DIGITALES ARCHIV

ZBW – Leibniz-Informationszentrum Wirtschaft
ZBW – Leibniz Information Centre for Economics

Babatunde, Damilola Elizabeth; Babatunde, Olubayo Moses; Akinbulire, Tolulope Olusegun et al.

Article

Hybrid energy systems model with the inclusion of energy efficiency measures : a rural application perspective

Provided in Cooperation with:
International Journal of Energy Economics and Policy (IJEEP)

Reference: Babatunde, Damilola Elizabeth/Babatunde, Olubayo Moses et. al. (2018). Hybrid energy systems model with the inclusion of energy efficiency measures : a rural application perspective. In: International Journal of Energy Economics and Policy 8 (4), S. 310 - 323.

This Version is available at:
http://hdl.handle.net/11159/2169

Kontakt/Contact
ZBW – Leibniz-Informationszentrum Wirtschaft/Leibniz Information Centre for Economics
Düsternbrooker Weg 120
24105 Kiel (Germany)
E-Mail: *rights[at]zbw.eu*
https://www.zbw.eu/econis-archiv/

Standard-Nutzungsbedingungen:
Dieses Dokument darf zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden. Sie dürfen dieses Dokument nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, aufführen, vertreiben oder anderweitig nutzen. Sofern für das Dokument eine Open-Content-Lizenz verwendet wurde, so gelten abweichend von diesen Nutzungsbedingungen die in der Lizenz gewährten Nutzungsrechte.

https://zbw.eu/econis-archiv/termsofuse

Terms of use:
This document may be saved and copied for your personal and scholarly purposes. You are not to copy it for public or commercial purposes, to exhibit the document in public, to perform, distribute or otherwise use the document in public. If the document is made available under a Creative Commons Licence you may exercise further usage rights as specified in the licence.

ZBW Leibniz-Informationszentrum Wirtschaft
Leibniz Information Centre for Economics

Mitglied der Leibniz-Gemeinschaft

International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2018, 8(4), 310-323.

Hybrid Energy Systems Model with the Inclusion of Energy Efficiency Measures: A Rural Application Perspective

[1]Damilola Elizabeth Babatunde[1]*, Olubayo Moses Babatunde[2], Tolulope Olusegun Akinbulire[3], Peter Olabisi Oluseyi[4]

[1]Department of Chemical Engineering, Covenant University, Ota, Ogun State, Nigeria, [2]Department of Electrical/Electronic Engineering, University of Lagos, Akoka, Yaba, Lagos, Nigeria, [3]Department of Electrical/Electronic Engineering, University of Lagos, Akoka, Yaba, Lagos, Nigeria, [4]Department of Electrical/Electronic Engineering, University of Lagos, Akoka, Yaba, Lagos, Nigeria. *Email: damilola.babatunde@covenantuniversity.edu.ng

ABSTRACT

The wide energy supply/demand gap has led the developing economies to the operation of the captive generators. This has contributed in no small way to the carbon footprint in the developing nations. Thus, the energy management initiative could assist in reducing the menace of greenhouse gas emission. Hence, the energy policy makers and planners have unanimously proposed adoption of demand side management (DSM) technique. Thus the adoption of energy efficiency technique (EET)-a DSM measures and hybrid energy system would be essential for rural electrification. This work investigates the effect of applying energy efficiency measures in rural electrification. A case study of an un-electrified rural settlement in Ibadan, Nigeria was considered. The utilization of EET techniques reduces the emission of CO2 by 62%, while the technical analysis indicates the possibility of a 100% renewable electricity production. Principally, the adoption of energy efficient techniques proved to be economically and environmentally friendly.

Keywords: Energy Efficiency Measures, Emission Reduction, Hybrid Energy System, Net Present Cost, Renewable Energy
JEL Classifications: Q4, P28

1. INTRODUCTION

It has been severally established that the energy, economy and environment (otherwise refers to as 3E's) are interwoven. Thus, metric of economic sufficiency is often based on the *per capita* energy consumption capacity of a nation; while its influence on the ecological balance of the environment cannot be overemphasized. It is broadly accepted that electricity is the cleanest form of energy, but its process of generation from the fossil fuel is at variance to the Kyoto protocol. This has made the conventional energy sources to have a major contribution to the climate change (Lim and Lam, 2014; Zhang and Yan, 2015; Watts et al., 2015). This means that the higher the energy consumption the bigger and wider the carbon footprint of the nation. Considering a typical developing nation; there is a disturbing wide gap between electric energy demand and energy supply. Several reasons has been adduced for this skewed imbalance as well as the versatility of demand-side management to overcome this myriad of challenges (Oluseyi et al., 2006; Thakur and Chakraborty, 2016). This has promoted the use of firewood (and other means of forest degradation) for energy generation in the rural areas (Oyedepo, 2012a) while the cities and towns are the largest consumers of energy from captive generators (Oluseyi et al., 2009). In both scenarios, the Kyoto protocol is being thoroughly sidetracked (Zhao et al., 2014; Carmichael et al., 2015; Subramanyam et al., 2017). In the sense that the carbon footprint keeps growing wider (in most developing nations) than the expected share of the global emission (Zhao et al., 2014; Oh and Chua, 2010; Oyedepo, 2012b) by the United Nations. In order to overcome this challenge, the United Nations Framework on climate change (UNFCC) inaugurated a credible clean development mechanism (CDM) which offers a number of emissions reduction programs (Carmichael et al., 2015; Karunanithi et al., 2017; Abolarin et al., 2013). Since the industrial nations have been identified as the contributors of noxious gas emission; the third world has been considered as the major source of greenhouse gas through the deforestation activities for producing cheap fuel. This is purely based on the discovery that the CDM would set a target for the reduction of emissions through human activities in the third world nation. Hence, generation of energy from the firewood in the rural areas and captive generation in towns and cities must be treated with urgent intervention (Odjugo, 2011).

The International Energy Agency (IEA) reported in 2007 that fossil fuels account for 80% of primary energy consumed making it to rank first in the global energy mix (IEA, 2009; Elliott et al., 2015). Due to the declining status of the world conventional energy reserves and the need for reduction of greenhouse effect caused by fossil fuel, it is in response to the enhancement of carbon stock in the developing countries that the REDD Plus was established by the UNFCC as the aftermath of the Kyoto Protocol. This strategic framework (i.e. UN-REDD plus programme) is designed to set 2016-2020 for the remarkable reduction in deforestation and its attendant forest emission. As an extension, a number of remedial actions have been suggested (Thakur and Chakraborty, 2016; Carmichael et al., 2015). This suggests in an all-inclusive approach to supply-side and demand-side energy management in rural areas. Thus, these energy management techniques would influence a reduction in energy consumption which will eventually reduce emission. Another school of thought established that the best approach to energy management is to reduce the energy consumption without impeding the comfort benchmark. This has encouraged the development of such approach as the supply-side management and demand-side management of energy resources. Since the role of energy in economic growth has been widely acknowledged, it is essential to manage the energy consumption creditably (Setlhaolo and Xia 2016; Behrangrad, 2015). Thus, any attempt at the reduction of carbon released to the environment is considered a fair means of observing the Kyoto agreement on climate change. In a report authored by the IEC and IPCC (i.e. Intergovernmental Panel on Climate Change), it is predicted that electricity consumers will use more of nuclear and renewable energy (RE) and less oil and coal by year 2100 (Chefurka, 2007). However, the current contribution of the conventional energy sources to the emission quantity in the atmosphere is high. But an in-depth advancement of research work on the introduction of energy management would mitigate the rising profile of carbon contents in the atmosphere.

In many African countries, electric power is largely generated by fossil fuel. This energy type has a very high tendency for pollution through its byproducts. So also, it has been observed that this category of energy is quite expensive for the urban poor and highly unreliable for manufacturing process while in the rural areas, it is mostly inaccessible (Collier and Venables, 2012; Oluseyi et al., 2006), so, there have been quite a number of suggestions on overcoming the above listed challenges. Meanwhile the basic solution is proficient energy management. This is best achieved by engaging both the supply side management and demand side management (DSM) techniques. Each of the foregoing methods is applicable for effective mitigation of emission. In the case of supply-side management, it has been suggested that the non-conventional energy sources would ensure equitable reduction in emission (Oluseyi et al., 2006; Oluseyi et al., 2016). This has been buttressed by the fact that the available statistics has identified Africa as a continent with good prospect in electricity generation from the abundant deposit of RE resources (Jha, 2008; Karekezi, 2002; Bugaje, 2006; Mentis et al., 2015). This includes hydro-power (where potential is estimated at about 1750 TWh) and geothermal energy (estimated at about 9000 MW). With respect to the solar source of energy; it has been established that over 80% of the continent have annual insolation of about 2000 kWh/m^2 of solar resources (Jha, 2008). This thus suggests that a number of solar generating facilities covering just 0.3% land space of North Africa could supply all the energy demand of the European Union countries (Jha, 2008). Ironically, for the purpose of the supply-side management; Africa is currently struggling to improve on RE penetration while Germany supply about 22% of its load using the RE (especially PV) in 2012 and Norway, Albania, Paraguay as well as Iceland are currently generating near 100% electricity from non-conventional energy sources, mainly hydro (Von Appen et al., 2013; Child and Breyer, 2016; Lund and Mathiesen, 2009). Whereas, in the case of African nations, there is electricity poverty (with the exception of Egypt and South Africa, which are leading the continent in green energy generation) in which case the captive generators are the inevitable energy source for most households, small scale and medium scale industries. The attendant problem of this occurrence has led to rise in the emission of greenhouse gases (Odjugo, 2011).

So also, in terms of generation of pollutant emission, it has been reported that Nigeria is closely behind both South Africa and Egypt in Africa. Figure 1 shows the emission of CO_2 by countries in West Africa. Since 2009, the CO_2 emission in Nigeria has been on the rise with no sign of plunging (Figure 2). Hence there is an urgent need for the suppression of CO_2 emission in Nigeria.

Figure 1: Emission of CO_2 by countries in West Africa

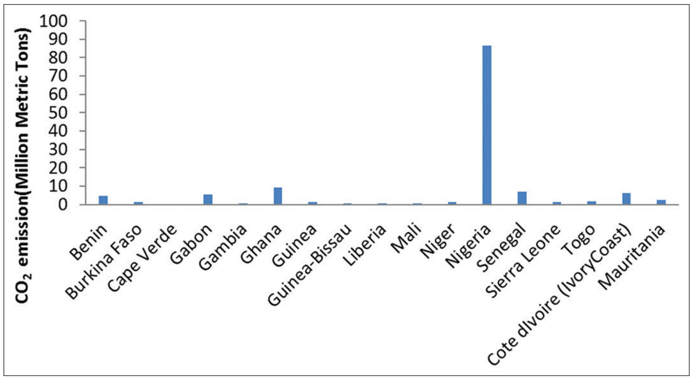
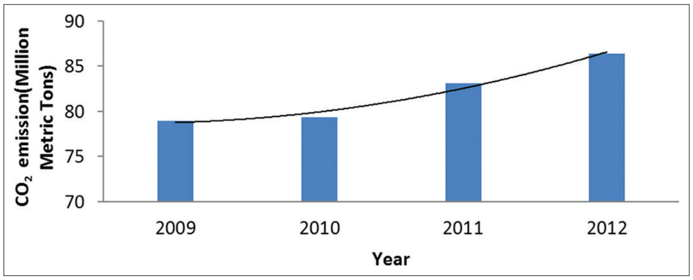


Figure 2: CO_2 emission in Nigeria 2009-2012



From the available record, the growing trend in emission in Nigeria is as shown in Figure 2. This has shown that there is an urgent need for the development of a template for emission reduction(Abolarin et al., 2013). This pattern could be initiated by both the utility and the consumers. In the case of the utility; certain measures are put in place to discourage energy consumption for this occasion. Research has shown that this helps in reducing energy utilization levels of the consumers based on disparity; which is mainly due to price-based designs. On the other hand, the DSM is basically the response of the consumers to reduce in energy consumption by using a number of activities that can conveniently reduce the peak load (as well as efficient energy management) without necessarily reducing comfort and productivity.

For obvious reasons, the application of energy conservation measures and energy efficiency techniques (EET) on connected loads has been identified to have great influence on emission reduction. This has found wide applications in energy and water management. The DSM approach is basically load-end/customers' activities carried out to influence either the quantity or time pattern of energy consumption. This is done in such a way that its application has no direct negative impact on the comfort and satisfaction of the customers while, at the same time, it significantly modifies or reduces the load end's energy demand (Bonneville and Rialhe, 2006; Macedo et al., 2015). Before this, there have been various suggested approaches to this activity in existing facilities; this ranges from behavioural attitude- which cost nothing- to retrofitting of inefficient load. Others are load shedding, peak clipping, valley filling time of use and special tariffs; to mention but a few (Oluseyi et al., 2006). These techniques help to improve appliance consumption, efficiently trim down utilization without jeopardizing service delivery and social welfare/pleasure (Macedo et al., 2015). All these have been well utilized in the urban load management (Oluseyi et al., 2016). The following studies have explored the use of DSM for energy savings in rural cummunities (Ghodmare et al., 2008; Pina et al., 2012; Rajanna and Saini 2016; Kies et al., 2016; Taneja, 2014; Sethi and Ullman, 2016; Hamid et al., 2014; Babatunde et al., 2018a). The application of DSM programmes in the rural areas is more than just for energy savings, but more importantly for economic savings (Babatunde et al., 2018a). This is due to the mandate of the UNFCC to the countries to reduce emission which is due to both industrial activities and deforestation.

A handful of studies have been conducted separately on rural electrification with hybrid RE system (HRES) without considering the effect of practical, simple and less costly energy efficiency measures on loads(Akinyele 2018; Akinyele, 2017; Babatunde et al., 2017; Babatunde et al., 2018b). This study focuses on the effects of energy efficiency and conservation methods applied on load of a rural community on the size of HRES. These effects are present in the results by comparing the technical, economic and environmental metrics of load with EET and loads without EET.

1.1. DSM

As stated earlier, the DSM protocol reduces the peak energy demand from the utilities, which could be a vital opportunity to delay investments in transmission and distribution capacity expansion. Thus, it indirectly, but greatly influences overall load demand, which is a feature that promotes reduction in emission by the generators. Since energy production is reduced as a response to the application of the DSM there is a remarkable reduction in the overall load demand. This is beneficial as it mitigates electrical system emergencies, reduction in frequency of blackouts; the foregoing thus lead to Improved system reliability.

In a nutshell, the adoption of DSM in the electricity sector will result in significant economic gain, improved system reliability, and environmental benefits. Some other benefits credited to DSM include reduction in energy bills of customers, delay in the need for capacity expansion, economic development and reduction in peak electricity prices (i.e. demand response) and improvement in installation of energy efficient appliances (Macedo et al., 2015). DSM has great potential in Africa essentially because of the deficits and poverty in energy supplied to consumers (Oluseyi et al., 2006).

DSM activities are classified into three broad categories namely; energy reduction program, load management programs, and the load growth and conservation programmes (Akinbulire et al., 2014). As earlier stated, energy reduction programmes involve reducing demand through the use of more efficient process, appliance or building. EET involves the utilization of technologies that leads to minimization of wastage in energy or consumption of less energy to perform same activity. It involves the implementation of energy saving technologies to reduce the quantity of energy consumed. The various load management programmes result in changes in the load pattern while encouraging reduced demand at peak period and higher tariffs (Bonneville and Rialhe, 2006). The load growth and conservation programmes cover large number of sectors.

The existing literature is rich in works that have separately addressed the DSM (energy efficiency, energy conservation etc) and the HRES of multiple countries. With regard to the DSM practices. Stefano (2000), presented a study to analyse the prospect of improving the energy efficiency of lighting systems at Melbourne University. Mahlia and Iqbal (2010),], explored the potential cost savings and emission reductions that can be achieved through the installation of different insulation materials of optimum thickness in building's walls. Mahlia et al. (2001), evaluated the amount of electricity that can be saved by implementing energy efficiency for electronic appliance in Malaysia. Glushkov et al. (2017) and Rahman et al. (2017), both explored initiative strategy for energy management system based on an analysis of energy consumption in residential building using energy efficiency and energy conservation.

Furthermore, in the domestic energy consumption category, one of the significant ways to save energy is through the use of energy efficient appliances or equipment. Some of which consume <50% of the previous consumption value in the residential buildings. So also, it has been discovered that the domestic lighting system offers a good opportunity for energy savings. Thus, some of the energy efficient and conservation techniques include; usage of energy saving lamps; i.e. light-emitting diodes (LED) or compact fluorescent lamps (CFLs), regular cleaning of luminaries, usage of natural light during day period, painting of internal walls with bright colors, green-supported building designs, etc. Apart from improving the lighting systems, outdated, inefficient appliances (such as washing machines, refrigerators, air conditioners, television sets, etc.) should be replaced or better retrofitted when the financial implication of replacement is huge. In this study, DSM technique is applied as a tool for both energy conservation and efficiency; using behavioral as well as technical metrics. It is noteworthy to state that for any existing building, the demand -side management methods that have attained popularity are:

1. Lighting retrofitting- this involves the replacement of existing inefficient lamps with energy efficient ones. (Comparison of the retrofitted lamps is shown in Table 1).
2. Lighting fixture delamping.
3. Switches modification and replacement of other inefficient appliances.

Some behavioral techniques applied include usage of natural light during daytime, painting of walls with bright paints and switching off of redundant lamps.

In providing sustainable electricity for rural and urban settlements in Nigeria; there is the need to consider the aspect of energy efficiency and RE as a tool of reducing carbon footprint. Although many RE projects are currently enjoying implementation in Africa, the operation of many RE facilities in Africa often fails, or the technologies are found to be unsustainable in the longer-term due to a myriad of factors. One of such factors is inefficient use of energy. According to Teitel (1978), other factors for the mal-operation of technology in developing countries are maintenance and repair difficulties; obsolescence of components; and the fact that the technology has not been adapted to the climate. In summary, technical sustainability, socio-political sustainability, environmental sustainability, and economic sustainability are important in implementing sustainable RE systems in Africa (Teitel, 1978). From the technical point of view, EET and conservation are foundational to energy sustainability. Sustainability makes sure every generation meets its own energy requirement without compromising the energy needs of future generations. Therefore, this study explores the techno-economic aspect of sustainable energy systems for a rural settlement in Nigeria.

1.1.1. Contribution of study

As earlier stated, a handful of studies has been conducted on rural electrification with hybrid RE sources without considering the effect of practical, simple and less costly energy efficiency measures on load demand (Olatomiwa et al., 2015; Akinyele, 2018; Olatomiwa et al., 2014; Akinyele, 2017; Adaramola et al., 2014). Meanwhile, other studies in energy efficiency (section 1.1) did not include HRES. In line with the foregoing, this work considers the effects of energy efficiency and conservation methods on optimal criteria metrics during the design and sizing of hybrid energy systems for rural electrification. The case study is a farming camp in the city of Ibadan southwestern Nigeria. Ibadan, a former capital of the old western region of Nigerian is the largest city in West Africa by land mass and ranks third in terms of population size in Nigeria. It serves as a major transit, city linking the southern and the northern part of Nigeria. Hence this makes it a suitable location for this study. Further to this, it was selected for this study due to the presence of commercial farming settlement for both cash and food crops. The particular study location is yet to be connected to the grid; it thus serves as a pilot study which can be adapted to any part of the country; or even some other West African countries.

2. MATERIALS AND METHODS

The proposed HRES for the pilot study is composed of photovoltaic (PV), wind technology (WD), diesel generator (DG) and the battery (BAT). This configuration was selected based on the available RE resource at the site under investigation (Sambo, 2010; Adaramola and Oyewola, 2011; Nwulua and Agboolab, 2011). The need for hybridization of the system configuration is the best approach to overcome the intermittent seasonal nature that is the source of unpredictability feature of RE sources (Olatomiwa et al., 2014; Olatomiwa et al., 2015). In line with the foregoing; the bank of batteries is also provided to ensure energy storage for times of shortage in supply from the RE sources. Thus, hybridization is mainly a criterion for system's reliability and system efficiency. Furthermore, the hybridization also has the advantage of a reduction in the quantity of storage facility requirement as compare to the use of single R.E. source. Figure 3 is a vivid presentation of the hybridized system.

In this case, the wind and solar generators complement each other to supply the load demand of the community. The DG, essentially serves as backup while the battery is expected to store D.C. energy harvested by the solar PV modules. In the event that the renewable sources are unable to sufficiently supply the load demand, then

Figure 3: Schematics of the proposed hybrid renewable energy system arrangement

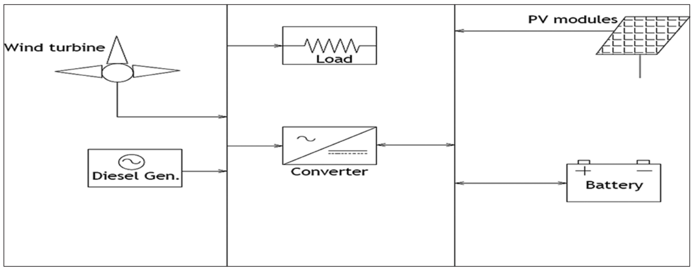


Table 1: Comparison of different lamp option

Specifications	Incandescent*	CFL**	Incandescent*	CFL**	Halogen*	CFL**
Lamp Wattage (W)	60	18	100	26	105	50
Average Life (hours)	1000	10000	750	10000	750	10000
Luminous flux (Lm)	710	740	1650	1500	1650	3600
Cost ($)	0.44	1.56	0.63	2.5	1.25	3.75

the generator could serve as the backup to supply the load while at the same time it also charges the bank of batteries through the bi-directional converter as shown in Figure 3.

2.1 Mathematical Models of System Components

This section gives the brief mathematical description of the individual system components of the proposed hybrid power system. A concise description of the models is outlined in the succeeding sections. The Hybrid Optimization Model for Electric Renewables (HOMER) software is used in the simulation of the ensuing hybrid energy systems (Givler and Lilienthal 2005).

2.1.1 Modeling of the Hybrid Energy System with HOMER

The Hybrid Optimization Model for Electric Renewables (HOMER), optimization software developed for the simulation, optimization and sensitivity analysis of micro-gird and nano-grid energy systems. It performs which performs the technical, economic and environmental analysis of a proposed hybrid energy systems (Rajbongshi et al. 2017). Unlike most commercially available software, HOMER has the added value as a means of eliminating some infeasible solutions without simulation. This is achieved from the previous results obtained earlier by simulations and recycles results from previous runs. The HOMER also has the propensity to model the performance of the hybrid energy system along with its life-cycle costing. Furthermore, it allows the evaluation of diverse design alternatives depending on their respective technical and economic benefits. During the process of optimization, HOMER simulates diverse system combinations to identify the one that satisfies the technical, economic and environmental constraints at the lowest life-cycle cost. Whenever a combination of bank of batteries and a diesel electricity generating set is part of any hybrid system configuration, a dispatch strategy is necessary. Homer uses one of load following or cycle charging (Akinbulire et al. 2014).

2.1.2. PV model

A PV system makes use of solar panels to generate power using the solar irradiation from the sunlight (Olatomiwa et al., 2015). The output power of the PV panel as employed by the HOMER software is given in equation 1:

$$P_{pv} = Y_{pv} f_{pv} \left(\frac{\overline{G_T}}{\overline{G_{T,STC}}} \right) [1 + \alpha_P \left(T_C - T_{C,STC} \right)] \tag{1}$$

Equation 1 simplifies to 2 in cases where the temperature effect of the panel is neglected.

$$P_{pv} = Y_{pv} f_{pv} \left(\frac{\overline{G_T}}{\overline{G_{T,STC}}} \right) \tag{2}$$

Where Y_{pv} *is the rated capacity of PV array,*
fpv is the PV derating factor (%),
$\overline{G_T}$ *is the solar irradiation incident on the PV array* $\left(\frac{kW}{m^2} \right)$,
$G_{T,STC}$ *is the solar irradiation incident at standard condition* $\left(\frac{1kW}{m^2} \right)$,
α_P *is the temperature coefficient of power (%/°C),*
T_C *is PV cell temperature (°C)*
$T_{C,STC}$ *is the PV cell temperature under standard test conditions (°C),*

Thus the annual energy output of the PV panel is determined as:

$$E_{pv} = \sum_{i=1}^{8760} P_{pv}(i) \tag{3}$$

2.1.3. Wind turbine model

The HOMER software estimates wind turbine power output at each time-step by first calculating the wind speed at the hub height of the wind turbine. It estimates the amount of power deliverable by the wind turbine using the wind speed at standard air density and finally adjust the power output value for the actual air density (Olatomiwa et al., 2015; Olatomiwa et al., 2014). The electrical power delivered by a wind turbine is estimated using:

$$P_{WT} = \rho \times C_e \times A \times v^3 \times 10^{-3} \times 0.5$$

Where C_e *is the maximum power extraction efficiency of the wind generator*

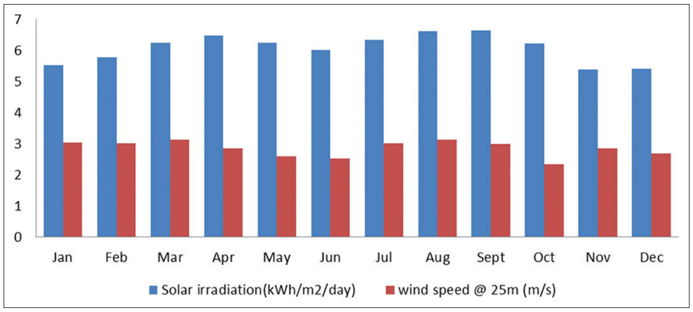
A is the swept area of turbine, ρ is the density of air and v is the wind speed

Meanwhile, as regards the solar electricity generation, the 22 years solar irradiation and wind speed for the site under review as retrieved from the National Aeronautics and Space Administration (NASA) website is given in Figure 4. In which it is evidently observed that the month of September recorded the highest solar irradiance while the highest wind speed occurred in the month of May.

2.1.4. DG model

This conventional generator consumes diesel so as to produce electricity and can be dispatched whenever there is need to back-up the system operation (Olatomiwa et al., 2015). The specific fuel consumption is evaluated as the average amount of fuel consumed by the generator per kWh of electricity generated. The specific fuel consumption is thus calculated as expressed in equation 4.

Figure 4: Wind speed and solar irradiance received at the understudied site



$$F_{spec} = \frac{F_{tot}}{E_{gen}} \tag{4}$$

Where F_{tot} is the annaul generator fuel consumption
E_{gen} is the total annual electricity production of generator (kwh/yr)

2.1.5. Battery model

The battery model in HOMER environment is based on Kinetic Battery Model which is based on the concept of electrochemical kinetics (Olatomiwa et al., 2015; Adaramola et al., 2014). This model estimates the quantity of energy in kWh that can be taken ‘from’ by or ‘given out’ by the battery bank for each time-step simulation. Illustratively, the model simulates the battery as a two-tank system in which the first tank denotes the instantaneously available energy ready to be converted to DC electricity while the second tank contains the energy that is chemically bound. This then means that the withdrawal of energy is instantaneously available. This is expatiated with the pictorial representation of the model as shown in Figure 5.

Going by the model, the total quantity of instantaneously available energy stored in the battery is the addition of the available and bound energy as given in:

$$Q = Q_1 + Q_2 \tag{5}$$

Where Q_1 is the available energy and Q_2 is the bound energy.

Based on differential equations the maximum amount of power that can be discharged by the battery a specific time Δ_t is given by:

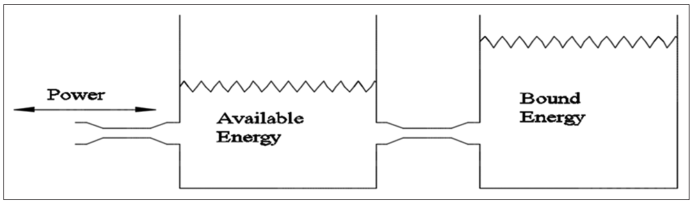
$$P_{batt,\ dmax,\ kbm} = \frac{KQ_1 e^{-k\Delta t} + QKC(1-e^{-k\Delta t})}{1-e^{-k\Delta t} + C(K\Delta t - 1 + e^{-k\Delta t})} \tag{6}$$

Similarly, the power absorbed by a battery over a specific time length is given as:

$$P_{batt,\ dmax,\ kbm} = \frac{-KCQ_{max} + KCQ_1 e^{-k\Delta t} + QKC(1-e^{-k\Delta t})}{1-e^{-k\Delta t} + C(K\Delta t - 1 + e^{-k\Delta t})} \tag{7}$$

Q_1 is the available energy at the start of the time step
Δ_t is the length of the time step
Q_{max} is the total amount energy/maximum battery capacity
K is the rate constant
C is the capacity ratio

Figure 5: Pictorial representation of kinetic battery model



2.1.6. Load model

At the time of this research, grid connected electricity is unavailable to the community. Thus the load profile was estimated using information gathered from the walk-through energy audit approach. This was achieved by serving energy audit questionnaire and by informal interviews with the community residents. It is observed that the load in the community is majorly domestic in nature. From the interview, it was established that some of the villagers employ the use of captive gasoline generators in supplying daily load requirements, while some burn firewood for cooking and the local lanterns for lighting purposes. The community consists of 54 houses/buildings, with a total of 7 detached shops. From the audit conducted, the majority of the houses are fitted with a number of 60W and 100W incandescent bulbs; which consume quite a sizeable energy. This is so because incandescent bulbs are cheap in the local market. For example, a 60W incandescent bulb cost about \$0.2 USD while an equivalent luminance can be produced by 26W CFL which costs \$1.96 USD. Other electrical gadgets used in the community include; ceiling fans, television sets, radio sets and in some other cases 36W fluorescent lamps. For the purpose of this study, lantern/kerosene lamp is assumed to be equivalent to a 60W power consumed by incandescent lamp unit.

In the meantime, the residential load is highly subsidized in Nigeria. Typically, the evening load of residential sector is majorly for illumination as well as poorly energy efficient television and radio sets. There are methods of demand-side management measures which are load shapes such as peak clipping, valley filling, time-of-use, load shifting and so on. Meanwhile, this kind of load cannot be shifted to any other hour of the day. Consequently, energy efficiency and conservation measure are the only load shaping method that can be adopted. This then follows that an incandescent or fluorescent lamp can be replaced by an equivalent CFL or LED tubes that produce an equivalent illumination level. This will yield a high level of energy as well as cost saving. Hence the retrofitting and some other low-cost energy saving techniques are introduced for the sake of this experimentation.

From the available climatology record, there are two major predominant seasons in Nigeria, each of which has its prevalently varying energy consumption pattern. With regard to the community, the wet season spans from March to October, while the dry season is encountered between November and February of every year. Thus, the load profile differs with the dry season obviously higher load demand/requirement. From the extracted data from the questionnaire; the load consumption model using the community’s load profile leads to equations 8-10:

$$Hourly\,demand\left(HD\right) = \sum_{t=1}^{24} AHD(t) \tag{8}$$

$$But\ AHD = D.F.(t) \times H_{WA} \times A_{PH} \times W \tag{9}$$

The demand factor (D.F) is the ratio of the number of equipment or appliance operational in a particular time interval (usually 1 h) to the total number of such appliances in the community. This is given as:

$$D.F.\,(t)=\frac{H_{UAH}}{H_{FA}} \tag{10}$$

$$\forall\, D.F\left(t\right):1\leq DF\leq 0 \tag{11}$$

Where, AHD is the hourly appliance demand,
H_{WA} *is the no. of houses with a particular appliance,* A_{PH} *is the no. of appliance per house,*
W is the power rating of appliance, H_{UAH} *is no. of houses using a appliance that hour*
H_{FA} *is the total no of house with such functional appliance*

To model the annual load profile, it is assumed that 10% daily randomness and 10% hourly noise is added. By doing this, the load data is more realistic. This stochastic property causes the load pattern to vary randomly daily. For this case study, a time step of 1 h is utilized. The load demand for the pre- and post-DSM is then evaluated separately.

It is assumed that the DF and hours of energy consumption during the dry season will increase due to the increase in the number of hours electric fans are switched ON for ventilation and cooling purposes. The energy consumption in the community is based on the analysis as shown in Table 2. For the purpose of this study, it is designed for the worst-case scenario, therefore the dry season load is used for the sizing of the R.E. components because it is serving the highest load. It is noticeable that the information in Table 2 is basically for energy consumption without the application of DSM. This was also repeated with the assumption that the DSM measures are employed.

2.1.7. RE resources

In Nigeria, the annual average solar radiation varies from approximately 4.0–7.0 kWh/m2/d (Figure 6) while the wind speed varied between Wind 2.0-4.0 m/s at a 10-m height Wind 2.0-4.0 m/s at a 10-m height.

From the foregoing therefore, Nigeria is a poor or moderate wind energy region, which makes wind energy consumption in Nigeria virtually minimal. As a confirmation of the aforementioned assertion, there exists very few wind based electricity generating projects in Nigeria, among which is the 5kWp (kilo watt peak) in Sayya Gidan Gada at Sokoto (Nwulua and Agboolab, 2011; Sambo, 2010). In addition, there is a 0.75 kWp wind electricity project in the center of the town is being run on an experimental basis to prove the viability of wind farms in the area.

3. EVALUATION CRITERIA

3.1. Economic Metrics

The flow chart for the economic performance analysis is given in Figure 7. From the preliminary study on the site, data were

Table 2: Extract of load estimation detail with varying season without the application of EET

Electrical appliance	Wet season		Dry season		Power (W)	Ave. No. per House	No. of Houses
	Time duration	Demand factor	Time duration	Demand factor			
20 inch Television	18:00-19:00	0.5	18:00-19:00	0.5	105	1	43
	19:00-20:00	0.8	19:00-20:00	0.8			
	20:00-21:00	1	20:00-21:00	1			
	21:00-22:00	0.9	21:00-22:00	0.9			
	22:00-23:00	0.6	22:00-23:00	0.6			
	23:00-00:00	0.4	23:00-00:00	0.4			
Ceiling fan (70W)	19:00-20:00	0.3	13:00-14:00	0.3	70	4	36
	20:00-21:00	0.3	14:00-15:00	0.3			
	21:00-22:00	0.3	15:00-16:00	0.3			
	22:00-23:00	0.3	16:00-17:00	0.3			
	23:00-00:00	0.3	17:00-18:00	0.3			
	00:00-01:00	0.4	18:00-19:00	0.4			
	01:00-00:02	0.65	19:00-20:00	0.6			
	02:00-03:00	0.4	20:00-21:00	0.9			
	03:00-04:00	0.4	21:00-22:00	0.7			
	04:00-05:00	0.4	22:00-23:00	0.7			
			23:00-00:00	0.7			
			00:00-01:00	0.7			
			01:00-00:02	0.7			
			02:00-03:00	0.7			
			03:00-04:00	0.7			
			04:00-05:00	0.7			
Incandescent lamp (60W)	05:00-06:00	0.65	05:00-06:00	0.65	60	4	49
	06:00-07:00	0.9	06:00-07:00	0.9			
	18:00-19:00	0.6	18:00-19:00	0.6			
	19:00-20:00	0.9	19:00-20:00	0.9			
	20:00-21:00	1	20:00-21:00	1			
	21:00-22:00	1	21:00-22:00	1			
	22:00-23:00	0.65	22:00-23:00	0.65			
	23:00-00:00	0.2	23:00-00:00	0.2			

collected for load modeling and the meteorological data for the geographical location was retrieved from the NASA website. Site visit reports revealed the possibility of utilizing only two possible RE resources to mitigate the energy challenges of the community under investigation. The favoured resources are the solar and the wind energy system. Generally, modeling of the proposed hybrid energy system is initiated by gathering of relevant information on such data as the community load requirement, energy resource potential (solar and wind), cost of individual system components, and capacity of generated power.

For this case study, it is essential to determine the size of the PV array, wind turbine, diesel generator, bi-directional converter and the capacity of the battery bank required to sufficiently meet the energy demand. Economic viability of individual component is based on the total net present cost (TNPC), levelized cost of energy (LCOE), and the renewable energy fraction (RF). To evaluate the environmental feasibility, essential factors such as greenhouse gasses (GHGs) emissions and quantity of diesel consumption are considered. All the input parameters are fed into HOMER software so as to evaluate the optimal system configuration. The system with the least COE is optimized to reduce its excess energy. The annual generated power is compared to the annual energy demand of the community to ensure there is no deficit demand. This study uses TNPC, COE and RF as performance metric in the evaluation of the best hybrid energy system.

3.2. Total Net Present Cost (TNPC)

The total net present cost of a system is the present worth of all the costs of purchasing and operating the system or project over its lifespan, minus the present worth of all the incomes that it is obtained over the equipment or project lifetime. HOMER computes the TNPC of each component and that of the entire system as a whole. This is evaluated using equation 12.

$$TNPC_{pj} = \frac{TAC}{CRF\,(i, N)} \tag{12}$$

Where NPC_{pj} is the total annualized cost ($/y) and , the capital recovery factor which is a function of the annual real interest rate (i) and N is the project lifetime. CRF is obtained through equation 13:

$$CRF(i, N) = \frac{i\,(1+i)^N}{(1+i)^N - 1} \tag{13}$$

3.3. Levelized Cost of Energy (LCOE)

According to Olatomiwa et al. (2015), HOMER expresses the LCOE as the average cost per kWh of useful electrical energy generated by the energy system configuration. To estimate the LCOE, HOMER divides the difference in the total annualized cost and the cost of serving the thermal load by the total energy demand served, using the following equation:

$$LCOE = \frac{C_{ann,tot} - C_{boiler} H_{served}}{E_{served}} \tag{14}$$

$C_{ann,tot}$ is the total annualized cost of the system ($/yr), $c_{boileris}$ is the boiler marginal cost ($/kWh), H_{served} is the total thermal load served (kWh/yr) and E_{served} is the total electrical load served (kWh/yr).

In this study, it is assumed that the system does not serve a thermal load. Therefore, the term "H_{served}"=0.

3.4. Renewable Fraction

The renewable fraction (RF) is the fraction of the energy supplied to the load that originated from renewable power sources (Olatomiwa et al., 2015). This is evaluated using equation 15:

$$RF = \left(1 - \frac{\sum P_{diesel}}{\sum P_{ren}}\right) \times 100 \tag{15}$$

Where P_{diesel} is the power output of the DG and P_{ren} is the power output of the connected RE sources.

4. COMPONENT DATA

The initial choice of system component is selected based on the load profile in Figure 7. The cost of system components is in US dollars (USD). As indicated below, the following assumptions were made for the components:

a. The capital cost of acquiring a 10kW AC DG is $1000, with a replacement cost of $875 and maintenance cost of $0.625/hour. The operational lifetime of the generator was taken as 15,000 h with a minimum load ratio at 30%.
b. Diesel price was allowed to fluctuate between $0.94/liter and $1.5/liter due to re-occurring fuel crisis predominant in the country.
c. The wind turbine considered is the WES 5 Tulipo with a capacity rating of 2.5kW. The investment capital of a unit is assumed to be $1875, while its replacement and operating cost are $1750 and $6/yr respectively. It is important to note that various sizes were considered to arrive at the optimally suitable size. In which case the lifetime of the turbine is assumed to be 15 years.

Figure 6: Solar radiation map of Nigeria (Nwulua and Agboolab, 2011)

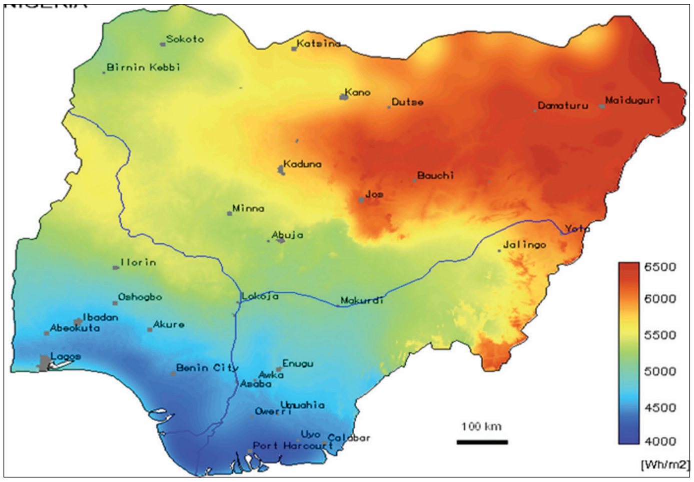


Figure 7: Flow chart for sizing calculations of hybrid renewable energy system (HRES)

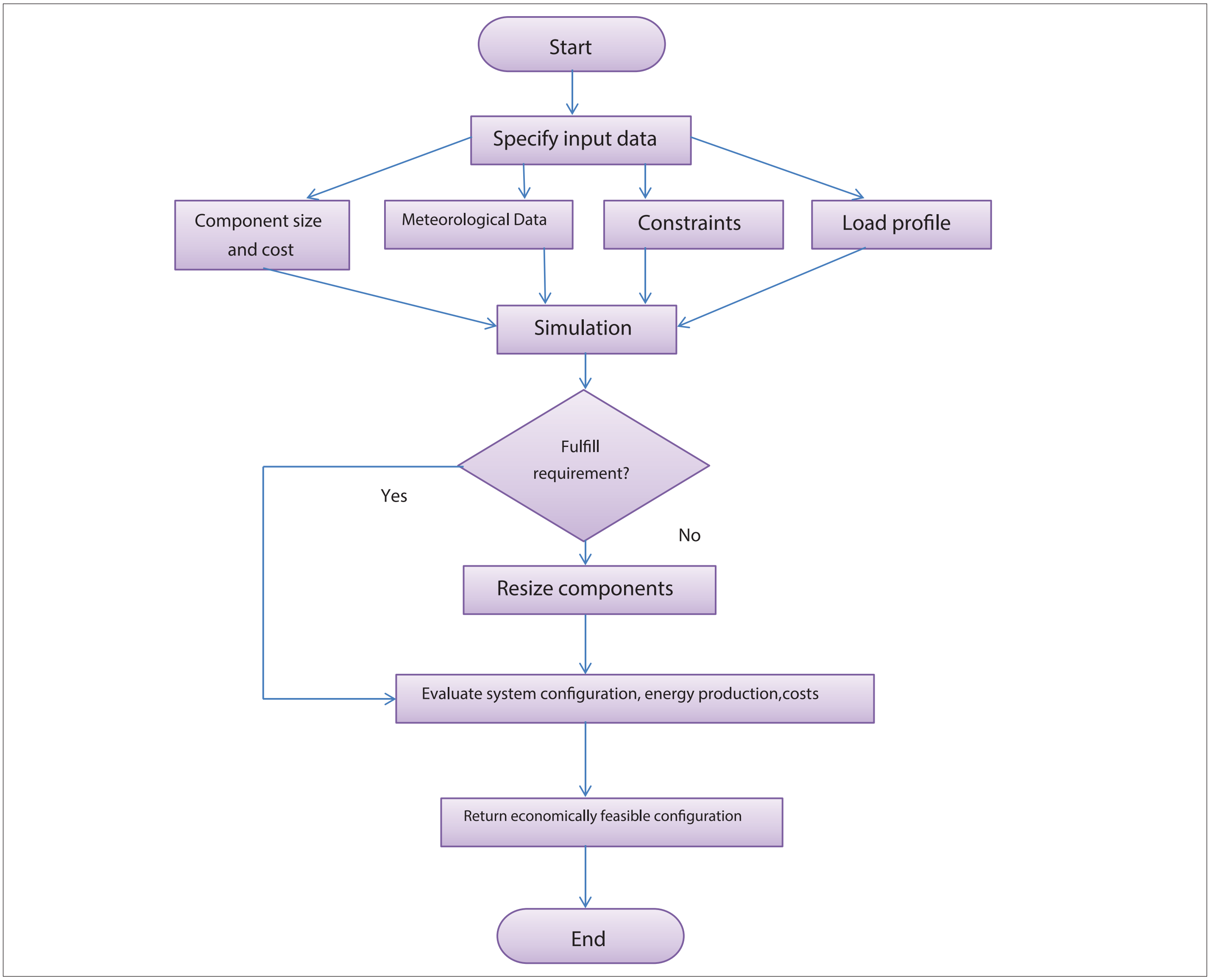
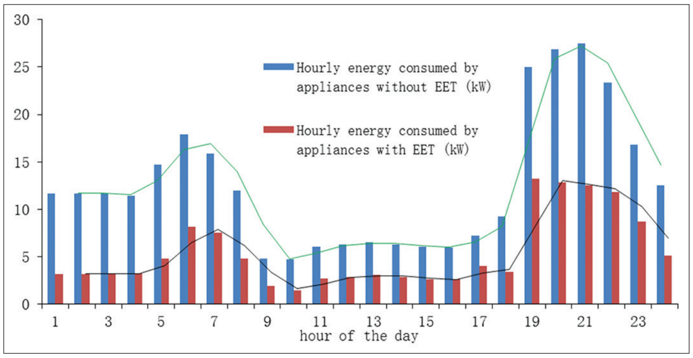


Figure 8: Daily load profile for design of hybrid energy systems in the village with and without energy efficiency technique



d. The capital cost of 1kW of PV array is taken to be $1125. While its replacement and operating cost were set at $1000 and $2/year respectively. With no tracking system, the derating factor for the PV panels is 0.8 over a lifetime of 20 years.

e. Surrette 6CS25P battery model with nominal voltage of 6V and a capacity of 1,156Ah capacity is selected in this study. Its initial cost per unit is $500, the replacement cost and maintenance cost is taken as $473 and $25/year respectively. A bank of battery containing 8 units of deep-cycle battery with its energy over lifetime is estimated as 9645kWh.

f. Another crucial component is the di-directional converter which serves both as the rectifier and inverter. With the initial cost of 3kW converter taken as $250 while its replacement and operational and maintenance cost were assumed as $225 and $10/year. Most of the times, the converter efficiency is set at 90% over a lifetime of 15 years.

g. Thus, the Automatic Transfer Switch (ATS) is used at the point of common coupling (PCC) of the generator and the other renewable generators. This allows for automatic switching of the DG as the need may arise.

h. The capacity shortage factor is set to 5% of the maximum hourly load.

i. The cost of lighting fixture retrofits which stands at $6000 is

Table 3: Results of simulation

Description	With EETs				Without EETs				Units
	PV/DG/BAT	PV/WD/DG/BAT	PV/BAT	PV/WD/BAT	PV/DG/BAT	PV/WD/DG/BAT	PV/BAT	PV/WD/BAT	
System configuration									
PV	150	150	150	150	150	150	300	300	kW
Wind	0	5	0	5	0	5	0	5	No.
DG	40	40	0	0	40	40	0	0	kW
Battery	50	50	100	100	200	200	200	200	No.
Converter	50	50	50	50	50	50	50	50	kW
Cost ($)									
Initial capital cost	207917	217292	228917	238292	276917	286292	441667	451042	$
Operating cost	6360	6531	5530	5742	16784	16988	10966	11178	$/yr
TNPC	257802	268512	272292	283329	408554	419535	527674	538711	$
LCOE	0.693	0.722	0.732	0.762	0.481	0.493	0.623	0.636	$/kWh
Production (kWh/yr)									
Electricity produced annually	172,208	172,254	168,116	168,222	179,681	179,756	336,232	336,338	kWh/yr
Excess electricity	110,763	110,825	106,147	106,271	41,572	41,658	195,036	195,158	kWh/yr
Renewable fraction	0.914	0.915	1	1	0.893	0.894	1	1	
Fuel									
fuel consumption	2,114	2,083	0	0	5,506	5,498	0	0	L/yr
fuel energy input	20,804	20,500	0	0	54,175	54,099	0	0	kWh/yr
Emission									
Carbon dioxide	5,567	5,486	0	0	14,498	14,478	0	0	kg/yr
Carbon monoxide	13.7	13.5	0	0	35.8	35.7	0	0	kg/yr
Unburned hydrocarbons	1.52	1.5	0	0	3.96	3.96	0	0	kg/yr
Particulate matter	1.04	1.02	0	0	2.7	2.69	0	0	kg/yr
Sulfur dioxide	11.2	11	0	0	29.1	29.1	0	0	kg/yr
Nitrogen oxides	123	121	0	0	319	319	0	0	kg/yr
Battery									
Storage depletion	195	195	205	205	827	827	529	529	kWh/yr
Losses	8,505	8,505	9,076	9,068	18,024	18,021	20,710	20,702	kWh/yr
Dispatch strategy	LF	LF	CC	CC	LF	LF	CC	CC	

assumed to be part of the system fixed cost and a 12% interest is assumed for the entire system.

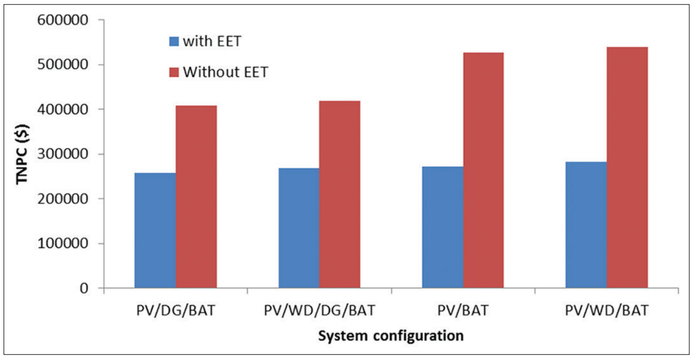
5. RESULTS AND DISCUSSION

This section presents and discusses the results obtained from the EET and HRES simulation in HOMER. As shown in Table 3, two scenarios were considered for the community, namely; the base case (load without EET) and load with implementation of the EET. The various results obtained are discussed in this section.

5.1. Energy Consumption

As can be seen in Figure 8, without the application of EET, the daily load demand pattern of the community indicates that a total daily energy demand of 297 kWh/day was consumed with a peak load of 27.516 kW between 8pm and 9pm. By putting "off" the redundant lamps and replacing the inefficient bulbs with energy efficient lamps of 16 W, 20W, and 25W CFL instead of 60W, 100W incandescent lamps, 36W fluorescent lamps and 105W halogen lamps respectively reduction in the total connected load is achieved. The alternative energy efficient lamp provides the same level of illumination, thus obviously ensuring that energy saving is achieved without tampering with the comfort of the users. Consequently, the consumption pattern with and without energy efficiency measure is similar.

Figure 9: Total net present costs with and without energy efficiency technique application



Load shedding (modeled as capacity shortage in this study) may also apply at times of diesel fuel shortage or scheduled maintenance. The gross daily energy demand after the application of EET reduced to 130kWh/day which represents a saving of more than 50%. Meanwhile a peak load of 13kW occurred between 6pm and 7pm, representing a 48% decrease from the existing system (Figure 2). The additional cost of retrofitting is estimated at $6000

Figure 10: Sensitivity analysis with energy efficiency technique

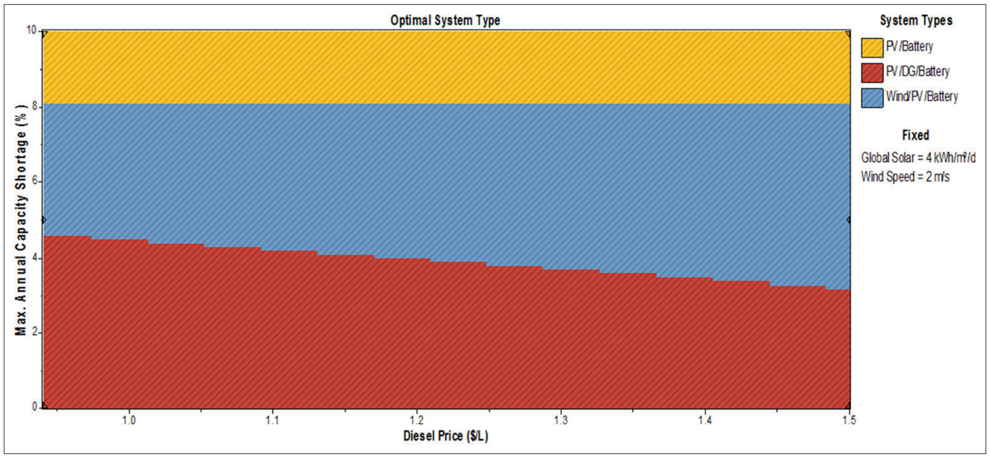
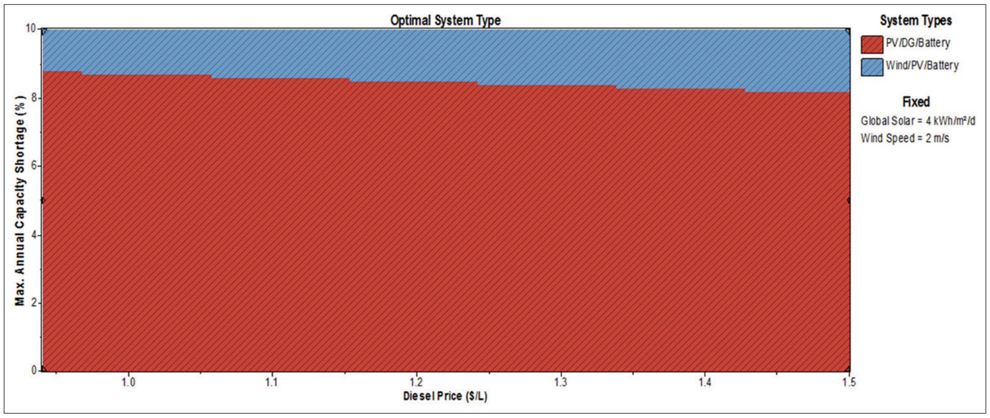


Figure 11: sensitivity analysis without energy efficiency technique



and replacement cost over the lifespan of the project is $11,500. This is taken as part of the investment cost of the project.

5.2. System Configuration

HOMER categorizes and ranks all feasible system technical architecture according TNPC. From the analysis, the PV/DG/Bat system is the most feasible with and without the application of EET. With the application of EET, the system configuration is 150 kW PV, 40 kW DG, 50 kW converter, and 50 batteries. Without the application of EET, the simulation returned 150 kW PV, 40 kW DG, 50 kW converter, and 200 batteries as the best system option. In both cases, the diesel price is maintained at $0.94/l. Other feasible system configurations are as shown in Table 3.

5.3. Cost

The main economic output of HOMER is the total net present cost (TNPC) and systems are ranked based on this economic index. From the simulation results (Table 3), the TNPC for the most feasible configuration with the application of EET is $257802 with a levilised cost of energy of $0.693/kWh. Initial capital cost and operating cost are $207917 and $6360 respectively. Without the application of EET, the TNPC, LCOE, initial capital cost and operating cost for the optimal configuration is $408,554, $0.481/kWh, $ 276917, and $16784 respectively. Comparing both systems (with EET and without EET), there was a reduction of at least 36.9% when EET is applied. The TNPC of all feasible system structure returned by the simulation for implementation at the site under consideration at a diesel price of $0.94/l is shown in Figure 9.

Table 4: Emission factors (Babatunde *et al*., 2018a)

Pollutant	Emission factor	Unit
Carbon monoxide	6.5	g/L of fuel
Unburned hydrocarbons	0.72	g/L of fuel
Particulate matter	0.49	g/L of fuel
Portion of fuel sulfur converted to particulate matter	2.2	%
Nitrogen oxides	58	g/L of fuel
CO_2	2.66	Kg/L of fuel

5.4. Energy Production

Electricity produced by various system architectures is dependent on the diverse mix of the hybrid system. In this study, the annual electricity produced, excess energy, unmet load, RE penetration and renewable fraction were evaluated. Details of this are given in Table 3. For the optimal configuration for both cases under configuration, the shortage capacity is zero, thereby unmet load is negligible. From Table 3, about 91% renewable fraction is achievable with the application of EET while a RF of 89% is possible without the application of EET. 110,763kWh/y of electricity can be sold to the grid if the system does not operate in the islanding mode. From the analysis, it is obvious that 100% of the community load can be supplied with PV contributing 91% and 9% from the DG penetration.

5.5. Fuel and Emission

Before the simulation, the weight of the pollutants released per unit of the fuel consumed for each pollutant is determined. After the simulation, the annual emissions are estimated by obtaining the product of emission factor and the total annual fuel consumption. It therefore estimates the quantity of CO_2, CO, unburned hydrocarbons, particulate matter, SO_2, and NO_x. The emission factor is used to compute the total emission from a source. Table 4 shows the average emission factors for all the pollutants that HOMER models. For the optimal configurations, application of EET will reduce the fuel consumption by 62%, while the hours of DG operation, reduced from 817 h/year to 341 h/year- a 58% reduction.

5.6. Sensitivity Analysis

Since the price of oil fluctuates both in the local and international market while more outage may occur due to the addition of load and/or reduction in meteorological climatic resources, it is necessary to carry out a sensitivity analysis on the system. In doing this, the effect of change in diesel price with respect to the annual shortage capacity is therefore analyzed as shown in Figures 10 and 11. With the application of EET, three system configuration types are considered viable. With an annual capacity of shortage that ranges from 0 to 4.6%, the PV/DG/Battery architecture is the best power system option while between 4.7 and 8.1% annual capacity shortage, the wind/PV/battery system is optimal. As the annual shortage capacity increases to 10%, the most feasible system configuration is the PV/battery architecture. The two system configuration types are achievable when the EET are neglected. The PV/DG/Battery is feasible until 8.8% annual capacity shortage while the PV/Battery is the best between 8.8 and 10% annual shortage capacities.

6. CONCLUSIONS

The investigation of the economic, technical and environmental feasibility of rural electrification with standalone hybrid energy system considering the implementation of the EET has been conducted. By choosing from a variety of energy efficiency and energy conservation activities such as retrofitting and switch off redundant lamps, the experimental load for a typical community was significantly reduced by 56.8%. Four system architecture, including: PV/DG/battery, PV/WD/DG/battery, PV/battery, and PV/WD/battery were obtained via HOMER simulations as the most economically and environmentally feasible electrification solution. A comparative analysis of load with and without EET has shown that the most feasible configuration for the village under consideration is PV/DG/Battery architecture with 0% capacity shortage. Technical analysis shows that it is possible to achieve 100% RE penetration for the rural community in the case study. This may be extended to areas of similar meteorological data. More explicitly, the application of energy efficient measure to the prospective load led to a hybrid energy configuration with decreased emissions at the site under consideration. This is at 61.6% when compared to the case without EET.

Due to the high investment cost of retrofitting and implementing hybrid RE systems, it is suggested that the government subsidizes (or supply free of charge to villagers) the distribution of energy efficient appliances; especially CFLs. This will boost investment in energy efficient practices by the energy poor population, enhance increased penetration of RE in the energy mix. This will eventually alleviate poverty by solving rural electrification problems while at the same time, mitigating the greenhouse gas (GHGs) emission to the environment. So also, it is also necessary to create public awareness on the economic and environmental benefits of EET and RE to the society. This will improve the behavioral paradigm change in the orientation of energy users so as to support the greener society phenomenon.

In the meantime, this work further contributes to the potentials of EETs as a means of load management for effective improvement in the supply of electricity without remarkable economic and environmental disintegration. Furthermore, it showcases the unexploited benefits of RE technologies in rural electrification especially in Africa. This study, therefore, presents viable opportunities for energy planners, energy policy makers as well as other stakeholders to explore in future researches, thereby allowing for effective and reliable management of sustainable energy systems.

REFERENCES

Abolarin, S.M., Gbadegesin, A.O., Shitta, M.B., Yussuff, A., Eguma, C.A., Ehwerhemuepha, L., Adegbenro, O. (2013), A collective approach to reducing carbon dioxide emission: A case study of four University of Lagos Halls of residence. Energy and Buildings, 61, 318-322.

Adaramola, M.S., Oyewola, O.M. (2011), Wind speed distribution and characteristics in Nigeria. ARPN Journal of Engineering and Applied Sciences, 6(2), 82-86.

Adaramola, M.S., Paul, S.S., Oyewola, O.M. (2014), Assessment of decentralized hybrid PV solar-diesel power system for applications in Northern part of Nigeria. Energy for Sustainable Development, 19, 72-82.

Akinyele, D. (2018), Analysis of photovoltaic mini-grid systems for remote locations: A techno-economic approach. International Journal of Energy Research, 42(3), 1363-1380

Akinyele, D. (2017), Techno-economic design and performance analysis of nanogrid systems for households in energy-poor villages. Sustainable Cities and Society, 34, 335-357.

Von Appen, J., Braun, M., Stetz, T., Diwold, K., Geibel, D. (2013), Time in the sun: The challenge of high PV penetration in the German electric grid. IEEE Power and Energy Magazine, 11(2), 55-64.

Babatunde, O. M., Oluseyi, P. O., Akinbulire, T. O., Denwigwe, H. I., Akin-Adeniyi, T. J. (2018a), The role of demand-side management in carbon footprint reduction in modern energy services for rural health clinics. In: Environmental Carbon Footprints. U.K: Elservier. p317-363.

Babatunde, O., Akinyele, D., Akinbulire, T., Oluseyi, P. (2018b), Evaluation of a grid-independent solar photovoltaic system for primary health centres (PHCs) in developing countries. Renewable Energy Focus, 24, 16-27.

Behrangrad, M. (2015), A review of demand side management business models in the electricity market. Renewable and Sustainable Energy

Reviews, 47, 270-283.

Bonneville, E., Rialhe, A. (2006), Demand Side Management for Residential and Commercial End-Users. Efficiency and Eco-Design.

Bugaje, I.M. (2006), Renewable energy for sustainable development in Africa: A review. Renewable and Sustainable Energy Reviews, 10(6), 603-612.

Carmichael, D.G., Ballouz, J.J., Balatbat, M.C.A. (2015), Improving the attractiveness of CDM projects through allowing and incorporating options. Energy Policy, 86, 784-791.

Chefurka, P. (2007), World energy and population: Trends to 2100. Canada: The Oil Drum. p17.

Child, M., Breyer, C. (2016), Vision and initial feasibility analysis of a recarbonised Finnish energy system for 2050. Renewable and Sustainable Energy Reviews, 66, 517-536.

Collier, P., Venables, A.J. (2012), Greening Africa? Technologies, endowments and the latecomer effect. Energy Economics, 34, S75-S84.

Elliott, R.J.R., Sun, P., Xu, Q. (2015), Energy distribution and economic growth: An empirical test for China. Energy Economics, 48, 24-31.

Ghodmare, K., Dharme, A., Ghatol, A. (2008), Techno-Economic Analysis of DSM Using Capacitors in Reral Sector.

Givler, T., Lilienthal, P. (2005), Using HOMER Software, NREL's Micropower Optimization Model, to Explore the Role of Gen-Sets In Small Solar Power Systems. Sri Lanka: Case Study.

Glushkov, S.V., Kuznetsov, G.V., Strizhak, P.A. (2017), Estimation of energy efficiency of residential buildings. In: MATEC Web of Conferences. Vol. 92. Les Ulis: Thermophysical Basis of Energy Technologies (TBET-2016). p1072.

Hamid, E., Perumal, N., Nor, N.B.M., Mohana, A.L. (2014), Intelligent demand side management technique for industrial consumer. In: Intelligent and Advanced Systems (ICIAS), 2014 5th International Conference. p1-6.

IEA. (2009), Key World Energy Statistics. Paris: IEA.

Jha, A. (2008), Solar Power from Saharan Sun Could Provide Europe's Electricity, Says EU. London: The Guardian.

Karekezi, S. (2002), Renewables in Africa-meeting the energy needs of the poor. Energy Policy, 30(11-12), 1059-1069.

Karunanithi, K., Saravanan, S., Prabakar, B.R., Kannan, S., Thangaraj, C. (2017), Integration of demand and supply side management strategies in generation expansion planning. Renewable and Sustainable Energy Reviews, 73, 966-982.

Kies, A., Schyska, B.U., von Bremen, L. (2016), The demand side management potential to balance a highly renewable European power system. Energies, 9(11), 955.

Lim, X.L., Lam, W.H. (2014), Review on clean development mechanism (CDM) implementation in Malaysia. Renewable and Sustainable Energy Reviews, 29, 276-285.

Lund, H., Mathiesen, B.V. (2009), Energy system analysis of 100% renewable energy systems - The case of Denmark in years 2030 and 2050. Energy, 34(5), 524-531.

Macedo, M.N.Q., Galo, J.J.M., de Almeida, L.A.L., de Lima, A.C. (2015), Demand side management using artificial neural networks in a smart grid environment. Renewable and Sustainable Energy Reviews, 41, 128-133.

Mahlia, T.M.I., Masjuki, H.H., Choudhury, I.A., Saidur, R. (2001), Potential CO_2 reduction by implementing energy e ciency standard for room air conditioner in Malaysia q. Energy Conversion and Management, 42, 1673-1685.

Mahlia, T.M.I., Iqbal, A. (2010), Cost benefits analysis and emission reductions of optimum thickness and air gaps for selected insulation materials for building walls in Maldives. Energy, 35(5), 2242-2250.

Mentis, D., Siyal, S.H., Korkovelos, A., Howells, M. (2015), Assessing the technical wind energy potential in Africa a GIS-based approach. Renewable Energy, 83, 110-125.

Nwulua, N.I., Agboolab, O.P. (2011), Utilizing renewable energy resources to solve Nigeria's electricity generation problem. International Journal of Thermal and Environmental Engineering, 3(1), 15-20.

Odjugo, P.A.O. (2011), Climate change and global warming: The Nigerian perspective. Journal of Sustainable Development and Environmental Protection, 1(1), 6-17.

Oh, T.H., Chua, S.C. (2010), Energy efficiency and carbon trading potential in Malaysia. Renewable and Sustainable Energy Reviews, 14(7), 2095-2103.

Olatomiwa, L., Mekhilef, S., Huda, A.S.N., Ohunakin, O.S. (2015), Economic evaluation of hybrid energy systems for rural electrification in six geo-political zones of Nigeria. Renewable Energy, 83, 435-446.

Olatomiwa, L.J., Mekhilef, S., Huda, A.S.N. (2014), Optimal sizing of hybrid energy system for a remote telecom tower: A case study in Nigeria. In: Energy Conversion (CENCON), 2014 IEEE Conference. p243-247.

Oluseyi, P.O., Akinbulire, T.O., Awosope, C.O.A. (2006), A Novel Improvement of Electric Power Reliability Scheme in Nigeria: Demand-Side Management Approach, 22nd NSE (Electrical Division) International in Conference Proceedings, ICEPT. p1-5.

Oluseyi, P.O., Babatunde, O.M., Babatunde, O.A. (2016), Assessment of energy consumption and carbon footprint from the hotel sector within Lagos, Nigeria. Energy and Buildings, 118, 106-113.

Oluseyi, P.O., Okoro, O.I., Chikuni, E. (2009), Energy efficiency programme in Nigerian industries: A lesson from India. In Power, 500(600), 700.

Oyedepo, S.O. (2012a), Energy and sustainable development in Nigeria: The way forward. Energy, Sustainability and Society, 2(1), p.15.

Oyedepo, S.O. (2012b), On energy for sustainable development in Nigeria. Renewable and Sustainable Energy Reviews, 16(5), 2583-2598.

Pina, A., Silva, C., Ferrão, P. (2012), The impact of demand side management strategies in the penetration of renewable electricity. Energy, 41(1), 128-137.

Rahman, K.A., Hariri, A., Leman, A.M., Yusof, M.Z.M., Najib, M.N.M. (2017), Energy consumption in residential building: The effect of appliances and human behaviour. In: AIP Conference Proceedings. p20018.

Rajanna, S., Saini, R.P. (2016), Employing demand side management for selection of suitable scenario-wise isolated integrated renewal energy models in an Indian remote rural area. Renewable Energy, 99, 1161-1180.

Rajbongshi, R., Borgohain, D., Mahapatra, S. (2017), Optimization of PV-biomass-diesel and grid base hybrid energy systems for rural electrification by using HOMER. Energy, 126, 461-474.

Sambo, A.S. (2010), Renewable energy development in Nigeria. In: Energy Commission of Nigeria Paper Presented at the World's Future Council and Strategy Workshop on Renewable Energy, Accra, Ghana.

Sethi, R., Ullman, J.D. (2016), Implementation of automatic demand management system (ADMS). In: Electricity Distribution (CICED), 2016 China International Conference. p1-3.

Setlhaolo, D., Xia, X. (2016), Combined residential demand side management strategies with coordination and economic analysis. International Journal of Electrical Power and Energy Systems, 79, 150-160.

Stefano, J.D. (2000), Energy efficiency and the environment: The potential for energy efficient lighting to save energy and reduce carbon dioxide emissions at Melbourne University, Australia. Energy, 25, 823-839.

Subramanyam, V., Ahiduzzaman, M., Kumar, A. (2017), Greenhouse gas emissions mitigation potential in the commercial and institutional sector. Energy and Buildings, 140, 295-304.

Taneja, J. (2014), Growth in renewable generation and its effect on demand-side management. In: Smart Grid Communications (SmartGridComm), 2014 IEEE International Conference. p614-619.

Teitel, S. (1978), On the concept of appropriate technology for less industrialized countries. Technological Forecasting and Social Change, 11(4), 349-369.

Thakur, J., Chakraborty, B. (2016), Demand side management in developing nations: A mitigating tool for energy imbalance and peak load management. Energy, 114, 895-912.

Watts, D., Albornoz, C., Watson, A. (2015), Clean development mechanism (CDM) after the first commitment period: Assessment of the world? Portfolio and the role of Latin America. Renewable and Sustainable Energy Reviews, 41, 1176-1189.

Zhang, C., Yan, J. (2015), CDM's influence on technology transfers: A study of the implemented clean development mechanism projects in China. Applied Energy, 158, 355-365.

Zhao, Z.Y., Li, Z.W., Xia, B. (2014), The impact of the CDM (clean development mechanism) on the cost price of wind power electricity: A China study. Energy, 69, 179-185.