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Economic Viability of Captive Off-grid Solar Photovoltaic and Diesel Hybrid Energy Systems for the Nigerian Private Sector

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Abstract

It is well established that lack of both electric supply capacity and reliability weaken the Nigerian economy. Recently, the reduction in solar photovoltaic (PV) costs along with the technical potential to couple PV to hybrid battery and diesel generators provides Nigerian businesses with an opportunity to reduce operating costs while defecting from the grid. This study investigates the potential of using off-grid hybrid energy systems for private industries within and near Lagos state currently with relatively high daily electricity demands that are met with supply through captive diesel generation. The results based on simulations of six industry sector load profiles developed from surveys found solar PV and diesel hybrid energy systems are economically viable for a wide array of industries in the Nigerian private sector including real estate, education, banking, automobile, hospitality and production. Five of the six sectors had discounted payback times for the systems under a year and ROIs >100%. The results established that the levelized cost of electricity is lower for every sector analysed with inclusion of solar PV, lower still with coupling of batteries and more reliable than the current grid-provided electricity. Nigeria as a whole will also benefit from widespread adoption of solar hybrid systems, as it will assist the balance of trade by reducing refined petroleum imports. In conclusion, the results of this study make it clear that every scale of Nigerian businesses could increase profitability with the use of solar hybrid systems.

Highlights

- Nigerian private sector does not need to rely on expensive diesel fuel for energy needs
- Using batteries in hybrid solar photovoltaic (PV) + diesel systems reduces LCOE
- Solar PV adoption is economically viable, offering ROIs >100% for five subsectors
- Results show high ROI and low discount payback for all – good indicators for lenders
- Security of solar PV infrastructure and increase awareness are key to investment

Keywords : autoproduction; captive power; diesel generator; off-grid; solar photovoltaic; Nigeria

Abbreviations

Ah	ampere hour
BAU	business as usual
CBN	Central Bank of Nigeria
CHP	combine heat and power
CO ₂	carbon dioxide
DG	distributed generator
GDP	gross domestic product
GW	gigawatt
h	hour
HOMER	Hybrid Optimization Model for Multiple Energy Resources
kW	kilowatt
kWh	kilowatt hour
L	litre
LCOE	levelized cost of energy
MW	megawatt
MWh	megawatt hour
m ²	square meter
N/A	not applicable
NGN	Nigerian naira
NPC	net present cost
OC	operation cost
O&M	operation and maintenance
PV	photovoltaic
RE	renewable energy
ROI	return on investment
TWh	terawatt hour
USD	United States dollar
Wdc	watt direct current
Wp	watt peak
%	percentage
\$	United States dollar
>	greater than

1. Introduction

Challenges associated with the centralized electric power generation in Nigeria weaken both the macro-economy as well as micro-economy, with the private sector being most heavily impacted [1-3]. Electric challenges appear to be undermining Nigeria's hopes of becoming a member of G20 by 2020 [4-6] as high electricity costs and lack of reliability cripple industrialization and domestic enterprises [4]. The electricity value chain of Nigeria [7] (Figure 1) shows an over 80% generation shortage from the total installed capacity of 12.5 GW. The transmission capacity limitation is 5.3 GW, which implies that there would be 7.2 GW shortage even if all the installed power plants were functioning and operating optimally. This value coincidentally equals the distribution capacity.

Figure 1: Nigerian electricity value chain (Data from [7]).

This is fundamental to the electricity problem in the country that has led to average annual generation going below 4 GW from the operational power plants [8-11] meant to service a country with over 170 million people [9]. This capacity shortage in Nigeria is due to various factors such as lack of fuel supply for the thermal power plants due to pipe vandalism, drought and seasonality of water supply for hydropower plants, and nonfunctional and large downtimes of some old generating plants [10]. Therefore, along the value chain from generation to distribution is a loss up to 86% of installed capacity leading to less than around 25% delivery [7,11-13]. The result of this inefficiency is insufficient electricity supply to meet the demand of both residential and commercial (i.e. private businesses) consumers [6,9,14-15]. Nigeria's average electricity consumption is approximately 126 kWh per capita per year [8], with the concomitant lack of performance in the human developmental index (HDI) [16-18]. This electricity is also expensive; with average grid cost of US\$ 0.12/kWh and average fixed charge of US\$ 805 for commercial and industrial consumers [19]. Additionally, cost of generating from diesel generator varies between \$0.28/kWh to \$0.33/kWh [2] when grid electricity is unavailable. The grid price for industrial and commercial customers, when compared to that of some other Sub-Saharan African countries such as Angola, Botswana, Kenya and Niger [20] also appears high.

Yet, Nigeria has enormous renewable energy (RE) resources potential from solar photovoltaic (PV) [3,5,11,13,14,21-23], wind [3,5,6,14,15,22,23] and hydropower [3,5,9,11,14,22,25,26]. However, the Nigerian government has failed to fully explore these solutions to the nation's energy situation as various energy and electric reforms and policies within the last two decades [10,22,27] have not yielded significant changes in the country's energy outlook. An alarming 83% of private businesses that were recently surveyed reported that they were not satisfied with current electricity supply from the grid [1,2].

1.1 Captive Diesel Power Generation in Nigeria

As the grid dependent era in Nigeria is characterized by power outages over extended time periods, there has been a shift to captive power generation [8], which refers to off-grid self-consumed power generation. Captive power generation with diesel generators are used by 71% of private businesses in Nigeria [1,2,4,5,23]. For example, MTN, which is one of the leading telecommunication companies in Nigeria, has about 6,000 diesel generators across the country [28]. The Nigerian private sector's high dependence on captive diesel generation has indirect effects on the economics of private industry due to increasingly high operation and maintenance (O&M) costs of diesel

generators for business activities. The upward trend of diesel prices, which have risen by more than 800% between 2002 and 2017, have moved the pump price of diesel from NGN 25 to around NGN 208 (i.e. from USD 0.08/L to USD 0.67/L, using the CBN February 15, 2019 exchange rate) [1,9,29]. This trend indicates that diesel generation is not sustainable for business and economic growth. Apart from the high pump price of this fuel, is the incessant scarcity of fuel [10,30] due to several issues within the oil and gas industries such as the country's four refineries operating far below capacity [31].

The Nigerian electricity tariff as contained in the multi-year tariff order (MYTO) is based on category of each user [19]. The electricity tariff varies widely depending on customer class and the distribution company (DISCO) among the 12 DISCOs [10] in the country providing services, with higher tariffs observed in far northern region customers. Lagos state is served by DISCOs: Ikeja electricity distribution company (IKEDC) and Eko electricity distribution company (EKEDC). IKEDC electricity prices for commercial categories (C2, low voltage maximum demand) and industrial (D2 low voltage maximum demand) customers are USD 0.12/kWh and USD 0.13/kWh, respectively and carry no fixed charges [19]. For EKEDC, the current prices are both approximately US\$0.10/kWh to US\$0.11/kWh (NGN 29.17/kWh and NGN 29.67/kWh) for those two categories [19].

1.2 Captive Power Generation and Solar PV in Nigeria

The levelized cost of solar electricity [32] has been competitive with conventional power sources throughout the world's largest economy [33,34]. Solar also has the greatest potential among RE resources in Nigeria [14, 27]. Solar potential across the country ranges from 4.0kWh/m²/day to 6.5kWh/m²/day [5,11] and its integration into the electric energy mix is important to move towards a sustainable society [35]. To move along this path, existing sites with diesel generators can integrate PV into hybrid systems to offload diesel use. Previous research has considered off-grid hybrid energy systems and compare costs of several combinations such as (i) PV and diesel, (ii) PV, diesel and battery, (iii) PV, wind and diesel, as well as (iv) PV and batteries [9,11,15,23,24,26,36-38]. The works of [9, 15, 24] consider hybrid energy systems of solar PV, diesel and battery for rural consumers in Northern Nigeria where hybrid COE range from 0.32 to 0.68 US\$/kWh and diesel is only over 1.0 US\$/kWh. These research works already indicate the economic viability of the hybrid system for rural users. The capital cost assumption of US\$3,200/kW for PV in these works, is however, very high and does not represent current costs of the renewable energy technology. Similarly, [11] in the grid-tied PV system for the same region in Nigeria, assumed costs of US\$2,400/kW for PV. Although the resulting PV LCOE from the research is much lower and shows viability, the challenges of supply reliability that emanates from being tied to the grid still exists. Older research works that assesses economic viability of hybrid systems in rural community in south west of Nigeria [23] also had high PV cost assumptions. More so, the price of diesel fuel has changed tremendously from the period of these researches. In these studies, the hybrid optimization model for electric renewable (HOMER) has been used by some of these researchers for simulation of hybrid energy systems in Nigeria.

In general, many of the previous research in this area focused on either residential or small commercial consumers in rural northern or southern part of Nigeria [9,23,24,39,41], while others on a mix of both residential and commercial [36]. There are also other studies that have considered hybrid systems for telecommunication operation sites [37,38,42]. Most of these studies are characterized by various limitations that do not provide sufficient information for businesses such as empirical case studies of small size consumers and the use of estimated load data for modelling and simulation [13,15,23,24]. There has not been a systematic study of large electricity consumers

like production factories, manufacturing industries or residential estates in metropolitan areas such as Lagos. Thus, this study investigates the potential for solar PV and diesel hybrid systems in the Nigerian private industry and business spaces. Specifically, this study focuses on off-grid hybrid energy systems for private industries within and near Lagos state currently with relatively high daily electricity demands that are met with supply through captive diesel generation. The methodology involved collection case study research from a pool of surveyed companies. Six case studies were selected to investigate the application of hybrid systems for a broad diversity of business types including: (1) production, (2) banking, (3) education, (4) automobile (sales, repair and distribution), (5) hospitality and (6) real estate sub-sectors. Modelling of the systems for each industry type was carried out using a sensitivity analysis on the cost of PV and diesel as well as using a battery system or not. The results obtained for case study companies as well as investment opportunities are presented along with an extrapolation of the economic impact on the country if widespread adoption of PV hybrid systems occurs.

2. Materials and Methods

To carry out this study, HOMER Pro 3.12.5 was used to model the energy system of each case under consideration. The methodology deployed include designing questionnaire focusing on quantitative energy data of each company and their perception on energy services received from their current system [1]. The questionnaire was sent to not less than 150 companies across Nigeria states covering Lagos, Ogun, Akwa Ibom, Rivers and Abuja the federal capital territory. The survey was sent via email, telephone interview and physical delivery [1]. 40 responses was received, more than 90% of which were from private companies from Lagos and Ogun states. Six case studies were selected to investigate the application of hybrid systems for a broad diversity of business types including: (1) production, (2) banking, (3) education, (4) automobile (sales, repair and distribution), (5) hospitality and (6) real estate sub-sectors. 5 out of the 6 selected sub-sectors are from Lagos while last one is from Ogun state. Other sub-sectors in the survey not represented in the case study sample are energy, telecommunication and service. These are not considered as their load pattern generally conform to one of the 6 already selected. Also, some of them did not provide sufficient load information needed to complete simulation. The energy and daily load data from the selected 6 represents respondents from private industries in Lagos and Ogun states [1]. Input data was: site location, daily or hourly load profile, diesel fuel prices, O&M cost and age of diesel generators. The O&M cost of generator, which does not include fuel costs, varies widely and there is wide variation of per hour cost responses from the survey. However, previous research [42-44] have used consistent values around US\$ 0.25/h for gensets O&M in Nigeria and this value is assumed for diesel genset modelling. Several other assumptions were used to complete modelling and simulations. The equivalent per kW cost of diesel generators used for replacement analysis was based on previous research, which is USD 408 [15]. The lifetime of the generator was assumed to be 7 years (15,000 hours, assuming 25% use) based on previous work [15,45]. To ensure consistent currency usage, current exchange rate of Central Bank of Nigeria (CBN) of NGN 306.75 to USD 1 being for February 15, 2019 was used. Load variability was set at 0%, Nominal discount rate and inflation rate of 14% and 11.37%, respectively [29,46], giving rise to 2.36% real interest rate. This real interest rate shares similarity with values that has been previously used in past research [23]. It must be pointed out that the real interest rate which HOMER uses in simulation is the difference between the interest rate and the inflation rate and that a sensitivity was done increasing it from the 2% to 6%, which was inconsequential on the economic metric results. Due to space constraints in the Lagos metropolis, rooftop monocrystalline solar PV were selected with a solar conversion efficiency of 18%. A project lifetime of 25 years was assumed for PV modules based on the power production warranty lifetime. This is conservative as the expected lifetime of a PV module is much longer [47].

3. Modelling and Simulation

To obtain optimized results for hybrid energy systems in Nigeria, simulations were carried for the system models for each of the six subsectors. In HOMER, four consecutive multipliers for the PV minimum cost of US\$0.25/Wp were input into the model. The multiplier follows an increment of US\$0.25 to the subsequent. The same incremental value as well as steps were done for the diesel price from the base price of US\$0.75/L. Then simulations were run to obtain optimized LCOE. Thereafter, a battery was added to the system. Simulations carried out after this allows comparing of results in optimized LCOE with and without a battery in the hybrid systems. These procedures were done for each of the subsectors. Real interest rates have decreased in the past two year, dropping from 6.68% in 2016 [46] to 5.79% [48]. The current real interest rate of 2.36% was used as the low value. Interest rate increment of 1% were initially considered for the systems. However, it did not produce a major effect in the LCOE results from the simulations. Input values of critical variables in the model are shown in the sensitivity analysis matrix in Table 1. The second column of the table represents the hypothetical lowest values relative to current obtainable values in the country. The discussion of each of the learning curve variables are described in the subsections below.

Table 1. Sensitivity analysis ranges for core variables for captive off-grid systems

Variable	Low	High	Increments
PV System Cost (USD/Wp)	0.25 [49]	1.00 [37,50]	0.25
Diesel Price (USD/L)	0.75	1.50	0.25
Battery Storage	None	200 Ah at USD175/Ah [9,51]	N/A

3.1 PV System Costs

The United States National Renewable Energy Laboratory estimates [52] that the total installed system cost has declined to US\$1.85 per direct current watts (Wdc) for commercial and US\$1.03 Wdc for fixed-tilt utility-scale systems. In Nigeria the current PV systems capital costs are lower because of the lower labor costs: US\$0.98 Wdc [37,50] and US\$0.67 Wdc [53]. The range depends on the type of PV system and the vendor. The value of US\$0.98 Wdc for fixed-tilt systems was used for the base analysis and then a sensitivity was run to US\$0.25 Wdc by USD\$0.25 increments, because previous learning rates for the global and rapidly expanding solar PV industry [49,54-57] has resulted in continuous and substantial reduction in PV module costs and resultant drops in PV system prices [58,59]. As of January 2019, the spot price of the lowest cost PV modules has dropped below US\$0.20/W [60]. The International Renewable Energy Agency (IRENA) predicts that the prices will fall by 60% in the next decade [61]. In addition, there are already slated technical improvements such as the PV industry moving to the use of black silicon, which are expected to drop those costs further [62]. The converter capital cost of US\$0.2/W was used, which was also based on recent literature. Finally, an annual cost of O&M US\$10 per kW was used [24].

3.2 Diesel Prices

In Nigeria, the price of diesel has been experiencing an upward trend for the last twenty years [64]. Based on the EOSTRA diesel pump prices from 2012 to 2017 (Figure 2), a linear prediction was carried out for the next 10 years. For this research, a low diesel price of US\$0.75/L and high price of US\$1.50/L were used.

Figure 2. Fuel price trend and prognosis for next 10 years. (Based on EO STRA, 2015 data [64])

3.3 Energy Storage System

The model also includes the addition of battery storage into the each of the systems for the with battery cases. The use of battery systems as energy storage is already popular in the Nigerian private sectors like banks where they function alongside inverters and diesel generators [65]. In sizing the battery subsystem, it is usually done to take on the excess energy produced by solar PV, which is utilized when solar is not available [66]. Batteries used must be at the same operational level in terms of type, age, manufacturer and temperature [67]. Cost of battery storage in Nigeria based on previous research is taken as 200 Ah at USD175/Ah [15]. However, the scope of this research and simulation is limited to this hypothetical cost of battery without consideration for a sensitivity in cost. This is left for future work.

4. Results

4.1 Business as Usual Scenario

On the business as usual (BAU) scenarios, all the variables are kept constant at the current prices given by each of the business sectors in the survey. Also, the BAU systems are run by only diesel generators. The LCOE, net present cost (NPC) and operational costs (OC) are shown for all six sectors in Table 2. First is the real estate subsector with a university campus, large church auditorium, conference centres, several business and residential buildings. Power supplied to every part of this estate community comes from a diesel generator plant that runs continuously. The LCOE achieved from simulation for the real estate subsector was US\$0.59/kWh with annual electrical energy consumption of 31.2 TWh. The NPC of energy system of this business subsector is US\$342 million. Furthermore, total operation cost over the lifespan of the system amounts to US\$348 million.

For the education subsector, which represents a high school complex has different amenities including student hostels, classrooms, meeting halls, staff offices, kitchens, and dining halls. The diesel generator runs for 24 hours, 7 days a week as in the case for the real estate, to supply

electrical energy needs of 1.8 TWh per annum for this school. Simulation results for this subsector gives an LCOE of US\$0.63/kWh and NPC of US\$20.6 million.

Thirdly is the banking subsector with regular operations of about 12 hours a day and energy demand of 0.5 TWh per annum. The LCOE for banking subsector is US\$0.67/kWh and NPC of US\$6.16 million.

The automobile subsector has two generators that supply electricity for its auto servicing factory and fully air-conditioned offices. Annual energy consumption of this company is 2.2 TWh. For the automobile subsector, simulation of systems produces LCOE of US\$0.21/kWh.

The system for the hospitality subsector represents a large and highly ranked hotel in Lagos state. Diesel generators used in this location service the load of not only luxury rooms, but other facilities such as kitchen and lounge. A total of 8.8 TWh presents the annual energy consumption of this hotel. The simulation result yields LCOE of US\$0.67/kWh at NPC of US\$109 million. The production subsector has LCOE of US\$0.57/kWh and NPC of US\$17.9 million. The system composed of two gensets of 150 and 160 kW to satisfy its daily load demand for 24 hours. The total annual energy demand of 1.7 TWh is recorded for this company.

As mentioned earlier, the LCOE simulation was based on current O&M cost of the business sector without annual increase in O&M. Thus, additional costs will push up the LCOE for these private companies. The real estate due to its very large system size and kWh consumption per annum, has the greatest OC of US\$18.3 million per yr.

Table 2. The business as usual LCOE, NPC and OC for the six business sectors in the Nigerian economy.

Subsector	Real Estate	Education	Banking	Automobile	Hospitality	Production
LCOE (US\$/kWh)	0.59	0.63	0.67	0.21	0.67	0.57
NPC (US\$ million)	342	20.6	6.16	8.38	109.00	17.90
OC (US\$ mi/yr)	18.3	1.1	0.33	0.45	5.45	0.95
<i>Interest rate = 2.63%, genset cost = 408 (US\$ /kW), O&M = US\$0.25/h and fuel price = US\$0.75/l</i>						

4.2 Hybrid Base Scenario

The hybrid base scenario includes the addition of solar PV into the system to compliment the operation of BAU with diesel only operation. For each of the subsectors a decrease in the LCOE of the system is observed as summarized in Table 3. Results of the hybrid scenario shows a per kWh drop of LCOE for all the systems with a range of USD\$0.11/kWh for real estate down to a USD\$0.03/kWh for banking. Real estate, on the other hand, shows a highest present worth (PW) and return on investment (ROI), which are US\$70 million and 193%. Discounted payback period, a measure of the year by which borrowed investment capital with interest will be completely settled, also has real estate with the fastest repayment or reimbursement rate of 6 months (0.5 years). For the automobile sector, the least ROI and latest discounted payback period are 43% and just over 2 years, respectively.

Table 3. The LCOE, LCOE savings, NPC, PW, OC, ROI and discounted payback period for solar PV hybrid diesel systems compared to the BAU from Table 1.

Subsector	Real Estate	Education	Banking	Automobile	Hospitality	Production
LCOE (US\$/kWh)	0.48	0.59	0.64	0.15	0.63	0.51
LCOE savings compared to BAU (US\$/kWh)	0.11	0.04	0.03	0.06	0.04	0.06
NPC (US\$ mi)	281.3	19.5	5.86	5.0	103.0	16.1
PW (US\$ mi)	61.0	1.1	0.3	2.4	5.5	1.8
OC (US\$ mi/yr)	15.0	1.0	0.3	0.3	5.5	0.9
ROI (%)	193	57	51	43	50	93
Disc. Payback (yr)	0.5	1.82	1.8	2.2	1.9	1.0
At interest rate = 2.63%, genset cost = 408 (US\$ /kW), O&M = US\$0.25/h and fuel price = US\$0.75/l						

4.3 Sensitivity Analysis

In the sensitivity analysis, all the variables, associated costs and increments detailed in Table 1 are added to the model. The optimum LCOE (see Figure 3) for all the subsectors improves with addition of battery storage to the hybrid system. This is expected as the battery makes better use of the solar generated electricity and enables the generator to operate more efficiently. The hospitality subsector has the greatest reduction, showing a LCOE drop of US\$0.47/kWh from the hybrid scenario without battery to the scenario with the addition of battery storage. The high energy cost lost due to the battery addition is seconded by real estate whose LCOE is reduced by US\$0.26/kWh. However, the automobile subsector still has the smallest LCOE of US\$0.12/kWh, despite having the least drop of just US\$0.03/kWh with battery storage. These cost changes are dependent on the specified variable cost given in Table 4.

Figure 3: LCOE of different scenarios: business as usual, hybrid PV+generator system, and hybrid system with storage across the six economic sectors.

Table 4. The LCOE, LCOE savings, NPC, PW, OC, ROI and discounted payback period for solar PV hybrid diesel systems with battery compared to scenario from Table 3 across the six economic sectors.

Subsector	Real Estate	Education	Banking	Automobile	Hospitality	Production
LCOE (US\$/kWh)	0.23	0.42	0.42	0.12	0.16	0.28
LCOE change (US\$/kWh)	0.26	0.17	0.22	0.03	0.47	0.23
NPC (US\$ mi)	134.0	13.8	3.9	5.0	17.3	8.82
PW (US\$ mi)	208.2	6.9	2.3	3.3	52.6	9.1
OC (US\$ mi/yr)	6.6	0.7	0.2	0.2	0.9	0.5
ROI (%)	117	131	158	42	332	140
Disc. Payback (yr)	0.9	0.8	0.65	2.3	0.3	0.7
<i>At interest rate = 2.63%, genset cost = 408 (US\$ /kW), O&M = US\$0.25/h and fuel price = US\$0.75/l and battery storage =US\$175/Ah for 200Ah</i>						

The NPC and OC for all the subsectors fall tremendously as battery storage is introduced into the system. NPC of the real estate sector reduces with difference between (from Table 3 to Table 4) of US\$147 million. It also possesses the greatest increment in present worth (PW) of US\$208.2 million among other subsectors, although discounted payback almost doubled from 0.5 to 0.9 year. It should be noted, however, that simple payback is a simplistic way of viewing economics as the ROI is more instructive for comparing across investment opportunities [68]. This particular investment earns an ROI of 117%. The automobile subsector has the longest discounted payback period of 2.3 years, which again is not a problem when viewing the ROI as compared to other legal investments. On ROI, the results for each subsector from the least to highest gives 42%, 117%, 131%, 140%, 158% and 332% for automobile, real estate, education, production, banking and hospitality respectively. Changes in price of the critical variables will affect the LCOE. Sensitivity results (Figure 4) also show the direction of impact of these changes. In general, higher fuel price and PV cost will lead to increased LCOE and vice-versa. Figure 4 also show degree of sensitivity of price of both solar PV and diesel fuel to LCOE. For solar PV, the increment sensitivity is marginal compared to that of diesel. One major reason to these differences is because of higher maintenance cost of diesel power plants compare to solar PV for the same size. This implies that even with higher PV prices, the system is still more economical than the diesel fuel.

Figure 4: Sensitivity results of changes in fuel price and PV cost with LCOE for the six economic sectors investigated in Nigeria superimposed (shown in red).

5. Discussion

The research and results obtained show that hybridized energy systems comprised of solar PV with battery as well as with diesel generator are highly beneficial for Nigerian private. Firstly, it should be noted that due to intermittency nature and organizational operation period (nights and periods of cloud cover), energy from solar PV alone cannot fulfil the electrical demands of these companies. This technical challenge means solar energy will need to be complemented by either incumbent predominant means of power generation, diesel plants or with storage. The same conclusions can be drawn for battery subsystem, which shows a better performance than diesel generators, both

economically and environmentally. However, private sector investment in these systems depends on availability of opportunities for capital and financial partnerships with investors and financial institutions. Furthermore, there are other social and political barriers that could prevent investment in these systems are all discussed in this section.

5.1 Investment Opportunity

For financing an attractive investment in an energy infrastructure project, return rate, payback period and capital availability are core parameters for consideration. The ROI and payback results obtained for all the subsectors in this study are indicator of high viability of solar PV investment in the Nigerian business sector. The simulation of economic metrics carried out for the six subsectors has shown that solar PV-DG hybrid project with storage can have as much as 332% ROI and least being 42% ROI, which is still substantial. The discounted payback in all cases are less than a year, except for the automobile sector that is 2.3 years. These values are all promising and for businesses with solid credit, financing should not be an issue. However, there are many businesses that could benefit from these solar hybrid systems that do not have well-enough established credit. This would be expected to hinder the deployment rate of PV in Nigeria. In past years, Nigeria has been lacking innovative models for financing and business ventures in renewable energy technologies established elsewhere throughout the world [69]. However, recently, there are several funding opportunities [1] that could be available to help companies and other private organization offset the initial capital required for solar PV-hybrid system. Some of these are in the form of partnerships, which could serve as security for international investors. A good example is Bettervest GmbH, a German crowdfunding organization used for RE projects and partnerships with private companies [70]. Sustainable Energy Fund for Africa (SEFA) also provides funds in the form of debt and equity contributions or capital for private SME renewable energy projects in Africa [71]. SEFA also serves as a channel for African Development Bank (AfDB) financing of small and medium scale RE projects in Africa. A few Nigerian banks are also focusing on sustainable business development with fund provision for energy projects, like renewable energy. One such bank is Ecobank, a multinational bank in Nigeria with a renewable energy help desk [72]. Furthermore, Winrock International provides financing and technical assistance to support RE projects for hospitals, homes, shopping malls, estates and individuals [73]. Winrock International has collaboration with Ecobank, Diamond Bank and Fortis Microfinance Bank. Companies whose potential cash flow will stabilise or increase with more reliable energy sources are given close consideration [73].

5.2. Potential Barriers to Investment

5.2.1 Security of Infrastructures

Although this study has shown that PV hybrid systems are profitable in Nigeria and there are mechanisms in place to finance them, security of the systems can be a barrier to the level of deployment one would expect of such high profit-potential projects. There are several pockets of civil unrest that are experienced in Nigeria, especially in the Northern and South-Eastern parts [74]. Unfortunately, these areas also possess the most solar energy flux in Nigeria. Northern Nigeria also has large land areas in which solar farms can be built. Unrest in the country can pose a security threat to development of infrastructure and facilities such as solar or wind power plants. Criminals capitalized on these unrest periods to perpetrate criminal acts such as theft and sometimes vandalism of public and private properties including energy infrastructure [5]. The government through its security agencies appears incapacitated to ensure lasting solutions to this problem [74]. A secure and stable environment is a prerequisite for any substantial infrastructure investment.

5.2.2 Awareness Level

The competitiveness of off-grid solar PV appears widely unknown in Nigeria based on the survey results of [1]. For the deployment level of solar in Nigeria to match the clear economic potential found in this study, greater awareness throughout the Nigerian business sector is needed. Small PV applications such as with solar lantern, streetlights and small water pumping systems seemed to be well known in Nigeria. The other technology in popular use is an inverter and battery as alternative by some individuals and businesses. It appears that RE experts, researchers, investors and solar energy business companies within the country will need to campaign to make the economic benefits of solar technology well known to create a robust market in Nigeria.

5.2.3 Inadequate Government Support System

Furthermore, a short comparative analysis of G20 countries with Nigeria on availability of domestic credit to private sectors in Figure 5 shows that the Nigeria lags behind many other countries throughout the world. Countries like the United State, China, France and Germany have more than 75 percent of their GDP available to private businesses. While others have more than 35%, Nigeria has only 15% of its GDP accessible to its private sector as shown in Figure 5. Rather, the cost of governance, current and capital expenditure, takes very large shares of the GDP [75]. If the country will achieve the vision 20:2020 of G20 membership, it can ensure robust credit facilities especially on RE energy projects nexus to benefit overall economic prosperity. Public sector control, unfavourable bureaucracy and corrupt practices are potential barriers to private sector investment in and growth of solar energy in many developing countries [76]. A strategic approach to curtail these challenges can be devised to facilitate investment in solar technology. The results of this study have shown that a wide array of the business sectors in Nigeria would benefit from PV and battery hybrid systems coupled to existing generators. As these systems reduce the reliance on the generator the need for refined petroleum would decrease if solar hybrid systems were adopted nation-wide. Refined petroleum accounted for the largest fraction of Nigeria's imports in 2017 (18% of the total \$34.2B) [77].

Figure 5. Domestic Credit Available to Private Sector in Some G20 Countries and Nigeria (based on The World Bank data: Domestic credit to private sector (% of GDP) 2018).

5.3 Future work

Although in this study energy storage from batteries was considered in the simulation, a sensitivity was not carried for battery cost decreases. As inclusion of a battery yielded a substantial difference in the model, future research will be required to carry out full investigation on storage technologies and costs. Further work is also necessary to look at these systems experimentally in Nigeria to compare to the economic simulations. Future work on increasing security for PV in troubled regions may also accelerate adoption. An additional method to increase the penetration rate of PV is to couple it with a combined heat and power (CHP) or cogen system rather than simply a generator [78]. As these systems also make usable heat, not only are they more efficient, but they can also be made more economic by careful attention to dispatch strategy of the CHP system [79]. CHP can offer a more economical solution especially for companies that require heat such as boiler in their operations. Also, future work can be extended to analysing the potential of hybrid PV and trigeneration (to make electricity, heat and chilled fluids), the latter may of greater utility in Nigeria [80]. These systems are particularly efficient at the large scale appropriate for industry [81]. Lastly, these systems have shown promise in colder regions to expand into the new communities [82] and may be of interest in growing areas in Nigeria or coupling to other technologies (e.g. waste to energy [83]). Although the use of CHP by Nigerian private industries is not new [27], integration of this in the hybrid energy system could offer interesting solutions to energy challenges. In addition, as all these subsectors are located in the south-western region of the country with relatively lower solar insolation, future case studies should cover industries and private businesses in northern and eastern Nigeria. Lastly, this work in the urban centres would be expected to reduce costs, which would help with rural energy needs as well [84]; and these benefits could be quantified.

Overall, future work is needed to look at the macro-economic impact of widespread deployment of solar hybrid systems in Nigeria. Under this scenario each of the subsector's annual energy savings based on annual demand is US\$ 8.1, US\$ 0.4, US\$ 0.1, US\$ 2, US\$ 4.5 and US\$ 0.4 million for real estate, education, banking, automobile, hospitality and production, respectively. Total savings for all the six subsectors considered amounts to US\$ 15.5 million annually. In Lagos, there are over 2,000 private companies; 1,230 are real estate and properties, 440 are from manufacturing, 240 schools and 130 from banking firm [85]. If all these private companies in Lagos, for example, decide to adopt solar PV technology to meet their energy demands, substantial savings would be expected. Not only will these companies reduce their energy costs, but they will also have more liquidity for business expansion and greater capacity to employ more staff rather than downsizing [86,87]. The country will also benefit from widespread adoption of solar hybrid systems as they will assist the balance of trade by reducing refined petroleum imports. The use of a more efficient and lower cost energy system would be expected to impact the GDP of Nigeria, while the human development index would likewise be expected to improve with better services from education and health care sectors as well as less noise and environmental pollutions from diesel generators. All of these benefits could be quantified in future work. In order to help other researchers complete this future work all of the HOMER files used to complete this study are shared under a GNU General Public Licence (3.0) on the Open Science Framework [88].

6. Conclusions

The results of this study clearly show that solar PV and diesel hybrid energy systems are economically viable for a wide array of industries in the Nigerian private sector including in real estate, education, banking, automobile, hospitality and production. This study has established that LCOE is lower for every sector analysed with inclusion of solar PV as compared to use of diesel alone and is more reliable than the current grid-provided electricity. Lower LCOEs for hybrid solar systems provide savings in energy costs that make up a substantial fraction of the overall operating cost of some business organizations, which have historically weakened the Nigerian private sector by crippling their profitability and sustainability. In addition, the results of this study showed that the savings increased with the addition of a batteries for the solar PV coupled to diesel generators hybrid systems. Storage facilitates provide a means for the increase in penetration of PV in the energy system, which reduces the diesel use further improving the financial benefits. Five of the six sectors (excluding the automobile sector) had discounted payback times for the systems under a year and ROIs over 100%. The hospitality industry stands to gain over a 300% ROI for using a solar hybrid system with battery support. In conclusion, the results of this study make it clear that every Nigerian businesses (small, medium and large scale) that is for profit should be strongly considering investment in to solar PV for hybrid systems to increase their profitability.

7. References

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