MIJST
MIST International Journal of Science and Technology

Cost and Reliability Analysis of a Hybrid Renewable Energy System - A Case Study on an Administration Building

Wenyuan Sun[1*], Cong Tian[2], and Yingai Jin[3]

State Key Laboratory of Automotive Simulation and Control, Jilin University, Changchun 130022, China

emails: *[*1]sunwy20@mails.jlu.edu.cn; [2]1452370936@qq.com; and [3]jinya@jlu.edu.cn*

ARTICLE INFO

Article History:

Received: 12th September 2022
Revised: 20th November 2022
Accepted: 24th November 2022
Published: 29th Decemebr 2022

Keywords:

Hybrid renewable energy systems
Wind
Solar
Hydrogen

ABSTRACT

Renewable energy generation systems have been developing rapidly in recent years. However, renewable energy systems have the problem of large power abandonment. In this paper, two different hybrid renewable energy systems (HRESs) have been designed for satisfying the electrical demand of a large office building in Changchun. A comparative analysis between two strategies is also presented to find out the best capacity for the proposed HRESs. The first HRES consists of solar PV, wind turbine, battery storage system (PV-WT-BATT) and load demand of 5,000 kWh/d. The second consists of solar PV, wind turbine, battery storage system, electrolyzer, hydrogen tank (PV-WT-BATT-EL-HT) and load demand of 5,000 kWh/d. The two HRESs are optimized for Net Present Cost (NPC), Levelized Cost of Energy (COE), Operating Cost and the rate of excess electricity minimization. The techno-economic analysis of the two HRESs is conducted using the HOMER Pro software platform. This study provides a complete guideline for determining the optimum component capacity to ensure costing estimation for the optimized performance of the two HRESs.

1. INTRODUCTION

Adequate energy supply has always been a crucial issue and is considered one of the prerequisites for a country's economic growth and development. Reducing fossil fuel consumption through utilizing renewable energy sources can offer an effective mitigation option to enhance energy security and reduce fossil fuel dependance (Byrne *et al.*, 1998; Heidari *et al.*, 2019; Shirmohammadi *et al.*, 2018). Taking this reality into account, the use of renewable energy sources, can be considered as an alternative solution to overcome energy deficiency for achieving sustainable development and economic prosperity (Armin *et al.*, 2019; Aslani *et al.*, 2018; Khatibi *et al.*, 2018; Khatibi *et al.*, 2018; Razmjoo *et al.*, 2019).

There is no doubt that solar and wind power are most suitable clean energy sources, and according to published statistics, the impact on energy services is growing (Bakhtiar *et al.*, 2020; Hosseini *et al.*, 2017; Mohammadi *et al.*, 2018). In addition, solar and wind have considerable potential to supply a significant portion of the world's energy demand. Furthermore, latest breakthroughs in solar and wind technology and related areas have increased the efficiency of power generation (Lotfi *et al.*, 2013; Soltani *et al.*, 2017). However, due to the intermittency and design constraints, the design and application of hybrid renewable energy systems are still challenging (Das *et al.*, 2019).

Hydrogen energy also has great development potential, proton exchange membrane (PEM) hydrogen production technology has a small footprint, low energy consumption, high flexibility, and good compatibility with wind power and photovoltaic, which are volatile and stochastic, so it has more application advantages and cost reduction potential in many scenarios. At present, this technology has not been commercialized on a large scale in China, but there are already many megawatt-scale applications in Europe. Cummins company has many large-scale commercial projects in Canada, the U.S. and Europe, including the 20 *MW* PEM electrolytic water project under construction in Canada.

With the continuous development, the price of equipment will drop as the proportion of localization becomes higher in the future. From the perspective of future trends, the cost of renewable energy will continue to decline. With the policy support of the government and the continuous exploration of enterprises in the hydrogen energy industry chain, the green hydrogen energy business model will become mature and more large-scale, which will bring significant room for equipment cost reduction. According to the research of major international energy institutions, green hydrogen energy will be economical and equal to the cost of fossil energy hydrogen production by around 2030.

In recent years, there has been a great deal of research into the design, the reliability and optimization of independent HRESs including the wind turbine-diesel generator (WT-DG), PV-DG, WT-PV-DG, and PV-Fuel cell (PV-F) and these systems with battery storages. A single energy independent system, i.e., wind system, solar system, or DG system cannot provide continuous power supply due to their intermittency (Yang *et al.*, 2008). Therefore, Energy Storage Systems (ESS) are considered crucial for the full adoption of HRESs. The integration of the solar and wind generations with storage resources can thus effectively lead to a flexible and reliable design for an HRES. As a result, it is necessary to develop a well-designed model for cost-effective and reliable operation of an HRESs.

The wind power generation had been compared in South Asian countries (Khan *et al.*, 2012). The analysis includes current generation capacity by fuel type, government initiatives and wind energy policies. The study shows that India has a clear lead in wind energy utilization compared to the other two countries, Bangladesh, and Pakistan. The main obstacle to wind power is the lack of clear policy and government initiatives. The combination of independent solar PV with DG was studied (Kolhe *et al.*, 2002), They reported that solar PV was more technically and economically efficient and gave an output of 68 kWh/day, making the solar PV market competitive. The performance of a hybrid PV-WT had been optimized on the HOMER software platform to replace DG used in a mobile phone base station in Bhopal, India (Nema *et al.*, 2010).

Hybrid performance of solar PV/wind turbine/Proton exchange membrane fuel cell (PEMFC) had been studied for remote applications (Agbossou *et al.*, 2001). The study shows that the performance of an independent solar PV/wind turbine/fuel cell/electrolytic cell/battery hybrid system could generate enough electricity to meet peak loads (Eroglu *et al.*, 2011). However, they did not discuss the economics of the system.

The report showed that adding an auxiliary power source from battery packs or fuel cells, or a utility grid, to this would ensure the reliability of the system without requiring excessive hardware (Luna-Rubio *et al.*, 2012). A renewable energy system had been developed based on HOMER platform to identify different cost components (Rajanna *et al.*, 2014). Three different configurations of HRES were developed in six geographic zones of Nigeria (Olatomiwa *et al.*, 2015), and it can be determined economic feasibility solution using HOMER software with sensitivity cases of \$1.1–\$1.3 based NPC and COE. Based on the availability of meteorological data, a statistical analysis of the wind and solar potential had been studied in rural Nigeria (Olatomiwa *et al.*, 2018). It used HOMER software platform to design and tune technologically and economically optimal hybrid energy system components. An off-grid hybrid microgrid consisting of solar PV, diesel generator, wind turbine, and battery storage devices had been built on the HOMER software platform (Hossen *et al.*, 2022). The proposed load following (LF) strategy performs as the best dispatch strategy with the lowest CO_2 emissions (0.3 kt/year), LCOE (0.03 \$/kW), and NPC (15.7 M\$). LF also performed the best in terms of system stability and reliability having stable voltage, frequency, active power and reactive power responses.

A framework composed of wind turbines, diesel generators and batteries, and output the optimal combination of 10 wind turbines, 4 diesel engines and 2 battery modules had been built on the HOMER software platform (Shezan *et al.*, 2022). The proposed framework is financially and ecologically feasible, and that the NPC and CO_2 outflow are diminished by around 74% and 92% separately every year contrasted with customary power plants. An island hybrid microgrid with solar PV, wind turbine, diesel enerator and battery storage system had been built, and four scheduling strategies, load following, cycle charging, generator order and combination dispatch had been evaluated (Shezan *et al.*, 2021). The stability of the method is verified by voltage, frequency, active power, and reactive power. Results show that the generator order scheduling strategy is the best in terms of minimum operating costs, net current costs, and CO_2 emissions.

Two hybrid off-grid renewable energy system is designed on the HOMER software platform, and a comparative analysis on the technical economy and system stability of five scheduling strategies had been studied, which had guiding significance for the energy management of Dhaka and Khulna region in Bangladesh (Shezan *et al.*, 2022). The optimal size and technical economics of hybrid microgrid systems consisting of solar PV, diesel generators, battery storage and wind turbines had been evaluated (Shezan *et al.*, 2022). They described the voltage, frequency, power performance and reliability indicators of the simulated microgrid. The results show that LF is considered to be the best in terms of system reliability and stability.

A technical and economic analysis of a cluster hybrid renewable energy system in Three villages in India had been studied (Vendoti *et al.*, 2018). For transient use, most use batteries, while for continuous use, hydrogen storage is profitable. According to the report, the use of PEM fuel cells stabilized the power supply of the communication station in severe weather conditions, and its hydrogen to electricity conversion efficiency exceeded 42%.

The core target of this study is to develop and assess a PV-WT-BATT-EL-HT stand-alone HRES for satisfying the electrical demand of a large office building in Changchun. The main contribution of this paper can be summarized as below:

1) Using HOMER Pro HRES platform, to determine the optimum sizes for its optimal operation which secures minimum NPC, COE, and operating cost.

2) Compared with the grid connected system, the output of this system is directly supplied to the load, and the discarded power is consumed internally. On the premise of ensuring its normal operation, it will not affect the external power grid, thus the system performs with higher stability and reliability.

2. METHODOLOGY

A. Study Area

Changchun is an industrial city of Jilin province, located in the north of China. The latitude and Longitude of Changchun is 43°75'N and 125°25'E. According to data from Changchun meteorological monitoring station, the highest wind speed is occurred in April with 7.84 m/s, and the lowest wind speed is occurred in August with 5.29 m/s. In addition, the lowest daily radiation is allocated to December with 1.73 kWh/m^2/day, while the highest daily radiation corresponds to May with 6.069 kWh/m^2/day. Thus, the abundance of wind and solar resources in Jilin province especially Changchun offers a suitable environment for the inclusion of hybrid renewable energy systems.

B. Load and Resources Assessment

The case study selected in this paper is an office building of Jilin University, covering an area of 5220 square meters, with a total office area of 165,635 square meters and a total of 10 floors high, the office building is shown in Figure 1. Table 1 Average and peak load of the study case. The total yearly power demand based on hourly and monthly loads has been determined using HOMER Pro software as shown in Figure 2.

Figure 1: The study case in Jilin University

Table 1
Average and peak load

Particulars	Details
Average (kWh/d)	5,000.00
Average (kW)	208.33
Peak (kW)	494.69

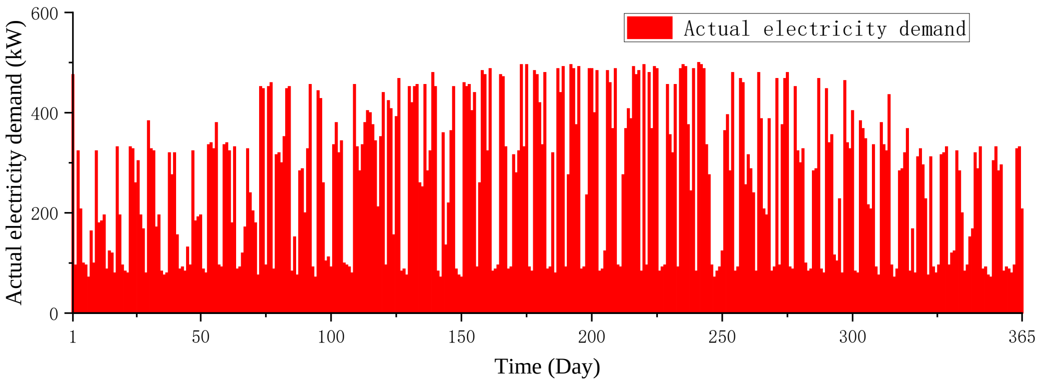

Figure 2: The load profile of a year

C. Optimization based on HOMER Software

As stated earlier, the primary purpose of the study is to determine the size and cost optimization of an off-grid hybrid energy system. Based on the database available, the proposed configuration is simulated using HOMER Pro software, developed by National Renewable Energy Laboratory (NREL), USA.

The design of the system under consideration comprises seven components: Wind Turbine Generator, Solar Photovoltaic, direct current (DC) to alternating current (AC) converter, battery, electrolyzer, hydrogen tank and primary load as presented in Figures 3 and 4. The time period of the project is 20 years with yearly unmet load of zero. The time period of the project is 20 years with yearly unmet load of zero. For the reactive power in the system, the reactive capacitor compensator is set to ensure the supply voltage and frequency. The total compensation capacity is as follows:

$$Q_c = \beta_{av} q_c P_c \quad (1)$$

Here, P_c is monthly maximum active calculated load supplied by the substation (kW). β_{av} is monthly average load rate, generally $0.7 - 0.8$. q_c is capacitor compensation rate ($kvar/kW$), reactive power to be compensated for each kilowatt of active load. Parameters of hybrid renewable energy systems are shown in Table 2.

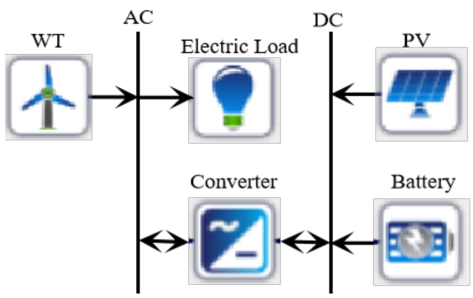

Figure 3: Solar PV, wind turbine and battery storage system (PV-WT-BATT)

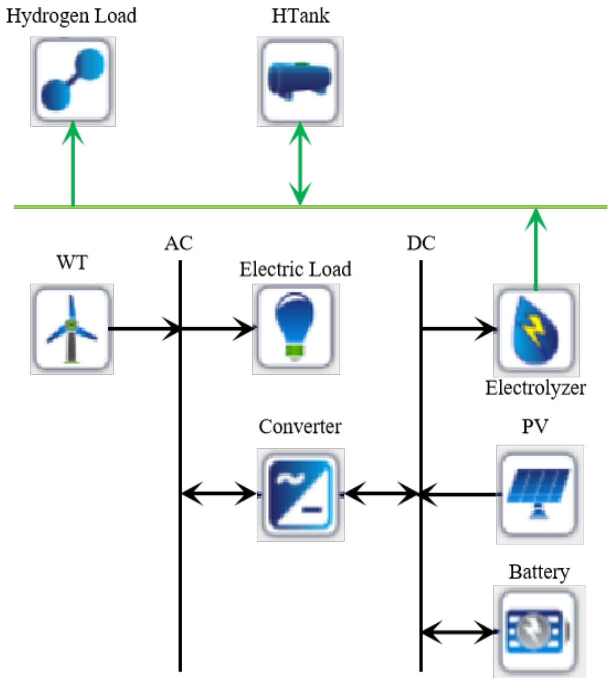

Figure 4: Solar PV, wind turbine, battery storage system, electrolyzer, hydrogen tank (PV-WT-BATT-EL-HT)

Table 2
Parameters of hybrid renewable energy systems

Quantity	Wind Turbine (kW)	PV (kW)	Battery (kWh)	Converter (kW)	Electrolyzer (kW)	Hydrogen tank (kg)
Size	1,000	1	100	1	5	1
Capital (¥)	500,000	2,500	70,000	300	5,000	6,000
Replacement (¥)	500,000	2,500	70,000	300	4,000	5,000
O&M (¥/yr)	5,000	10	1,000	0	300	4,380
Lifetime (year)	20	25	15	15	20	25

Here, as a financial measure, the total net present cost is considered for assessing of the proposed hybrid system. It includes net present capital cost (NPC), operation & maintenance cost, and replacement cost of components. The levelized cost of energy (COE) is defined as the average cost per kWh of useful electrical energy produced by the system. HOMER determines the system operation combinations based on capital cost, net present cost, and levelized cost of energy (COE).

Cost of Energy (COE): To compute the optimal COE for a hybrid system in HOMER, the following equation has been used:

$$COE = \frac{C_{ann,tot}}{E_{prim}+E_{def}+E_{grid,sales}} \quad (2)$$

Here, $C_{ann,tot}$ is total annualized cost, E_{prim} is total amounts of primary load, E_{def} is total amounts of deferrable load, and $E_{grid,sales}$ is amount of energy sold to the grid per year.

Net Present Cost (NPC): To calculate the total net present cost，the following equation has been used:

$$NPC = \frac{C_{ann,tot}}{CRF(i,R_{proj})} \quad (3)$$

Here, $C_{ann,tot}$ is total annualized cost, i is annual real interest rate, R_{proj} is Project lifetime, and $CRF(.)$ is Capital recovery factor.

3. RESUITS AND DISCUSSION

Once all input parameters are completed, the lowest cost is selected as the optimization target. Thereafter, the simulation calculation has been undertaken. Among many combinations, only two combinations are selected and the results of each of these two are discussed below:

A. Combination 1: PV-WT-BATT

In Combination 1, as shown in Figure 3, excess power generated by PV and wind turbine is stored in the battery. The size of PV, WT and battery are 778 kW, 6,000 kW and 2,300 kWh respectively.

The lowest COE of Combination 1 is 0.433 CNY/kWh and total NPC is 9.70M CNY. Among all components, the wind turbine shows the highest cost as 3,805,242.38 CNY. The power generation of each component is shown in Table 3.

As Figure 2 shows that the off-grid hybrid energy system needs a large amount of unit capacity to meet the load demand, which not only increases the total cost of the system, but also generates a large amount of excess electricity, as shown in Figure 5.

B. Combination 2: PV-WT-BATT-EL-HT

In order to reduce the excess power, the wind turbine generator, electrolyzer and battery system are considered in the system of Combination 2, as shown in Figure 4. In this combination, the excess electricity is further used by the electrolyzer to produce hydrogen and stored in the hydrogen tank, where the fuel cell uses the hydrogen to generate electricity to meet load requirements when wind and solar power are insufficient. To find the most optimal solution for the proposed hybrid energy system and evaluate the effect of uncertainty and/or changes within the variables, the sensitivity analysis has been undertaken. HOMER software is used to simulate each configuration and determine the effects on changing factors. The system has two sensitivity variables electrolyzer and hydrogen tank and size are considered during this study.

From Table 4, it is noted that the difference in the absorption of excess electricity is only 0.2% between configuration 2 and 4, whereas the NPC of configuration 2 increases by ¥2,200,000, while the NPC of configuration 4 increases by only ¥1,100,000, so configuration 4 is considered superior to configuration 2. The absorption of excess electricity in configuration 2 and 4 is 17.8% and 18.9% respectively, with corresponding NPC increases by ¥2,300,000 and ¥2,400,000. Through comparative analysis of configuration 4, which absorbs 16% excess electricity with NPC increased by ¥1,100,000, we conclude that configuration 4 utilizes a relatively large amount of excess electricity, with the least cost price increase. The final optimization result is shown in Figure 5.

Table 3
Comparison of NPC, COE and operating cost of different hybrid renewable energy systems

PV (kW)	WT (kW)	Battery (kWh)	Converter (kW)	Dispatch	NPC (CNY)	COE (CNY)	Operating cost (CNY/yr)
778	6×1000	23×100	550	CC	9.70M	0.433	140,366
	10×1000	43×100	426	CC	11.1M	0.505	230,415
1931		51×100	541	CC	13.7M	0.618	169,448
4916	49×1000		631	CC	51.6M	2.3	562,897

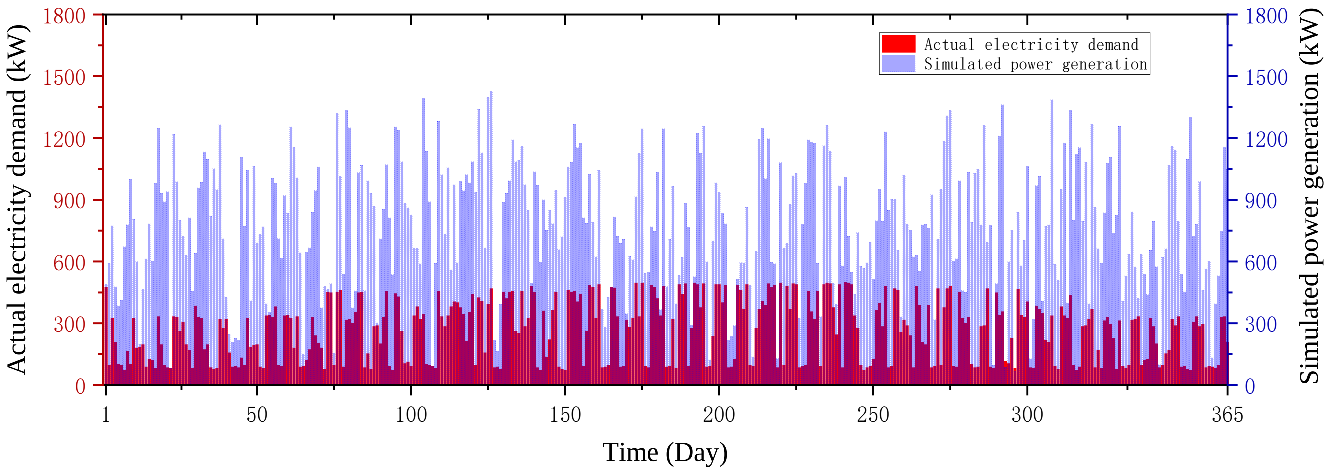

Figure 5: Excess electricity production

Table 4
Sensitivity analysis

Configurations	Electrolyzer (kW)	Hydrogen tank	NPC (¥)	COE (¥)	Excess Electricity
1	0	0	9.7M	0.433	45.4%
2	150	30	11.9M	0.530	29.6%
3	200	30	12.0M	0.534	27.5%
4	250	10	10.8M	0.483	29.4%
5	250	30	12.1M	0.539	26.5%

Table 5
The result of NPC, COE and operating cost of PV-WT-BATT-EL-HT

PV (kW)	WT (kW)	Battery (kWh)	Electrolyzer (kW)	HTank (kg)	Converter (kW)	Dispatch	NPC (CNY)	COE (CNY)	Operating cost (CNY/yr)
778	6×1000	23×100	250	10	499	CC	10.8M	0.483	204,082

This paper selects a relatively small electrolytic cell with a capacity of 250kW, which can reduce the annual discarded electricity by 19.7%. However, it increases the cost by 1.1 million CNY.

C. System Comparison

The comparative analysis between the Combination 1 and the Combination 2 have been articulated in Figure 5 and 6. For Combination 2, NPC, COE, and operating cost are higher (10.8M yuan, 0.483 yuan/kWh, and 204,082 yuan; respectively). On the other hand, it is found to be lower in excess electricity (29.4%). In general, it is critical to balance production and consumption in the case of renewable source-based microgrids with hydrogen as backup load. This is of great significance to improve system stability.

4. CONCLUSIONS

In this work, two hybrid renewable energy systems (HRES) have been optimized and evaluated using different sizes of the system. Simulation analysis shows that the optimal combination of HRES components for this study is 778 kW PV array, 6,000 kW wind turbine, 250 kW electrolyzer, 2,300 kWh battery and 10 kg hydrogen tank. The cost of energy (COE) is 0.483 CNY/kWh, and the total net present cost (NPC) is 10.5M CNY. As can be seen from the analysis in this paper, the cost of PV-WT-BATT is lower than PV-WT-BATT-EL-HT, but the reliability of the former cannot be guaranteed unless other technical options are considered. The summary of these results is listed as follows:

a) The combination of multiple energy systems improves the reliability of energy supply and therefore makes more business sense.

b) Unless properly supported by the government sector, the cost of electricity supply based entirely on renewable energy may not always be a cost-benefit option.

ACKNOWLEDGEMENT

The authors express their sincere gratitude and thanks to Royal Academy of Engineering of United Kingdom (UK) for the financial support under the UK-China Industry Academia Partnership Program scheme (UK-CIAPP\201).

REFERENCES

Byrne J, Shen B, & Wallace W. (1998). The economics of sustainable energy for rural development: A study of renewable energy in rural China. Energy Policy. 26(1):45-54.

Heidari A, Hajinezhad A, & Aslani A. (2019). A Sustainable Power Supply System, Iran's Opportunities via Bioenergy. Environmental Progress & Sustainable Energy. 38(1):171-88.

Shirmohammadi R, Soltanieh M, & Romeo LM. (2018). Thermoeconomic analysis and optimization of post-combustion CO_2recovery unit utilizing absorption refrigeration system for a natural-gas-fired power plant. Environmental Progress & Sustainable Energy. 37(3):1075-84.

Armin R. A, Sumper A, & Davarpanah A. (2019). Development of sustainable energy indexes by the utilization of new indicators: A comparative study. Energy Reports. 5:375-83.

Aslani A, Mazzuca-Sobczuk T, Eivazi S, & Bekhrad K. (2018). Analysis of bioenergy technologies development based on life cycle and adaptation trends. Renew Energy. 127:1076-86.

Khatibi A, Pourebrahim S, & Bin Mokhtar M. (2018). Simulating carbon sequestration using cellular automata and land use assessment for Karaj, Iran. Solid Earth. 9(3):735-44.

Khatibi A, Pourebrahim S, & Danehkar A. (2018). A Cellular Automata Model for Monitoring and Simulating Urban Land Use/Cover Changes toward Sustainability. Journal of Environmental Engineering and Landscape Management. 26(1):1-7.

Razmjoo A, Sumper A, Marzband M, Davarpanah A, Shahhoseini A, & Sarlak S. (2019). Energy sustainability analyses using feasible indicators for urban areas. International Journal of Energy and Water Resources. 3(2): 127-40.

Bakhtiar A, Aslani A, & Hosseini SM. (2020). Challenges of diffusion and commercialization of bioenergy in developing countries. Renew Energy. 145: 1780-98.

Hosseini S.M, Aslani A, Naaranoja M, & Hafeznia H. (2017). Analysis of Energy System in Sweden based on Time series Forecasting and Regression Analysis. International Journal of Energy Optimization and Engineering. 6(3): 97-113.

Mohammadi M, Ghasempour R, Razi Astaraei F, Ahmadi E, Aligholian A, & Toopshekan A. (2018). Optimal planning of renewable energy resource for a residential house considering economic and reliability criteria. International Journal of Electrical Power & Energy Systems. 96: 261-73.

Lotfi B, & Wang Q. (2013). Robust multi-objective optimization of state feedback controllers for heat exchanger system with probabilistic uncertainty. 796-809.

Soltani S, Kasaeian A, Sarrafha H, & Wen D. (2017). An experimental investigation of a hybrid photovoltaic/thermoelectric system with nanofluid application. Solar Energy. 155: 1033-43.

Das M, Singh MAK, & Biswas A. (2019). Techno-economic optimization of an off-grid hybrid renewable energy system using metaheuristic optimization approaches – Case of a radio transmitter station in India. Energy Conversion and Management. 185: 339-52.

Yang H, Zhou W, Lu L, & Fang Z. (2008). Optimal sizing method for stand-alone hybrid solar–wind system with LPSP technology by using genetic algorithm. Solar Energy. 82(4): 354-67.

Khan, Iftekhar, Chowdhury, H., Rasjidin, R., Alam, F., Islam, T. & Islam, S. (2012). Review of Wind Energy Utilization in South Asia. 2012. doi: 10.1016/j.proeng. 10.130.

Kolhe M, Kolhe S, & Joshi JC. (2002). Economic viability of stand-alone solar photovoltaic system in comparison with diesel-powered system for India. Energy Economics. 24(2): 155-65.

Nema P, Rangnekar S, & Nema RK, (2010). Pre-feasibility Study of PV-Solar / Wind Hybrid Energy System for GSM Type Mobile Telephony Base Station in Central India. 2nd International Conference on Computer and Automation Engineering (ICCAE); 2010 Feb 26-28; Singapore, SINGAPORE2010.

Agbossou K, Chahine R, Hamelin J, Laurencelle F, Anouar A, & St-Arnaud JM, *et al.* (2001). Renewable energy systems based on hydrogen for remote applications. Journal of Power Sources. 96(1): 168-72.

Eroglu M, Dursun E, Sevencan S, Song J, Yazici S, & Kilic O. A (2011). Mobile renewable house using PV/wind/fuel cell hybrid power system. International Journal of Hydrogen Energy. 36(13): 7985-92.

Luna-Rubio R, Trejo-Perea M, Vargas-Vázquez D, & Ríos-Moreno GJ. (2012). Optimal sizing of renewable hybrids energy systems: A review of methodologies. Solar Energy. 86(4):1077-88.

Rajanna S, Saini RP, (2014). Optimal Modeling of Solar/Biogas/Biomass based IRE System for a Remote Area Electrification. 6th IEEE Power India International Conference (PIICON); Dec 05-07; New Delhi, INDIA. NEW YORK: Ieee; 2014.

Olatomiwa L, Mekhilef S, Huda ASN, & Ohunakin OS. (2015). Economic evaluation of hybrid energy systems for rural electrification in six geo-political zones of Nigeria. Renew Energy. 83: 435-46.

Olatomiwa L, Blanchard R, Mekhilef S, & Akinyele D. (2018). Hybrid renewable energy supply for rural healthcare facilities: An approach to quality healthcare delivery. Sustainable Energy Technologies and Assessments. 30: 121-38.

Hossen M D, Islam M F, Ishraque M F, *et al.* (2022). Design and Implementation of a Hybrid Solar-Wind-Biomass Renewable Energy System considering Meteorological Conditions with the Power System Performances. International journal of photoenergy, 2022.

Shezan S K A, & Lai C Y, (2017). Optimization of hybrid wind-diesel-battery energy system for remote areas of Malaysia, 1-6.

Shezan S A, Hasan K N, Rahman A, *et al.* (2021). Selection of appropriate dispatch strategies for effective planning and operation of a microgrid[J]. Energies (Basel), 14(21): 7217.

Shezan S A, Ishraque M F, Muyeen S M, *et al.* (2022). Selection of the best dispatch strategy considering techno-economic and system stability analysis with optimal sizing. Energy strategy reviews, 43: 100923.

Shezan S A, Ishraque M F, Muyeen S M, *et al.* (2022). Effective dispatch strategies assortment according to the effect of the operation for an islanded hybrid microgrid[J]. Energy conversion and management. X, 14: 100192.

Vendoti S, Muralidhar M, & Kiranmayi R, (2018). HOMER Based Optimization of Solar-Wind-Diesel Hybrid System for Electrification in a Rural Village. 8th International Conference on Computer Communication and Informatics (ICCCI); Jan 04-06; Coimbatore, INDIA2018.