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Economic viability of a generator/ photo-voltaic/battery hybrid system to powerpetrol stations in Ibadan, Oyo State, Nigeria

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Abstract
Nigeria falls in a region where weather conditions favour access to solar energy. Also, the irregular supply of electricity from the grid in the country reduces access to energy, thereby making it compulsory for firms to source alternative sources of energy in meeting their energy needs. This present study sought to ascertain the economic viability of a generator/photo-voltaic/battery hybrid system to power petrol stations in Nigeria and attempted to uncover the cost benefits of the hybrid system over the conventional Stand-alone generator system that is commonly used. Data were collected from six different petrol stations with different energy demands in Ibadan, Nigeria, and used HOMER software to simulate a 25-year production scenario for the hybrid and standalone systems. The analysis showed that implementing a generator/photo-voltaic/battery hybrid system in a grid load connection application to power petrol stations in Nigeria is not only feasible but also viable.When compared to the standalone system, the hybrid system had a lower net present cost and levelized energy cost.
Keywords: *Cost analysis; Energy cost; Hybrid system; Petrol station; Grid load*

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I. INTRODUCTION

The need to find alternative sources of electricity has been an issue of interest to researchers over the years. This is particularly so given that over two billion persons in the world are estimated to lack access to any public electricity networks [1]. Scholars also note that the quality of electricity infrastructure is of vital importance to the success of production activities [2-3]. The impact of unreliable electricity infrastructure on productive activities is particularly more pronounced in developing countries that are characterized by irregular electricity supply and high distribution losses [3]. Among sub-Saharan African countries alone, it is estimated that electricity disruptions account for 2.1 percent of GDP while firms' performance in these countries is on average, 4.9 percent lower than it should have been with dependable electricity [4].Indeed, World Bank data identifies inadequate electricity as the most pressing constraint to business ventures in developing countries.

One approach to resolving the issue of inadequate energy suggested by energy conservation proponents is the gradual transition toward renewable energy sources [5-8] because they are mostly inexhaustible and environmentally sustainable, unlike typical fossil fuels. Kaygusuz and Katgusuz[8] identified energy from biomass, geothermal, hydroelectric, ocean, solar, and wind sources as examples of renewable energy.Concerning the use of solar power, several studies demonstrate that the use of photo-voltaic panels and other hybrid energy systems that include solar power is not only feasible but also viable. For example, Yang et al. [9] found that maintenance and operating costs and the interest on the loan are smaller for Concentrated Solar Power (CSP) operated by power towers compared to that operated by parabolic through. The authors also showed that solar tower-operated CSPs had a better Internal Rate of Return (IRR) and longer static payback period as a result of the higher initial investment.

Acakpovi et al. [10] compared the relative costs of solar power transmission based on different optimization procedures. The authors revealed that HOMER optimization showed hybrid-solar-wind-hydroelectrical energy supply incurred lower costs as compared to the self-optimization procedure. Glykas et al.[11] examined the cost-effectiveness of installing solar hybrid systems on merchant ships and concluded that the installation of solar hybrid systems was profitable for merchant ships and its relative profitability was sensitive to fuel prices. The authors estimated a payback period of 16 to 27 years for an annual increase in average fuel price of about 10 to 15 percent. Nelson et al. [12] compared the traditional wind/photo-voltaic/battery system to the wind/photo-voltaic/fuel cell/electrolyzer system and concluded that the former had substantial economic advantages over the latter for home-use in the Pacific Northwest of the United States. Ajao et al.[13] arrived at contrary conclusions that Nigeria's central grid power was relatively viable compared to the solar hybrid system and estimated a payback period of 33 years which is nonviable given the existing cost of electricity.

Kaldellis et al. [14] bemoaned the high electricity costs and the inconsistency of supply for islands along the Southeast Mediterranean Sea. Toalleviate the quality of life, the solar energy for electrification in these areas was examined and found viable to offer minimal costs relative to existing methods. The authors justified the implementation of solar electrification on the grounds of positive macroeconomic impact and decreased environmental costs.

The justification for the implementation of solar electrification based on environmental implications has been echoed by other researchers. Issues such as global warming as a result of fossil emissions and greenhouse gases have received considerable attention in the literature [15-16]. The overriding conclusions recognized solar energy as a cleaner, and environmentally friendly alternative to conventional energy sources [17], although it could involve considerable initial capital outlay [9]. In this respect, scientific data has shown the feasibility and relative viability of solar electrification in a variety of contexts. For instance, Ramadhan and Naseeb[18]documentedthe feasibility of implementing photo-volcanic systems in Kuwait albeit for prices of crude oil around 100 USD. The authors also demonstrateda significant decline in the economic costs of solar systems with decreased CO_2 emission as a result of solar electrification is accounted for.

Li et al. [19] compared the relative viability of coal-fired plants to reinforced concrete solar chimney power plants. The author'sfindings show that although the minimal electricity price of the proposed system was initially higher than the existing market price,it declined enough subsequently to justify the implementation. Ma et al. [20] associated excessive fuel costs, noise pollution, soil pollution, and other negative environmental impacts with the use of diesel-fueled generators. On these grounds, the authors proposed a hybrid system of solar, wind, and battery for electrification of a remote village or small island in Hong Kong. Their findings show that the solar-wind-battery system can be feasibly implanted in the small island. Investigating the possibility of Solar Thermal Energy (STE) systems for India, Beerbaum and Weinrebe[21] identified air pollution, ash disposal, environmental degradation, and exhaustibility as some of the constraints associated with Coal Thermal Energy (CTE) systems. Their findings suggest that the levelized cost of electricity for STEs can be substantially lower than those of CTEs under favorableconditions.

The primary goal of this study is to investigate the economic feasibility of solar hybrid power systems to power petrol stations in Nigeria. The oil and gas industry has interested researchers all over the world, but most studies carried out are largely focused on the upstream and midstream sectors. Studies on petrol fuel stations, which are in the downstream sector, are extremely limited, particularly in Nigeria. This paucity of research constitutes concern since the petrol stations deal directly with the end-users making it very imperative for adequate research assessing the needs and challenges preventing the effective running of the stations.

II. METHODOLOGY

In this present study, the costs associated with a solar hybrid power system constructed for a typical petrol station were examined and compared with the cost of grid power usage complemented with a diesel power generating set. The proposed hybrid system is comprised of four components (battery, generator set, inverter, and photo-voltaicpanels) in a grid-connected application and is presented in Figure 1.

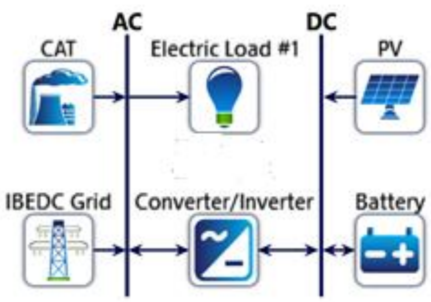

Figure 1: Proposed Hybrid System

2.1 Data and Sample

The research instrument used collected information on daily activities, energy consumption, production/sales, and power supply from the grid about the petrol stations. The study coveredsix petrol stations operating within Ibadan, Oyo State, Nigeria. The choice of Ibadan within Oyo State derives from the fact that it is the commercial capital center of the state. As a result, petrol station operations are likely to be more concentrated in Ibadan than in other parts of the state. The petrol stations were selected based on geographical distribution around Ibadan. For proper coverage, petrol stations that are located in the urban (city) and semi-urban (less city) areas of Ibadan were considered and three stations each were selected based on willingness to participate. The petrol stations covered include EnyoBodija Petrol Station, Lagos-OjooExpressway; Total Petrol Station, Sango; and Total Petrol Station, Samonda in the urban areas; and IyanjuPetrol Station, Lakoto, Ajibode; Bright-Honey Petrol Station, Ile-Tuntun and Samog Petrol Station, Wire and Cable, Apata, Ibadan in the semi-urban areas.

2.2 Criteria and Model Assumptions

Non-parametric cost analysis was used to derive the economic criteria for determining the viability of a hybrid solar panel system. Specifically, viability was examined via net present costs, annualized costs, and Levelized Cost of Energy (CoE), for each of the petrol stations considered. An expected project lifetime of 24 years was assumed based on the expected lifetime of 25 years for the photo-voltaic panels of the hybrid system. A much lower lifetime is expected for the batteries and diesel generators depending on use and maintenance. All monetary values were expressed in dollars in the HOMER software environment, using an average dollar to naira exchange rate value of ₦380. The average cost of diesel and petrol were set at ₦200/litre and ₦145/litre, respectively. Grid energy cost was set at the current commercial tariff of ₦38.87/unit. The discount rate and inflation rates are set at 6% and 2%, respectively.The other model parameters used weresummarized in Table 1.

Table 1: Model Parameters

Component	Type	Lifetime	Efficiency (%)	Capacity	Capital cost	Rep. cost	O&M cost
Diesel Generator	CAT	25,000 Op. Hours	-	1kW	$847.53	$860	$0.3/Op. hrs.
PV	Preimar SG325P	30 years	16.7	1kW	$789.47	$760	$3/yr.
Battery	Optimuz	6 years	90	201Ah, 12V	$394.74	$401	$3/yr.
DC-DC Converter/ DC–AC Inverter	Studer AJ 275-12	10 years	93	1kW	$100	$102	$3/yr.
MPPT	MPP SOLAR	15 years	95	1kW	$100	$92	$3/yr.

HOMER optimization software was used to estimate the costs in Table 1. The estimation procedure involves a process of simulation that makes energy balance computations in each time period (in this case, annual). In each period, HOMER computed the flow of energy to and from each component in the hybrid system in addition to comparing electric and thermal energy demand to the energy capacity of the system in a given period. When the system incorporated fuel-powered generators or batteries, HOMER also decided on optimal operation for the generators and when to discharge or charge the batteries. The HOMER's cost estimation gave the estimated cost over the lifespan of the system. The estimation accounted for capital, fuel, interest, and operation and maintenance costs.

2.3 Net Present Costs

Net Present Costs (NPC) is the discounted lifetime cost of the system which can be computed usingEquation (1):

$$NPC = C_k + C_r + \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - S \quad (1)$$

Where $C_k$represents initial capital cost; C_r is the cost of replacement; C_t is expenses in year t; r is the real discount rate; S is the salvage value, and T is the expected lifespan of the system. Yearly expenses are computed as the sum of maintenance and operating and fuel costsusingEquation (2).

$$C_t = C_{mo,t} + C_{f,t} \quad (2)$$

Where, $C_{mo,t}$ represents maintenance and operation cost while $C_{f,t}$ is fuel cost. The NPC, therefore, covers initial capital investment, replacement costs, and the present values of energy (fuel) cost, maintenance cost, and operation cost.

2.4 Annualised Cost of Energy

The annualized cost is computed by multiplying the net present cost of the system by the Capital Recovery Factor (CRF) as shown in Equation (3).

$$C_{an} = CRF(r,T) \cdot NPC \quad (3)$$

where C_{an} represents annualized cost and CRF is computed using Equation (4).

$$CRF(r,T) = \frac{r(r+1)^T}{(r+1)^T - 1} \quad (4)$$

2.5 Levelized Cost of Energy

The LevelizedCoE(LCoE) estimates the monetary value of electricity generated by the proposed energy system. Specifically, the LCoE computes the average cost per kilowatt hours of electricity produced by an energy system [22]. The LCoE is computed using Equation (5).

$$LCOE = \frac{C_{an}}{EEC} \quad (5)$$

where, $EEC = EEC_a + EEC_d$, andEEC_a = yearly total ac load and EEC_d = yearly total dc load.

III. RESULTS AND DISCUSSION

3.1 Descriptive Analysis

The electricity consumption profile of the sampled stations is shown in Table 2. The stations are categorized as follows: Station A = Enyo Petrol Station, Bodija Ibadan; Station B = Total Petrol Station, Sango, Ibadan; Station C = Total Petrol Station, Samanda, Ibadan; Station D = Iyanju Petrol Station, Ajibode, Ibadan; Station E = Bright Honey Petrol Station, Ile-tutun, Jericho, Ibadan; and Station F = Samog Petrol Station, Wire & Cable, Apata, Ibadan. As seen in Table 2, Station A has the highest electricity consumption (58.99 kWh) and operates for 14 hours a day on average. Station B, with the highest hours of operation (18 hours), consumes less electricity (45.25 kWh) than Station A. Station C also operates for relatively more working hours (16 hours per day) than Station A, but consumes relatively less electricity (30.87 kWh).

Table 2: Electricity Consumption Profile of Petrol Stations

Station	Working Hours	Hours of Grid Supply	Average Monthly Grid Utility Bill Received ($)	Electricity Consumption (kWh)
A	14	4	26.32	58.99
B	18	5	117.11	45.25
C	16	8	117.11	30.87
D	14	0	0	21.05
E	15	4	39.47	35.19
F	15	5	7.89	8.07

Source: Author's computation from field survey.

Station D has the least working hours (14 hours) among the sampled petrol stations and its average electricity consumption is 21.05kWh. Station E and F operate for an average of 15 hours per day but electricity consumption for Station E (35.19 kWh) is relatively higher (8.07 kWh). The average hours of grid supply per day are quite low with the highest being associated with Station C (8 hours) followed by Station B and Station F with 5 hours. Station A and Station F enjoy just 4 hours of grid electricity per day on average while station D relies solely on self-generated electricity. The average monthly utility bill due to grid electricity consumption seems not to be reflective of electricity consumption, hours of grid supply, or average hours of daily operation. This is because the stations with very high utility bills compared to their electricity consumption are not using pre-paid electricity meters which makes their bills to be estimated. Nonetheless, Stations A and B which have the highest operating hours are associated with the largest monthly utility bills from grid connection ($117.11). Surprisingly, Station A, with 14 hours of operation daily pays higher utility bills ($26.32) than Station F with 15 hours of operation and utility bills of $7.89.

The generator usage profile of the Petrol Stations is presented in Table 3. Comparing the average running hours of running generators to the hours of grid supply shown in Table 1, it is found that some form of pattern seems to exist between both. For instance, Station B with the least hours of grid supply is also associated with the longest duration of daily generator operation (14 hours). Similarly, Station C is associated with the most hours of grid supply and has the least hours of generator operation among the sampled petrol stations. Except for Station F which uses petrol-powered generators, the other petrol stations utilize diesel-powered generators. The operation and maintenance costs of the generators appear to be reflective of their initial costs as seen in Table 3. Surprisingly, the monthly fuel consumption does not appear to reflect the average daily hours of use for the generators. It is also noted that in Station F where a petrol-powered generator is used, the monthly fuel cost is least.

Table 3: Generator Usage Profile of Petrol Stations

Station	**Type**	**Capacity (KVA)**	**Cost ($)**	**Running Hours**	**Monthly Fuel Consumption ($)**	**Monthly O&M Cost ($)**
A	Diesel	25	9210.53	10	434.21	31.58
B	Diesel	25	9210.53	13	868.42	31.58
C	Diesel	25	9210.53	8	473.68	31.58
D	Diesel	9	789.47	14	236.84	15.79
E	Diesel	15	1500	10	315.79	39.47
F	Petrol	7.5	631.58	10	157.89	10.53

Source: Author's computation from field survey

The performance of grid-provided electricity for the sampled stations is presented in Table 4. The mean failure time is defined as the projected instances of gridfailure per year. It is found that the projected mean failure frequency is highest for Station A with 1000 hours of grid failure per year. This is followed by Station E with a projectedfailure of 900 hours. Stations B, C, and F all have projected failure instances of 800 hours per year. The mean duration per day of grid outages in hours is represented by the mean repair time. Stations A, C, and E all have 5 hours as mean repair time, while Stations B and C have 4 hours as mean repair time.

Table 4: Grid Performance

Indicator	**Station**					
	A	***B***	***C***	***D***	***E***	***F***
Mean failure frequency (Hours)	1000	800	800	No Grid Supply	900	800
Mean repair time (Hours)	5	4	4		5	5
Variability in repair time (%)	70	60	60		70	70
APC for optimization (Watts)	6000	5000	4000		5000	1500

The standard deviation of a grid failure period expressed in percentage of the mean is the variability in repair time. It is observed relatively higher repair time in Stations A, E, and F (70 percent) as compared to Stations B and C (60 percent). The variability is reflected in the mean failure frequency in each station. The APC for optimization represents the maximum amount of power drawn from the grid at any given time. This is highest for Station A (6000 watts) and least for Station C (4000 watts). For Station B and Station E, 5000 watts of electricity from the grid is required for optimization.

The relative dependence on grid supply is emphasized in Figure 2 where the proportion of off-grid supply in total operation time per day is plotted. Station D depends totally (that is 100 percent of the time) on a generator for power supply during operating hours. The dependence on generators for operation is also relatively high for Stations A, B, and E with 71.43 percent, 72.22 percent, and 73.33 percent dependence on generators, respectively during operating hours. Station C depends on the least proportion, depends on the generator for about half of its operating hours on average while Station F depends on generators for 66.67 percent of its operating time.

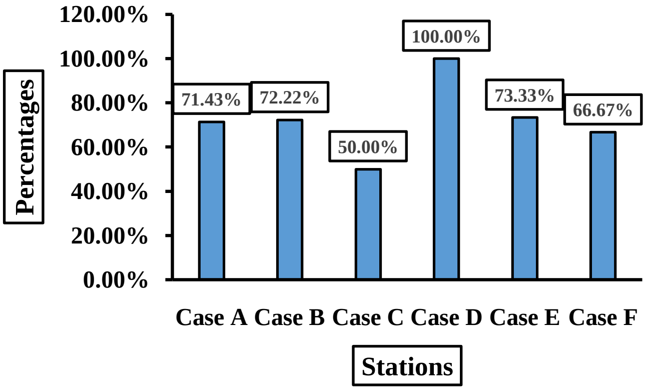

Figure 2: Proportion of Generator Hours in Operation Time

3.2. *Cost Analysis*

The cost analysis covers 25 years as given by the life cycle of an average PV panel while inflation and interest rates are chosen as6 percent and 2 percent, respectively. Fuel cost is chosen to be ₦200/litre for diesel and ₦145/litre for petrol. The summary of present valued costs for the standalone system is presented in Table 5. The figures in Table 5 represent the total cost for each component which is a sum of capital, operating, replacement, salvage, and resource costs. Looking at the cost structure of the standalone system, the generator component appears to constitute more cost than the grid component. This is not surprising since there is relatively lesser dependence on the grid power supply as observed in the previous section. Across stations, both net present costs and annualized costs are highest for station A and least for station D. This is not strangesince C relies solely on a power generating set.

Table 5: Simulated Present Values of Costs for the Standalone System

Cost	Station					
	A	***B***	***C***	***D***	***E***	***F***
Net Present Costs ($)						
Auto-size Gen Set	$165,800	$100,091	$74,733	$13,419	$128,846	$25,897
IBEDC Grid	$13,465	$16,775	$11,458	-	$9,926	$2,648
System	$179,265	$116,867	$86,191	$13,419	$138,772	$28,545
Annualized Costs ($)						
Auto-size Gen Set	$10,525	$6,354	$4,744	$851.87	$8,179	$1,644
IBEDC Grid	$854.78	$1,065	$727.37	-	$630.10	$168.07
System	$11,380	$7,419	$5,472	$851.87	$8,810	$1,812

Source: Simulated with Homer Software

The costs associated with the standalone system are better comparedto the present values of costs for the hybrid system as listed in Table 6. It is found that the net present costs associated with the hybrid system are lower than that of the standalone system for all the petrol stations except for station D. In the case of station D, the hybrid system's cost is higher because of the complete independence on grid supply. Across stations, the cost pattern for the hybrid system is fairly similar to that of the standalone system with Station A having the largest cost and Station D having the least cost.

Table 6: Simulated Present Values of Costs for the Hybrid System

Cost	Station					
	A	*B*	*C*	*D*	*E*	*F*
Net Present Costs ($)						
Auto-size Gen Set	$28,721	$9,599	$7,125	$5,303	$12,351	$1,721
IBEDC Grid	$29,245	$22,726	$13,612	-	$15,636	$1,887
Optimuz 12V 200Ah	$42,779	$25,270	$16,531	$6,430	$21,566	$4,090
Peimar SG325P	$3,907	$2,899	$3,322	$5,173	$4,466	$2,307
PV Dedicated Converter	$187.20	$187.20	$187.20	$187.20	$187.20	$187.20
Studer Con/Inv.	$11,136	$6,559	$5,136	$2,114	$6,473	$1,510
System	$115,976	$67,240	$45,913	$19,207	$60,678	$11,702
Annualized Costs ($)						
Auto-size Gen Set	$1,823	$609.35	$452.34	$336.64	$784.06	$109.25
IBEDC Grid	$1,857	$1,443	$864.11	-	$992.59	$119.78
Optimuz 12V 200Ah	$2,716	$1,604	$1,049	$408.18	$1,369	$259.66
Peimar SG325P	$248.04	$184.03	$210.90	$328.42	$283.50	$146.48
PV Dedicated Converter	$11.88	$11.88	$11.88	$11.88	$11.88	$11.88
Studer Con/Inv.	$706.94	$416.38	$326.04	$134.21	$410.92	$95.84
System	$7,362	$4,269	$2,915	$1,219	$3,852	$742.89

Source: Simulated with Homer Software

3.3 Summary of Electricity Analyses

The summary of electricity analyses for the standalone system is presented in Table 7. The excess electricity is highest in the case of Station E (1,051 kWh per year) and lowest for station A (59.3 kWh per year). Station A has the highest electricity shortage with an annual unmet electricity load of 13.3 kWh per year whereas station F has the least (1.17 kWh per year). In terms of capacity shortage, Station A has the highest (14.6 kWh per year) while Station C has the least (1.58 kWh per year). Concerning electricity production, the bulk of total production for the system is due to generator generation for Station A and Station E (13,222 kWh and 7728 kWh per annum respectively). For Stations B, C, and F, the bulk of production come from grid purchases (10,410 kWh, 7,110 kWh, and 1,643 kWh, respectively). Looking at the consumption summary, per annum kilowatt-hoursare reflective of hours of generator operation which is highest for Stations A, B, and E.

Table 7: Annual Electricity Production and Consumption of Standalone System

	Station					
	A	*B*	*C*	*D*	*E*	*F*
Excess and Unmet (kWh/Yr.)						
Excess Electricity	59.3	605	473	640	1,051	272
Unmet Electric Load	13.3	12.9	1.44	5	8.19	1.17
Capacity Shortage	14.6	14.2	1.58	6	9.01	1.29
Production Summary (kWh/Yr.)						
Auto-size Gen Set	13,222	6,699	4,629	4,241	7,728	1,574
Grid Purchases	8,356	10,410	7,110		6,159	1,643
Total	21,577	17,109	11,740	4,241	13,887	3,217
Consumption Summary (kWh/Yr.)						
AC Primary Load	21,518	16,503	11,266	3,601	12,836	2,944
DC Primary Load	0	0	0	0	0	0
Deferrable Load	0	0	0	0	0	0
Total	21,518	16,503	11,266	3,601	12,836	2,944

Source: Simulated with Homer Software

The annual production and consumption of electricity for the hybrid system are presented in Table 8. The simulations show that the proportion of total production due to the components is not the same across petrol stations. For instance, the generator component of the system accounts for most of the produced electricity in Stations A, B, C, and E (18,148 kWh, 14,103 kWh, 8,447 kWh, and 9,703 kWh per annum, respectively). Only for Stations D and F are the solar PV production higher than grid production.

Table 8: Annual Electricity Production and Consumption of Hybrid System

	Station					
	A	***B***	***C***	***D***	***E***	***F***
Production Summary (kWh/Yr.)						
Peimar SG325P	3,379	3,108	3,235	3,601	3,489	2,859
Auto-size Gen Set	3,087	868	581	-	1,158	88.7
Grid Purchases	18,148	14,103	8,447	428	9,703	1,171
Total	24,614	18,079	12,263	4,028	14,349	4,118
Consumption Summary (kWh/Yr.)						
AC Primary Load	21,531	16,516	11,268	3,606	12,844	2,946
DC Primary Load	0	0	0	0	0	0
Deferrable Load	0	0	0	0	0	0
Total	21,531	16,516	11,268	3,606	12,844	2,946

Source: Simulated with Homer Software

3.4 Economic Criteria

The summary of the estimated indicators is presented in Table 9. The net present cost of the hybrid system is consistently lower when compared to that of the standalone system for all the petrol stations. On the other hand, the initial capital outlay (CAPEX) required for implementation is much higher for the hybrid system as compared to the standalone system for all the petrol stations. However, when operating expenses are considered, the estimatesshow that the hybrid system performs better over the projected period as the associated expenses are lower across all the petrol stations. Also, the LevelizedCost of Electricity (LCoE) is quite lower for the hybrid system than for the standalone system for all the petrol stations. Regarding emissions, the hybrid system is necessarily more efficient than the standalone system since it involves less dependence on generators. The annual kilograms of CO_2 emission is lower for the hybrid system in all the petrol stations.

Table 9: Summary of Economic Indicators

Indicator	**Station**					
	A	***B***	***C***	***D***	***E***	***F***
Net Present Cost ($])	179,265	116,867	86,191	75,198	138,772	28,545
	[115,976]	[67,240]	[45,913]	[19,207]	[60,678]	[11,702]
CAPEX ($)	6,017	4,831	4,068	1,610	4,916	1,187
	[33,182]	[21,460]	[17,115]	[10,318]	[21,855]	[6,101]
OPEX ($)	10,998	7,112	5,213	4,672	8,498	1,737
	[5,256]	[2,906]	[1,828]	[564.35]	[2,465]	[355.60]
LCOE per kWh ($)	0.53	0.45	0.49	1.33	0.69	0.62
	[0.34]	[0.26]	[0.26]	[0.34]	[0.30]	[0.25]
CO_2 Emitted (kg/Yr.)	16,920	12,859	8,963	4,239	11,481	2,549
	[13,874]	[9,578]	[5,788]	[353]	[7,032]	[815]
Fuel Consumption (L/Yr.)	4,447	2,399	1,707	1,620	2,899	577
	[919]	[254]	[172]	[135]	[344]	[28.8]

Note: Figures in brackets represent values simulated for the hybrid system
Source: Estimated with HOMER Software

In connection with emission, the fuel consumption profile of the two systems across the petrol stations also suggests that the hybrid system is relatively more efficient as its fuel consumption is relatively lower for all the petrol stations considered. By and large, the economic indicators suggest that the hybrid system is a more economically viable project as compared to the standalone system given the parameters and assumptions behind the simulations.

IV. CONCLUDING REMARKS AND POLICY IMPLICATIONS

Nigeria falls in a region where weather conditions favour access to solar energy. Also, the irregular supply of electricity from the grid in the country reduces access to energy thereby making it compulsory for firms to source alternative sources of energy in meeting their energy needs. This studysought to ascertain the economic viability of a generator/photo-voltaic/battery hybrid system to power petrol stations in Nigeria. The cost benefits of the hybrid system over the conventional stand-alone generator system wereuncovered. The study used data collected from six different petrol stations with different energy demands in Ibadan, Nigeria via questionnaires, and data analysis was done using the HOMER software. The analysis showed that implementing a generator/photo-voltaic/battery hybrid system in a grid load connection application to power petrol stations in Nigeria is not only feasible but also viable. The structure of a petrol station (canopy or station building roof) gives an advantage for the deployment of the photo-voltaic panels for effective access to the sun.The findings established that the capital cost of implementing a generator/photo-voltaic/battery hybrid system in a grid load connection application is higher when compared to a stand-alone generator system which is about six times lesser. However, the operating cost of the hybrid system is four times lesser than that of the Stand-alone system which makes the annualized cost of the hybrid system lesser.

The findings further established that a generator/photo-voltaic/battery hybrid system in a grid load connection application to power petrol stations in Nigeria is viable because its net present cost is lower throughoutthe 25-years life span of the system. The system also gives a stable and cheaper levelized cost of energy which has a long-run advantage because the levelized cost of energy of the grid system increases over time due to inflation and other factors. By and large, an economic analysis of the two systems favours the viability of the hybrid system over the stand-alone system. The following recommendations were madebased on the findings:

a) Policies should be put in place to support investment in the hybrid system through a form of waiver or rebate by the government to encourage its development like what is applicable in the USA, India,and other countries.
b) Regulatory agencies can enforce emission tariffs to encouragethe use of clean sources of energy.
c) The ability and efficiency of renewable sources of energy (solar) to power business/service-providing outfits should be publicized via adverts, lectures, and workshops.

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