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# Determination of Energy Storage Capacity Requirement for a Hybrid Renewable Power Generation System

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***Authors' contributions***

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*

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## ABSTRACT

The sector of energy storage is increasingly becoming prominent in the context of renewable energy applications. The objective of this study was to ascertain the necessary energy storage capacity for a hybrid renewable power producing system. The utilization of the Bat optimization algorithm improved the sizing strategy by reducing the financial costs and mitigating losses in the system, particularly in relation to load shedding and wind curtailment. The study examined and analysed five primary categories of battery systems. The evaluation and comparison of these entities were conducted using techno-economic and environmental parameters within the context of the Nigerian power market scenario. The findings of the study indicate that the lead-acid battery exhibits the lowest investment costs and quickest payback times. Additionally, the NaS battery demonstrated superior state of charge (SOC) characteristics and the highest net present value (NPV) when compared to the lead-acid battery. Therefore, they offer an improved solution characterised by decreased maintenance issues and an extended lifespan. Despite their high efficiency, Li-ion batteries are considered less favourable due to their significant capital investment requirements. Flow batteries have been shown to have limited advantages due to their high initial

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costs. The study thus suggests that in order to address energy deficit, it is imperative to stimulate the adoption of grid and off-grid renewable energy technology systems through various mechanisms, such as subsidies.

*Keywords: Energy storage; energy applications; power generation.*

## 1. INTRODUCTION

The issue of the global energy crisis, which arises from an overdependence on fossil fuels, has attracted considerable attention due to its detrimental effects on the environment and the limited availability of these resources. The combustion of fossil fuels results in the emission of greenhouse gases, hence contributing to the occurrence of climate change and environmental degradation [1]. Renewable energy sources, including solar, wind, and hydro, have emerged as feasible alternatives for addressing the interconnected issues of the energy crisis and climate change [2]. The growing emphasis on renewable energy sources can be ascribed to their significant environmental benefits. Solar energy, derived from the sun's rays, demonstrates considerable promise as a source of electricity through the utilization of photovoltaic (PV) systems or concentrated solar power (CSP) facilities [2]. Wind energy is a plentiful and environmentally sustainable source of energy that is captured through the conversion of the kinetic energy of air in motion into electrical energy via wind turbines [3]. The widespread adoption of hydropower has been made possible by the utilisation of gravitational force derived from the descent or movement of water, achieved via the construction of dams and turbines [1].

Renewable energy sources have a multitude of advantages in comparison to conventional fossil fuels. Renewable resources include inherent regenerative capabilities and are essentially limitless, hence guaranteeing sustained availability and mitigating issues related to resource depletion. In contrast to fossil fuels, which necessitate expensive and ecologically detrimental extraction methods, renewable energy sources are plentiful and exhibit geographical diversity. The decentralised character of the energy system allows for the generation of energy in close proximity to the point of consumption, resulting in a reduction of transmission losses and the promotion of self-sufficiency in energy production [2].

Energy storage devices are essential components in hybrid systems since they enable the efficient collection and utilisation of surplus energy produced during periods typified by a significant abundance of renewable energy. These technologies have been purposefully designed to store excess energy for future utilisation, so ensuring a dependable power supply even in situations where energy generation is limited or absent. Energy storage encompasses a diverse array of technologies, including but not limited to lithium-ion batteries and flow batteries. Furthermore, the realm of energy storage encompasses conventional techniques such as pumped hydro storage and compressed air energy storage. According to Maleki and Pourfayaz [3], the integration of energy storage technologies inside hybrid systems is of paramount importance in mitigating the intermittent characteristics of renewable energy sources, hence facilitating a dependable and continuous provision of electrical power.

In essence, the incorporation of contemporary modelling methodologies and optimisation algorithms is of paramount importance in ascertaining the optimal energy storage capacity for a hybrid renewable power generation system [1]. The aforementioned models encompass a variety of variables pertaining to energy generation patterns, demand profiles, and system limits in order to ascertain the design that is both economically efficient and reliable. Various methodologies, such as techno-economic optimisation models, machine learning algorithms, probabilistic modelling, and simulation-based optimisation, have made significant advancements in understanding the trade-offs between storage capacity, system performance, and economic feasibility [1]. By employing these modelling techniques, decision-makers and energy planners can make informed evaluations about the design and implementation of hybrid renewable power generation.

To determine the energy storage capacity requirement for a hybrid renewable power generation system, various studies have been conducted to optimize the capacity and operation of energy storage systems in the context of renewable energy integration. proposed an approach to determine the minimal requirement of power capacity and the appropriate location for energy storage, aiding cost-effective planning of energy storage in power grids with intensive renewable generation [4] Similarly, summarized and classified the capacity optimization of hybrid renewable power systems with energy storage, providing insights into the efficient utilization of energy storage in such systems [5]. Furthermore, proposed a renewable energy hybrid power system based on photovoltaic and wind power generation equipped with Superconducting Magnetic Energy Storage (SMES), highlighting the potential of advanced storage technologies in hybrid renewable systems [5]. Moreover, studies such as those by and focused on the optimal allocation and configuration of energy storage capacity in distributed micro-grids and regional power grids, providing valuable insights into the efficient utilization of energy storage at different scales of renewable energy integration [6,7]. Additionally, 's research aimed to optimize the allocation of battery energy storage to minimize total cost while satisfying operational constraints in active distribution networks with high-level renewable energy resources, emphasizing the importance of optimal storage allocation in grid integration [8]. Furthermore, the influence of different energy storage modes on the confidence capacity of renewable energy was studied by, highlighting the role of energy storage in improving the active support capacity of renewable energy at unit, power station, and regional grid levels [9]. Additionally, discussed methods for estimating the capacity credit of energy-limited resources, including energy storage, indicating the evolving nature of capacity credit calculations for energy storage in renewable systems [10].

The synthesis of these studies provides valuable insights into the determination and optimization of energy storage capacity for hybrid renewable power generation systems. These findings contribute to the efficient integration of renewable energy sources with energy storage, addressing the challenges of variability and intermittency in renewable generation.

## 2. METHODOLOGY

### 2.1 Materials

The materials to be used in this study includes:

1. HOMER software
2. Microsoft Excel

### 2.2 Methods

The research will employ a quantitative methodology to determine the required energy storage capacity for a hybrid renewable power generation system. The population for this study will encompass all wind turbine locations situated inside the borders of Nigeria. The study will utilise the simple random sampling method. The process of data collection will involve several factors pertaining to the generation of renewable energy, profiles of load demand, technologies for energy storage, and modelling of the system. The process of gathering historical data on renewable energy generation, which includes sources like solar and wind power, will be carried out by accessing relevant sources such as meteorological stations, renewable energy installations, and energy organisations. The load demand profiles will be obtained by the analysis of energy consumption records, data provided by electrical grid operators, or relevant databases. These sources will provide information regarding peak demand periods and fluctuations.

The specifications pertaining to energy storage technology are as follows: The collection of data on diverse energy storage technologies, such as batteries, pumped hydro, and other relevant options, will be conducted through sourcing information from scholarly literature, manufacturers' specifications, and industry reports. The objective of this project is to develop a precise mathematical model or simulation framework that represents the hybrid renewable power generation system and its interactions with the energy storage system. The model will include various factors, including the characteristics of renewable energy sources, load demand patterns, energy storage technologies, system efficiency, and other relevant factors. The inclusion of several factors, including the capacity for renewable energy generation, the capacity for energy storage, the rates of charging and discharging, and the limitations of the system, was carried out. The application of HOMER software enabled the assessment of storage capacity for different power batteries.

### 2.3 Energy Storage Capacity Sizing

The capacity requirement for energy storage in a hybrid renewable power production system, which incorporates a diesel generator, solar generator, wind turbine, and battery storage system for ample supply, will be determined using the HOMER programme.

The storage system within the model is distinguished by the following parameters, which are expressly defined as:

- Maximum energy capacity

The previously stated quantity represents the maximum amount of energy that can be stored within the system while it is at its full charge.

- Minimum energy capacity

The minimal energy threshold in the storage system refers to the point below which the storage is not discharged in order to supplement supply generation and satisfy the grid load.

- Maximum power capacity

The designated quantity is the upper limit of energy that can be introduced into or extracted from the storage system at any given instant (or within any given hour, as determined by the time interval analyzed in this investigation). While the magnitudes of charge and discharge power can vary, they are considered to be equal for the purpose of this analysis.

- Cycle efficiency

The determination of cycle efficiency involves the multiplication of the efficiencies pertaining to both the charging and discharging processes of the storage system. In this particular Investigation, a methodology is utilized wherein the assessment of the charging or discharging efficiency is achieved by calculating the square root of the cycle efficiency.

- Total discharge time

This refers to the time period during which the energy storage capacity is fully depleted due to the discharge of power at its highest rate. The computation inside the proposed model is derived by dividing the energy capacity by the power capacity. Nevertheless, the veracity of this assertion in real-world systems is contingent upon the discharge magnitude and the particular operational circumstances of the system under consideration. Distinguishing between the power and energy aspects of storage systems is a significant problem, hence complicating the determination of an ideal time constant for various storage techniques.

- Self-discharge

The natural decline or reduction in the available capacity of a storage system takes place at a consistent pace, irrespective of the device's active usage. The statement described above indicates a fundamental reduction in the overall capability of the storage system. Nevertheless, the result is dependent on other factors, such as the prevailing environmental conditions.

In the suggested model, the storage losses are simplified to include only the cycle efficiency (ncycle) and self-discharge. Based on the study conducted by Chen et al. [6], it has been determined that the cycle efficiency for battery energy storage is estimated to be 80%. Furthermore, we will make the assumption that the rate of self-discharge is equivalent to 10% every month of the total energy capacity.

To commence the evaluation, it is imperative to define an initial generation capacity that serves as a foundational basis, denoted as a ratio relative to the maximum load. This criterion stipulates the minimal threshold of conventional plant generation that must be upheld at any given hour on the grid, regardless of whether it is on an annual or seasonal timeframe [11]. Consequently, the value serves as a determinant of the degree of flexibility demonstrated by the grid. The major goal during each hour is to fulfill the grid load or demand by effectively utilizing the base generation. Subsequently, when there is a disparity between the net load and energy supply, for instance, in the context of EmBase, efforts are made to address the shortfall in power generation by utilizing photovoltaic (PV) and wind energy resources. After conducting an assessment of the photovoltaic (PV) and wind power production, any surplus or deficit in the supply of electricity generated by EmPV/Wind sources is then obtained from or stored in the energy storage system. Nevertheless, the discharge procedure is subject to several constraints, encompassing the minimum capacity for energy storage, the maximum capacity for power, and the efficiency of discharge.

The architectural design depicted in Fig. 8 illustrates a model energy storage integrated hybrid (PV-Wind) grid power system. The region on the load-generation graph denoted by the plus (+) symbol relates to the segment in which there is a surplus of generated power, resulting in the replenishment of energy storage systems. The converse holds for the numerical magnitude denoted by the negative (-) symbol.

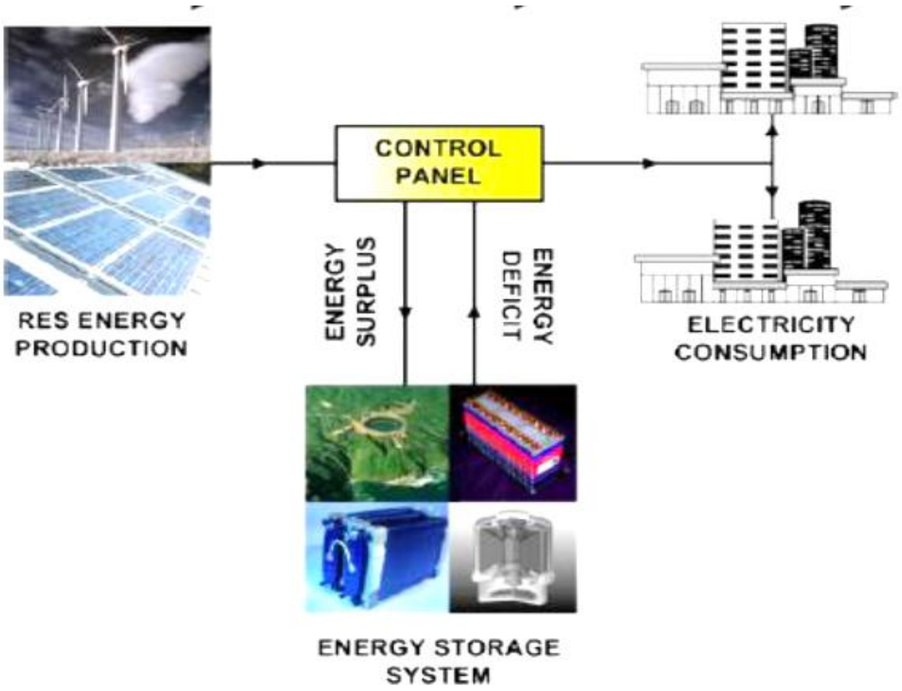


**Fig. 1. Typical PV-wind-storage grid power system**

The charging and discharging process is typically mathematically represented by the equation. (3.3) below.

$$E_{str}(t) = (1 - DsgRate) \times E_{str}(t-1) + \begin{cases} eff_{chg} \times E_{mPV/Wind} & if\, E_{mPV/Wind} > 0 \\ \dfrac{1}{eff_{dsg}} \times E_{mPV/Wind} & if\, E_{mPV/Wind} < 0 \end{cases} \quad (3.3)$$

where:

- *t* is time
- The charging and discharging efficiencies, represented as *effchg and effdsg* respectively, are directly associated with the cycle efficiency mentioned before.
- *DsgRate* is the self-discharge rate.

The time series Estr(t) represents the state of charge of the storage system. The disparity between the highest and lowest values of Estr(t) is the determining factor for the necessary storage energy capacity. The maximum storage power capacity is determined by the time series' maximum value, as expressed by the equation (*eff_c.EmPV/Wind or eff_d-1.EmPV/Wind*) [12]. The algorithm that has been built possesses the ability to discern, among various other entities, the:

- ➢ The necessary values for the energy and power capacities of the storage system are required;
- ➢ The study examines the yearly and seasonal energy penetration of a PV-wind system and a PV-wind-storage system;
- ➢ The daily net storage energy capacities;
- ➢ The ability to achieve annual or seasonal peak load reductions for any desired period throughout the year;
- ➢ The energy losses inside the system, which can be attributed to inefficiencies in storage and the disposal of generated energy.

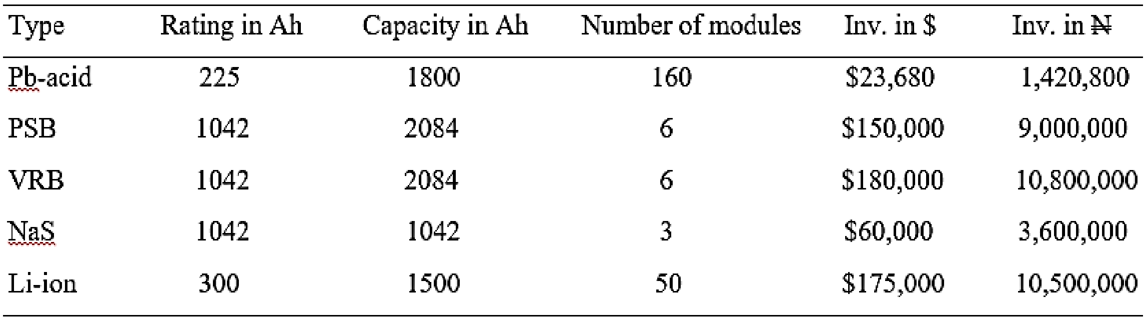
## 2.4 System Description

Table 1 presents the detailed specs of the wind turbine. Data on solar and wind patterns were collected for a duration of one year at a wind location located in Northern Nigeria. Fig. 1 displays the sun irradiation statistics over a 24-hour period. Fig. 2 displays the wind data recorded at a height of 30 metres, with measurements taken every 10 minutes. In Nigeria, wind power generation is limited to the rainy season, which occurs from May to September. In the next months, the level of generation is insufficient to warrant consideration. Based on the data collected from the site, it has been discovered that the total power output of the wind-PV system over the course of a year, consisting of the production of wind power for a period of five months and PV power generation for a period of twelve months, is approximately five times greater than the power generated exclusively by the entire system in the month of June. Therefore, to mitigate the complexities connected with computational processes, the month of June is regarded as the optimal choice for conducting the simulation.

## 3. RESULTS AND DISCUSSION

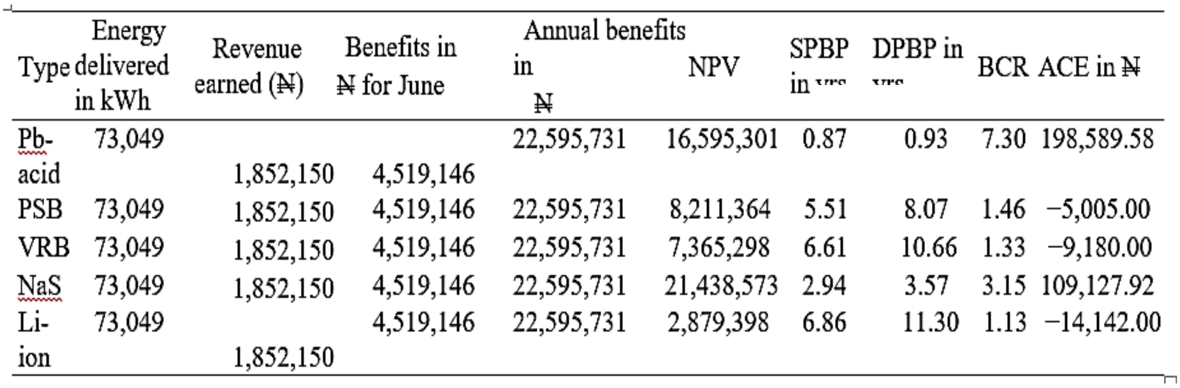
During the month of June 2023, the wind-photovoltaic (PV) system demonstrated a cumulative electricity production of 145.77 MW. It is important to highlight that the wind turbine component accounted for 90% of the overall electricity generated by the system. The power graph of the wind-PV system, as illustrated in Fig. 4(a), indicates that the generated power is inadequate to align with the prescribed dispatch curve in the absence of Battery Energy Storage Systems (BESS). The system's financial losses can be attributed to wind power curtailment, load spillage, and shedding. The total annual losses reach a value of N350,288,350.10, accompanied by a Loss of Power Supply Probability (LPSP) ratio of 19.72%. The battery storage system selection process entails the evaluation of five discrete battery types, namely lead-acid, sodium sulphide, vanadium redox, polysulphide bromide, and lithium-ion batteries. The assessment of the dimensions and financial expenses associated with each battery tabulated in Table 2. The results indicate that NaS batteries demonstrated the least amount of capacity in comparison to alternative battery technologies. The VRB batteries have demonstrated the highest cost when compared to the range of options that have been under evaluation. The optimization of battery size is accomplished by the utilization of the bat optimization approach, with the objective of reducing both investment expenses and incurred losses. In the bat algorithm, the loudness and pulse rate parameters are both assigned a value of 0.5.

**Table 1. Specification of proposed wind turbine**



| Type | Rating in Ah | Capacity in Ah | Number of modules | Inv. in $ | Inv. in ₦ |
|---|---|---|---|---|---|
| Pb-acid | 225 | 1800 | 160 | $23,680 | 1,420,800 |
| PSB | 1042 | 2084 | 6 | $150,000 | 9,000,000 |
| VRB | 1042 | 2084 | 6 | $180,000 | 10,800,000 |
| NaS | 1042 | 1042 | 3 | $60,000 | 3,600,000 |
| Li-ion | 300 | 1500 | 50 | $175,000 | 10,500,000 |

**Table 2. Economic analysis without optimization**



| Type | Energy delivered in kWh | Revenue earned (₦) | Benefits in ₦ for June | Annual benefits in ₦ | NPV | SPBP in yrs | DPBP in yrs | BCR | ACE in ₦ |
|---|---|---|---|---|---|---|---|---|---|
| Pb-acid | 73,049 | 1,852,150 | 4,519,146 | 22,595,731 | 16,595,301 | 0.87 | 0.93 | 7.30 | 198,589.58 |
| PSB | 73,049 | 1,852,150 | 4,519,146 | 22,595,731 | 8,211,364 | 5.51 | 8.07 | 1.46 | −5,005.00 |
| VRB | 73,049 | 1,852,150 | 4,519,146 | 22,595,731 | 7,365,298 | 6.61 | 10.66 | 1.33 | −9,180.00 |
| NaS | 73,049 | 1,852,150 | 4,519,146 | 22,595,731 | 21,438,573 | 2.94 | 3.57 | 3.15 | 109,127.92 |
| Li-ion | 73,049 | 1,852,150 | 4,519,146 | 22,595,731 | 2,879,398 | 6.86 | 11.30 | 1.13 | −14,142.00 |

**Table 3. Economic analysis after optimization**

| Type | Energy delivered in kWh | Revenue earned (₦) | Benefits in ₦ for June | Annual benefits in ₦ | NPV | SPBP in yrs | DPBP in yrs | BCR | ACE in ₦ |
|---|---|---|---|---|---|---|---|---|---|
| Pb-acid | 73,049 | 185,2149.097 | 4,519,146.58 | 122,595,732.72 | 17,472,912.71 | 0.58 | 0.61 | 10.95 | 217.757.96 |
| PSB | 73,049 | 185,2149.097 | 4,519,146.58 | 122,595,732.72 | 14,144,121.35 | 3.67 | 4.69 | 2.19 | 54,610.06 |
| VRB | 73,049 | 185,2149.097 | 4,519,146.58 | 122,595,732.72 | 14,708,352.93 | 4.41 | 5.93 | 2.00 | 28,950.8 |
| NaS | 73,049 | 185,2149.097 | 4,519,146.58 | 122,595,732.72 | 26,422,617.02 | 1.47 | 1.63 | 6.30 | 182,611.32 |
| Li-ion | 73,049 | 185,2149.097 | 4,519,146.58 | 122,595,732.72 | 11,089,989.38 | 4.28 | 5.72 | 1.81 | 14549.16 |

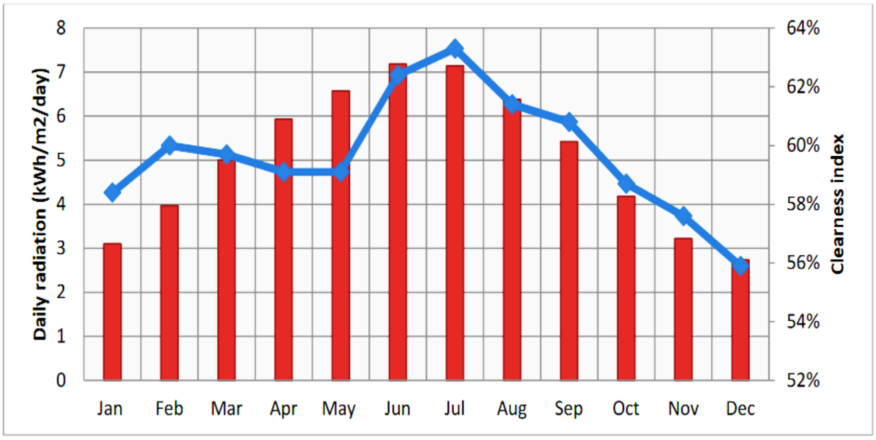


Fig. 2. Monthly mean solar radiation and clearness index

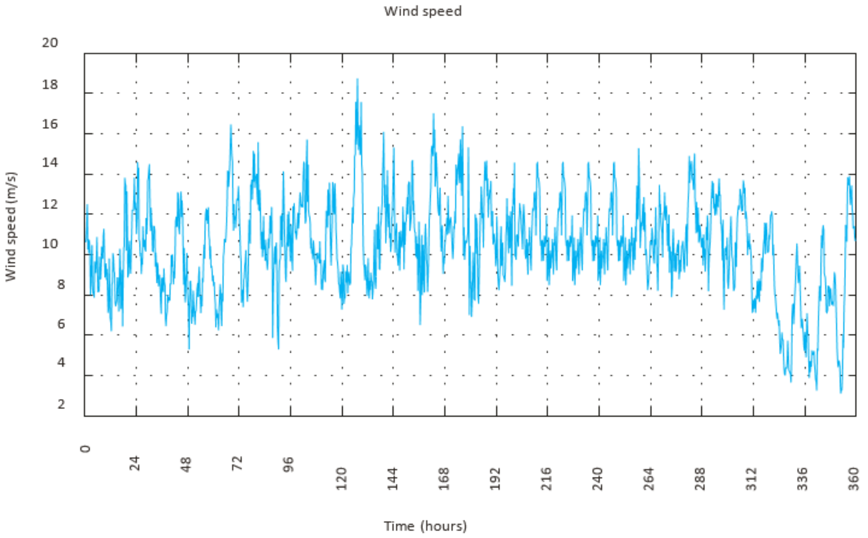
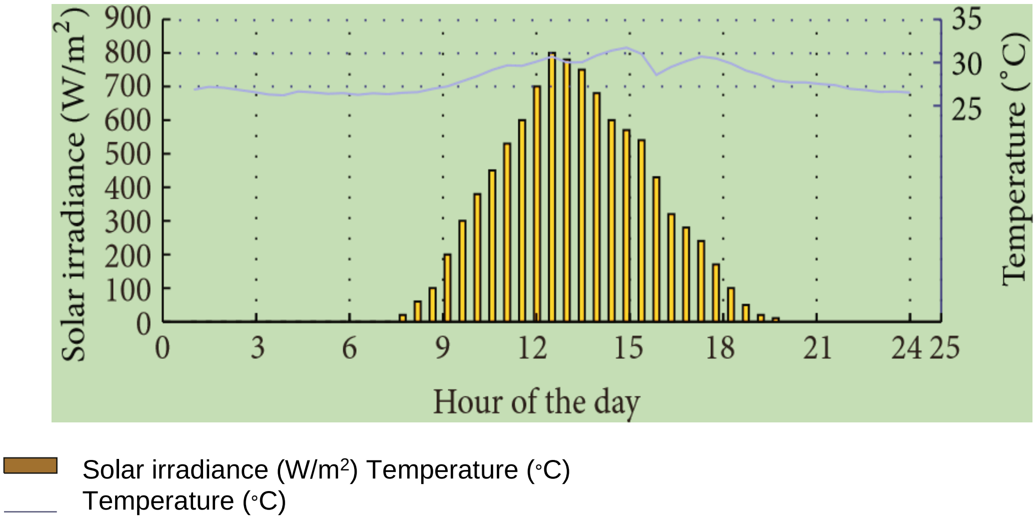


Fig. 3. Solar irradiance and temperature in 24 hrs



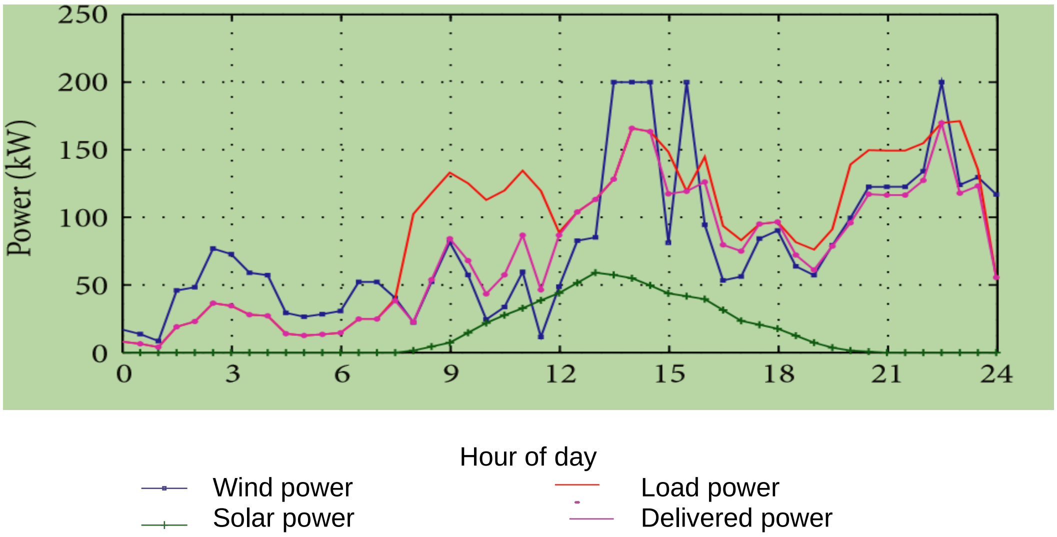


**Fig. 4. Solar irradiance and temperature in 24 hrs**

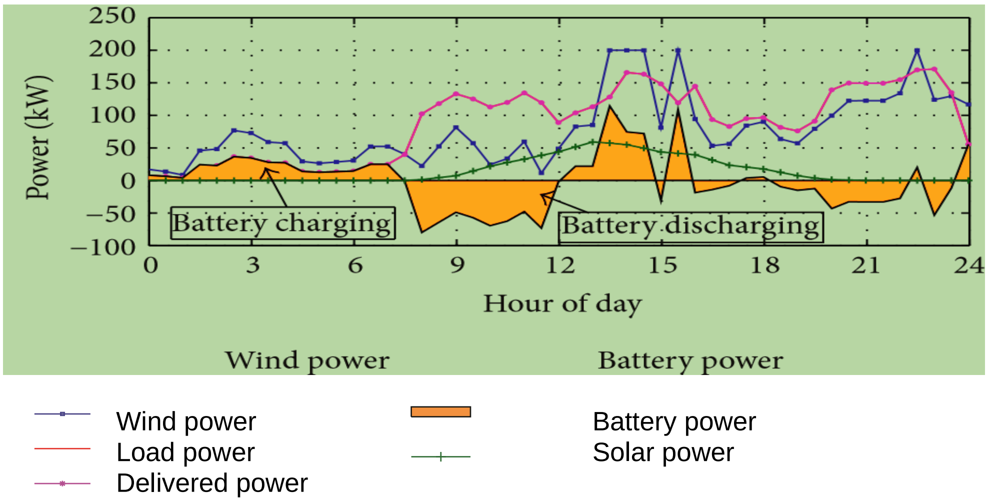


**Fig. 5(b). Hybrid system output with battery storage**

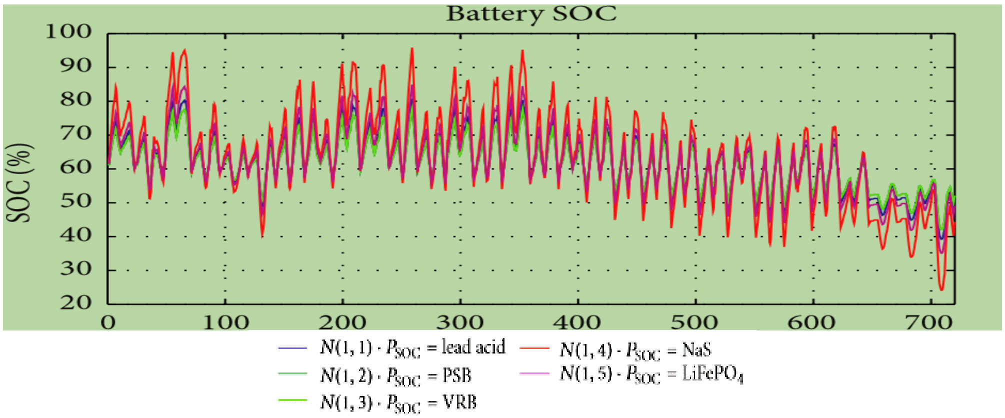


**Fig. 6(a). SOC of batteries**

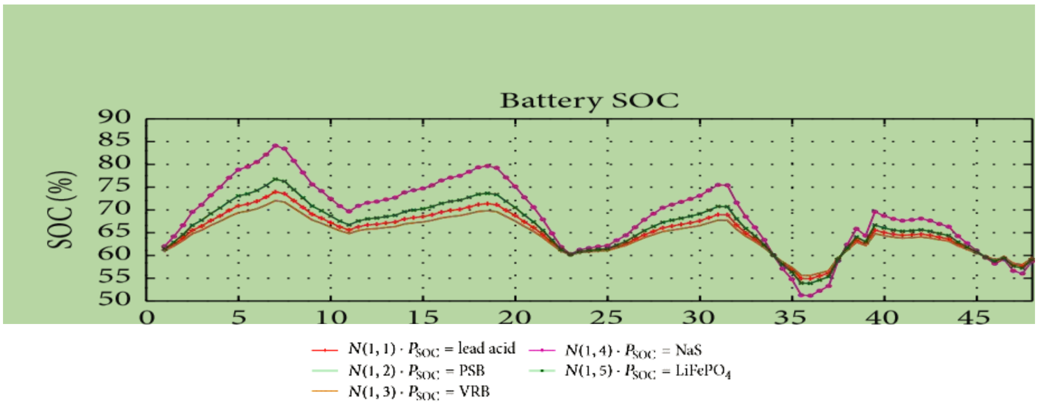


**Fig. 7(b). SOC of batteries for 48 hrs**

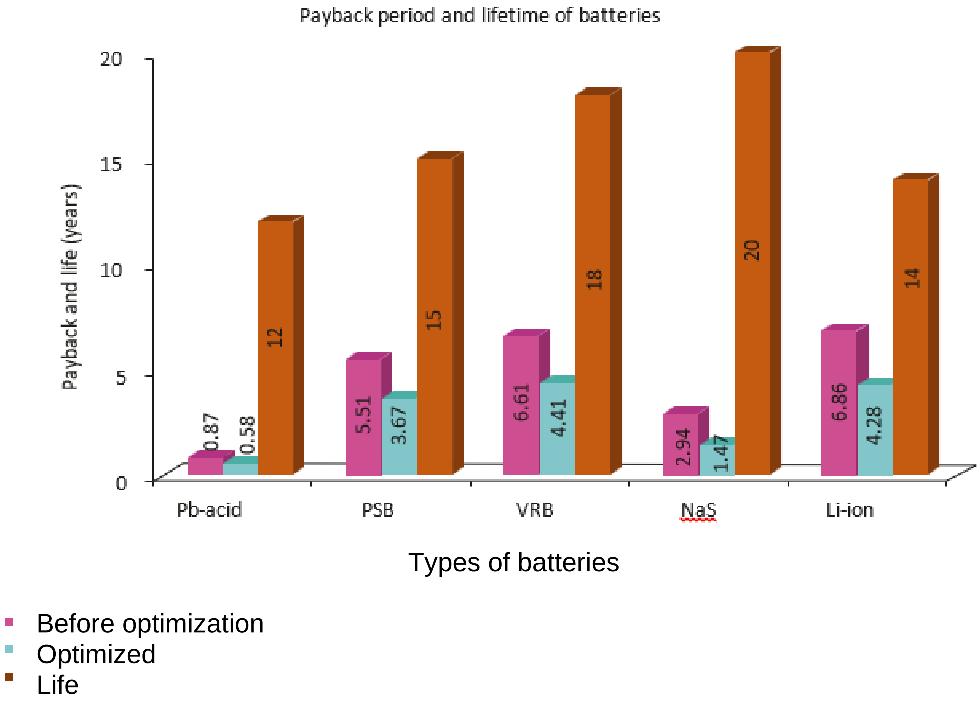


**Fig. 8. Payback period and lifetime of batteries**

The results obtained from the optimization process are displayed in Table 2. The increase in battery capacity resulted in significant changes in investment expenditures (as shown in Fig. 4.5), payback periods, and benefit-cost ratio (BCR) values of the system. After conducting an examination of NaS batteries, it becomes apparent that their dimensions experience a reduction of 50% in comparison to the battery size. The batteries in alternative models exhibit a reduction in size of approximately 30-40%. The battery sizes investigated in this study encompass a range of around 4% to 7.5% of the wind-PV rating. The NaS batteries had the most compact battery dimensions, measuring a diminutive 4% in size as reported. On the other hand, the flow batteries demonstrated the largest recorded battery size, measuring at 7.5%.

A comparative analysis is conducted to examine the energy output and cost advantages achieved before and after the incorporation of Battery Energy Storage Systems (BESS) into Hybrid Renewable Energy Systems (HRES) [13]. The utilization of energy storage technology led to a notable enhancement of 24.56% in the power generation [14]. The successful integration of the update facilitated the Hybrid Renewable Energy System (HRES) in maintaining a continuous adherence to the predetermined dispatch curve. This resulted in the complete elimination of the Loss of Power Supply Probability (LPSP), as illustrated in Fig. 4(b). The integration of battery storage technology leads to a discernible convergence between the power supply curve and the predetermined dispatch curve [15]. The total eradication of losses caused by spillage and wind curtailment leads to a complete reduction to zero, hence enabling the efficient utilization of conserved energy to fulfill peak demand. The wind power tariff rate in Nigeria, as determined by the Nigerian Power Holding Company (NPHC) in 2020, has not undergone any modifications. Thus, the financial advantages derived from wind power are contingent purely upon the reduction of power losses, without any additional incentives offered for the use of time shifting strategies [16].

The findings of this study indicate that batteries functioning within category 5 exhibit optimal performance and demonstrate a comparatively limited susceptibility to the effects of aging. As a result, the incorporation of the size approach in combination with the energy management system enables an effective and intelligent utilization of battery storage. This is in line with the finding of Ma et al. [17,18,19.20].

## 4. CONCLUSION

The assessment of the Hybrid Renewable Energy System (HRES) involves an examination of economic and environmental issues to determine its feasibility. Multiple inferences can be deduced from the data mentioned above.

(1) The lead-acid battery has been shown to possess the lowest initial investment prices and the shortest durations of time required for financial returns. Nevertheless, the NaS battery exhibited superior state of charge (SOC) characteristics compared to the lead-acid battery, resulting in the highest net present value (NPV). Therefore, they offer a more effective solution with decreased maintenance issues and an extended lifespan.
(2) Although lithium-ion batteries demonstrate remarkable efficiency, their least favourable aspect is the significant capital investment costs associated with their implementation. Flow batteries have been shown to have limited advantages due to their high initial costs; nonetheless, they remain a viable option due to their exceptional cycle life.

## 5. RECOMMENDATIONS

Based on the findings of the study, the study recommends that;

1. Therefore, the integration of wind and solar energy sources should be duly acknowledged and considered as a viable option due to its potential cost-effectiveness and ability to provide uninterrupted electrical supply throughout the day.
2. Enhancing the purchasing power of rural people through the growth of income derived from renewable generated electricity is of paramount importance.
3. In order to address energy shortfall, it is imperative to promote the utilisation of grid and off-grid renewable energy technology systems through various means, including the provision of subsidies.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

## REFERENCES

1. Dipti D. A Review on Unit Sizing, Optimization and Energy Management of HRES. Int. J. Trend Sci. Res. Dev. 2018; 2:419–426.
2. Alkafaji AS, Al-Samawi AA, Trabelsi H. Hybrid Energy Storage Review for Renewable Energy System Technologies and Applications. In Proceedings of the 2021 18th International Multi-Conference on Systems, Signals & Devices (SSD), Monastir, Tunisia. 2021;22–25;1059–1067.
3. Maleki A, Pourfayaz F. Sizing of stand-alone photovoltaic/wind/diesel system with battery and fuel cell storage devices by harmony search algorithm," Journal of Energy Storage. 2015;2:30–42.
4. Han X, Liao S, Ai X, Yao W. Determining the minimal power capacity of energy storage to accommodate renewable generation. Energies. 2017;10(4):468.
5. Gan J, Li J, Qi W, Kurban A, He Y, Guo S. A review on capacity optimization of hybrid renewable power system with energy storage. E3s Web of Conferences. 2019; 118:02055.

   Available:https://doi.org/10.1051/e3sconf/201911802055
6. Chen Z, Zhang Z, Kong W, Xu D. Optimal allocation of energy storage capacity in distributed micro-grid based on improved whale algorithm. Journal of Physics Conference Series. 2023; 2503(1): 012096.
7. Lv X, Wang Z, Li Z, Shao Y, Cheng Z, Hao L. Research on optimal ratio of wind-pv capacity and energy storage optimization configuration of regional power grid. Journal of Physics Conference Series.2023;2418(1):012044.
8. Li Y, Cai H. Improving voltage profile of unbalanced low-voltage distribution networks via optimal placement and operation of distributed energy storage systems. Iet Renewable Power Generation; 2022.

   Available:https://doi.org/10.1049/rpg2.12485
9. Guo Y, Li F, Tian X, Zhang H, Li W, Wang X, Zhao W. Study on the influence of different energy storage modes on the confidence capacity of renewable energy. E3s Web of Conferences. 2022;360: 01046.

   Available:https://doi.org/10.1051/e3sconf/202236001046
10. Mills A, Rodriguez P. A simple and fast algorithm for estimating the capacity credit of solar and storage. Energy. 2020;210: 118587.

    Available:https://doi.org/10.1016/j.energy.2020.118587.
11. Manoj K. MV, Mishra MK, Kumar C. A grid-connected dual voltage source inverter with power quality improvement features. IEEE Trans Sustainable Energy. 2015; 6(2):482–90.
12. Ammari C, Belatrache D, Touhami B, Makhloufi S. Sizing, optimization, control and energy management of hybrid renewable energy system—A review. Energy Built Environ. 2021;3: 399–411.
13. Dicorato G, Forte M, Pisani M, Trovato M. Planning and operating combined wind-storage system in electricity market," IEEE Transactions on Sustainable Energy. 2012; 3(2):209–217, 2012.
14. Dufo-Lopez R. Optimisation of size and control of gridconnected storage under real time electricity pricing conditions," Applied Energy. 2015;140:395–408.
15. Hemmati R, Saboori H. Emergence of hybrid energy storage systems in renewable energy and transport applications – a review. Renewable and Sustainable Energy Reviews. 2016;65:11-23.

    Available:https://doi.org/10.1016/j.rser.2016.06.029
16. Li SS. Choi YY uan Q. Yao DL. On the determination of battery energy storage capacity and short-term power dispatch of a wind farm," IEEE Transactions on Sustainable Energy. 2011; 2(2):148–158.
17. Ma H, Yang T, Lu L. A feasibility study of a stand-alone hybrid solar–wind–battery system for a remote island, Applied Energy. 2014;121:149–158.
18. Maleki A, Askarzadeh A. Optimal sizing of a PV/wind/diesel system with battery storage for electrification to an off-grid remote region: a case study of Rafsanjan, Iran," Sustainable Energy Technologies and Assessments. 2014;7:147–153.
19. Mazzeo D, Matera N, De Luca P, Baglivo C, Congedo PM, Oliveti G. A literature review and statistical analysis of photovoltaic-wind hybrid renewable system research by

considering the most relevant 550 articles: An upgradable matrix literature database. J. Clean. Prod. 2021; 295:126070.

20. Zhao Q, Wu S, Hu H, Xu, CN. Rasmussen H. Review of energy storage system for wind power integration support, Applied Energy. 2015;137:545–553.

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