modeled and optimized to satisfy the energy needs of the areas. A report published by the World Bank and many foreign organizations has shown Nigeria taking the appalling position of the second country with the topmost electricity shortage, having a 45% electricity access rate [9]. Moreover, about 80% of those with access to electricity from the grid also rely on diesel generators as an alternative source of electricity as a result of reliability anxieties [10-11]. It is assessed that the Nigerian economy misses US$ 29.3 Billion yearly owing to the insufficient power supply and is valued to have lost US$ 470 Billion in GDP from the year 2000 as a result of inadequate investment to develop power system infrastructure [12]. The provision of access to affordable electrical energy is commonly believed as a qualification for sustainable development [13-18]. The poor rural dwellers would be deprived of the essential lucrative opportunities required to enhance their standard of living without access to electrical energy [19].

All geo-political zones in the country are blessed with abundant renewable energy resources [20-21], which remain largely unexploited. The mean solar insolation per day varies between 3.5-7.0 kWh/m^2/day, while yearly wind speed varies between 2-4m/s on a height of 10m, and the estimated potential of identified small hydropower in Nigeria is 735MW [22]. The hydrological locations in Nigeria are split into different geopolitical areas. The aggregate number of both the current dams and those under the proposal in each of the hydrological areas is 428 [23]. The major purpose of the existing dams is either to supply drinking water or for irrigation but, they have the inbuilt potential for electrical energy generation. The reserves of oil and gas in Nigeria are about 37,453 million barrels and 5,627 billion cu. m respectively [24]. It is also the largest oil producer and exporter in Africa [22].

The socio-economic development of rural areas in Nigeria remains a challenge even, after more than 50 years of independence, as the country's national electric grid is yet to be extended to them due to the unbearable cost of transmission and distribution of power to these areas; dispersed features of the area and low average load factor. Energy is an essential commodity that is urgently needed in rural areas to contribute to social and economic development [25] and also to create employment opportunities. Usually, the prices of traditional energy sources such as kerosene, candles, gas, and batteries in rural areas are costlier than in urban areas. This is due to the long distance traveled by retailers in rural areas to obtain their goods and the corresponding associated overhead costs. There are so many factors associated with traditional energy sources in rural areas. For instance, women need to walk for more than 4 hours to get the required wood needed to prepare food for the family daily also, the cost of lighting is costlier for rural dwellers compared to urban dwellers who even have access to the national electric grid. Likewise, charging the battery in a nearby community can take a whole day.

Off-grid rural electrification projects based on viable multiple renewable energy sources, where electrical load demand for rural household or industrious usages is produced without a link to the electrical grid network, is recognized by various government and researchers [26-27] as playing a significant and balancing role in attaining rural electricity access targets. Some studies in the literature reveal that a prospective opportunity is opened to the qualify investors for investment in the provision of affordable energy systems by openly involving the consumers which are rural dwellers in the development of the project [28-29]. Though, such prospects are directly influenced by government policies. Although, it is generally known that Africa has the lowest access to electricity for both rural and urban settings [30-38] as compared to other continents as presented in Figure 1 [39].

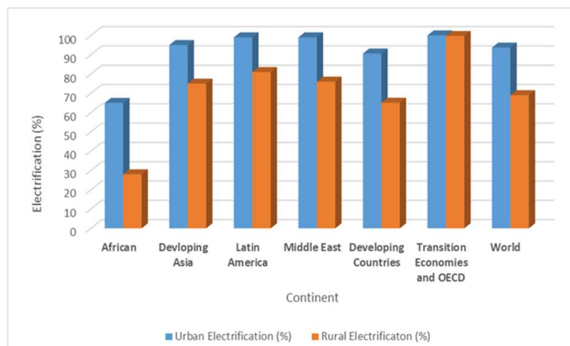

Fig. 1. Continents aggregates for rural electricity access

Depending on the topographical feature of the area, the potential of the available energy resources, the nature of electrical load demand, and socio-economic conditions, energy models can be established and optimized in other to satisfy the energy demand of the area [40]. It is common knowledge that renewable energy resources are variable and intermittent but, several research works have been conducted to give improved forecast of renewables (wind, solar-PV) and their combination into stand-alone systems [41]. Under the policy objectives of the government of Nigeria for rural electrification and the roadmap set up by the National Energy Policy (NEPO), an off-grid, stand-alone hybrid energy system consisting of viable renewable energy sources is a promising approach for the electrification of the off-grid rural communities in Nigeria. In this paper: the mini-grid value chain for the effective planning, implementation, operation, and maintenance of mini-grid projects was developed and various generation technologies used in typical rural areas were presented; the overview of electric power generation in Nigeria was discussed; likewise, the Nigerian Electricity Programme with the major objective of increasing access to electricity in rural areas of the country was discussed; Governmental guidelines and legislations that favor rural electrification projects were briefly presented; the survey of identified mini-grid electrification projects in Nigeria was carried out and results presented; and lastly, a business model for the sustainability of off-grid rural electrification project was developed.

2. THE MINI-GRID VALUE CHAIN

The development and operation of mini-grids is a complicated practice that encompasses a wide range of investors and needs a trained workforce. Figure 3 shows the developed primary components of the mini-grid value chain, which are: plan development, project construction, and operations. The individual stage of the mini-grid value chain plays a crucial role in the overall worth and cost of service delivered to electricity consumers.

Depending on the sources of power generation for the mini-grid, the plan development stage which involves identification of the site and electrical load assessment, system design and planning, and acquisition of different user classes of consumers normally takes more than three months. Site selection is of utmost importance when developing a mini-grid and numerous factors such as existence of or distance to other mini-grids; population density; social and economic activities; mean income and purchasing power; accessibility; security; and availability of potential renewable resources must be considered when deciding on a site for mini-grid. For brevity, the process involved in selecting a site for a mini-grid is represented in Figure 2. After identifying a favorable site for a mini-grid project, the next step is to design an optimal system configuration in terms of capacity/number of units for each component of the mini-grid using modern optimization techniques or dedicated commercially available optimization software.

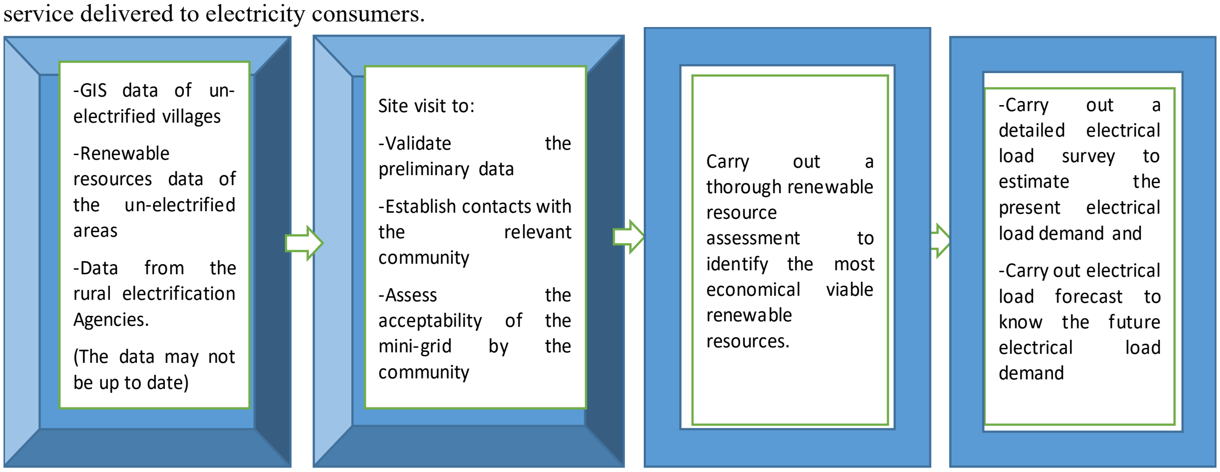

Fig. 2. The Process Involved in Selecting a Site for a Mini-grid Project.

The second stage which is the construction of the mini-grid project, which involves procurements of various equipment, installation of the various components of the system and commissioning usually takes between three to twenty- four months depending on the renewable resources employed. The gestation period for the solar mini-grid is usually between 6-8 months while that of a small hydropower-based mini-grid is around 24 months. This process can either be undertaken directly by the developer or contracted out. If contracted, the supervision and management roles should be done by the developer. Procurement is the act of acquiring technical equipment and services from an external source through a tendering process. Generally, two available practicable procurement models that are used by the mini-grid developers as follows: (i) Tenders for different components of the mini-grid where the developer installs and commissions the system themselves; and (ii) Tenders for a turnkey solution where the Engineering, Procurement, and Construction (EPC) would be done by a contractor. But, for the subsidized projects either via government or international donors, transparent procurement instructions would be fully observed.

Certified engineers and technicians must be engaged in the installation and supervision of mini-grids. Sequence to the installation of mini-grids, developers must have secured the necessary legal rights for the project site. Quality controls of all the delivery equipment and services/locally manufactured products must be carried out before the commencement of the installation. Safety training must also be provided to all personnel. Dedicated installation tools and indigenous language training manuals for the installation of the equipment should be readily available and used accordingly.

All unwanted material must be properly disposed of in an environmentally responsible way and done as specified in the environmental impact assessment. The commissioning will follow immediately after the installation of all the components of the mini-grid. Commissioning is the process of guaranteeing that all mini-grid systems and constituents are designed, fitted, confirmed, activated, and maintained according to the operational requirements of the developer. Also, all the required technical tests such as frequency, voltage, and start/stop test must be done accordingly. The commissioning agreement/ protocol must be endorsed by all the concerned parties involved.

Lastly, the operations stage depends on the reinvestment, but a mini-grid project usually lasted between 20–40 years). A single, vertically incorporated company can finish all components within the value chain; however, projects more frequently need numerous companies with each major in different areas of the value chain. Operation and maintenance (O & M) of the mini-grid should be properly planned even before the commencement of the operation as it is a critical determinant for the long-term sustainability of the mini-grids. A good design mini-grid may fail if the O & M is not well executed. O&M may either be managed directly by the developer or contracted to an indigenous company. Nevertheless, local operators on the ground must be well trained and have detailed O&M techniques, and should also have access to higher level technical specialists as mandatory. The corporate management of the mini-grid must make sure that local staff understands and follow the O & M procedures. The O&M procedures should include but not be limited to emergency response to accidents and fires; Emergency response to electricity outages for individual and multiple customers; Emergency response for theft and vandalism; Standard technical O&M activities; Fuel or resource management; Customer contract signing; Revenue collection; Reporting of cost; Installation and quality control of customer connections; Installation and quality control of indoor installations; and Safety training for customers. Figure 3 provides more details on the respective component of the recommended value chain. Meanwhile, various generation technologies used in the typical rural area are presented in Figure 4.

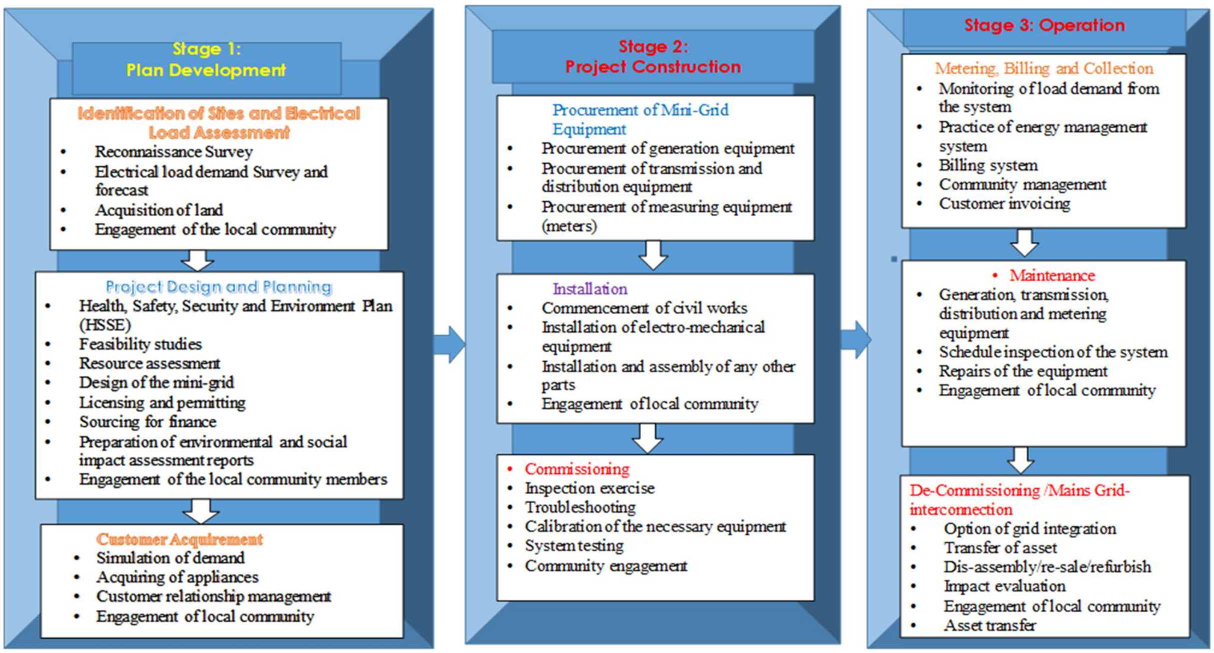

Fig. 3. Stages involved in the implementation and the operations of the mini-grid

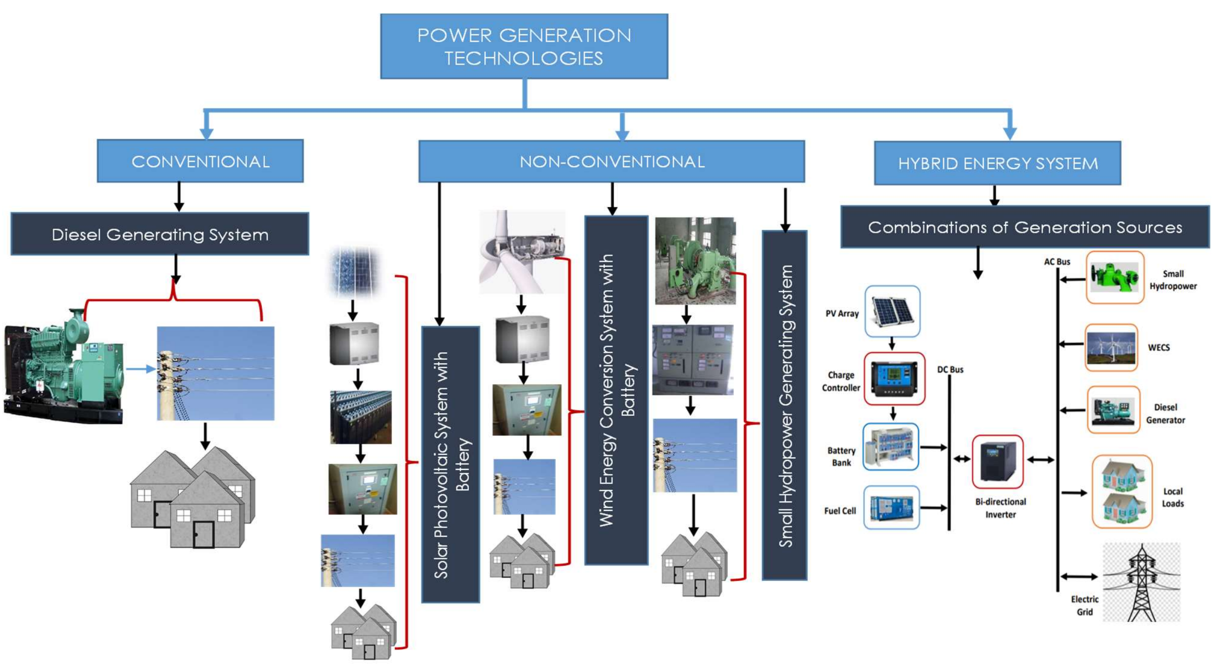

Fig. 4. Generation technologies for rural electrification

The technologies are divided into conventional, non-conventional, and hybrid of the two. The conventional includes a diesel generating set whose output is distributed to the end-users via a low-tension network. Sometimes, the voltage output is stepped up to serve more distant members of the community. The non-conventional include the use of renewable energy resources such as solar photovoltaic systems, wind energy conversion systems, and small hydropower, in the production of electricity. The third category is the combination of both conventional and non-conventional. The purpose is for the diesel generator to provide alternative energy to the community in the event of low or non-availability of renewable energy resources at a particular point in time.

3. OVERVIEW OF ELECTRIC POWER GENERATION

The generation of electricity in Nigeria began in the year 1886 when two generators were set up to supply the electricity needs of the former Colony of Lagos. By the Parliament Act of 1951, the Electricity Corporation of Nigeria was set up likewise, the Niger Dams Authority in the same year intending to produce electricity using hydropower technology. The two organizations were merged in 1972 to form National Electric Power Authority (NEPA) with statutory responsibilities of generating, transmitting, and distributing electric power for the entire country. Due to the power sector restructuring procedure, NEPA was changed to the Power Holding Company of Nigeria (PHCN) in the year 2005. In March 2005, the Electric Power Sector Reform (EPSR) Act which permits private companies to be involved in the generating, transmitting, and distributing of electric power was signed into law. The government later divided the PHCN into three arms which are eleven electricity distribution companies (DisCos), six electricity generating companies (GenCos), and one electricity transmission company (TCN).

Presently, the Government has stopped being interested in all the GenCos and the government's 60% share in all DisCos has been sold to private companies. The TCN remains the property of the Federal Government although it's being managed by a private company. The 2005 reform Act also established the Nigerian Electricity Regulatory Commission (NERC) as a self-governing regulator for the energy sector. The list of GenCos with their installed capacity and privatization status is given in Table 1. At present, the electricity generation sub-sector has 23 grid-connected electricity generating stations in operation having "a sum of 10,396 MW installed capacity (obtainable capacity of 6,056 MW) with thermal based generation possessing an installed capacity of 8,457.6MW (obtainable capacity of 4,996 MW) and hydropower possessing

1,938.4 MW of total installed capacity (obtainable capacity of 1,060 MW)" [32]. IPPs are power plants that are operated by the private sector alongside to privatization process. They are: "Shell-operated named Afam VI (642MW), Agip operated named Okpai (480MW), Ibom Power, NESCO and AES Barges (270MW)" [42].

Table 1. List of electricity generation companies in Nigeria after the unbundling of PHCN

Generating Stations	Installed Capacity (MW)	Type of System	Privatization Level
Afam Power PLC	776	Gas	Completely Sold
Sapele Power PLC	414	Gas	51% has been Sold
Egbin Power PLC	1,020	Gas	Completely Sold
Ughelli Power PLC	900	Gas	Completely Sold
Kainji Hydropower Plant	760	Hydropower	Long Term Consideration
Jebba Power Plant	578	Hydropower	Long Term Consideration
Shiroro Power PLC	600	Hydropower	Long Term Consideration

Source: [42]

As parts of the Government attempts to boost the electric power supply, the Niger Delta Power Holding Company (NDPHC) was incorporated in 2004 with the mandate of overseeing the National Integrated Power Projects (NIPP) which entails the building of recognized critical infrastructure in the electric power supply chain network. It is expected that NDPHC will add about ten new gas-fired power stations to the national grid, of which some have already been finished and commissioned, while the remaining ones are under construction across the country. "It is expected that after completion of all NIPP power projects, the addition of about 4,774MW of power would be added to the national grid network" [42]. The list of NIPP-generating stations is given in Table 2.

Table 2. List of NIPP stations in Nigeria.

Generating Plant	Capacity (MW)	Location
Alaoji	1, 074	Abia State
Benin (Ihovbor)	451	Edo State
Calabar	563	Cross River State
Egbema	338	Imo State
Gbarain	225	Bayelsa State
Geregu	434	Kogi State
Olorunsogo	-	Ogun State
Omotosho	451	Ondo State
Omoku	225	River State
Sapele	-	Delta State

Presently, several NIPP power generating stations have been sold while strategies are already in place to privatize the rest to escalate private sector involvement in the sector hence, strengthening the power sector reform of the Federal Government. To advance the power sector reform program, NERC has formerly licensed numerous IPPs, which numbers of which are at different stages of development. It enables the investors, communities, and state and local governments to produce and sell or consume electric power without the direct involvement of TCN. As regards the post-privatized power sector, the power generated by GenCos and IPPs will be purchased by the Nigerian Bulk Electricity Trading PLC (NBET) at approved prices specified in Power Purchase Agreements (PPA) and sells the same to the distributions companies who will, in turn, distribute the power to the consumers.

Table 3. Amount spent to boost power generation between 1999 and 2007.

Year	N (Billion)	US$ (Million)	Average Exchange Rate (N per US$)
1999	6.7	72.28	92.6934
2000	498	487.73	102.1052
2001	70.9	633.36	111.9433
2002	44.2	394.84	111.9433
2003	5.2	43.00	120.9702
2004	54.5	421.32	129.3565
2005	70.3	531.97	132.1500
2006	72.4	562.77	128.6500
2007	61.1	485.58	125.8300
TOTAL	**435.1**	**3, 642.83**	

Given the huge amount of revenue realized from oil, the major setback is the wasteful expenditure of foreign exchange on electric power generation via maintenance and upgrading of the power supply network without any significant results. For, example huge amount had been spent on the repair and maintenance of the Kanji hydropower station without any worthy output. More so, the available data from the Office of the Account General of the Federation (OAGF) between 1999 and 2007 revealed that the Federal Government had spent about US$3.6 billion to boost the electric power generation in the country as presented in Table 3. Despite this enormous spending, the shortage of electric power supply in the country remains unchanged.

4. SOURCES OF ENERGY IN RURAL AREAS IN NIGERIA

Although, there is no unanimity as regards the meaning of rural areas, which essentially differs from country to country. A rural area is defined here as an area of land outside the densely populated urban areas in a town or city. It is an area with a low population density. It is common knowledge that the extension of grid electricity to rural areas that have low load factor and complex topography is usually associated with the higher cost of distribution and transmission [43] coupled with the global concern about the issues of emissions associated with the fossil fuel-based power generating system [44]. Moreover, due to the low load factor, the extension of grid electricity might not be economically viable. It is evident from the study carried out in [45] on short- and long-run impacts of rural electrification among American farmers that access to electricity increased from nearly 10% to 100% over three decades, 1930–1960.

In Nigeria, the percentage of the rural population is estimated as 51.4% in 2016, based on the World Bank gathering of development indicators, which was compiled from officially accepted sources and still keeps on increasing yearly. The principal source of lighting in rural areas of the country that lack access to electrical energy is kerosene among other unfriendly ones [46] as presented in Figure 5.

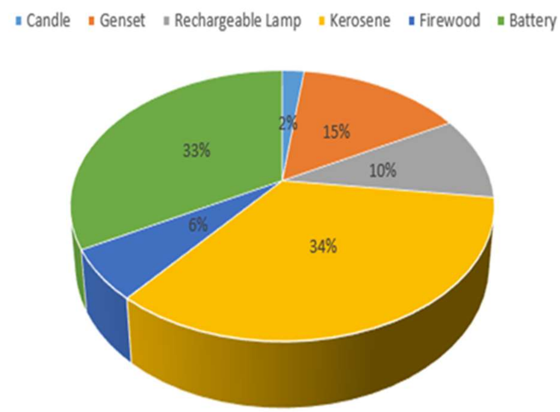

Fig. 5. Sources of energy in off-grid rural areas of the country without access to electricity

The overall percentage of the rural population which has access to electricity in Nigeria was estimated as 41.1% as presented in Figure 6.

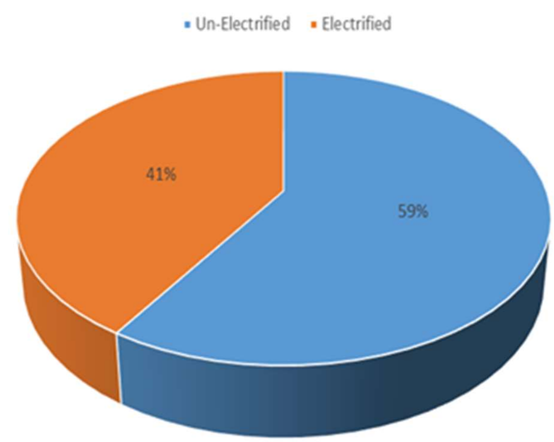

Fig. 6. Rural electrification rate in Nigeria

The electricity access rate data for each of the states in the country was compiled from the Nigeria Electrification Project (NEP) document that was submitted to the World Bank [46] and plotted as presented in Figure 7 with the maximum access rate in Lagos State which is located in South West Region of the Country. Although, the rural and urban electrification rate in African Continent is low as compared to other Continents [39] as evident in Figure 1 previously presented above, since they are commonly dispersed populated, geographically remote, and not easily accessible [39, 47-48]. The well-known sources of income for rural dwellers are animal husbandry, farming, fishing, and tourism [46, 48]. The piety conditions of the rural roads and remoteness from urban areas worsen the partial accessibility, and also the service providers cannot pledge steady visits, therefore foiling rural populations from partaking in national or district markets. Furthermore, well-educated individuals will be extremely discouraged to live in such regions [49]. Among other factors that usually affect rural areas are illiteracy, gender disparity, poor health care services, and lack of access to clean water supply [26, 50]. Although, practical surveys have revealed that the larger percentage of the rural settlements that have access to electricity are those that are very close to the urban areas and are located along the main roads.

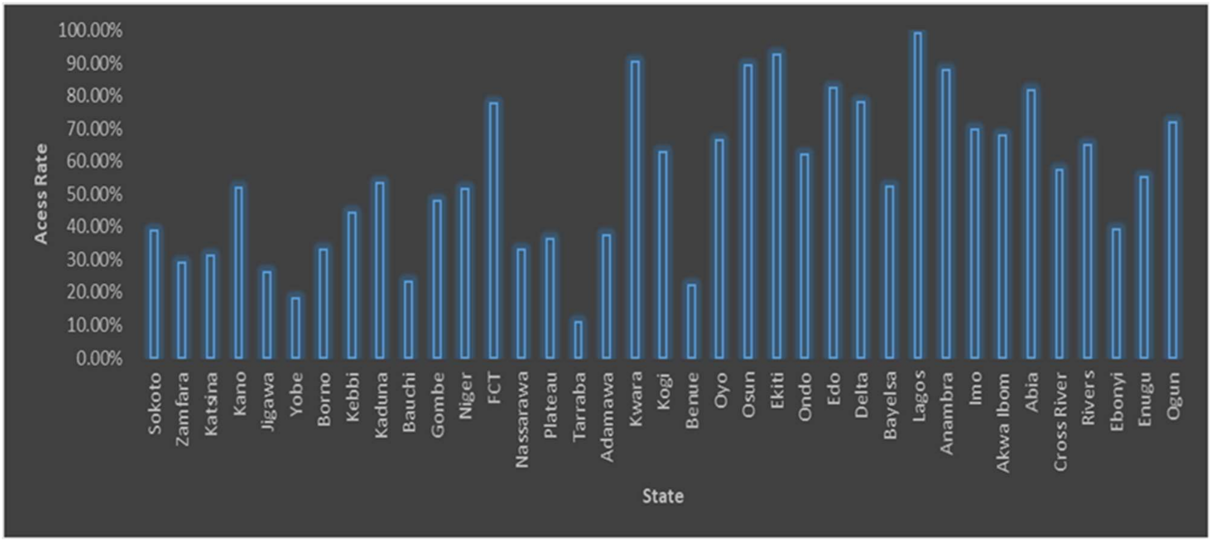

Fig. 7. Percentage of access to Electricity by State in Nigeria.

A report released by the National Bureau of Statistics (NBS) (Labour Force Statistics, volume 1, NBS) has revealed that the unemployment and underemployment report for 3rd quarter 2018 showed that the rate of unemployment escalated yearly by 3.3 million from 3rd quarter 2017 to 20.9 million in 3rd quarter 2018 while it escalated by 3 percent quarterly [51]. The rate of job losses in the rural areas of the country exceeds that of the urban areas. The Federal Government of Nigeria in its effort to provide cost-effective electricity to all rural areas across the country, established the Nigerian Rural Electrification Agency (REA) through the Electric Power Sector Reform Act in the year 2006. The main objective of REA is to expedite the provision of affordable electricity supply in all the rural areas of the country. Initially, REA focused on the extension of the national electric grid to off-grid rural areas, but, due to global concern about the effects of climate change as related to emissions produced by fossil fuel-based power generating stations, the agency has now been mandated to give attention on providing reliable and affordable electricity to remote rural dwellers using available renewable sources of energy.

5. NIGERIA ELECTRIFICATION PROJECT

The Nigeria Electrification Project (NEP) proposal was submitted to African Development Bank in May 2018 to borrow a total sum of US$ 350 million to finance the electrification project. In November 2018, another NEP proposal was submitted to the African Development Bank (AFDB) to borrow US$ 200 million to finance the project. NEP is a nationwide creativity and is meant to deliver energy access to off-grid and underserved communities in Nigeria and is to be managed by the REA. The Project is intended to provide the least cost of electrical energy to rural and urban households, small and medium-sized enterprises, and public institutions in the form of a micro-grid system. The objective of the NEP is to offer over 500,000 people access to cheap sources of electrical energy. The estimated annual disbursements from the World Bank which has commenced in year 2018 and it is expected to end in year 2024 as contained in [46] presented in Figure 8 The fund released so far has been dedicated to the electrification of the off-grid rural areas in the country. If the fund is properly utilized for its intended purpose as contained in the World Bank Report Number PAD2524, the electrification access in the rural areas of the country would greatly increase by the end of year 2024. The four major components of NEP are:

a) Solar Mini-Grids for Rural Economic Development: this entails the funding of the rollout of a minimum subsidy tender for mini-grids in 250 locations in six geo-political zones in the country;
b) Productive Appliances and Equipment for Off-Grid Communities: this entails funding performance-based contributions to both mini-grid and stand-alone solar installation companies that increase the number of productive appliances in their operations;
c) Energizing Education (Phase 3): this is dedicated to the funding of the installation of dedicated power systems for eight federal universities across the six geo-political zones in the country; and
d) Institutional Capacity Strengthening: this entails the provision of technical support and capacity building to REA and other relevant stakeholders to support national rural electrification scale-up activities.

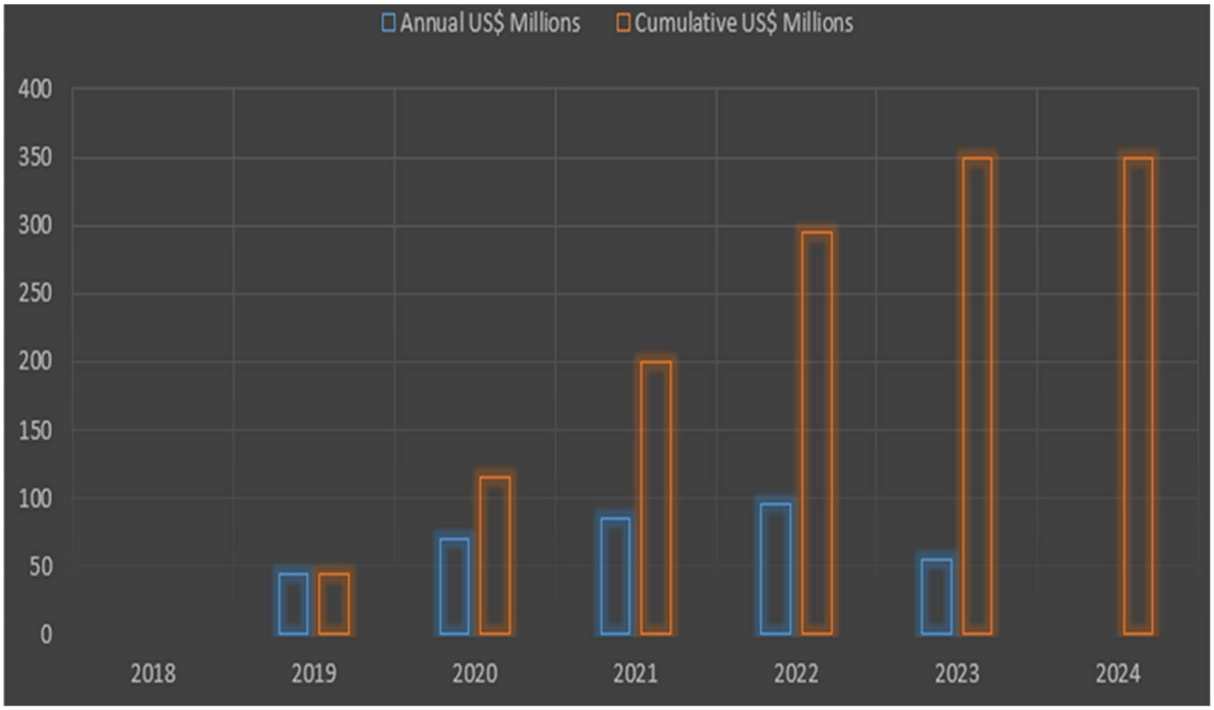

Fig. 8. Annual disbursement from World Bank for NEP

The Government through REA has divided the market segment to be assisted into four in her effort to increase access to affordable electricity which are; solar home systems; mini-grid systems; energizing education; and energizing economies as illustrated in Figure 9.

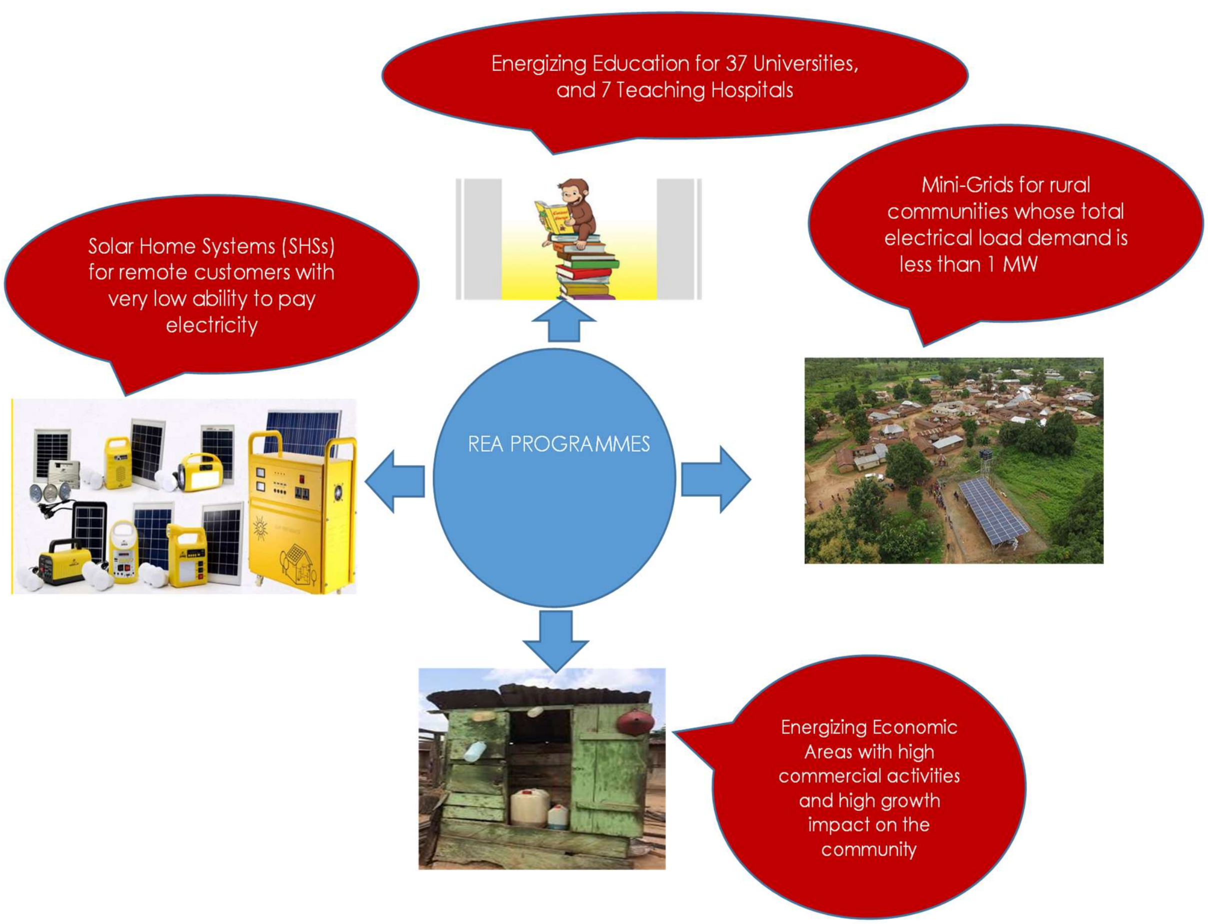

Fig. 9. Summary of the proposed segments to be supported by REA

The strategies employed by the Government through REA to increase access to electricity in rural areas through support from foreign grants for each of the segments in Figure 9 are presented in Figure 10.

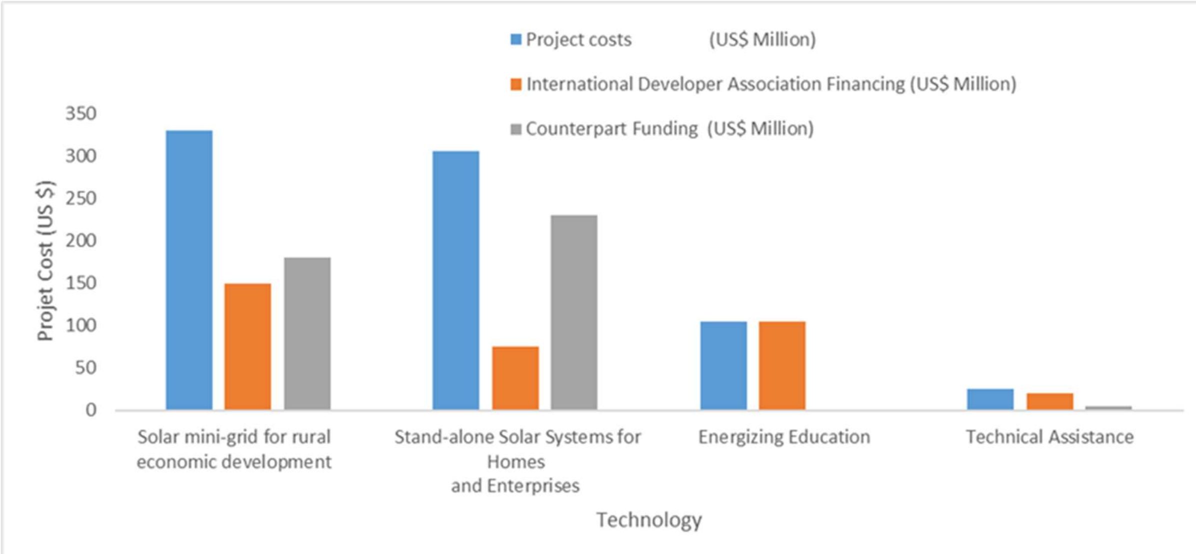

Fig. 10. The financial strategies employed by the Government to ease access to electricity in rural areas.

Strategies employed by the Government through REA to increase access to electricity in rural areas are summarized in Figure 11.

Before the commencement of the off-grid electrification by REA, in the forms of subsidy and feed-in-tariff to the mini-grid developers, the proposed grant used by GIZ's Nigerian Energy Support Programme (NESP) for CAPEX grants of nearly US$500-600 per customer was adopted.

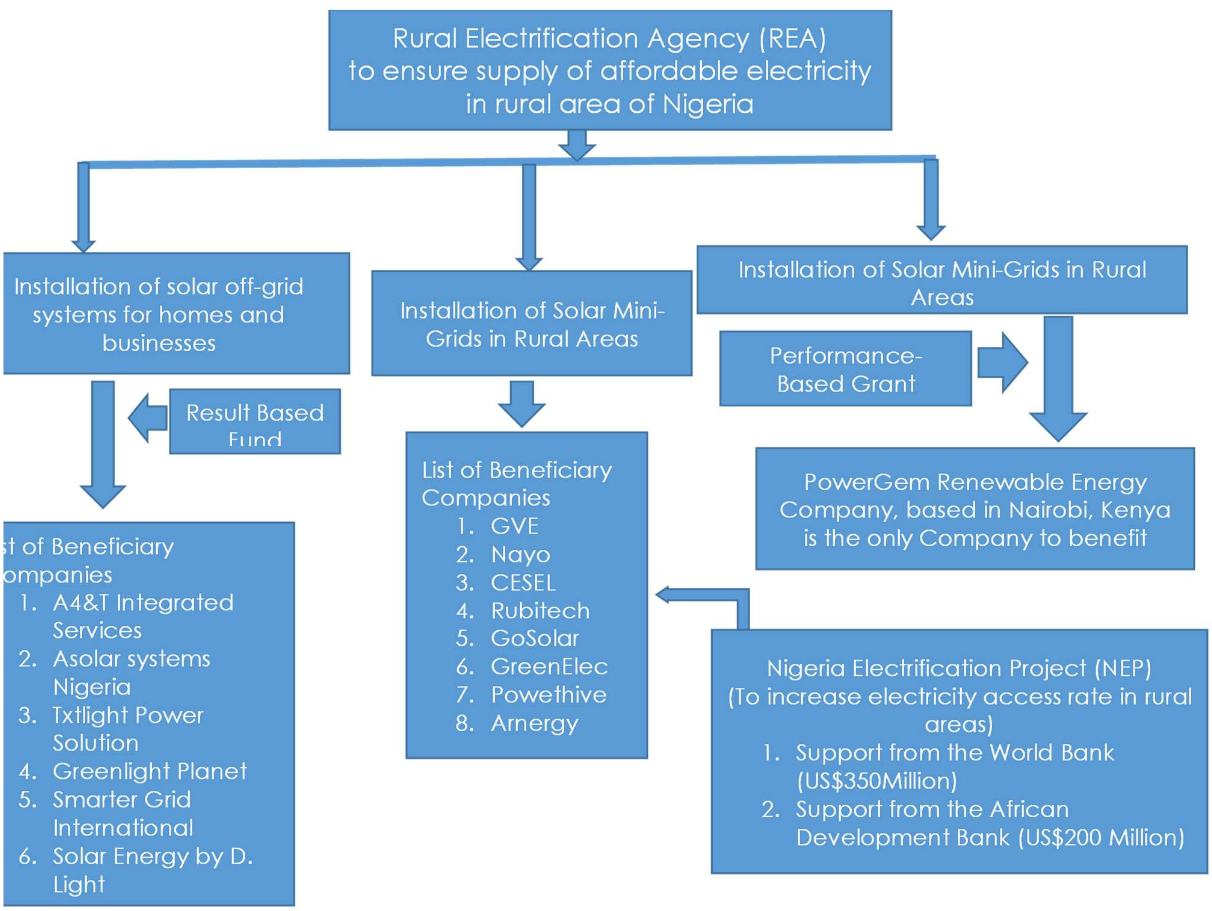

Fig. 11. Electrification Strategies employed by the Government through REA.

Analysis of the cost of GIZ pilot projects has revealed that the present subsidy should be between US$300-350 for each new connection to the mini-grids before the project can be sustainable. For brevity, the projection of up to 1,167 mini-grid projects may seek co-financing from performance-based grants as detailed in Table 4.

Table 4. Number of mini-grid projection

Company	Number of Mini-Grids Projections						
	2018	2019	2020	2021	2022	2023	Total
GVE	48	75	100	135	150	167	675
Nayo	4	6	8	11	13	14	56
CESEL	10	16	21	28	31	35	141
Rubitec	2	3	4	6	6	7	28
GoSolar	12	19	25	34	38	42	169
GreenElec	3	5	6	8	9	10	42
Powerhive	2	3	4	6	6	7	28
Arnergy	2	3	4	6	6	7	28
Total							**1, 167**

The overall annual installed capacity linked with the projection in Table 4 as determined in the NEP document submitted to the World Bank is presented in Table 5 assuming the usual capacity of the mini-grids each of the developers is presently operating which is expected to yield an overall installed capacity of approximately 87 MW. The total estimated cost for all the mini-grids is around US$380 million based on the US$4,400 per kW cost.

Table 5. Projections based on the installed capacity

Company	Projection of Installed Capacity (MW)						
	2018	2019	2020	2021	2022	2023	Total
GVE	2.0	3.1	4.1	5.5	6.1	6.8	27.6
Nayo	0.4	0.6	0.8	1.1	1.3	1.4	5.6
CESEL	2.0	3.1	4.2	5.6	6.3	6.9	28.1
Rubitec	0.2	3	4	6	6	7	24
GoSolar	1.1	1.7	2.3	3.0	3.4	3.8	15.2
GreenElec	0.3	0.5	0.6	0.8	0.9	1.0	4.2
Powerhive	0.0	0.3	0.4	0.6	0.6	0.7	2.7
Arnergy	0.1	0.1	0.2	0.2	0.3	0.3	1.1
Total							**86.9**

Based on the allocation of 250 W for each user as recommended by six of the eight mini-grid developers, the expected number of new connections gathered if the whole 1,167 mini-grids totaling 87 MW capacity were to be funded and assessed at 342,423 as presented in Table 6.

Table 6. Projections based on the installed capacity

Company	Projection of Installed Capacity (MW) Total (MW)						
	2018	2019	2020	2021	2022	2023	
GVE	11,000	18,000	24,000	32,400	36,000	40,065	161, 465
Nayo	1,600	2,500	3,333	4,500	5,000	5,556	22,489
CESEL	4,000	6,250	8,333	11,250	12,500	13,889	56,222
Rubitec	680	1,063	1,417	1,913`	2,125	2,361	9,558
GoSolar	4,320	6,750	9,000	12,150	13,500	15,000	60,720
GreenElec	1,200	1,875	2,500	3,375	3,750	4,167	16,967
Powerhive	160	1,250	1,667	2,250	2,500	2,778	10,604
Arnergy	320	500	667	900	1,000	1,111	4,498
Total							**342,423**

NEP, if fully and properly implemented will help the government to achieve universal access to electricity by the year 2030, by connecting between 500,000 to 800,000 households annually through extension of electrical grid, off-grid, and stand-alone energy systems as stated in the proposals submitted to the AFDB and World Bank. But, given the numerous challenges such as congestion of the central grid, and insufficient capacity of the electrical transmission infrastructure that have hindered the development and transformation of the on-grid infrastructure in the country, off-grid energy systems are expected to be the most promising means of electrifying the rural dwellers in rural settlements through renewable sources of energy.

6. GOVERNMENTAL GUIDELINES AND LEGISLATION

Federal Government has drawn its pledge and method to rural electrification in several official policies and strategies, among which are National Electric Power Policy (NEPP) (2001), the Electric Power Sector Reform Act (EPSRA) (2005), the Rural Electrification Strategy and Implementation Plan (RESIP) (2016) and Nigerian Electricity Regulatory Commission (NERC) Mini Grid Regulation (2017) as illustrated in Figure 12. The Policy Guidelines on Renewable Electricity (REPG) is the Government of Nigeria's principal policy on all electrical energy obtained from renewable energy sources. It describes the Government's concept, policies, and objectives for advancing the participation of renewable energy in the overall energy mix. In the policy document, renewable energy is considered as means to expand the electrical energy services to the parts of the country that have not been linked to the nation's electric grid; such as new communities in urban areas and for electrification of off-grid remote rural areas of the country.

The major goal is the integration of renewable energy into the energy mix of the national grid in the mid-term, which will: add additional capacity to the constrained system; enhance the stability of the system by relieving local disturbances in electrical energy supply, and also minimizing emissions.

The summary of the policy objectives with respective strategies is given below:

1. Enlargement of the market for renewable sources based electricity generation of not less than five percent of overall electricity generating capacity and at least 5 TWh of electrical energy production;
2. Creation of stable and long-term promising pricing mechanisms and ensuring unconstrained access to the electric grid with assured purchase and transmission of all electrical energy generated by renewable electricity producers and helping the grid operators to update the system appropriately;
3. establishment of stand-alone renewable electricity generating systems in an off-grid area where grid electricity has not been extended to;
4. Establishment of a Renewable Electricity Trust Fund (RETF) to be managed by the Rural Electrification Fund;
5. Set up a multi-shareholder partnership for the provision of green electricity to satisfy national development goals;

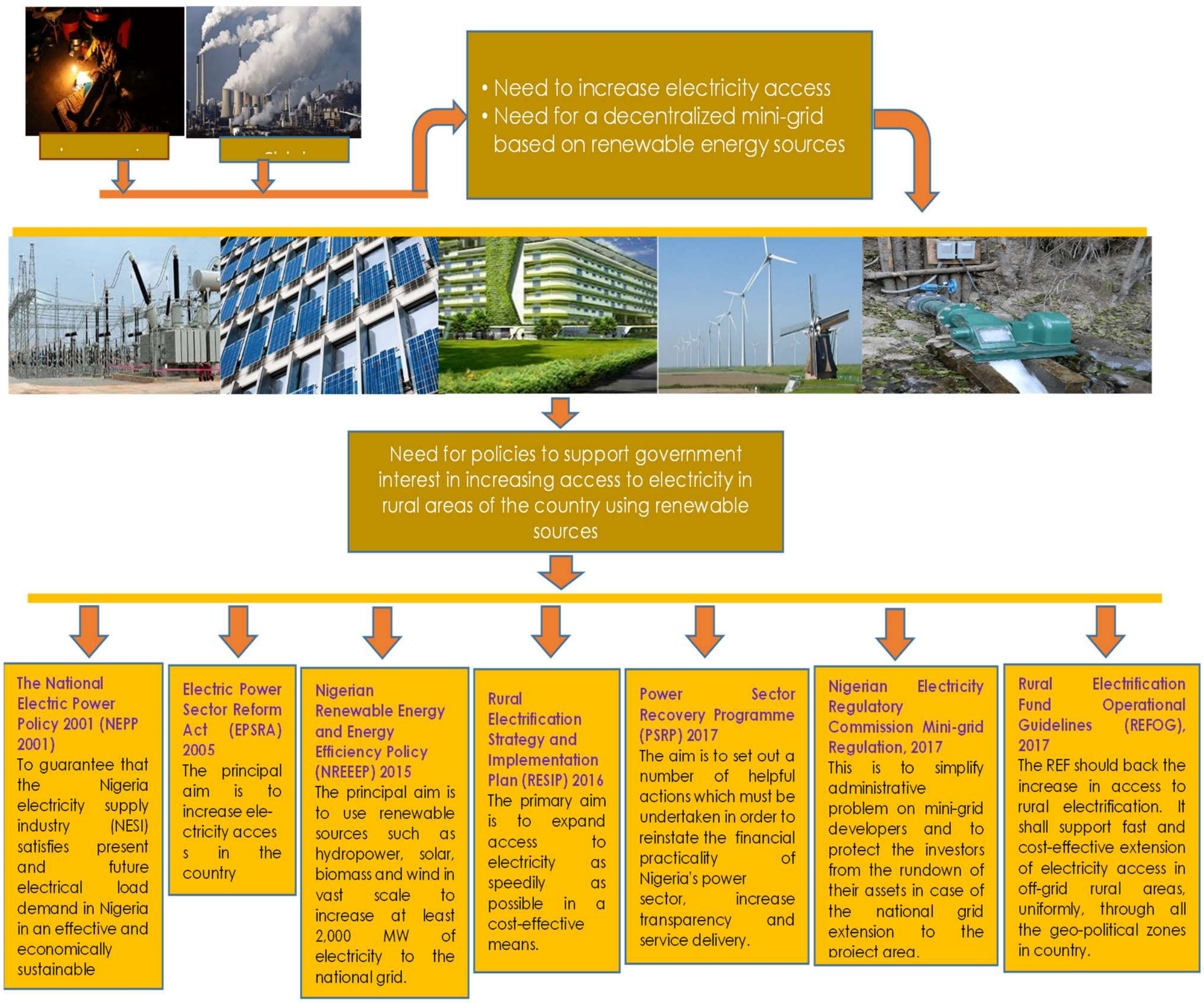

Fig. 12. Policy objectives supporting the use of renewable sources to increase the electricity access rate

7. MINI-GRID ELECTRIFICATION PROJECTS IN NIGERIA

The mini-grid projects for off-grid rural electrification in Nigeria are speedily growing. the number of active mini-grid developers in Nigeria has increased to nine in the Nigerian section of the Africa Mini-Grid Developers Association (AMDA). The outcome of the meeting convened by REA and mini-grid experts across the globe on how to achieve a tariff of ₦70/kWh (US$0.19/kWh) by the end of the year 2020, had revealed that there must be cost discounts for major seven groups which are: "hardware, load management equipment, customer meeting, project development, operation and maintenance, funding, and policy". Though, the current tariffs for the mini-grid are costlier compared to that of the mains grid from distribution companies, , they are reliable and environmentally friendly if they are properly developed. The current cost-reflective tariffs for mini-grid projects are normally around ₦ 200/kWh (US$0.55/kWh), which is lower than the cost to run a small petrol electricity generator set coupled with the associated environmental problems. Of the solar mini-grid projects that are fully in operation in which some are privately owned by investors and others are through the NEP (a partnership between the Federal Government of Nigeria, the World Bank, and the African Development Bank) which are targeted at electrifying the rural communities with solar mini/hybrid grid were surveyed.

Figures 13-16 show the pictures of the selected solar photovoltaic projects that are currently in operation to supply the energy needs of rural areas. The success of these projects, which have implemented cost-reflective tariffs through financial support from relevant organizations and generated customer demand, exhibits the potential viability of commercial mini-grid projects. Also, the details of the solar mini-grid project being country used to supply the basic electrical needs of rural communities in the country are presented in [19]. In addition, the Map of Nigeria showing different means of serving the electricity needs of each of the regions with planned strategies to electrify rural communities with renewable sources of energy is presented in Figure 17. Likewise, the survey of the potential rural off-grid locations in Nigeria for mini-grid (which can be a combination of multiple viable renewable sources of energy) with the corresponding available renewable sources is presented in [19].

Fig. 13. 157 kW capacity solar photovoltaic power plant at Rokota, a community in Niger State, Nigeria

Fig. 14. 100 kW solar photovoltaic mini-grid in Akpabom Community, Onna LGA,, Akwa Ibom, Nigeria, being managed by GVE

Fig. 15. 46 kW Solar Photovoltaic Pilot Project in Kolaku, Community implemented by Green Village Electricity Projects Ltd in collaboration with the BOI, Nigeria and UNDP

(a)

(b)

Fig. 16. (a) and (b): 134.64 kW solar photovoltaic power plant in Akipelai and Oloibiri, Bayelsa State under the Nigeria Electrification Project (NEP)

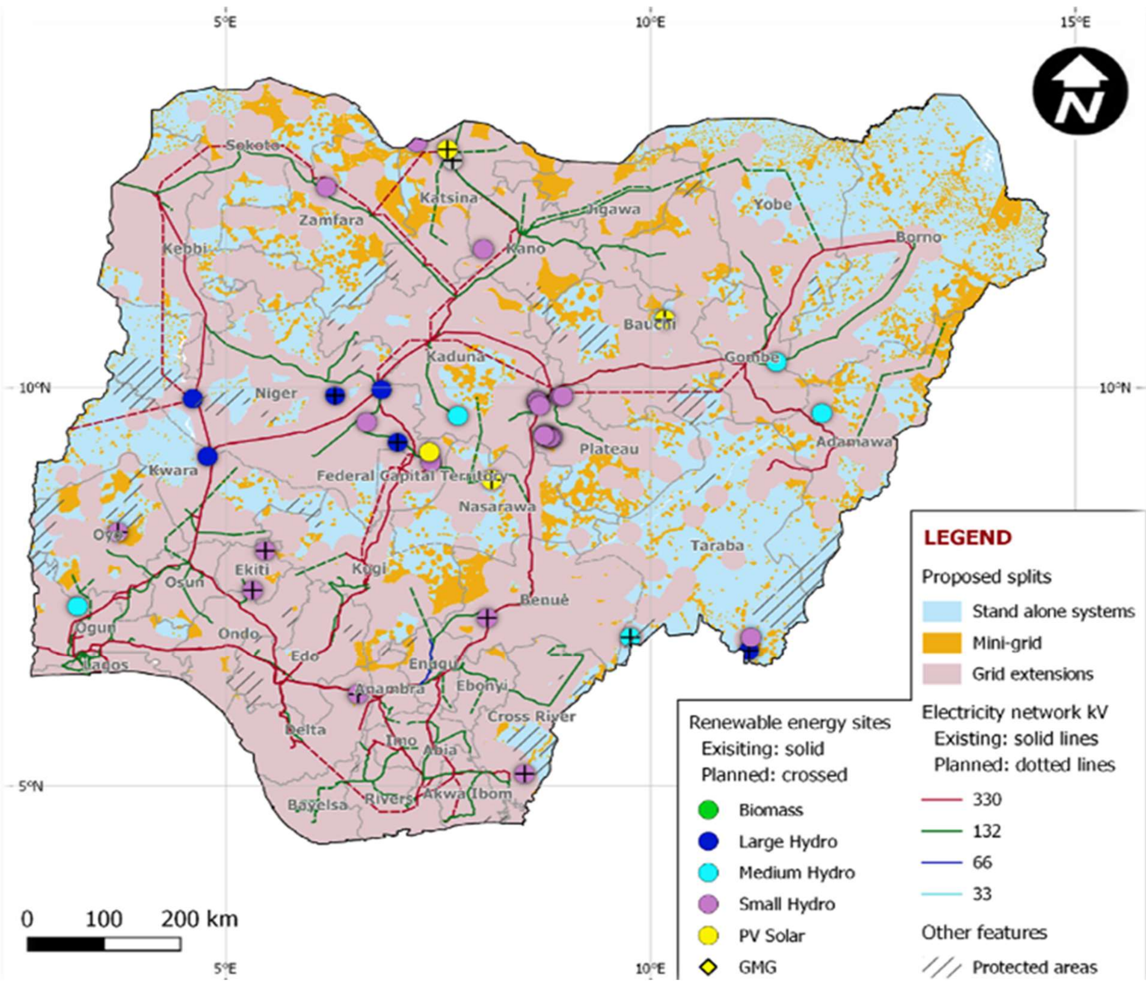

Fig. 17. Map of Nigeria showing means of serving various regions via grid extension, mini-grid, and intended renewable energy sites [52]

8. IMPROVED LOCAL ENERGY COMMITTEE BUSINESS MODEL (ILEC) FOR OFF-GRID RURAL ELECTRIFICATION

Taking modern-day electricity services to a larger percentage of low-income off-grid rural dwellers calls for a range of innovative mechanisms since it is not always economically viable. A major determinant of successful rural electrification projects is affordability, willingness to pay, and sustainability. The business model is defined here as a total structure within which the project works considering the choice of technology, monetary practicality of the model, institutional setup, duty of different stakeholders, and the regulatory and policy structure. It is common knowledge that the major interest of an investor in a typical business model is to make a profit, but in a community model, the underlying interest is to increase access to electricity via sustainable partnerships with indigenous communities. The involvement of the local communities is the key to a successful business model for off-grid rural electrification. Experiences from India and other developing countries [53-56] specify how collaboration with the local community had helped to expand electricity access in rural areas, thus confirming the importance of participatory models for increasing energy access in rural areas. Numerous authors from the literature have established their classifications for electrification models [57-59]. We have attempted mainly to develop an improved local energy committee model (ILEC) for off-grid rural electrification to demonstrate how the involvement of local communities as part of the stakeholder in an electrification project can affect the outcomes of a project.

In Nigeria, most of the NEP was implemented under REA to manage off-grid projects. Recently, most of these projects have been implemented in an off-grid village, majorly using solar mini-grid and in some places using solar-diesel generator hybrid technology by mini-grid developers with financial support in the form of subsidy from the Federal Government. Low successes have been recorded so far from the majority of these projects due to lack of proper maintenance among other factors. The failures of some of these projects may be a result of high cost of energy, and low load factor among others. For the sustainability of remote electrification projects in Nigeria and other developing countries, a rural electrification model called ILEC has been developed. The limitations of the village electrification committee model (VEC) which is commonly used in majority of the developing countries were employed to develop an ILEC model. According to the VEC approach, 90 % of the overall project cost is provided to the rural community for installation of the mini-grid project which can satisfy essential energy needs of the area (typically lighting and low energy consumption appliances). The rural community will then contribute an equity contribution (10%) which can either be in cash or kind to qualify the community as co-owner of the project. The formation of the LEC would then be done by the REA which is the Implementing Agency of the Federal Government.

By adopting VEC, the LEC will consist of 9–13 members with about 50 % representation from women members. A consultant would be engaged to design, develop a detailed project report and supervise the proposed mini-grid project based on the availability of renewable resources. The supply and construction of the project would be awarded to the most responsive contractor. Under this model, the contractor/equipment manufacturer would be given an Annual Maintenance Contract (AMC) for the first 5 years for preventive maintenance and continuous training of a minimum of two technicians in the operation and maintenance of the project. The REA would ensure the successful set up of energy generation systems and hand over the hardware to the LEC for daily operation and maintenance. The LEC will thus be responsible for the operation and management of the systems. A local mini-grid will be set up for the distribution of electricity to all the members of the community. The tariff and the mode of payment which can either be through pre-paid meters or a graded tariff system will be set by the LEC in collaboration with the REA which should be enough to take care of the salaries of the operator, fueling if applicable, and the minor and annual O&M of the project throughout the lifetime of the project. Furthermore, a special fund called Local Energy Fund (LEF) would be generated by the LEC to cater for any emergency component replacement and also for sustained operation and management of the project. The fund would be managed by the LEC with two signatories which shall be nominated by the Committee. It should be noted that the involvement of the LEC is majorly to make sure that the community participates in the project, resolve the grievances of the community, and act as the interface between the REA and the community. The developed ILEC is briefly represented in Figure 18. It is belief that this model would be successful as there is an expert (contractor/equipment supplier) who would be involved in the major technical operation and maintenance and also, there are trained technicians by the contactor at the community level for the preventive maintenance which happened to be a major limitation of the VEC model in the literature.

9. CONCLUSION

This paper has presented an overview of the rural electrification program in Nigeria. The survey of current rural electrification projects that have been implemented by the rural electrification agency in conjunction with the World Bank and African Development Bank through the Nigerian electrification program as well as privately owned solar mini-grids have been reported. Similarly, the list of available off-grid sites with their corresponding renewable sources was presented in the survey. Moreover, a practicable participatory business model for the sustainability of off-grid rural electrification projects was developed. It can be concluded that a mini-grid is a better and more viable option than grid extension to rural communities. The reason is that the latter involves the building of more conventional power plants, which are more expensive and do not have environmental benefits. In this paper, several configurations of mini-grid based on a combination of viable renewable energy sources were recommended for off-grid rural electrification in Nigeria. The identified benefits include low cost and ease of maintenance of the grid; reduced line losses since less power is now transported via the long transmission lines; less bureaucratic bottlenecks in terms of government legislation; among others. It was proposed in the paper, the involvement of local firms in the implementation of rural electrification projects so that the forgotten off-grid rural communities could be reached.

Conflict of interest
The authors declare that they have no conflict of interest concerning the publication of this paper.

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