# Design of a stand-alone energy hybrid system for a makeshift health care center: A case study

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A B S T R A C T

Worldwide, health care sectors are experiencing massive pressure due to the emergence of COVID-19. Many temporary health care centers have been set up to treat infected patients. Increasing energy consumption in these centers is responsible for both rising energy demand and emission. Implementation of renewable energy-based hybrid stone-alone systems can play a vital role in optimizing increasing energy demand. The aim of this analysis is to design a stand-alone system for a temporary health care center located in Saint Martin Island, Bangladesh. This is the first study which highlights the power management of a hospital load. Homer Pro software is used to design the preliminary model, and the proposed configuration comprises PV/Converter/ WIND/Battery/Generator. It is observed that the Levelized cost of the proposed system is $0.4688. This system's Levelized cost of energy (LCOE) is 35% lower than the solar home system (SHS). The payback period (PB), rate of investment (ROI), and internal rate of return (IROR) of the optimized system are seven years, 10, and 13%, respectively. The proposed configuration is environmentally sustainable as it generates 27% less $CO_2$ than a diesel-based fuel system.

## 1. Introduction

Access to electricity is essential to improve the economic and social life of the people living in rural areas. Global electrification has reached 89% in 2017, which was 83% in 2010. However, almost 840 million people are remaining in the dark, and the possibility of these people having access to electrification is relatively low [1]. So, these people are getting deprived of one of their essential needs; proper health care facilities. Due to the lack of proper medical facilities in rural areas, most women die during childbirth and pregnancy. Having access to electricity could reduce the high mortality rate by 70% [2]. Diesel generators are frequently used in these rural places to provide electricity to the health care system. Using diesel generators is not only costly but also affects the environment severely. So, the optimum solution for these rural areas can be the proper utilization of the available natural resources. Several studies were conducted to determine the feasibility of providing electricity to remote people. Razmjoo et al. [3] proposed a hybrid system

consisting of a 15 kW PV array, 1 kW generator, 2 WES 5 Tulipo wind turbine, 1 kW Inverter, 13,603 Surrette 6CS25P models of battery for Semirom city in Esfahan province, Iran. Another study by Razmjoo et al. [4] analyzed the obstacles preventing developing countries from achieving energy sustainability goals. Kasaeian et al. [5] investigated the performance of two-hybrid systems for a coastal area named Bandar Dayyer in Bushehr province, Iran. Two studies conducted by Ramzoo et al. investigated how a hybrid system can help achieve Iran's sustainable development goals [6,7]. These studies modelled and analyzed hybrid systems using Homer software.

Olatomiwa et al. [8] analyzed solar and wind resources for different locations of Nigeria and identified proper renewable hybrid systems for each location. Babatunde et al. [9] observed the subsidy's impact on fuel prices and recommended a proper hybrid system for Nigeria's rural areas. Ighravwe et al. [10] evaluated several criteria and performed a techno-economic analysis. This research highlighted that operational and net present cost was the most important criteria to be considered

| Resources data | Load Profile | Economic Details | Technical Details | System Constraints | System Control | Emission Data |
|---|---|---|---|---|---|---|
|  |  |  |  |  |  |  |

**HOMER Simulation and optimization**

**Minimize constrained objective functions**

- Objective function: NPC
- System constraints: Power balance, charging and discharging of batteries, and other technical constraints

**Output data**

- Optimal system components
- Net present cost (NPC)
- Cost of energy (COE)
- Capital cost
- Excess energy generation
- Capacity shortage
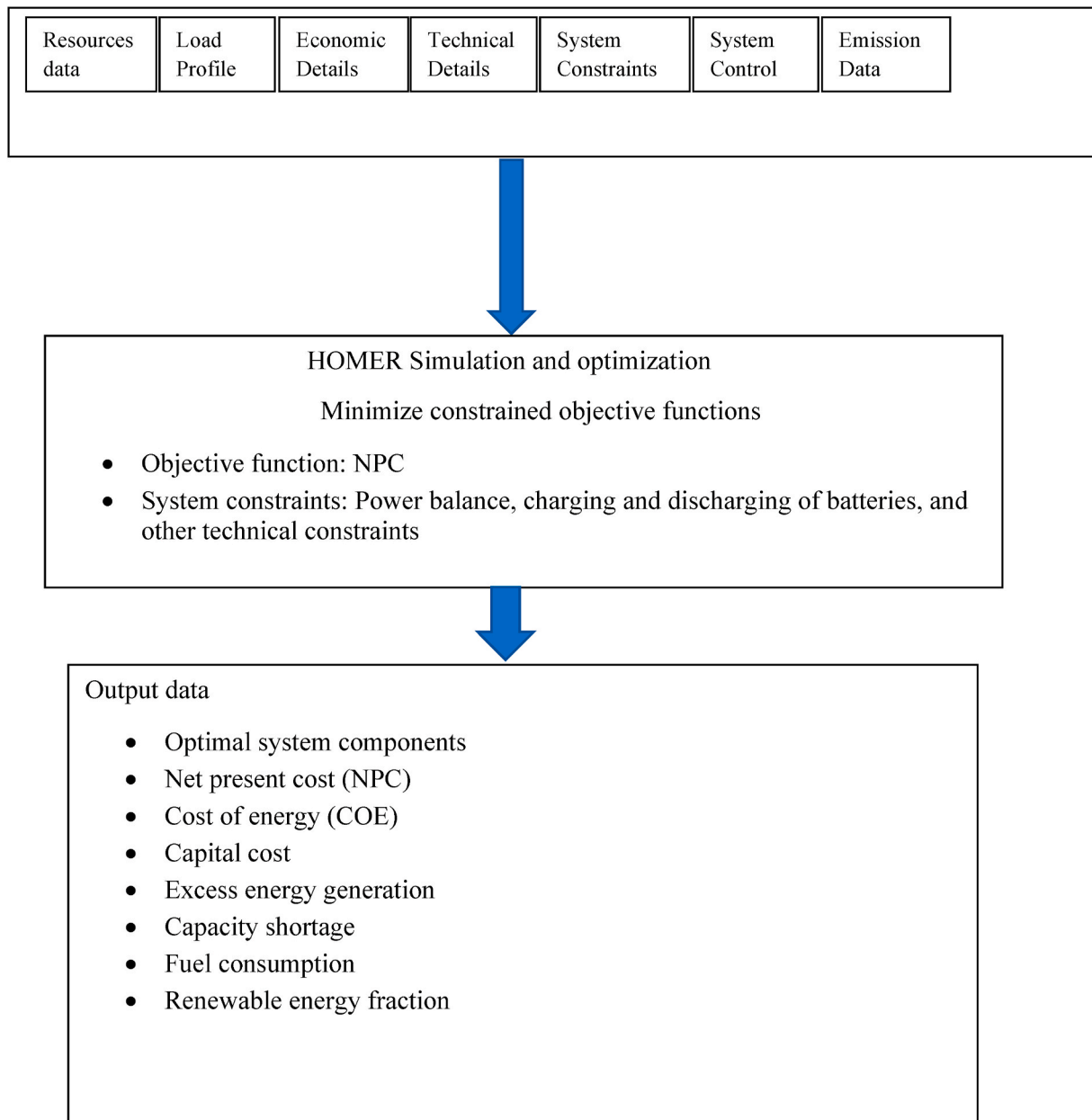- Fuel consumption
- Renewable energy fraction

**Fig. 1.** Flowchart of the Homer software framework [19].

before setting up a hybrid system for rural hospitals. Sonja Saari [11] analyzed the opportunities and obstacles of renewable energy penetration in the humanitarian cold supply chain and reported that environmental sustainability is not maintained in emergency camps. Adeyeye et al. [12] similarly performed a techno-economic analysis for rural health care centers and suggested that when the price of diesel increases, the number of batteries and solar panels capacity to meet up the demand increased. Olatomiwa et al. [13] and Olatomiwa and Mekhilef [14] also performed similar techno-economic analyses for Nigeria and suggested an optimum hybrid system. Olatomiwa and Blanchard [15] showed how the maximum penetration of hybrid renewable energy technologies could help to achieve sustainable development goals through a demand-side management strategy. However, best to the author's knowledge, no attempts were made for the power management of a hospital load. So, in this article, a techno-economic, environmental analysis, and optimization of a grid-independent hybrid renewable energy system for a remote health care system in Bangladesh have been carried out. A demand-side management technique is applied to observe

the power management of the hospital. Three scenarios are modelled to determine the best optimum system to meet the health care system's electrical and thermal load. This analysis also sought to cope with the optimal sizes of the hybrid model's various equipment. Similarly, a defined and ideal framework is proposed to determine the optimal system configuration for attaining techno-economic-environmental feasibility. For this purpose, the maximum renewable fraction, net present cost, and cost of electricity are considered. In the next section, the methodology of this study is delineated. The third section provides the outcome of this study.

## 2. Methodology

Homer software is utilized in this research to simulate the system. Data on solar and wind resources are collected from Refs. [16,17]. Optimization problems such as economic, environmental, and reliability analyses are discussed in this study.
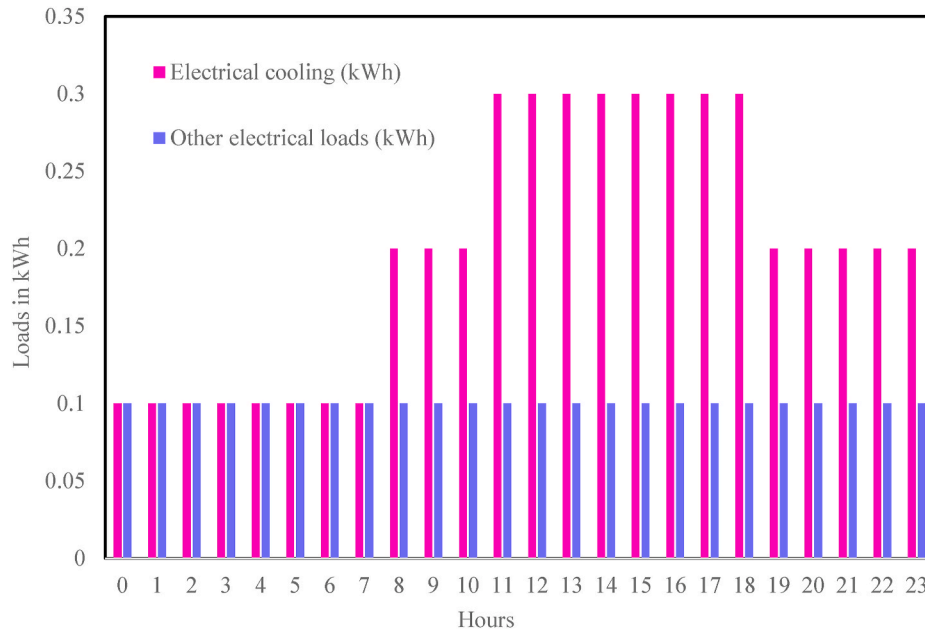
**Fig. 2.** Hourly load distribution profile.

**Table 1**
Electrical load of the health care system.

| Equipment | Qty | Power (W) | Total Hours/ day | Total Energy (kWh/ day) |
|---|---|---|---|---|
| Refrigerator-nonmedical | 2 | 125 | 6 | 1.5 |
| Refrigerator-Vaccine | 2 | 40 | 10 | 0.8 |
| Desktop computer | 1 | 65 | 5 | 0.325 |
| Wall fan | 8 | 65 | 8 | 4.16 |
| Tube fluorescent lights | 8 | 18 | 8 | 1.152 |
| halogen lamp (security) | 2 | 50 | 11 | 1.1 |
| Centrifuge | 2 | 242 | 4 | 1.936 |
| Microscope | 2 | 20 | 6 | 0.24 |
| Blood chemical analyzer | 1 | 45 | 4 | 0.18 |
| Hematology Analyzer | 1 | 230 | 4 | 0.92 |
| CD4 Machine | 1 | 200 | 4 | 0.8 |
| Radio | 2 | 15 | 8 | 0.24 |
| TV | 1 | 150 | 5 | 0.75 |
| Fan | 3 | 70 | 5 | 1.05 |
| Electric iron | 1 | 1000 | 0.5 | 0.5 |
| Washing Machine | 1 | 700 | 0.5 | 0.35 |

### 2.1. Software and load data

To design and model the stone-alone system, the Homer pro software is used [18]. The National Renewable Energy Laboratory (NREL) developed the software, and it can be used for many purposes, for example, techno-economic, feasibility, and optimization problems. The general flow diagram of Homer Pro software can be found in Fig. 1 [19]. For modelling load data of HCC, the load data is taken from the Homer pro database and provided in Fig. 2. Two electrical loads of 34,000 kWh/day and 10,000 kWh/day are modelled by Homer pro in this study. Electrical loads of the health care system can be found in Table 1.

### 2.2. Site location

Saint Martin Island is located at 20° 37′ 57.04″ north latitude and 92° 19′ 11.80″ east longitude. Almost six thousand people live on this island,

and most of these people's main occupation is fishing [16]. The island has abundant wind and solar resources. At present, these people are using diesel generators to meet up their electricity demand [16].

### 2.3. Solar resources

From NASA (National Aeronautics and Space Administration), monthly average solar radiation data is collected [16,17]. These data are used in the Homer Pro software for developing a stand-alone system. Fig. 3 shows that the highest solar radiation of 6.41 kWh/m$^2$/day is in April. It means that solar panels can produce the highest energy in April.

### 2.4. Wind resources

Bangladesh's metrological department data is used for wind resources, and these data are inputted to the Homer Pro software [20]. From Fig. 4, it is evident that the average wind speed is 4.84 m/s, and the highest wind speed is observed in July. It indicates that the wind turbine can generate the highest energy in July.

### 2.5. Optimization problem

Three optimization problems, such as economic, environmental and reliability, are highlighted in this study [21]. The fulfilment of electricity demand by different energy generation technologies can be determined from the reliability index. On the other hand, economic and environmental indicators show these technologies' economic and environmental performance to produce energy. These indicators are illustrated below:

#### 2.5.1. Reliability index

When there is less energy generated compared to demand, power shortage can occur. Therefore, a widely utilized index denoted 'Loss of Power Supply Probability' (LPSP) can come in handy in evaluating a hybrid system's durability. The LPSP is denoted as the ratio of the total load that is unfulfilled to the total electric load demand. The LPSP is manifested as below [21]:

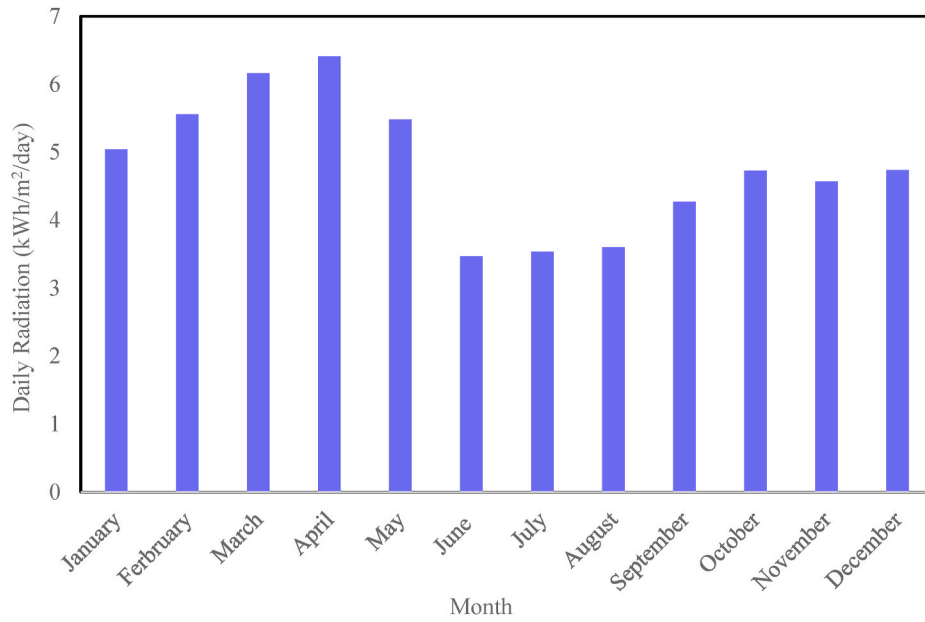$$LPSP = \frac{\sum_{h=1}^{H} E_{unfulfilled}(h)}{E_{demand}} \tag{1}$$

**Fig. 3.** Monthly solar radiation (kWh/m$^2$/day) in Saint Martin Island.
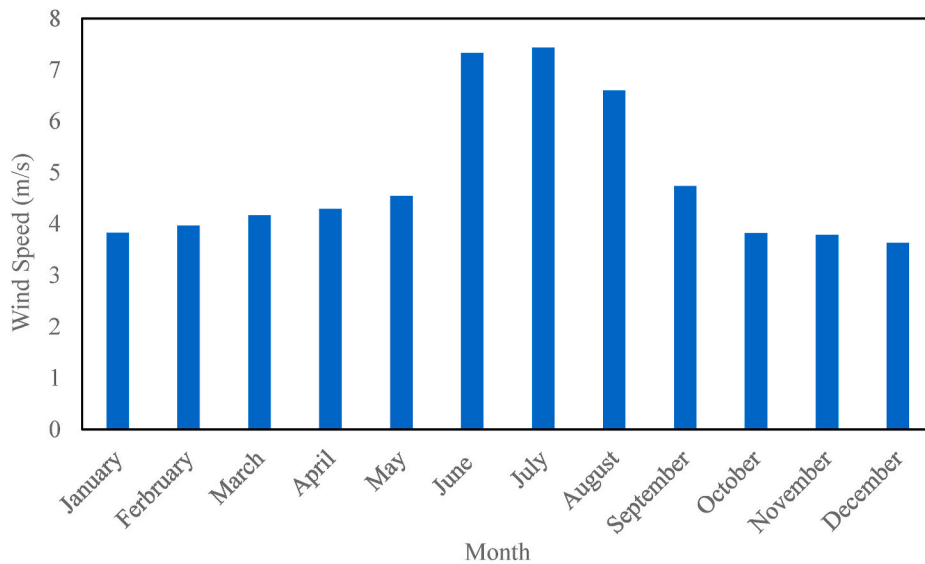


**Fig. 4.** Monthly wind speed (m/s) in Saint Martin Island.

The amount of unmet or unfulfilled load can be manifested through the following equations [21]:

$$E_{unfulfilled}\ (h) = \begin{cases} 0, for & P_{load}(h) < P_{total}(h) \\ P_{load}(h) - P_{total}\ (h), for & P_{load}(h) > P_{total}\ (h) \end{cases} \quad (2)$$

Loss of Load Expected (LOLE) is an additional criterion which is employed as a reliability restraint in this investigation. LOLE can be described as the number of interruption hours when the power generation cannot meet the load demand [21].

$$LOLE = \sum_{h=1}^{H} LOL\ (h) \quad (3)$$

LOL (h) is the power deficiency sign in h hour and can be manifested as below [21]:

$$LOL(h) = \begin{cases} 0, for & P_{load}(h) < P_{total}(h) \\ 1\ , for & P_{load}\ (h) > P_{total}\ (h) \end{cases} \quad (4)$$

*2.5.2. Economic investigation*

Homer Pro is used in this research to determine the cost of this project. Homer Pro utilizes the two-factor named cost of energy (COE) and Net Present Cost (NPC) to evaluate the optimal system. The mathematical Eq. (5) has been used to determine the COE of this project, where $C_a$ ($/year) is the total cost incurred in a year, and this can be found after summing up the annual capital, maintenance and replacement cost and $E_s$ is the total energy that will be needed to fulfil the demand of the hospital [22].

$$COE = \frac{c_a}{E_s} \quad (5)$$

The mathematical Eq. (6) has been used to determine NPC of this project NPC can be found after dividing $C_a$ by capital recovery factor (CRF), which can be evaluated by using Eq. (20) [23].

**Table 2**

Assumption of economic and technical parameters used for simulation [24–27].

| Component | Technical Description | Capital cost ($) | Replacement cost ($) | O and M cost ($) | Lifetime | LCE (kg $CO_2$-eq/kWh) |
|---|---|---|---|---|---|---|
| PV module | 327 W | 1300/kW | 0 | 20/year | 25 year | 0.045 |
| Diesel Generator | 57 kW, 50 Hz | 370 k/W | 296 k/W | 0.05/h | 15,000 h | 0.88 |
| Wind turbine | 1 kW, 12–48 VDC | 4450 | 4450 | 110 | 20 year | 0.011 |
| Battery | 6 V, 820 Ah (4.92 kWh) | 1100 | 1000 | 10 | 12 year | 0.028 |
| Inverter | 1 kW | 800 | 750 | 8 | 15 year | 0 |
| Discount rate | 10% and 8% | | | | | |

$$NPC = \frac{Ca}{CRF(i, N)} \tag{6}$$

$$CRF(i, N) = \frac{i(1+i)^N}{(1+i)^N - 1} \tag{7}$$

$$i = \frac{i' - f}{1 + f} \tag{8}$$

To calculate the payback period, the following expression has been manifested [24].

$$Payback \ period = \frac{I}{R - E} \tag{9}$$

### 2.5.3. Emission analysis

The energy utilized to transport and manufacture the hybrid systems results in the emission of different harmful gases. In this research, life cycle emission (LCE) is manifested to calculate the emanation, delineated in Eq. (10) [25].

$$LCE = \sum_{i=1}^{x} BiEl \tag{10}$$

The projected emission of different components during the life cycle can be found in Table 2. Table 2 shows that to generate 1 kW electricity in an hour, PV generates 0.045 kg $CO_2$ while diesel generator generates 0.88 kg $CO_2$. This proves the environmental benefit of renewable energy technologies over fossil fuel technologies.

### 2.6. Mathematical modelling of the hybrid system

### 2.6.1. Inverter

The primary objective of the inverter is to transform direct current (DC) into alternating current (AC). Eq. (11) can be conveyed to evaluate how much energy can be obtained from the inverter [24]. In this research, a bi-directional inverter has been connected between DC and AC bus. The efficacy and life span of the inverter was contemplated as 95% and 15 years, respectively. The capital and replacement cost of the inverter are considered as $800/kW and $750/kW, respectively [26,27].

$$P_{in} = \frac{Pout}{\eta} \tag{11}$$

### 2.6.2. Generator

An auto-sized generator fueled by diesel is used in designing the model. Per kW capital and replacement costs considered here are US $370 and US$296, respectively. The maintenance and operation cost of the generator is considered as US$0.05 per hour. Eq. (12) can be used to design the fuel consumption pattern of these generators [24].

$$L = L_{0,dg}Y_{dg} + L_{1,dg}P_{dg} \tag{12}$$

### 2.6.3. Designing of photovoltaic (PV) system

The variability of weather is an essential parameter for modelling a photovoltaic system [28]. In this investigation, a flat plat PV manufactured by Generic is considered. Derating factor and lifetime have been considered as 80% and 25 years, respectively. Several sizes of PV modules (1–10,000 kW) are employed in designing the model. It has been widely researched that a minor increase (0.1%/$°C$) in temperature coefficient can result in an increment in annual PV power output [24]. In this respect, Eq. (13) is employed to investigate the hourly PV power output [26].

$$P_{PV} = Y_{PV}f_{PV}\left(\frac{I_T}{I_S}\right)\left[1 + \alpha_P(T_C - T_S)\right] \tag{13}$$

Eq. (14) can be employed to calculate the cell temperature (Tc) of PV. In this investigation, effective transmittance-absorptance, the ratio of the heat conveyed to the fluid to the heat generated on the absorber surface by absorbed solar radiation is considered 0.95 [26].

$$T_C = T_a + I_T\frac{T_{c,NOCT} - T_{a,NOCT}}{I_{T,NOCT}}\left(1 - \frac{\eta_{PV}}{0.9}\right) \tag{14}$$

Per KW capital cost considered for the PV panel was US$ 1300. The operation and maintenance cost are considered US$ 20 per year for the PV. Different parameters of the PV panel can be obtained from Table 2.

### 2.6.4. Wind Turbine model

Turbines are widely used to transform energy available in the wind into electricity. The selection of a wind turbine depends on several parameters, such as the cut-in wind speed, hub height, and expense of components. In this respect, the wind turbine's power is a corollary of the velocity of the wind at hub height. At a specific place for a fixed height, the estimation of wind speed necessary for power production can be evaluated via Eq. (15) [24]. Here the characteristics of land play an essential role in determining the value of γ [26]. Eq. (19) manifested the wind turbine power output, while Eq. (18) calculates the turbine's actual electric power.

$$V = V_{ref}\left(\frac{H}{Href}\right)^\gamma \tag{15}$$

$$a = \frac{P_r}{\left(V_r^3 - V_1^3\right)} \tag{16}$$

$$b = \frac{V_1^3}{\left(V_r^3 - V_1^3\right)} \tag{17}$$

$$P_{wt} = P_wA_w\eta_w \tag{18}$$

$$P_w(V) = \begin{vmatrix} 0 & for & v < v_1 \\ aV^3 & for & V_1 < V < V_r \\ P_R & for & V_r < V < V_2 \\ 0 & for & V > V_2 \end{vmatrix} \tag{19}$$

Here the value of $V_1$ generally deviates from 2.5 to 3.5 m/s, and the value of $V_2$ fluctuates from 20 to 25 m/s [24]. In this analysis, a generic manufactured wind turbine of different capacities (1–10,000 kW) is considered for simulating wind turbines. The height of the hub and the turbine's lifetime have been considered 17 m and 20 years, respectively. The wind turbine's capital and maintenance cost are considered $4450, and the operation and maintenance cost is considered $110. Different characteristic parameters of wind turbines are presented in Table 2.
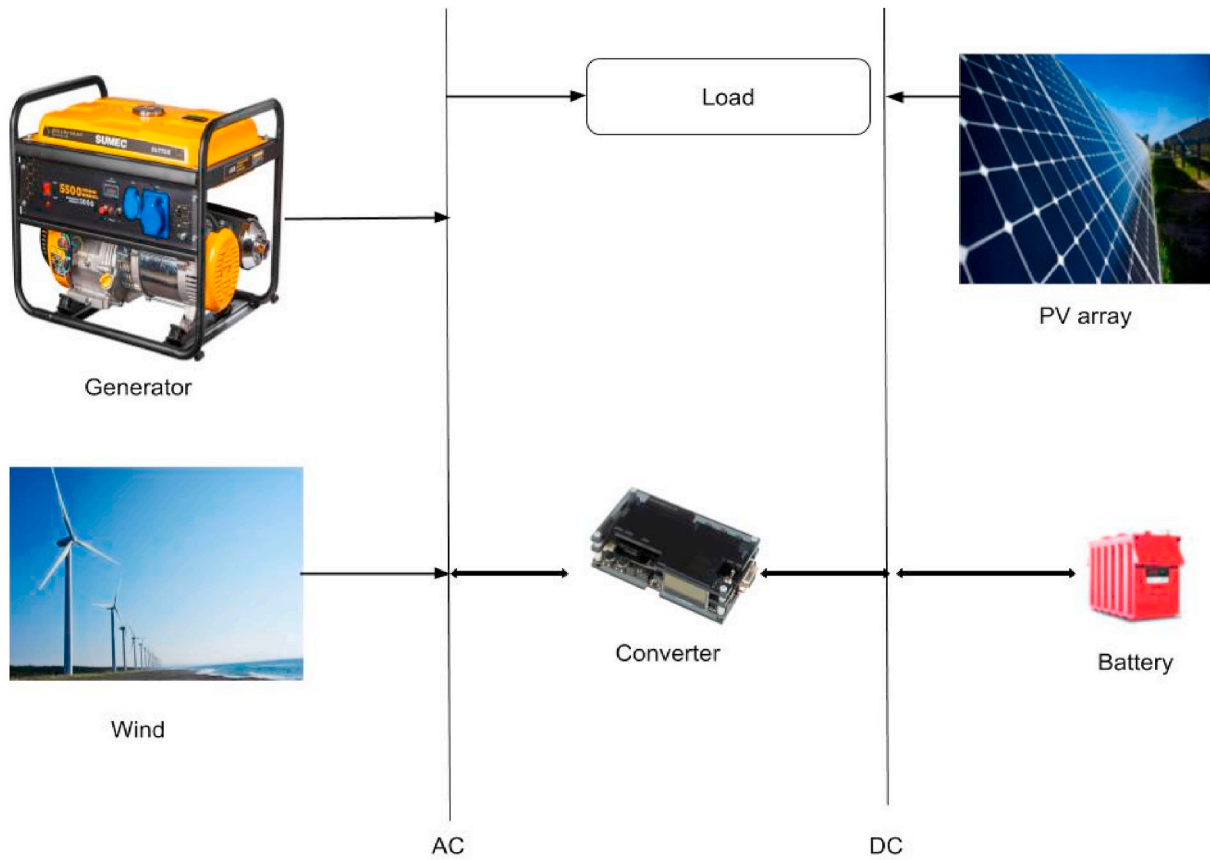
**Fig. 5.** Schematic diagram of the analyzer system.

### 2.6.5. Battery

When the generation is much more than the demand, surplus energy can be stored and utilized if the generation falls below the demand. For ensuring longer service of battery, the battery charge should be maintained carefully. The following expression is necessary to evaluate the quantity of battery energy ($Q_{bat}$) [28–32].

$$Q_{bat} = Q_{bat,0} + \int_0^t V_{bat} I_{bat} dt \qquad (20)$$

The state of battery charge ($B_{SOC}$) can be delineated as below:

$$B_{soc} = \frac{Q_{bat}}{Q_{bat,max}} \times 100(\%) \qquad (21)$$

The utmost power that can be stored and discharged by battery backup is calculated using the battery kinetic model. The following two expressions are conveyed to determine the highest power that the storage system can absorb and discharge.

$$P_{batt, abs} = \frac{kQ1e^{-k\Delta t} + Qkc(1\Delta e^{-k\Delta t})}{1\Delta e^{-k\Delta t} + c(k\Delta t\Delta 1 + e^{-k\Delta t})} \qquad (22)$$

$$P_{batt,dis} = \frac{\Delta kcQmax + kQ1e^{-k\Delta t} + Qkc(1\Delta e^{-k\Delta t})}{1\Delta e^{-k\Delta t} + c(k\Delta t \ \Delta 1 + \ e^{-k\Delta t})} \qquad (23)$$

In this investigation, the generic 1 kWh lead-acid battery whose round-trip efficacy is 80% is employed [33]. The nominal voltage and the theoretical and maximum capacity of the battery are 12 V, 1 kWh, and 83.4 Ah, respectively. The storage's lifetime is considered 12 years, and per kW capital and maintenance costs are considered $1100 and $1000, respectively. Different variables considered for designing storage are shown in Table 2. A schematic diagram of the system configuration is presented in Fig. 5.

### 2.7. Renewable fraction (RF)

RF is an environmental indicator that is depicted as the fraction of electrical load that has been met up by renewable sources. RF should be manifested as following [25].

$$RF = \frac{E_{ren}}{E_{demand}} \qquad (24)$$

### 2.8. Demand-side management

Demand-side management has already been applied in the smart grid system due to its swift and smart ability. Researchers have made many attempts to save energy in residential buildings by applying demand-side management. An algorithm regarding demand-side management has been applied here in this study (Fig. 6). It has been assumed that a smart distribution system can perform automatic switching between load lines based on priority. When the power demand is equal to power consumption, both the low priority and high priority load lines remain active. When the total power consumption of both lines is more significant than the total power generation but the power generation is greater than the power needed by High Priority Load Line, then the High Priority Load Line remains fed, and Low Priority Load Line gets disconnected until the production outbalances the consumption of both lines. Load shedding resumes until the production of power is less than the power consumption in the low priority load line leading to disconnection of all the connected lines. Washing machine, computer, TV, and Hydrogen lamp are considered low priority load. The flow chart of the algorithm is shown in Fig. 6.
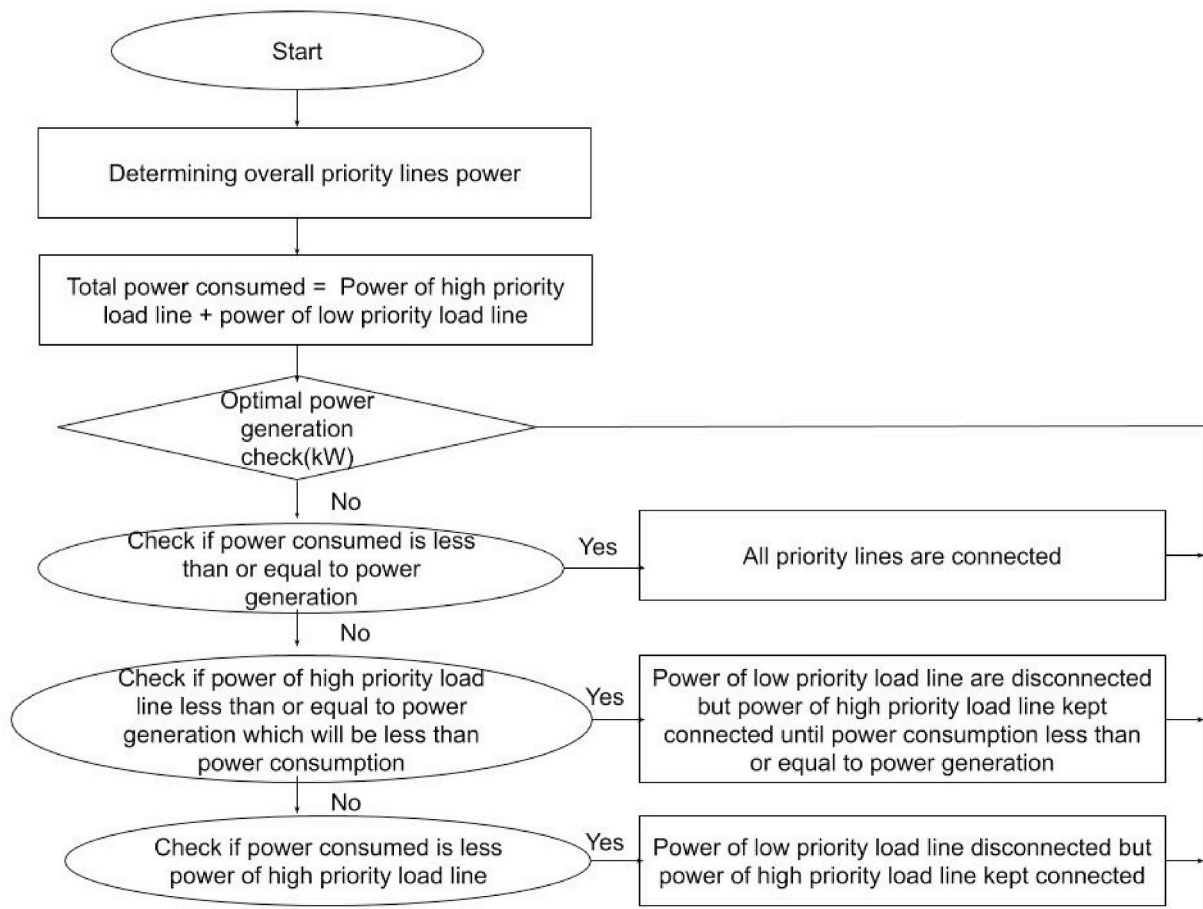
**Fig. 6.** Applied algorithm for hospital load management.

**Table 3**
Annualize cost of different cases considered in this study (before applying demand-side management).

| Case | Capital cost ($) | Replacement cost ($) | O and M cost ($) | Total operating cost ($) | Total NPC $ | Total fuel cost ($) |
|------|------------------|----------------------|------------------|--------------------------|-------------|---------------------|
| 1 | 1,924,000.00 | 7,920,581.44 | 20,989,541.97 | 7,633,048.00 | $72,267,430 | 41,492,721.99 |
| 2 | 2,977,146.34 | 7,987,207.32 | 21,124,513.75 | 7,500,610.00 | $72,100,070 | 40,079,335.37 |
| 3 | 14,461,540.63 | 6,701,370.75 | 18,305,630.77 | 5,958,974.00 | 69,377,300.00 | 30,045,160.67 |

## 3. Results and discussions

In this analysis, three cases are considered for meeting up the load. The first case comprises of Wind/Generator/Converter/Battery. The second case consists of PV/Generator/Converter/Battery, while the third case comprises Wind/PV/Generator/Converter/Battery. Since weather plays a vital role in producing energy, a diesel generator has been considered with renewable energy technologies in every case of this study.

**Case 1.** Wind/ Generator/ Converter/ Battery

Before Applying DSM:

In this system, the COE is found to be $0.4883, while the value of NPC is observed to be $72,267,430 (Table 3). During the simulation, it is observed that the diesel generator meets up the whole load, and the optimum size of the generator is found to be 5220 kW. The total amount of generated electricity is 16,248,422 kWh/year. After meeting the electricity demand, the excess energy that can be stored is 188,422 kWh/year. The average fuel consumption per day is found to be 12,335 L. From the environmental analysis, it is also observed that this system emits a higher amount of pollution than any other system. The system emits 32.3-ton $CO_2$ daily. Since the whole load is met up by a diesel
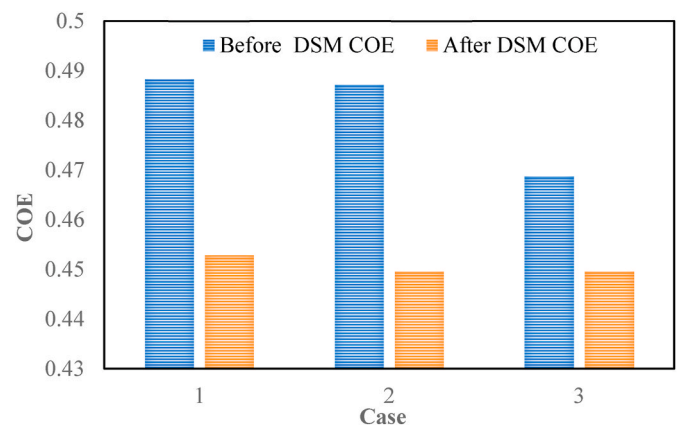


**Fig. 7.** Effect of applying demand side management on COE.

generator, this system emits more $CO_2$ than any other system.

After Applying DSM:

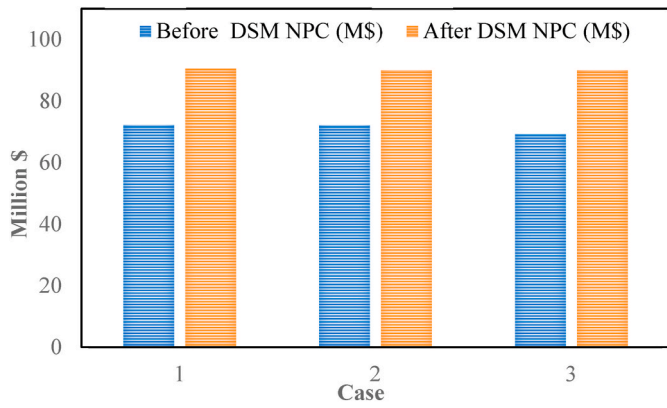After applying the demand-side management, it has been found that

**Fig. 8.** Effect of applying demand side management on NPC.

the COE came down to \$0.4529 (Fig. 7) while the value of NPC goes up to \$90,623,820.00 (Fig. 8). A reduction of 8% in COE and an increment of 25% in NPC have been observed after applying the DSM. Besides, the generator's optimum size was reduced to 4400 kW, and the average fuel consumption found is 10,602 L/day. Excess electricity that can be stored in the battery is 133,287 kWh/year. The mean electrical efficiency of the generator is found to be 36.8%. Specific fuel consumption for producing per kW of energy is observed to be 0.276 L. The performance of the generator is illustrated in Fig. 9. It is also observed that after applying the demand-side management, the system emits less emission than before, which is shown in Table 4. After applying DSM, the system emits 27.75-ton $CO_2$ daily. This is 14% less than before applying DSM.

Figs. 7 and 8 show the aftermath of applying DSM on COE and NPC.

**Case 2.** PV/ Generator/ Converter/ Battery

Before Applying DSM:

In this system, COE and NPC values are \$0.4872 and \$72,100,070, shown in Table 3. The simple payback period obtained is eight years, while the ROI and IRORs are 9 and 12%, respectively. It is observed that
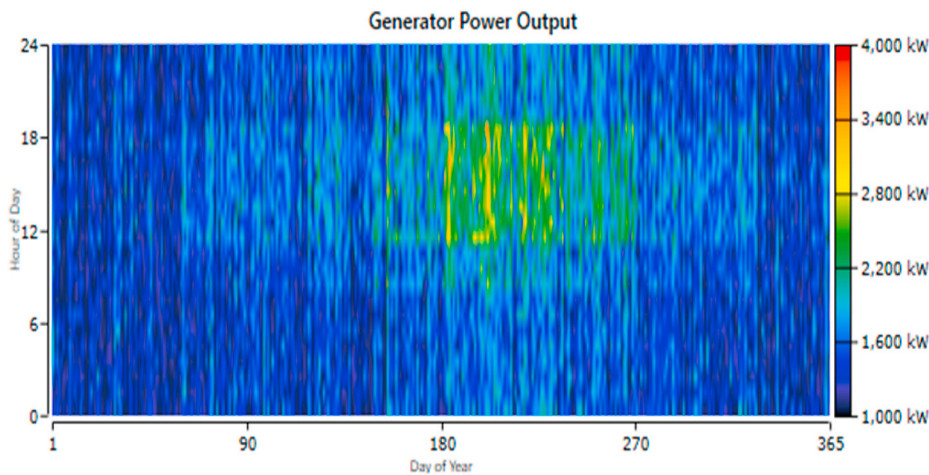


**Fig. 9.** Generator power output (case 1).

**Table 4**
Ejection of different gases from different cases considered in this study.

| Emissions during operation (kg/year) | Scenario 1 | | Scenario 2 | | Scenario 3 | |
|---|---|---|---|---|---|---|
| | Before DSM | After DSM | Before DSM | After DSM | Before DSM | After DSM |
| $CO_2$ | 11,785,613 | 10,129,720 | 11,384,154 | 9,611,742 | 85,34,042 | 9,611,742 |
| CO | 74,290 | 63,852 | 71,759 | 60,587 | 53,794 | 60,587 |
| PM | 450 | 387 | 435 | 367 | 326 | 367 |
| UHC | 3242 | 2786 | 3131 | 2644 | 2347 | 2644 |
| $SO_2$ | 23,810 | 20,464 | 22,999 | 19,418 | 17,241 | 19,418 |
| NOx | 69,788 | 59,982 | 67,410 | 56,915 | 50,534 | 56,915 |
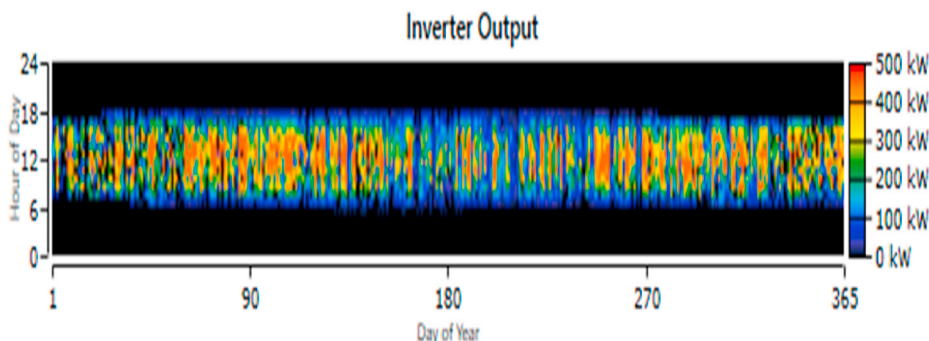


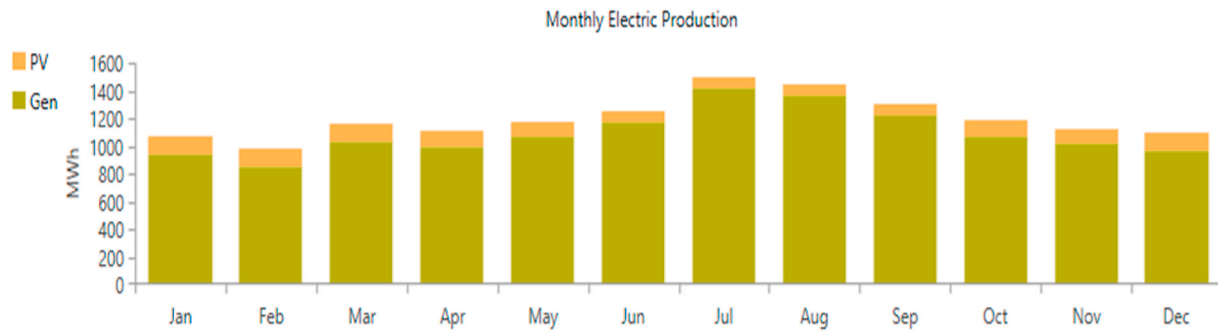**Fig. 10.** Invertor power output (case 2).

**Fig. 11.** Monthly electricity production of the system.

the optimum size of the generator, PV, and converter is found to be 5220 kW, 588 kW, and 361 kW, respectively. The total amount of generated electricity is 16,490,754 kWh/year, in which almost 6% of total electricity is produced using the PV system, while the rest of the electricity is produced using the diesel generator. After meeting the electricity demand, the excess energy that can be stored is 396,547 kWh/year. This system's RF is 2.90% as the significant percentage of the generated electricity has come from a generator. Per day the average fuel consumption is estimated as 111,915 L. Furthermore, it is observed that this system emits 3.4% less $CO_2$ than case 1 (Wind/Generator/Converter/Battery) based on the environmental analysis, as shown in Table 4.

After Applying DSM:

DSM is also applied in designing of case 2 system. After the implementation of DSM, a 7.72% reduction in COE (Fig. 7) and an increment of 24.86% in NPC is observed (Fig. 8). The present and the annual worth of this system is found to be $ 0.6 M and 0.45 M ($/year), respectively. The optimum system now consists of a 4400-kW generator, 866 kW PV, and 473 kW of the converter. Only 9% of the total electricity has been generated from PV while the rest has been from the generator. The capacity factor of the PV and generator is found to be 16.4% and 34.2%, respectively. The inverter's capacity factor has been calculated at 20.2%, and the energy gained from the convertor is 837,596 kWh/year, which is represented in Fig. 10. The output of the inverter is delineated in Fig. 10. The renewable fraction of the system is estimated to be 5.10%. The excess electricity that can be stored for future purposes is 3.41%. After applying DSM, 14.52% daily $CO_2$ reduction is also observed in the environmental analysis.

**Case 3.** Wind/ PV/ Generator/ Converter/ Battery

In this system, the COE is obtained to be $0.4688, whereas the value of NPC is observed to be $69,377,300, as exhibited in Table 3. The simple payback period, ROI and IRORs obtained are seven years, 10, and 13%, respectively. During the simulation, the generator, PV, and converter's optimum size are found to be 5220, 7750, and 3078 kW, respectively. The total amount of generated electricity, in this case, is 23,334,441 kWh/year. Almost 51% of total electricity has been generated using the PV system, while the rest of the energy is produced using the diesel generator. The excess energy is stored and estimated as 70,30,883 kWh/year after fulfilling the electricity demand. This system's RF is observed to be 28% since the significant percentage of the generated electricity has come from the PV system. Moreover, based on the environmental analysis, it is observed that this system emits 27 and 25% less $CO_2$ compared to cases 1 and 2, respectively, as shown in Table 4.

After Applying DSM:

The COE showed a 4.1% reduction after applying the DSM (Fig. 7), while the NPC showed an increment of 29.77% (Fig. 8). The simple payback period, the ROI, and IRORs of the case 3 system obtained are six years, 8, and 9%, respectively. The system's total electricity production is 14,405,042 kWh/year, which is illustrated in Fig. 11. Energy loss and the capacity factor from the converter is found to be 44,084 kWh/year

**Table 5**

Comparison among different hybrid systems that considered hospital load.

| System | Location | LCOE | References |
|---|---|---|---|
| PV/DG/Battery | Six locations in Nigeria. | 0.507 $/kWh −0.542 $/kWh | [10] |
| PV/DG/Battery | Six regions in Nigeria. | 0.507$/kWh −0.542 $/kWh | [9] |
| PV/wind/diesel/ battery | Iseyin, Sokoto, Maiduguri, Jos and Enugu, | For Iseyin, LCOE is 0.311 $/kWh For Sokoto, LCOE is 0.215 $/kWh For Maiduguri, LCOE is 0.246 $/kWh For Jos, LCOE is 0.207 $/kWh For Enugu, LCOE is 0.272 $/kWh | [8] |
| PV/DG/Battery | Kalema village under Mokwa Local Government Area (LGA) of Niger State | 0.33 $/kWh | [12] |
| PV/diesel/ battery | Port Harcourt | 0.482 $/kWh | [14] |
| PV/DG/Battery | Fatika rural village in northern Nigeria | 0.530 $/kWh | [13] |
| PV/diesel/ battery | Pulau Banggi Malaysia | 0.276 $/kWh | [33] |
| PV/Converter/ WIND/ Battery/ Generator | Saint Martin Island, Bangladesh | 0.4688 $/kWh | |

and 20.2%, respectively. Maximum output from the PV is estimated to be 856 kW. The levelized cost to produce electricity from solar PV is 0.0768 $/kWh. Average fuel consumed by the generator per hour is 419 L. From the environmental analysis, it is found that after applying DSM, this system daily emits 11% higher $CO_2$ than before. High diesel consumption and burning is the reason behind high $CO_2$ emission.

The proposed system, which is so-called case 3 (Wind/PV/Generator/Converter/Battery), is found to be economically viable than other cases (1 and 2). The lower payback period and COE and a higher IROR proved that this case is much more viable than other cases. Besides, the LCOE of this system is 35% lower than the SHS. The LCOE of the SHS is $0.72/kWh [34]. So, it is more viable than SHS. The Bangladesh Government purchases electricity from the diesel-operated power plants at the rate of $0.34/kWh, and while from the heavy fuel oil operated power plants at the rate of $0.11–0.22/kWh [35,36]. However, these systems contaminate the environment severely. For example, to meet the demands mentioned above only by diesel fuel systems, the estimated emission of $CO_2$ will be 11,785,613 kg/year. It can be noted that the proposed system will generate 27% less $CO_2$ in comparison to diesel fuel-based systems. This study's finding has been compared with other studies, and this has been delineated in Table 5. Since the Levelized cost of energy is an important parameter to decide to carry on with the

**Table 6**
Effect of changing discount rate on cost parameters.

| Discount rate % | Case 1 | | | Case 2 | | | Case 3 | | |
|---|---|---|---|---|---|---|---|---|---|
| | COE | NPC (M $) | Operating cost (M $) | COE | NPC (M $) | Operating cost (M $) | COE | NPC (M $) | Operating cost (M $) |
| 10 | 0.453 | 90.7 | 6.17 | 0.450 | 90.0 | 6.02 | 0.450 | 90.0 | 6.02 |
| 12 | 0.455 | 75.7 | 6.17 | 0.453 | 75.4 | 6.03 | 0.453 | 75.4 | 6.03 |
| 4 | 0.448 | 176 | 6.15 | 0.440 | 173 | 5.97 | 0.440 | 173.0 | 5.98 |
| 10 | 0.453 | 90.7 | 6.17 | 0.450 | 90.0 | 6.02 | 0.450 | 90.0 | 6.02 |
| 12 | 0.455 | 75.7 | 6.17 | 0.453 | 75.4 | 6.03 | 0.453 | 75.4 | 6.03 |
| 4 | 0.448 | 176 | 6.15 | 0.450 | 173.0 | 5.97 | 0.440 | 173.0 | 5.98 |
| 10 | 0.453 | 90.7 | 6.17 | 0.450 | 90.0 | 6.02 | 0.450 | 90.0 | 6.02 |
| 12 | 0.455 | 75.7 | 6.17 | 0.453 | 75.4 | 6.03 | 0.453 | 75.4 | 6.03 |
| 4 | 0.448 | 176 | 6.15 | 0.440 | 173.0 | 5.97 | 0.440 | 173.0 | 5.98 |

project or not, in this study, a comparison has been made with other studies based on other LCOE (Table 5).

### 3.1. Sensitivity analysis

For the sensitivity analysis, the discount rate and inflation rate have been varied. Different capacities of PV, wind turbines and generators were considered. The discount rates of 8 and 10% and the inflation rates of 2 and 5% have been considered for simulation. When the inflation rate increased, the value of COE reduced to $0.431, while the value of NPC increased to 30%. The simple payback period increased up to 8 years, while the ROI and IROR decreased up to 9 and 12%, respectively. The effect of changing discount rates on different cost parameters is shown in Table 6.

### 4. Conclusion

This study investigated the feasibility of providing electricity to a makeshift HCC via renewable energy sources, and for this purpose, three scenarios have been analyzed both environmentally and economically. The optimized hybrid system is comprised of PV/Converter/Wind integrated diesel generators. The LCOE of this optimum system is $0.4688, and this LCOE is compared to a solar home system. Itis observed that the proposed system is economically more lucrative than the SHS. The system exhibits better environmental performance than a diesel-fueled-based system since it produces 27% less $CO_2$ than a diesel fuel-based system. The PV system has provided almost 51% of electricity, and higher RF of this case in comparison with the other two cases also proves this. Moreover, the sensitivity analysis shows that the NPC and COE are highly sensitive regarding the discount rate. The HCC needs to be improved and managed for the people since it is located in a remote area. The electricity provided using this hybrid system will improve the HCC and the inhabitants' daily lives on this island. Future studies should be done based on considering different renewable energy technologies such as micro-hydro, biomass with different storage technologies.

### CRediT authorship contribution statement

**Tamal Chowdhury:** Conceptualization, preparation of first draft, Method development. **Hemal Chowdhury:** Software, modelling by Homer in both first draft and revised draft. **Samiul Hasan:** Preparation of revised draft and addressing reviewer comment. **Md Salman Rahman:** Preparation of revised draft and addressing reviewer comment. **M. M.K. Bhuiya:** Supervision, and proof reading. **Piyal Chowdhury:** Writing – review & editingEditing.

### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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