NIPES

Journal of Energy Technology and Environment

Journal homepage: www.nipesjournals.org.ng

Modelling and Optimisation of Levilised-Cost-of-Energy Optimisation for Plant Selection in an Off-Grid Hybrid Energy System

Eyere Emagbetere* **and Idowu Temitope Adeleye**
Department of Mechanical Engineering, Federal University of Petroleum Resources, Nigeria
*Corresponding Author: emagbetere.eyere@fupre.edu.ng

Article information

Article History
Received 20 September 2024
Revised 14 October 2024
Accepted 2 November 2024
Available online 19 Dec 2024

Keywords:
LCOE, Simplex method, integer programming, energy optimisation.

OpenAIRE

https://doi.org/10.5281/zenodo.14525374

https://nipes.org

Abstract

This study aims to develop a selection tool that would optimise levelized-cost-of-energy (LCOE) for a hybrid energy generating and distribution systems using FUPRE as a case study. The research begins with a detailed LCOE modelling process, dissecting the cost components of the hybrid energy system. A sensitivity analysis is conducted to identify and assess the impact of various factors such as capital costs, operational expenses, and energy output on the LCOE. Optimum solutions for selecting a suitable plant for 9 different supply areas with various energy sources, including, diesel generator, petrol generator, solar and grid, were sought using ACO and simplex method simultaneously, for varied energy need. The result revealed that PV type solar energy which has a fixed operational cost has the least LCOE. However, diesel generators of capacity over 100 kVA could present LCOE that is lower than grid under load conditions over 90% of its capacity. In all, petrol generators are least economical, having least capacity of energy and very high LCOE. Simplex method was shown to be effective for selecting the most economical energy sources among different sessional energy supplies using the developed linear integer optimisation model, whereas, ACO technique failed to solve the optimisation model accurately. This research contributes to advancing the understanding of LCOE modelling and optimization in hybrid energy systems, shedding light on the intricate balance between economic factors and sustainable energy practices. The methodologies presented offer practical applications for decision-makers in the energy sector, guiding the development of cost-effective and environmentally conscious energy solutions.

1. Introduction

In the pursuit of sustainable energy solutions, off-grid hybrid energy systems have emerged as a vital component in providing reliable and clean energy access to remote and isolated regions worldwide [1-3]. These systems integrate multiple renewable energy sources, such as solar, wind, and generators, alongside energy storage technologies and possibly conventional energy sources, to meet the energy needs of off-grid communities[4]. A large proportion of Nigerians and other Africans lack access to steady electricity supply [5], driving the adoption of off-grid hybrid energy solutions that combine different sources like diesel generators, solar and with energy storage.

Large communities, such as university campuses have a huge number of energy sources supplying different areas based on availability and cost. Designing and optimizing off-grid hybrid energy systems present unique challenges, particularly in selecting the most cost-effective combination of energy generation plants to ensure long-term sustainability and affordability[6].

The literature on plant selection via LCOE optimization in hybrid energy systems reveals a rich landscape of methodologies and models aimed at designing cost-effective and sustainable energy infrastructures [7-8]. Researchers have developed mathematical programming approaches and metaheuristic algorithms to minimize LCOE by assessing capital costs, operational expenses, and energy yields of various energy generation technologies[7,9-10]. Techno-economic analyses have emphasized the integration of diverse renewable and conventional sources, alongside energy storage technologies, to maximize energy production while reducing environmental impacts [11-14]. Additionally, studies have addressed uncertainties and risks through probabilistic methods and explored multi-objective optimization techniques to balance conflicting objectives such as cost minimization and emissions reduction [15-17]. Real-world case studies have demonstrated the practical relevance of LCOE optimization in optimizing the design, operation, and planning of hybrid energy systems across different scales and sectors [18-19], highlighting opportunities for future research to address emerging challenges and integrate evolving technologies and policies.

The optimization of plant selection in off-grid hybrid energy systems via LCOE presents significant challenges. Existing methodologies primarily focus on grid-connected systems, neglecting the unique complexities of off-grid environments [18,20]. Off-grid systems operate in remote areas with limited access to conventional energy sources, requiring diverse renewable energy technologies and energy storage systems for reliability. Additionally, the dynamic nature of off-grid energy demand and renewable resource availability complicates plant selection[21-22]. Current models are not readily easy to solve, leading to conservative solution[1]. Thus, there is a pressing need for tailored optimization methodologies and decision support tools specifically designed for off-grid hybrid energy systems to maximize economic viability and sustainability.

This study aims to explore and evaluate the optimised solution of LCOE for plant selection in hybrid energy systems, using the Federal University of Petroleum Resources as a case study. The primary objective is to provide a comprehensive methodology that models and minimises the LCOE of energy generation and distribution using a suitable case study, thereby offering insights into an effective way and opportunities for improving the operation and planning of hybrid energy systems. Through its exploration of LCOE optimization, the article ultimately aims to contribute to informed decision-making and strategic planning in the utilisation of different energy sources.

2. Methodology

The methodology of this study involved, energy data collection for a set of energy sources and supplies within the Federal university of Petroleum Resources Campus, development of a model for energy generation of the hybrid system and optimisation solution of the model

2.1 FUPRE Energy System

The data utilised in this project was collected from the Department of Works at the Federal University of Petroleum Resources, Effurun (FUPRE). FUPRE is a federal university located in Effurun, Delta State Nigeria. The different facilities located within the campus and their power need is summarised in Table 2. The plant specifications, including data used to compute the LCOE is shown in Table 3. The overall energy system consists of several energy sources and building sessions that are described as follows

2.2 Available power sources

a. 500 KVA 33/11KV injection substations (BDEC public power supply).
b. 500KW solar-diesel hybrid power plant which delivers a maximum 80% efficiency of rated power capacity (400KVA /400KW respectively).
c. Several petrol generators of capacity between 3 KVA to 5 KVA located at different session.
d. Different capacities of diesel generators providing alternative power supply to each building complex. The buildings serviced by the different energy sources are shown in Table 1

Table 1: Different sessions and available designated diesel generators

Session	BUILDINGS / FACILITIES	DIESEL GENERATOR ATTACHED
Session 1	Administrative buildings/Water plant / Library complex/ Workshop/Laboratory (Petroleum Engineering Buildings)	500 KVA
Session 2	College Of Technology, Workshop/Laboratory (Chemical Engineering) Workshop/Laboratory (Marine Engineering Workshop/Laboratory (Elect/Elect Engineering Workshop/Laboratory (Mechanical Engineering) buildings Student Centre Building.	500 KVA
Session 3	Health Centre/security, Convocation hall, and corpers members lodge, physical planning b uilding	135 KVA
Session 4	Hostels B1, B2 And A buildings	100 KVA
Session 5	College of Science Buildings Phase 1 and 2 /Entrepreneurship Building , PG-School building, Civil Engineering building	250 KVA
Session 6	Tetfund classroom and office Building 1	50 KVA
Session 7	Tetfund classroom/Office Building 2 / Twin lecture theatre /College of marine studies building	60 KVA
Session 8	ICT building	60 KVA
Session 9	Ugbomro Female Hostel	8 KVA

Table 2: Different facilities / buildings and their average power need

S/NO	BUILDING	LOAD
1.	Administrative buildings/Water plant	84 kw
2.	Health Centre/security and corps members lodge/ICT buildings	46 kw
3.	Library Building /Lecture theatre 1	47kw
4.	College of Technology building	45 kw
5.	Hostel B1, B2 And A.	38 kw
6.	College of Science Building	72 kw
7.	Student Centre Building	10 kw
8.	Workshop/Laboratory (Chemical Engineering)	23 kw
9.	Workshop/Laboratory (Marine Engineering	20kw
10.	Workshop/Laboratory (Elect/Elect Engineering	22kw
11.	Workshop/Laboratory (Mechanical Engineering)	26 kw
12.	Workshop/Laboratory (Petroleum Engineering)	23kw
13.	Entrepreneurship Building	32 kw
14.	Ugbomro Female Hostel	15kw
15	Tetfund classroom/Office Building 1	42 kw
16	Tetfund classroom/Office Building 2	30kw
17	Twin lecture theatre	32kw
18	Street Light poles/ fittings	11 kw

Table 3 Plant capacity and other specifications

Plant type	Capacity (KVA)	Specification	Capital cost (million Naira)	Fuel consumption rate at max capacity (lit/hr)	Fuel consumption rate at 1/4 capacity (lit/hr)	Max output (kw)
Diesel generator	500	Perkins 2800	23.5	135.00	41.60	400
Diesel generator	135	FG Wilson	5.05	37.10	12.40	108
Diesel generator	100	FG Wilson	4.05	27.98	9.83	80
Diesel generator	250	Perkins PF_P275	10.1	68.07	21.55	200
Diesel generator	8	Hyundai	0.8	3.50	1.50	6.5
Diesel generator	50	Mikano	7.2	17.02	6.43	40
Diesel generator	60	Mikano	8.5	18.15	6.81	45
Petrol generator	5.5	Varied	0.74	1.20	0.80	4.8
Petrol generator	3.5	Varied	0.53	1.00	0.65	3
Petrol generator	3	Varied	0.45	1.00	0.60	2.8
Petrol generator	2.5	Varied	0.35	0.80	0.50	2
Solar plant	500		1500	0.00	0.00	450

2.4 Other utilities and energy requirement

1. 2 x 15kw central water plant
2. Surface/submersible water pumping machines attached to each building.
3. 80 number streetlight poles with energy lamp fittings on campus and environs.

2.5 Levelized Cost of Energy

Calculating the LCOE for a hybrid power system involves estimating the total cost of purchase, operating, and maintaining the system over its lifetime and then dividing that cost by the total amount of electricity it is expected to generate during its lifetime. The LCOE was calculated using the formula for LCOE given in Equation 1.

$$\text{LCOE} = (\text{Total present value of Costs}) / (\text{Total present value of energy output}) \quad (1)$$

Total Present Value of Costs, which is calculated using Equation 2, represents the sum of all costs associated with the energy system over its lifetime, including initial capital costs (C), operational and maintenance costs (OM), and any financing or incentive-related costs (F) expressed in present value terms. This is typically calculated using a discount rate (r) and the number of years (n) over the project's lifetime.

$$\text{Total Present Value of Costs} = \sum \frac{C+OM-F}{(1+r)^n} \quad (2)$$

Total Present Value of Energy Output, which is calculated using Equation 3, represents the sum of all energy produced by the system over its lifetime (E), also expressed in present value terms. Like costs, this is typically calculated using the same discount rate (r) and the number of years (n) over the project's lifetime.

$$\text{Total Present Value of Energy Output} = \sum \frac{E}{(1+r)^n} \quad (3)$$

The discount rate (r) was taken as 5% for all the energy sources, which is an average value between the range of discounted values used for cases with low LOCE.

2.6 Optimisation model

The optimisation modelling entails the derivation of an objective function and constraints that would be suitable for minimising the total cost of energy for the hybrid system.

2.6.1 Objective function: the objective function which represents the total cost of energy (T_i) for n number of plants is given as a product of the LCOE of each plant (C_i) multiplied by an integer factor x_i as shown in Equation 4.

$$T_i = \sum_{i=1}^{n} C_i * x_i \quad (4)$$

2.6.2 Equality constraints

This is the set of equations that limits the energy source that supplies a particular session to just 1. This equation validates the fact that only one energy source can be used to supply a session or building per time. It is of the form of Equation 5. Where Q_i is one for all energy source i for session Q.

$$\sum Q_i * x_i = [1] \quad (5)$$

2.6.3 Bound constraints

This is the constraint that subjects the variables to either 1 or 0. It is of the form of equation 6

$$0 \leq x_i \leq 1 \quad (6)$$

2.7 Solving the Model

The solution to the model was determined using Python solver in the Scipy library. This library was selected based on factors like ease of use, documentation and community support that were available. The solution was determined using Simplex method.

2.8 Simulation and Sensitivity analysis

Based on the obtained data and developed model, energy needs for different session were statistically described, the different sessions LCOE were estimated, and energy sources were selected for different sessions for the different plants for minimal cost based on the proportion of energy need.

3. Results and Discussions

This session presents the results generated from the LCOE analysis for the different energy sources and the optimisation solutions using both simplex and ACO techniques.

3.1 Effect of Energy utilisation on total LCOE

Figure 1 shows the total levelized cost of energy (LCOE) as the energy need increases. This was an estimation of value of energy cost per unit consumed when all power plants are assumed running. It can be observed that the total LCOE decreased exponentially as the need increases. This is due to the fact that the amount spent on fuel to generate energy does not decrease commensurately as the energy consumed is decreased; implying that the excess cost would then reflect on the cost of energy per unit consumed (LCOE). Thus, the more the energy supplied by plant, the cheaper the LCOE.

The explanation for this is that there are several diesel and petrol generators in the system being considered (FUPRE), and the rate at which these generators dispense fuel to produce energy do not change commensurately with the amount of energy being consumed (Thiruvengadem, et al. 2020).

Hence the total LCOE would decrease appreciably while running those engines at considerably high load demands.

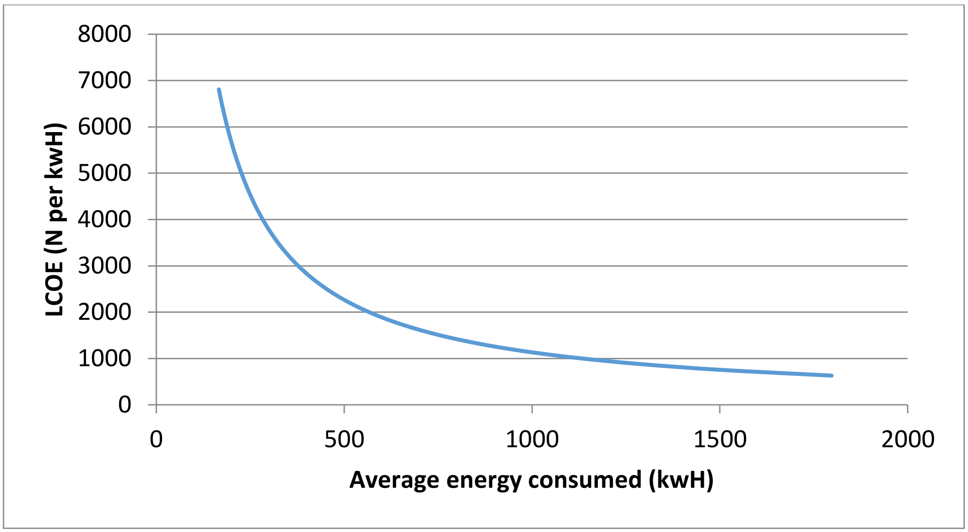

Figure 1: Cost of energy per energy need

3.2 Sessional LCOE of different plants

The Sessional Levelized Cost of Electricity (LCOE) analysis, as shown in Figures 2 – 4, provides valuable insights into the economic performance of different plants within the organization. These values were estimated based on Table 3. The Sessional LCOE were examined for four plants: diesel generator, Petrol generator, solar plant and grid supply. Data for each plant's electricity generation, costs, and other relevant factors were collected and analysed to calculate the LCOE for each plant in different sessions. However, the current value of electricity in Nigeria, being 36 naira per KWH.

The LCOE of different plants vary from one session to another, and there are some sessions with relatively high LCOE compared to other sessions. As can be seen, sessions 1 and 2 had the highest LCOE which implies higher energy expenditure and energy consumption, while session 9 had the least values of LCOE.

The results show that the LCOE of different plants vary from one session to another, and there are some sessions with relatively high LCOE compared to others. The petrol generator has the highest LCOE for all sessions regardless the power need. Solar energy was found to present the lowest LCOE, indicating that it is the most cost-effective plant among the four plants. Previous studies had indicated that solar systems are one of the cheapest source of energy (Osman et al., 2023; Sonawane et al., 2018). Depending on the session, energy need and specifications of the diesel plant, diesel engines present LCOE lower than that of grid, especially when the energy consumed is at maximum value from the diesel generator. The changes in the use of petrol and diesel generators are insignificant for 100% and 80% power consumption respectively. The LCOE of renewable energy plants has been decreasing steadily over the past decade, leading to increased cost-competitiveness compared to conventional energy sources (Uddin et al., 2023).

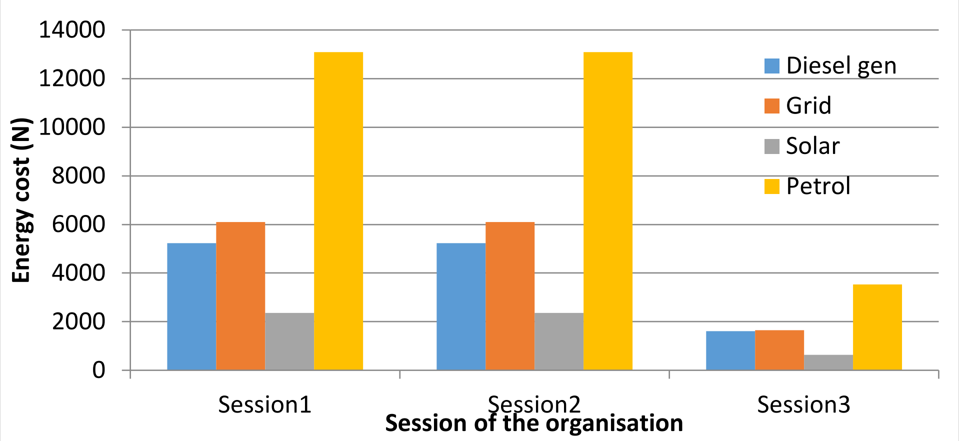

Figure 2: LCOE of different energy plants for optimum plant energy utilisation – A

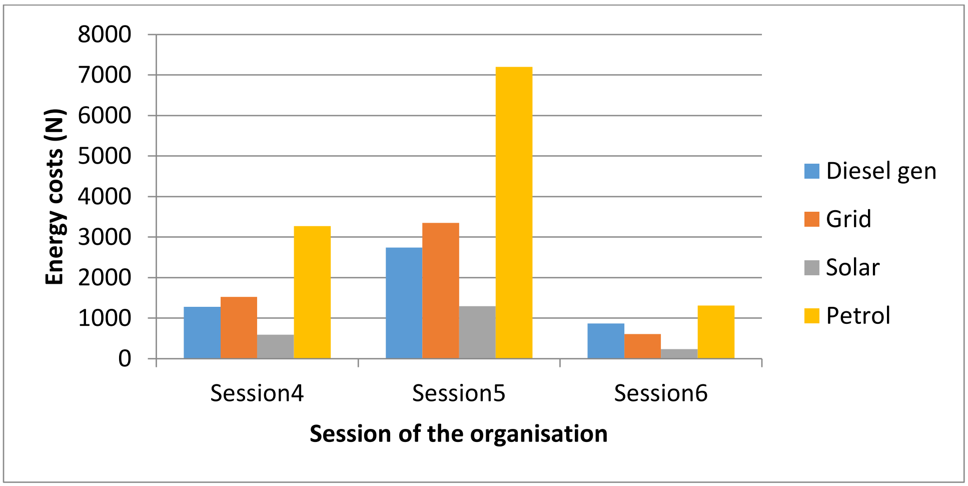

Figure 3: LCOE of different energy plants for optimum plant energy utilisation – B

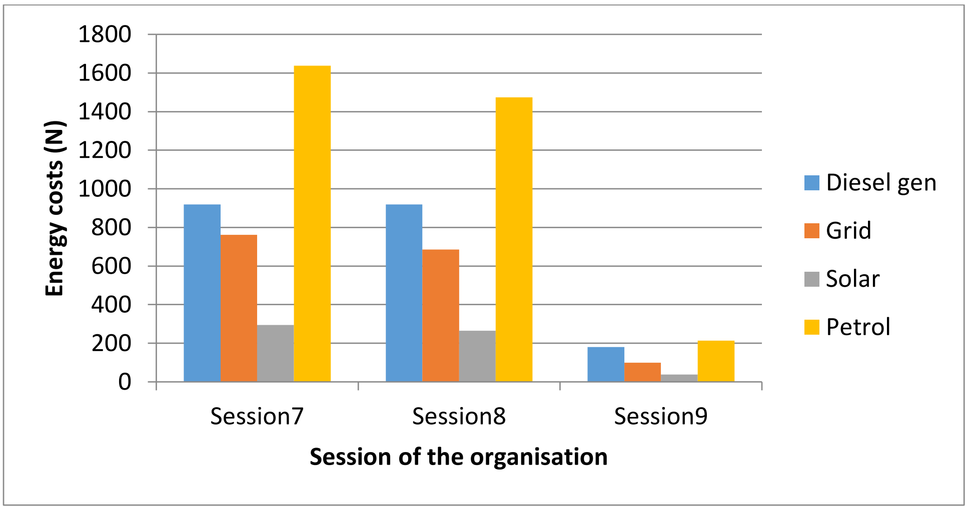

Figure 4: LCOE of different energy plants for optimum plant energy utilisation - C

3.3 Cost of energy using a singular source type

Figure 5 shows what the cost of energy would be if a singular plant type is utilised. The least cost of energy is that of solar which increase linearly with the energy need. Solar energy has shown a significant decrease in cost over the past decade, making it one of the most competitive sources of

renewable energy (Alharthi et al., 2018; Hai et al., 2023; Osman et al., 2023). This substantial cost reduction is primarily due to advancements in technology, increased production scale, and policy support (Elagtal & Khamis, 2016; Mitali et al., 2022). However, the limitation of storage systems and relatively high initial capital cost are limiting the available capacity for most organisation.
For lower energy need, grid source of electricity is cheaper than diesel, but as the energy need increases to certain level, diesel generator becomes cheaper than grid. Also, for very small energy need, the use of petrol energy may be cheaper than diesel as well. This informs that the most suitable plant for energy source greatly depends on the energy need, and this is in line with previous findings (Alharthi et al., 2018).

All energy need shows a linear relationship with the energy cost. However, the slope varies and it is steepest for petrol generators, while it is least for solar generators. This shows that the more the energy utilised the more the cost, but the rate of increases depends on the energy source.

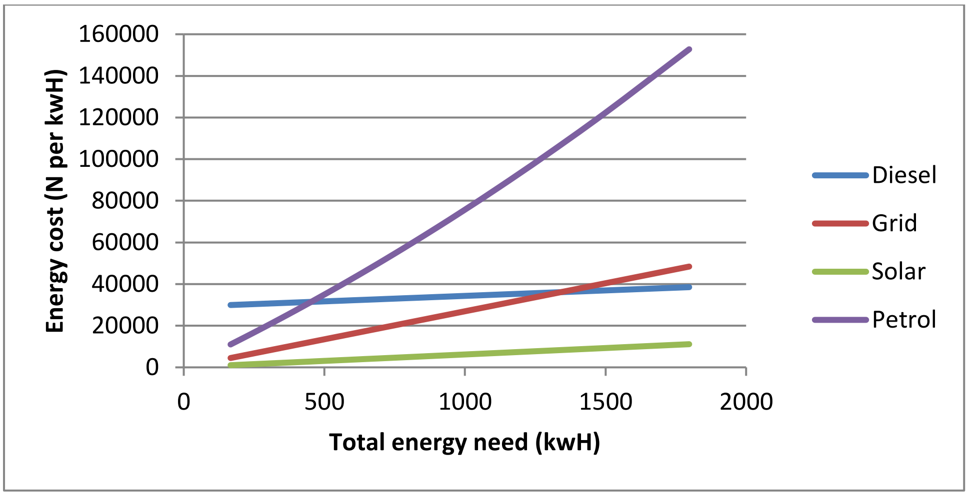

Figure 5: Energy cost versus total energy need for different plants

3.4 Optimisation results for conditions of grid supply and cases where there is no grid supply
This session presents results of selected plants for different sessions based on the energy need and other constraints. The significance of economic trade-offs in renewable energy systems has been well emphasized (He & Huang, 2022), reinforcing our findings that system optimization is crucial for achieving a favourable LCOE while meeting sustainability goals. Similarly, (Ammari, et al. 2022) (Ammari et al., 2022), emphasized the importance of optimizing the mix of energy sources in a hybrid system to minimize LCOE.

The selected plant for the different session as determined by simplex method for different proportion of energy need is presented as follows. For this case, it was assumed that grid power supply is available. Table 4 shows the different plant selected for 95, 50 and 10 per cent energy utilisation, respectively, of the designated diesel generator installed within the session. 1 indicates that that particular plant is selected, while 0 indicates that the plant is not sleeted for that session. As shown, those sessions with large diesel generators were selected, while grid and solar supply were selected for other sessions. This implies that at very high capacity usage, the diesel generators could be more viable to utilise for energy supply for those sessions. The solar energy supply which is usually the cheapest for that level of energy demand is selected for some sessions only due to the its limited capacity of about 450 watt-hour.

When total energy need per session was set at 50%, the selected power supply source was either solar or grid. Although the solar energy supply is cheaper, its supply is limited to the available

power source. However, when the energy need is 10% of the designated diesel generator installed within each session, the solar power source was selected for all because the total power need at 10% for each section is lower than total solar capacity
.

Table 4: Plant selected at different % of plant capacity when there is grid supply

% usage of total capacity	Power source	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7	Session 8	Session 9
95	Diesel	1	1	0	0	0	0	0	0	0
	Grid	0	0	0	0	0	1	1	0	0
	Solar	0	0	1	1	1	0	0	1	1
	Petrol	0	0	0	0	0	0	0	0	0
50	Diesel	0	0	0	0	0	0	0	0	0
	Grid	1	1	0	0	0	1	1	0	0
	Solar	0	0	1	1	1	0	0	1	1
	Petrol	0	0	0	0	0	0	0	0	0
10	Diesel	0	0	0	0	0	0	0	0	0
	Grid	0	0	0	0	0	0	0	0	0
	Solar	1	1	1	1	1	1	1	1	1
	Petrol	0	0	0	0	0	0	0	0	0

Table 5 shows the different plant selected when the energy need was 95, 50 and 10 per cent of the designated diesel generator installed within the session, and there is power outage (no grid supply). Only solar supply was selected when energy demanded was at 10%, while diesel generator was selected for some areas to supplement for the limited capacity of solar supply when more energy is needed. This can adequately address the issue of energy availability and reliability at minimum costs. The reviews by (Hassan et al., 2023b; Kavadias, 2021; Zhang & Wei, 2022) on optimal configuration of hybrid energy systems using mathematical optimization techniques supports our findings, emphasizing the significance of considering multiple energy sources for system efficiency.

Table 5 Plant selected for the different sessions when there is no grid supply

% usage of total capacity	Power source	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7	Session 8	Session 9
95	Diesel	1	1	0	1	1	0	0	0	0
	Grid	0	0	0	0	0	0	0	0	0
	Solar	0	0	1	0	0	1	1	1	1
	Petrol	0	0	0	0	0	0	0	0	0
50	Diesel	1	1	0	0	1	0	0	0	0
	Grid	0	0	0	0	0	0	0	0	0
	Solar	0	0	1	1	0	1	1	1	1
	Petrol	0	0	0	0	0	0	0	0	0
10	Diesel	0	0	0	0	0	0	0	0	0
	Grid	0	0	0	0	0	0	0	0	0
	Solar	1	1	1	1	1	1	1	1	1
	Petrol	0	0	0	0	0	0	0	0	0

The optimised solution in terms of levelized cost of energy when there is grid supply or not is shown in Figure 6. The total cost of energy was lower when there is grid supply and the energy need is greater than the capacity of the solar plant. The change in cost as energy need increases does not form a perfect linear curve.

The Simplex Method suitably solved the mathematical equations and constraints within the energy system, ensuring feasibility. By optimizing the system within the defined constraints, the hybrid energy system could be used to provide energy at a minimum cost. Alquatanni, et. Al. (Alqahtani et al., 2021) showcased the importance of constraint handling in optimization problems, supporting our approach in using the Simplex Method to ensure system stability while accommodating various operational constraints. Simplex method can thus be suitably used for economics analysis of plant selection for different sessions of a complex powered by various energy sources for monetary efficiency. A similar economic analysis in the context of hybrid energy systems was conducted by (Gangwar 2014) [27], reinforcing our findings that optimizing with the Simplex Method contributes to economic sustainability in energy solutions.

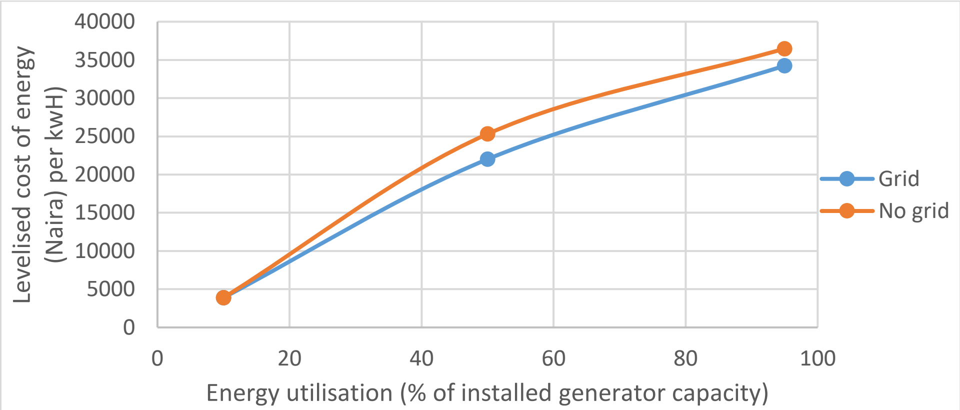

Figure 6: Optimised solution for total levelized cost of energy

3.5 Optimisation result for average plant utilization per sessional buildings

The result of assigned plant based on the average energy need in the different sessions is shown in Table 6. The sessions selected to use solar plant, as shown, is slightly different for cases where there is grid supply and no grid supply. However, the solar power was split among 6 sessions for both cases. The optimised solutions of total energy cost were 29429 and 32029 naira per KWH, respectively for grid and no grid supply, respectively.

Table 6 Selected plants based on average energy need

Condition	Power source	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7	Session 8	Session 9
Grid available	Diesel	0	0	0	0	0	0	0	0	0
	Grid	1	1	1	0	0	0	0	0	0
	Solar	0	0	0	1	1	1	1	1	1
	Petrol	0	0	0	0	0	0	0	0	0
Grid unavailable	Diesel	1	1	0	0	1	0	0	0	0
	Grid	0	0	0	0	0	0	0	0	0
	Solar	0	0	1	1	0	1	1	1	1
	Petrol	0	0	0	0	0	0	0	0	0

4. Conclusion and Recommendation

Through the integration of mathematical models for the energy supply and appropriate constraints equations, the study identified an optimal plant selection for the hybrid energy system under different conditions of energy need. This involved determining the appropriate selection of solar, diesel generator, petrol generator and conventional grid source that minimizes energy costs while satisfying operational constraints. The modelling and analysis of the LCOE in a hybrid energy generation and distribution system provide valuable insights into the economic viability of such systems. The simplex optimisation technique was successfully applied to optimise energy source selection for different plants available in FUPRE. The end result of this investigation has provided priceless knowledge in the field of hybrid energy generating and distribution systems. The findings underscore the importance of optimizing the mix of energy sources, conducting sensitivity analyses, and considering economic trade-offs to achieve a resilient, efficient, and economically viable energy infrastructure. These revelations have the potential to help create a future where operating hybrid energy systems would be more reliable and sustainable.

However, there are several key areas for further research in hybrid energy generating and distribution systems. There is the need for exploring the integration of machine learning and artificial intelligence to enhance system performance, developing holistic energy management strategies for more precise optimization outcomes, and integrating hybrid energy systems into smart grids and microgrids for improved stability and distribution. Additionally, researching the economic viability and policy implications of these systems, conducting comprehensive environmental impact assessments, analysing socio-cultural acceptance and community engagement, and evaluating the long-term performance and durability of hybrid energy systems is recommended. These suggestions underscore the importance of a multidisciplinary approach to advancing hybrid energy systems, considering technological, economic, environmental, and social factors.

References

[1] Suresh, V., Muralidhar, M., & Kiranmayi, R. (2020). Modelling and optimization of an off-grid hybrid renewable energy system for electrification in a rural areas. *Energy Reports*, *6*, 594–604. https://doi.org/10.1016/j.egyr.2020.01.013

[2] Ighodaro OO, Egwaoje SO (2020) – Design and Feasibility Study of a PV-Micro Hydro Off-Grid Power Generating System. *Journal of Science and Technology Research*, 2(1): 213 -224

[3] Ighodaro OO, Olaosebikan F, Egware H.O (2020), Technical Analysis and Economic Assessment of a Stand Alone Solar PV/Fuel Cell Hybrid Power System, *Nigerian Journal of Engineering Science Research (NJESR),* Vol 3(1):27-34

[4] Ighodaro OO, Aburime BA (2011) – Exergetic Appraisal of Delta IV Power Station Ughelli. *Journal of Emerging Trends in Engineering and Applied Sciences (JETEAS)*. 2(2): 216 – 218

[5] Kolawole, A., Agboola, O. O., Ikubanni, P. P., Raji, O. G., & Osueke, C. O. (2019). *Reliability and power loss analysis : A case study of a power plant in Nigeria Reliability and power loss analysis : A case study of a power plant in Nigeria*. https://doi.org/10.1080/23311916.2019.157942

[6] Kavadias, K. A. (2021). *Hybrid Renewable Energy Systems ' Optimisation . A Review and Extended Comparison of the Most-Used Software Tools*.

[7] Alharthi, Y. Z., Siddiki, M. K., & Chaudhry, G. M. (2018). Economic Analysis and Environmental Impacts of a Hybrid PV System in Arid Climate Considering Different Types of Solar Trackers. *Smart Grid and Renewable Energy*, *9*, 199–214. https://doi.org/10.4236/sgre.2018.910013

[8] Shezan, S. K. A., Das, N., & Mahmudul, H. (2017). Techno-economic analysis of a smart-grid hybrid renewable energy system for Brisbane of Australia Cost of Energy. *Energy Procedia*, *110*(December 2016), 340–345. https://doi.org/10.1016/j.egypro.2017.03.150

[9] Hai, A., Olabi, A. G., Mdallal, A., Rezk, A., & Radwan, A. (2023). Concentrating solar power (CSP) technologies : Status and analysis. *International Journal of Thermofluids*, *18*(March), 100340. https://doi.org/10.1016/j.ijft.2023.100340

[10] Rajendra, A. S. (2018). *Cost-Effective Load Scheduling for Hybrid Renewable Energy Systems*. *December*

[11] Ammari, C., Belatrache, D., Touhami, B., & Makhloufi, S. (2022). Sizing , optimization , control and energy management of hybrid renewable energy system — A review. *Energy and Built Environment*, *3*(4), 399–411. https://doi.org/10.1016/j.enbenv.2021.04.002

[12] Ezennaya, S. O., Yuan, Z., & Kowal, J. (2023). *Techno-Economic Analysis of Redox-Flow and Lithium-Iron-*

Phosphate Battery Storages at Different Imbalance Settlement Intervals.

[13] Hunter, C. A., Michael, M., Reznicek, E. P., Rustagi, N., Baldwin, F., & Baldwin, S. F. (2021). Article Techno-economic analysis of long-duration energy storage and flexible power generation technologies to support high-variable renewable energy grids storage and flexible power generation technologies to support high-variable renewable energy grids. *Joule*, *5*(8), 2077–2101. https://doi.org/10.1016/j.joule.2021.06.018

[14] Ighodaro OO, Osikhuemhe M (2019) – Thermo-Economic Analysis of a Heat Recovery Steam Generator Combined Cycle. *Nigerian Journal of Technology (NIJOTECH)*, 38(2): 345-350. http://dx.doi.org/10.4314/njt.v38i2.10

[15] Alzahrani, A., Hafeez, G., Ali, S., Murawwat, S., Khan, M. I., Rehman, K., & Abed, A. M. (2023). *Multi-Objective Energy Optimization with Load and Distributed Energy Source Scheduling in the Smart Power Grid*. 1–21

[16] Sarkar, B., & Omair, M. (2018). *A Multi-Objective Optimization of Energy , Economic , and Carbon Emission in a Production Model under Sustainable Supply Chain Management*. 1–25. https://doi.org/10.3390/app8101744

[17] Wang, Y., Lu, Y., Ju, L., Wang, T., Tan, Q., Wang, J., & Tan, Z. (2019). A Multi-objective Scheduling Optimization Model Wind-Photovoltaic-Conventional Gas Turbines , CHP Considering Heating Storage Mechanism. *Energies*, *12*(425), 1–28. https://doi.org/10.3390/en12030425

[18] Elagtal, I. A., & Khamis, A. A. (2016). *Smart Grid Technology for Better Integration of Renewable Energy Resources*. *April*.

[19] Rafique, M. K., Haider, Z. M., & Mehmood, K. K. (2018). *Optimal Scheduling of Hybrid Energy Resources for a Smart Home*. 1–19. https://doi.org/10.3390/en11113201

[20] Hassan, Q., Algburi, S., Zuhair, A., Salman, H. M., & Jaszczur, M. (2023a). Results in Engineering Review article A review of hybrid renewable energy systems : Solar and wind-powered solutions : Challenges , opportunities , and policy implications. *Results in Engineering*, *20*(September), 101621. https://doi.org/10.1016/j.rineng.2023.101621

[21] Alqahtani, B., Paul, M. C., Yang, J., & Liu, X. (2021). *Optimisation of a Grid-Connected Hybrid Renewable System at Peak Load*. 2–7.

[22] Maghami, M. R., Guseni, A., & Mutambara, O. (2023). Challenges associated with Hybrid Energy Systems : An artificial intelligence solution. *Energy Reports*, *9*, 924–940. https://doi.org/10.1016/j.egyr.2022.11.195