

“Optimization and techno-economic environmental analysis of a grid-tied hybrid renewable energy system – A Review”

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Abstract:- The utilization of solar-powered electricity represents a highly effective strategy for enhancing renewable energy generation in India. The abundant energy from solar radiation and the decreasing costs of PV modules have led to an increased demand for grid-tied PV power plants (GTPV-PP). This study outlines a net metering which utilizes GTPV-PPs and the HOMER-Pro (V-3.16.2 model) to meet the building's electricity needs. This version of HOMER determines the most economical setup, evaluates unprocessed data, and creates a demand cycle using load survey data. Furthermore, this software evaluates various scenarios, including both grid-tied and off-grid options, depending on the availability of renewable energy sources (RESs). The HOMER Pro program subsequently simulated these scenarios over the course of a year, utilizing economic and technical data as input. The results indicate that the most economical and eco-friendly design consists of a 100-kW solar photovoltaic system connected to a 100-kW converter and integrated with the utility grid. We project the system to last for 25 years, with an estimated levelized cost of energy (LCOE) of 0.0404 USD/kWh and a net present cost (NPC) of 104.598 thousand USD. The estimated payback period (PBP) is around 6 years. The optimized system significantly reduces carbon dioxide emissions, with a reduction of 101.875 tons compared to the existing grid and 243.244 tons compared to diesel generator (DG) systems. This reduction is attributed to its renewable component, which accounts for 59.70% of the total emissions.

Keywords:- Life-cycle cost, HRES, NPC, LCOE, Emissions, Solar energy, Grid-tied PV system, HOMER pro model

I. INTRODUCTION

Electricity, one of the most essential infrastructure components worldwide, is critical to a nation's prosperity and well-being. Technologists all over the world have thought about using RESs because the supply of coal and petroleum is rapidly decreasing and power consumption is rising dramatically [1–3]. Environmental degradation and its severe repercussions have brought RES to global attention. Although renewable energy sources (RES) require a higher initial investment, their low operating costs and minimal pollution encourage increased adoption worldwide [4–6]. Production of solar and wind energy is a plentiful and affordable resource. As an outcome, several countries are starting to recognize wind and solar power as an attractive possibility for future electrical power generation [7–9]. Since then, annual improvements in installed wind and solar capacities have surpassed 30%. Compared to other energy options, both solar and wind power offer numerous desirable features, including lower greenhouse gas emissions, reduced reliance on fossil fuels, mitigation of global warming, decreased setup and installation costs, elimination of fuel costs, and lower operation and maintenance (O&M) charges [10–12]. The fact that India is the seventh largest country in terms of its total land mass presents a number of opportunities for making use of the readily available potential of renewable energy sources. Nearly 20% of people on earth currently have no access to electricity [13]. As of February 28, 2023, India had 412 GW of installed capacity, with fossil fuels accounting for 236.4 GW and renewable energy accounting for about 175.7 GW. As a result, there is an imperative necessity to tap commonly accessible RES for use in electricity production and achieve the goal of “electricity for all.” India has demonstrated a strong commitment to pioneering climate change mitigation efforts [14]. In addition to achieving short-term objectives such as increasing renewable capacity to 500 GW by 2030, meeting 50% of its power needs from renewable energy sources, decreasing overall emissions by one billion tonnes by 2030, and reducing the emissions intensity of India's GDP by 45% by 2030, the nation's long-term goal is to achieve net zero emissions by 2070. An HRES made up of two or more renewable energy sources can be a better option for providing electricity in rural areas because it offers more

flexibility in choosing power sources, is more reliable, can be better sized for needs, lasts longer, and is more cost-effective than using just one energy source [15]. Over the last 40 years, India's potential to generate electricity has increased at an outstanding rate. It was 30 GW in 1981, and by February 28, 2023, it was over 412 GW. The demand for generation is significantly higher than the demand for load despite this growth. India has 416,058 MW of installed capacity, as of the most recent data [16]. Renewable energy contributes 30.1% of total installed capacity, second only to thermal energy. The significant proportion of both conventional and renewable energy-based power plants in the country is shown in Figure 1. Thermal power plants, which account for 57.02% of total capacity, among other things, contribute to global warming, greenhouse gas emissions, and health issues. An increase in the number of RES can bolster the current situation, as shown in the figure, which shows that RES only generate 30.1% of the total power [17, 18]. As depicted in Figure, RES is in its current state as of March 31, 2023. 2. Exploring and making use of the RES that are already present is the most efficient strategy for rural areas to use to address these issues and achieve the goals of government programs like "Power to All," "Green and Clean Energy," and "Digital India," among others. Renewable energy use can enhance the well-being and quality of life of rural individuals, provide access to better educational and employment opportunities, and ultimately decrease the number of people compelled to leave their residences for urban areas. Researchers are looking into hybrid systems that integrate numerous energy sources due to the unpredictability and intermittent nature of renewable energy sources (RESs) throughout the year [19]. The superiority and affordability of hybrid systems with multiple sources have been demonstrated by more recent research. The site's geography and ecology influence these factors, necessitating site-based studies to determine the hybrid structure's size, investment requirements, and O&M costs. Additionally, the initial cost of systems that primarily rely on RESs is higher than that of systems that rely on conventional energy sources. Therefore, compactness (size) is a must for cost-effective power generation.

II. LITERATURE REVIEW

Recent studies show that the average installed cost of solar PV plants globally in the year 2021 was approximately 857 USD/kW. This is a decline of 6.0% from 2020 and an overwhelming 82.0% from 2010 [20]. The LCOE of utility-scale solar PV declined from 75.0% to 90.0% at the national level between 2010 and 2021. Numerous studies have investigated the most effective way to set up HRESs for various of scenarios and purposes. An Iranian study by Shiroudi et al. recommended a PV/WT/DG/BES system for autonomous applications [21]. Additionally, an Odisha, India, investigation revealed that a PV/BES combination can achieve 100% RES [22]. Several studies employ simulation simulators like HOMER Pro and RETScreen to improve the efficiency of HRESs. For example, such models provide the ability to simulate PV autonomous structures, PV/ wind hybrid structures, and solo wind structures. But there remains a lack of transparency and depiction of temporal unpredictability concerns that require resolution [23–25]. Researchers have examined HRESs from a techno-economic standpoint. To illustrate the concept, the authors noted that an Indonesian study indicated that a PV/DG system could produce around 309.60 kWh/yr at a cost of 0.318 USD per kWh [26]. Thai researchers proposed a system that combined PV, converters, and BES, which produced a 100% renewable portion at a cost of 0.728 USD per kWh [27]. According to a feasibility study, a PV, WT, and BES together make up the ideal HRES architecture for a remote Nigerian health facility [28]. As a case study, the authors analyzed a Maldives resort and utilized the HOMER Pro tool to find the best technical design for an HRES [29]. The studies deemed the systems practicable based on LCOE and NPC criteria. Another study focused on the techno-economic impacts of an HRES on the generation of power in remote areas of Nigeria, emphasizing how RESs affect COE and NPC numbers [30]. Al Asfar et al. conducted a techno-economic evaluation of small-grid installation in Jordan and analyzed the economic effects of a household's HRES. Utilizing data for average, least, and highest winds and solar radiation, the authors created several scenarios and evaluated three different HRESs that could operate small grids. The study determined that the most suitable arrangements for the HRES were a 9 kW WT, a bank of six batteries, a 1.3 kW PV power source, and a 1.6 kW DG [31]. Research in Barwani, India, suggested that the WT/PV/DG/BES integrated system was the most effective setup from a carbon footprint and financial perspective [32], while research in a far-flung Saudi Arabian village demonstrated the feasibility of meeting electricity demands via an HPS [33]. More studies that looked at Bandar Dayyer's techno-economic evaluation of two different HRESs found that the area would be a favorable place to study HRE due to sufficient solar irradiation and wind speed (WS) [34]. The modeling and feasibility studies of HPS/PV/BES systems have shown that they lower LCOE by 59.6% in terms of NPC and by 80.7% in terms of operating costs [35]. The HOMER Pro program/tool reliably and steadily tested energy-

efficient systems and self-sustaining dwellings with regard to producing electricity [24, 36]. Another study looked at the possibility of a WT (10-kW) and a PV (20-kW) system working together to fulfill the electrical power needs of a Jordanian hotel. They determined that the system could pay for itself in 11 years [37]. The authors also found that a PV/WT/DG/BES converter structure worked best in Sudan, out of a few different technology combinations. It had a 40% return on investment (ROI), a TNPC of 24.16 million USD, a 95% reduction in CO₂ emissions, and an LCOE of 0.387 USD/kWh [38]. In another investigation, the authors mapped out the best PV/wind hybrid power plants for six different Nigerian cities' residential electricity demands. The payback periods for these systems ranged from 3.7 to 5.4 years, and their LCOEs were between 0.459 and 0.562 USD/kWh [39]. A case study was carried out in various Peruvian villages to ascertain the economic viability of hybrid WT/PV/DG systems. The results show that the integrated optimal

design architecture costs for Campo Serio, El Potrero, and Silicucho are 227,335 USD (LCOE: 0.478 USD/kWh), 183,851 USD (LCOE: 0.460 USD/kWh), and 146,583 USD (LCOE: 0.504 USD/kWh), respectively. El Potrero succeeded in an exceptional 97% renewables portion, while Campo Serio and Silicucho achieved a substantial 94.00%. Additionally, the expected environmental impact shows big financial savings, as the new configuration releases 6.10% of the GHG found in Campo-Serio, 02.70% in El-Potrero, and 09.90% in Silicucho compared to DG-only units [40]. A massive-scale HRE plant can improve its configuration and O&M by integrating a newly developed energy storage technology, known as gravity energy storage (GES), and validate its viability in comparison to battery storage. In an optimal configuration, there will be 418 PV panels, 477 WTs, and a 15 MWh GES capacity. While RE-Battery has an LCOE of 0.05–0.25 Euro per kWh, RE-GES has an LCOE of 0.018–0.3 Euro per kWh [41]. Researchers present and assess an innovative intelligent building power system that uses a combination of solar panels and other unconventional energy sources. The system utilizes intriguing photovoltaic thermal cooling panels, bidirectionally connected to power, heat, and cooling networks, and integrates both cold and hot storage. As per the study's findings, the suggested approach is the most affordable and viable option, with an initial expenditure of 0.457 million USD and a PBP of 6.6 years [42]. Researchers used HOMER to study the environmental and economic effects of different hybrid systems that combine solar panels, wind turbines, diesel generators, and battery energy storage in five different climate areas. The findings revealed that when comparing the Rajshahi area to other locations, the isolated hybrid PV/DG/BES system had a slightly reduced LCOE (USD/kWh) and NPC while weighing the costs and greenhouse gas emissions. In comparison to a grid-only system, the grid-tied HRES was able to reduce CO₂ emissions by about 45,582 kg/year, while the solitary hybrid PV/DG/BES system was able to reduce CO₂ emissions by approximately 32,905 kg/year [43]. The authors have articulated the significance of large-scale rooftop PV system installations in airport precincts for power planning and policy in an appealing way. Findings demonstrate that the 21 Australian leased government airports can produce 466.68 GWh of power per year, which is equivalent to almost 10 times the production of 17 thousand PV panels installed on household rooftops. Using the entire 2.61 km² of rooftop space at these airports could significantly alleviate the electricity shortage. This could be sufficient electricity to power 136,000 houses and mitigate 151.6 kg-tons of hazardous emissions of greenhouse gases annually [44]. Another study utilized HOMER for optimization and modeling to investigate the feasibility of HRES in Benin. The investigation suggested that the PV/DG/BES system would prove to be the optimal long-term solution for Benin because solar radiation is prevalent there. The employed approach demonstrated a 97% reduction in CO₂ emissions and a 70% decrease in the required number of batteries [45]. An analogous study looked at the possibilities of a PV/WT hybrid structure in Nigeria. The authors used the HOMER program for conducting techno-economic and environmental assessments to figure out the optimal NPC, COE, GHG, and RF. Based on this assessment, the structure has a 98.30% renewable share and emits just 2,889.4 kgs of carbon emissions annually, making it globally beneficial [46, 47].

III. Research Gap

The previously mentioned critical literature review identifies several research challenges related to methods for feasibility analysis, hybrid model development, and cost-effectiveness, specifically regarding LCOE, NPC, emissions, and other factors. Based on the literature study, HRES is a better energy solution than a conventional power grid when reliability and affordability are the parameters taken into account. The mentioned studies have also not considered the electricity demand of educational institutions, they have only looked at the rural home electrification sector. As far as the author is aware, no study has been done comprehensively on HOMER-Pro to do a tech-economy evaluation of such HRES locally. After these discussions, the authors were inspired to create some hybrid models for the chosen site, then

the top models were picked based on their reliability, cost and size. The feasibility of different RES or power generating abilities should be the first point of discussion before any hybrid system is planned or constructed. Consequently, the authors made the feasibility study of different RES in particular locations one of their objectives. The next stage after the feasibility study mandates the estimation of load demand for the specified area. On top of that, a step by step guide is necessary to recognize and build different configurations that are practical for the given specific scenario, then choosing the optimal one for these explored configurations to secure the cost effectiveness and the reliability. Moreover, in order to make the best use of RES in a cheap and effective way, the optimal size is needed. Consequently, the power source selection process of renewable energy-based hybrid systems' optimization revolves around the functions of selecting the most suitable components, their right size, and operational planning, thereby delivering a system that is cost-effective, reliable, and of high energy efficiency.

IV. Materials and methodology

In order to find a solution that is both technologically and economically viable, as well as ecologically friendly, this study shows how to implement a hybrid energy distribution system. A systematic modeling approach is essential for designing and building the best hybrid electrical system for rural areas because it ensures that the people living there have stable, foreseeable power availability. In order to identify the best solutions that can manage the load demand considering the constraints and presumptions, HOMER-Pro was utilized. The NREL in the US developed HOMER Pro, an optimizing program for distributed electrical systems. It carries out a sensitivity assessment to address these unpredictability issues and examine how different input parameters impact the optimized outcomes. Figure 3 illustrates this system modeling and analysis procedure. The chapters that follow provide an overview of the chosen site, evaluate the possibility of RESs, estimate electrical loads, and detail the steps required for designing and optimizing the system, all of which are examples of the modeling approach used in the present study.

3.1 Study site selection

The planet receives an extraordinary quantity of light from the sun, which can be harnessed to generate power. The database of the Indian Meteorological Service reveals that India has between 250 and 300 bright days each year, which suggests that the nation can readily use solar energy. Historically, only things like pickles, jam, and clothes were dried using solar energy [40]. Additionally, a solar-powered heater can heat water, and a solar-powered cooker can cook food using solar energy. Modernized solar thermal and solar PV systems also utilize solar energy to produce electricity. Solar PV technology uses PV cells, a thin layer of semiconductor substances, to convert solar energy into electricity. In the range of 0.5 to 0.8 V, a single PV cell generally generates a small amount of voltage. It connects PV cells in a series arrangement to construct a PV module, which can then be coupled in a parallel/series arrangement to construct a PV panel or array. This design facilitates the implementation of this technology and the increase in voltage. Therefore, when exposed to solar radiation, PV panels or arrays generate high voltages and currents at their output terminals, which we can utilize to meet our electricity needs. PV panels, however, are unable to produce power when there is a lack of solar radiation, such as at night or in overcast conditions. For usage throughout the day and at night or when visibility is low, a power-storing device, like a pack of batteries, is essential. Solar PV panels generate DC power. However, many electrical appliances require AC power. For this reason, an instrument that can convert DC power into AC power is essential. An inverter can achieve this. So, the PV system constitutes the PV panels, batteries, a converter, and a charge regulator. The charge regulator is a vital part of the solar PV system. By regulating the power transfer via RESs to the batteries and fulfilling load demands. Depending on what you require, the solar PV system can run either on or off the grid. When operating in grid-tied mode, the solar PV system connects to the grid, unlike its independent-grid counterpart. To plan and create a solar PV system, it is necessary to assess the total amount of solar irradiance in a particular spot. It inputs the investigating location's longitude, latitude, and time zone into the HOMER Pro program to acquire data for each month of solar irradiance. Furthermore, it estimates the selected site's annual solar energy potential (EPV) using Eq. (1). $EPV = QPV \times 365$ (1) where QPV represents the mean annual daily solar irradiance in kWh/m² /day. A WT is a device that harnesses the wind's kinetic energy to produce power. Aerogenerators, which are small WTs manufactured in India, can endure gusts of 10 m/s or more.

VI. OBJECTIVES

- To analyze the global trends in solar PV costs and LCOE over the last decade and highlight their impact on the economic feasibility of hybrid renewable energy systems.

- To evaluate the techno-economic performance of hybrid systems in terms of Net Present Cost (NPC), Cost of Energy (COE), Payback Period (PBP), Return on Investment (ROI), and Levelized Cost of Electricity (LCOE).
- To identify the role of simulation tools such as HOMER Pro and RET Screen in optimizing hybrid energy system design, performance prediction, and cost analysis.
- To explore the feasibility of advanced energy storage technologies (Battery Energy Storage, Gravity Energy Storage, etc.) for improving the efficiency, reliability, and sustainability of HRESs.
- To propose suitable HRES architectures for different case studies (health centers, resorts, rural villages, small grids, and airports) based on resource availability and techno-economic parameters.

REFERENCES

1. Khan AA, et al. Feasibility and techno-economic assessment of a 128kWp grid-tied SPV system using HOMER Pro. *J Phys Conf Ser.* 2024;2777: 012008. <https://doi.org/10.1088/1742-6596/2777/1/012008>.
2. Duan J, Wang P, Ma W, Fang S, Hou Z. A novel hybrid model based on nonlinear weighted combination for short-term wind power forecasting. *Int J Electr Power Energy Syst.* 2022;134: 107452.
3. Minai AF, Husain MA, Naseem M, Khan AA. Electricity demand modeling techniques for hybrid solar PV system. *Int J Emerg Electr Power Syst.* 2021;22(5):607–15. <https://doi.org/10.1515/ijeeps-2021-0085>.
4. Wang Y, Xu H, Zou R, Zhang L, Zhang F. A deep asymmetric Laplace neural network for deterministic and probabilistic wind power forecasting. *Renew Energy.* 2022;196:497–517.
5. Ahmad T, Zhang D. A data-driven deep sequence-to-sequence long-short memory method along with a gated recurrent neural network for wind power forecasting. *Energy.* 2022;239: 122109.
6. Minai AF, Siddiqui MA, Laskar SH, Khan AA, Pachauri RK. Performance evaluation and assessment of 100-kW grid-tied SPV system in subtropical climatic conditions. In: Gabbouj M, Pandey SS, Garg HK, Hazra R, editors. *Emerging Electronics and Automation E2A 2022 Lecture Notes in Electrical Engineering*, vol. 1088. Singapore: Springer; 2024. https://doi.org/10.1007/978-981-99-6855-8_27.
7. Wang H, Li G, Wang G, Peng J, Jiang H, Liu Y. Deep learning based ensemble approach for probabilistic wind power forecasting. *Appl Energy.* 2017;188:56–70.
8. Khan AA, Minai AF, Pachauri RK, Malik H. Optimal sizing, control, and management strategies for hybrid renewable energy systems: a comprehensive review. *Energies.* 2022;15:6249. <https://doi.org/10.3390/en15176249>.
9. Hanifi S, Liu X, Lin Z, Lotfian S. A critical review of wind power forecasting methods-past, present and future. *Energies.* 2020;13(15):3764.
10. Akhtar I, Kirmani S, Ahmad M, Ahmad S. Average monthly wind power forecasting using fuzzy approach. *IEEE Access.* 2021;9:30426–40.
11. Bochenek B, Jurasz J, Jaczewski A, Stachura G, Sekuła P, Strzyżewski T, Wdowikowski M, Figurski M. Day-ahead wind power forecasting in Poland based on numerical weather prediction. *Energies.* 2021;14(8):2164.
12. Kisvari A, Lin Z, Liu X. Wind power forecasting—a data-driven method along with gated recurrent neural network. *Renew Energy.* 2021;163:1895–909.
13. Jung J, Broadwater RP. Current status and future advances for wind speed and power forecasting. *Renew Sustain Energy Rev.* 2014;31:762–77.
14. Zhang Y et al. Forecasting solar photovoltaic power production at the aggregated system level. In 2014 North American Power Symposium (NAPS). IEEE; 2014. pp. 1–6.

15. Ghadim HV, Ardashir JF. Technical design and environmental analysis of 100-kWp on-grid photovoltaic power plant in north-western Iran. *Clean Energy*. 2022;6:362–71.
16. https://www.business-standard.com/article/economy-policy/states-add-1-1-million-families-to-unelectrified-list-shows-d-ata-122062701222_1.html (Accessed on 15 January 2024)
17. CEA-MoP-GoI.2023. <https://cea.nic.in/distribution-village-electrification-report/?lang=en> (Accessed on 15 January 2024).
18. CEA-GoI. 2023. <https://cea.nic.in/installed-capacityreport/?lang=en> (Accessed on 15 January 2024).
19. Ahmad J, Imran M, Khalid A, Iqbal W, Ashraf SR, Adnan M, Ali SF, Khokhar KS. Techno economic analysis of a windphotovoltaic-biomass hybrid renewable energy system for rural electrification: a case study of Kallar Kahar. *Energy*. 2018;148:208–34.
20. IRENA. Renewable power generation costs in 2021. 2022. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Jan/IRENA-2017_Power_Costs_2018.pdf.
21. Shiroudi A, et al. Case study: simulation and optimization of photovoltaic-windbattery hybrid energy system in TaleghanIran using HOMER software. *J Renew Sustain Energy*. 2012;4(5): 053111.
22. Pradhan AK, et al. Techno-economic evaluation of stand-alone hybrid renewable energy system for remote village using HOMER-pro software. *Int J Appl Power Eng (IJAPE)*. 2017;6:73.
23. Ramli MS, et al. A comparison of renewable energy technologies using two simulation softwares: HOMER and RETScreen. *AIP Conf Proc*. 2017;1875: 030013.
24. Khan AA, Minai AF. A strategic review: the role of commercially available tools for planning, modelling, optimization, and performance measurement of photovoltaic systems. *Energy Harvest Syst*. 2024;11(1):20220157. <https://doi.org/10.1515/eh-s-2022-0157>.
25. Ringkjob HK, et al. A review of modelling tools for energy and electricity systems with large shares of variable renewables. *Renew Sustain Energy Rev*. 2018;96:440–59.
26. Rumbayan M, Nagasaka K. Techno economical study of PV-diesel power system for a remote island in Indonesia: a case study of Miangas Island. *IOP Conf Ser Earth Environ Sci*. 2018;150: 012024.
27. Park E, Kwon SJ, Del Pobil AP. Can large educational institutes become free from grid systems? Determination of hybrid renewable energy systems in Thailand. *Appl Sci*. 2019;9: 2319.
28. Ani VA, Abubakar B. Feasibility analysis and simulation of integrated renewable energy system for power generation: a hypothetical study of rural health clinic. *J Energy*. 2015;2015:1–7.
29. Jung TY, Kim D, Lim S, Moon J. Evaluation criteria of independent hybrid energy systems. *Int J Low-Carbon Technol*. 2019;14:493–9.
30. Oyedepo SO, Uwoghiren T, Babalola PO, Nwanya SC, Kilanko O, Leramo RO, Aworind AK, Adekeye T, Oyebanji JA, Abidakun OA. Assessment of decentralized electricity production from hybrid renewable energy sources for sustainable energy development in Nigeria. *Open Eng*. 2019;9:72–89.
31. Al-Asfar J, Atieh A, Al-Mbaideen R. Techno-economic analysis of a microgrid hybrid renewable energy system in Jordan. *J Eur Des Syst Autom*. 2019;52:415–23.
32. Sawle Y, Gupta SC, Bohre AK. PV-wind hybrid system: a review with case study. *Cogent Eng*. 2016;3: 1189305.
33. Al-Ammar EA, Malik NH, Usman M. Application of using hybrid renewable energy in Saudi Arabia. *Eng Technol Appl Sci Res*. 2011;1:84–9.
34. Kasaeian A, et al. Deployment of a stand-alone hybrid renewable energy system in coastal areas as a reliable energy source. *Environ Prog Sustain Energy*. 2020;39:1–20.

35. Aderemi BA, Chowdhury DSP, Olwal TO, Abu-Mahfouz AM. Technoeconomic feasibility of hybrid solar photovoltaic and battery energy storage power system for a mobile cellular base station in Soshanguve, South Africa. *Energies*. 2018;11:1572.
36. Oladeji AS, Balogun OS, Aliyu SO. Use of standalone photovoltaic system for office building: the case study of national centre for hydropower research and development, Nigeria. *Niger J Technol*. 2018;36:1208.
37. Okonkwo EC, Okwose CF, Abbasoglu S. Techno economic analysis of the potential utilization of a hybrid PV-wind turbine system for commercial buildings in Jordan. *Int J Renew Energy Res*. 2017;7:908–14.
38. Elkadeem MR, et al. Feasibility analysis and techno-economic design of grid isolated hybrid renewable energy system for electrification of agriculture and irrigation area: a case study in Dongola, Sudan. *Energy Convers Manage*. 2019;196:1453–78.
39. Diemuodeke EO, et al. Optimal mapping of hybrid renewable energy systems for locations using multi-criteria decisionmaking algorithm. *Renew Energy*. 2019;134:461–77.
40. Rinaldi F, Moghaddampoor F, Najafi B, Marchesi R. Economic feasibility analysis and optimization of hybrid renewable energy systems for rural electrification in Peru. *Clean Technol Environ Policy*. 2021;23:731–48.
41. Emrani A, Berrada A, Arechkik A, Bakhouya M. Improved techno-economic optimization of an off-grid hybrid solar/ wind/ gravity energy storage system based on performance indicators. *J Energy Storage*. 2022;49: 104163.
42. Arabkoohsar A, Behzadi A, Sulaiman A. Techno-economic analysis and multiobjective optimization of a novel solar-based building energy system; an effort to reach the true meaning of zero-energy buildings. *Energy Convers Manage*. 2021;232: 113858.
43. Das BK, Alotaibi MA, Das P, Islam MS, Das SK. Feasibility and technoeconomic analysis of stand-alone and grid-connected PV/wind/diesel/batt hybrid energy system: a case study. *Energy Strateg Rev*. 2021;37: 100673.
44. Teofilo A, et al. Investigating potential rooftop solar energy generated by leased Federal Airports in Australia: framework and implications. *J Build Eng*. 2021;41: 102390.
45. Odou ODT, Bhandari R, Adamou R. Hybrid off-grid renewable power system for sustainable rural electrification in Benin. *Renew Energy*. 2020;145:1266–79.
46. Salisu S, Mustafa MW, Olatomiwa L, Mohammed OO. Assessment of technical and economic feasibility for a hybrid PVwind-diesel-battery energy system in a remote community of north central Nigeria. *Alex Eng J*. 2019;58:1103–18.
47. Shezan SKA, Das N, Mahmudul H. Techno-economic analysis of a smart-grid hybrid renewable energy system for Brisbane of Australia. *Energy Procedia*. 2017;110:340–5.
48. Shafiullah GM. Hybrid renewable energy integration (HREI) system for subtropical climate in central Queensland, Australia. *Renew Energy*. 2016;96:1034–53.