Techno-economic Analysis of Hybrid Renewable Energy System for Healthcare Centre in Northwest Bangladesh

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Abstract
Assessments for the techno-economic viability of the hybrid renewable energy system have been stimulated due to the frequent price hike and falls of fossil fuels, the derivatives generated during the burning of the fuels that are emitted into the environment, and the very high installation cost of the present day’s conventional photovoltaic energy system. This paper reports on the techno-economic performance assessments of a hybrid renewable energy system for a rural healthcare center in Bangladesh. These healthcare centers are essential for the residents of rural areas in Bangladesh. In this regard, a microgrid solar hybrid photovoltaic system has been designed to power a healthcare center in Gangachara Upazila (sub-district), Rangpur district, a northwest region in Bangladesh. The rooftop PV system comprises 400 Wp solar panels, a 25 kW bi-directional inverter, a 28 kW generator, connecting wires, a mounting system, and related accessories. In this assessment, state-of-the-art PV design software, HOMER Powering Health Tool, has been utilized for estimating the load requirements and for techno-economic and environmental evaluation of the microgrid system. The load analysis revealed that a 32 kW grid–connected solar PV system was required for the selected healthcare and the estimated net present cost was US$ 33,818, with a levelized cost of energy was US$ 0.022.

Keywords Photovoltaic system · Techno-economic assessments · Healthcare · HOMER Powering Health Tool · PVsyst

Introduction
Currently, the main source of electricity in Bangladesh comes from fossil fuel sources such as natural gas, imported diesel, and heavy furnace oil, coal, etc. (Al-tabatabaie et al. 2022) (Ahsan et al. 2022). The main problems with these sources are limited, and the sources are diminishing gradually (Bhuiyan et al. 2021). The use of these fossil fuels has a negative impact on the environment as it produces greenhouse gases that cause global warming. The global community has received various political persuasions in support of switching energy from fossil fuels to renewable energy sources (Karim et al. 2019). In this circumference, affordable clean energy is the most desirable source of reliable, sustainable, and uninterrupted power supply for achieving sustainable development goals of the nations and protecting the environment from pollution. The level of action varies from country to country, and countries have their own views on how persistently ventilation is completed (Salvia et al. 2019). In many nations around the world, renewable energy already accounts for more than 20% of the power delivered, and a list of countries have already taken some serious actions to generate 100% of their required power from renewable energy sources by 2050 (Guerra et al. 2022), (Zakeri et al. 2022), (Ram et al. 2022). Renewable electricity markets are projected to grow strongly in the coming decade and beyond. Nearly half of the growth in renewable energy in 2021 was attributed to China (Global Energy Review...
2021). Since electrification using renewable energy is more environmentally friendly, primary power consumption is dramatically reduced. The techno-economic feasibility of the hybrid photovoltaic (PV) energy system demonstrated the beneficial features that appreciated this system installation worldwide (Ghaithan and Mohammed 2022).

Bangladesh has many opportunities to use renewable energy resources to generate clean electricity. The country has an enormous number of hospitals ranging from 50 to 2700 beds that depend entirely on the national grid for electric power supply. Nevertheless, due to the shortage of power generation, poor transmission lines, and power rationing, the mentioned source is unreliable. Incorporating renewable energy technology, especially solar photovoltaic systems, on the rooftop of those healthcare centers could ensure an uninterrupted and sustainable power supply. Meanwhile, Bangladesh has already started a list of mega-projects to generate 40,000 and 60,000 MW of electricity by 2030 and 2041 (Islam et al. 2021) (Rosaidul Mawla and Ziaur Rahman Khan 2020). Among this generation, according to the power system master plan, the government of Bangladesh is determined to generate 40% of its energy from renewable energy sources by 2041 (Al-tabatabaie et al. 2022). The country has already set up more than 4951 healthcare facilities in its urban, rural, and remote areas (Siddiqui et al. 2007). It is reported that Bangladesh has about six hundred large hospitals having 50 to 2700 beds mounted in specific Upazila (sub-district), district, and metropolis corporation regions (Kowsar et al. 2022). There are electricity scarcity issues in most rural areas and certain urban areas, which frequently result in electric power rationing (load-shedding) and blackouts. Due to the lack of proper medical facilities in rural areas, villagers face critical conditions, such as women losing their lives during childbirth and pregnancy. Having access to electricity could decrease the high mortality rate by 70% (Chowdhury et al. 2021). Numerous surgical procedures and different medical devices require a constant supply of energy. The fact that COVID-19 is a pandemic condition has recently led to an increase in the number of patients at the medical facility. More electrical demand is therefore required (Vaziri Rad et al. 2022).

Researchers from all around the world have conducted a great deal of research on microgrid photovoltaic systems with an emphasis on the planning and design of on-grid and off-grid systems (Roﬁqul Islam et al. 2008). The techno-economic assessments for renewable electricity generation for the healthcare centers have been reported in references (Alsagri et al. 2021; Aziz et al. 2020; Chowdhury et al. 2021; Kowsar et al. 2022; Isa et al. 2016; Kapoor and Sharma 2021; Mat Isa et al. 2017; Olatomiwa and Mekhilef 2015; V et al. 2020; Vaziri Rad et al. 2022). In Iraq, a study was conducted to determine the feasibility of a solar PV microgrid system for supplying load during grid availability and outages from an economic, technological, and environmental standpoint (Aziz et al. 2020). Another case study for a grid-connected photovoltaic system for a hospital building was reported in Malaysia (Mat Isa et al. 2017). The outcome of this study was an average load of 0.922 MW, a total net present cost (NPC) of US$ 2,615,252, a levelized cost of energy of US$ 0.022/kWh, and a carbon dioxide (CO₂) emission of 318,746 kg/yr. Another publication revealed the techno-economic analysis using the HOMER Pro approach for a grid-tied PV system for Fatehpur Village, India (Kapoor and Sharma 2021). The authors of this work analyzed the load requirement and component cost, and determined the levelized cost of energy (LCOE) is US$ 0.022/kWh, the NPC is US$ 116,482.01 and the reduction of CO₂ emission is 85,193 kg/yr. The technological and economic advantages of an off-grid PV system have also been performed using the HOMER Program for a rural health facility in northern Nigeria (Olatomiwa and Mekhilef 2015). The proposed system, which consists of batteries and photovoltaic solar panels, has a cost of energy (COE) of US$ 0.530/kWh, an NPC of US$ 41,512, and a reduction of CO₂ emission is 2297 pounds/yr. During the COVID-19 outbreak in Saudi Arabia, a researcher looked into ways to manage extra electricity (Alsagri et al. 2021). Utilizing HOMER software, a dependable and affordable energy system comprised of PV, diesel, and battery banks was shown to be possible for electricity generation. The LCOE, and NPC of their system were estimated as US$ 0.105 and US$ 22,275 respectively. The application of this genre is extended to the medical facilities in south-western Europe recently (Montero et al. 2022; Ouedraogo et al. 2022). Furthermore, a 25–30% annual electric power possibility is shown by applying the PV system modernization technique and using 30–50% of the rooftop space of the hospitals.

Photovoltaic integration in the health sector has been reported in the literature mentioned above. Bangladesh possesses promising solar potential. The country has a substantial range of hospitals with multi-megawatt energy demand, but there is not any initiative yet taken to power healthcare partly or entirely with PV electricity though the healthcare centers play a crucial role in our country. In this paper, the layout and techno-economic evaluation of a microgrid hybrid PV system have been carried out to power the Gangachara Upazila (Sub-district) health facility in the Rangpur district in Bangladesh. The HOMER Powering Health Tool and HOMER Pro were used to analyze the technical and financial data. HOMER Pro allows mathematical computation of the load in the term effective solution (Singh et al. 2015).

Materials and Methodology

Study Location

In this work, the electric power supply for the hospital is supposed to come from the PV module and the
utility grid. In case of the failure of the earlier-mentioned power sources, the diesel generator will supply the necessary power for uninterrupted medical facilities. For the techno-economic assessments, the Gangachara sub-district health complex has been considered. Figure 1 demonstrates the location of the chosen medical facility (50-bed hospital) on a Google map. The proposed site is in the northwestern region of Bangladesh, where load-shedding occurs frequently.

**Climate Data**

The evaluation of any photovoltaic system’s output power considerably depends on the solar insolation that incidents on the photovoltaic solar panels and the ambient temperature. Hence, the month-to-month average solar radiation and the encircling temperature were included as entering parameters in HOMER powering health tool. For solar insolation, the HOMER tool utilized the NASA SSE satellite database.

Figure 2 shows the average monthly solar radiation at the place that was selected for this case study. The graph illustrates that the horizontal solar radiation spans from 3.8 kW/m²/day to 6.3 kW/m²/day found for the Gangachara area, with a scaled annual average value of 4.86 kW/m²/day. The figure also elucidated that April and September were the months with the highest and lowest quantities of solar radiation, respectively. The solar insolation records stages at Gangachara indicate the ability for the established order of PV technology compared with other remarkable areas all through Bangladesh.

![Fig. 1](image1)  (a) The Google map location of the site of the selected hospital, (b) the map of the Gangachara sub-district situated in the northwest region of Bangladesh, and (c) the Upazila Health Complex

![Fig. 2](image2)  The annual average solar radiation and clearness index of the Gangachara sub-district area

![Graph](image3)  Scaled annual average 4.86 kWh/m²/day
Estimation of Load Requirements

The selected area for the assessment experiences load-shedding frequently. During a blackout, the neighboring populace typically receives all of the electricity they need from suppliers of generators. The HOMER Powering Health Tool’s dialog boxes in this microgrid system were already filled with the necessary input data. To do so, the program automatically inputs all geographic data, and the chosen location, Gangachara, was entered into the HOMER location field using its own searching system. The envisioned system will receive 17 h of daily power from the grid, and the other 7 h must be powered by solar energy. Aside from that, input load data was gathered from the vaccination unit, outpatient treatment unit, obstetric delivery unit, maternity ward, general wards, laboratories, operating room, Covid-19 isolation ward, Covid-19 basic care ward, administrative office, and residential apartments of hospital-related staff members, among other places. The total energy consumption of the specified hospital can be computed by summing the electric load used in different wards of this hospital. Both conventional mathematical techniques were used to calculate the load demand. The estimation of load requirements is presented in Table 1 as follows. All inputs for the 50-bed Upazila hospital were given to the HOMER tool’s electric load input dialog boxes. The Run HOMER Pro procedure has been used to run the simulation. The hospital’s necessary peak load is 25.29 kW, but simulation results pointed to the need for a 32 kW rated PV system to ensure a continuous power supply. Additionally, the outcome demonstrates the need for a 28 kW auto-size generator for an electric blackout that could occur in an emergency.

The collected data from different types of electric loads have been inserted into the dialog box of the online HOMER Powering Health Tool. From Table 3, the peak demand of electricity was determined as 22,760 watts or 22.76 kW, and the daily demand was estimated as 81.88 kW. So, the peak demands determined from the HOMER Health Tool estimation and general electrical power calculation were close.

Simulation Tool

The Hybrid Optimization Model for Electric Renewables (HOMER) Powering Health Tool and HOMER Pro software has been used to analyze technical, electrical, and economic

| Load description       | Quantity | Power (W) | Total power (W) | On time (h/d) | Total energy (kWh/days) |
|------------------------|----------|-----------|-----------------|---------------|-------------------------|
| Lighting               | 90       | 15        | 1350            | 6             | 8.1                     |
| Wall fan               | 40       | 50        | 2000            | 6             | 12                      |
| Vaccine refrigerator   | 6        | 60        | 360             | 24            | 8.6                     |
| Domestic refrigerator  | 3        | 100       | 300             | 24            | 7.2                     |
| Centrifuge             | 3        | 200       | 600             | 1             | 0.6                     |
| Centrifuge(mini)       | 2        | 25        | 50              | 1             | 0.05                    |
| Microscope             | 1        | 20        | 20              | 4             | 0.08                    |
| Hematology analyzer    | 3        | 60        | 180             | 3             | 0.54                    |
| Incubator              | 1        | 200       | 200             | 1             | 0.2                     |
| Suction machine        | 1        | 80        | 80              | 1             | 0.08                    |
| Surgery spot lights    | 4        | 50        | 200             | 4             | 0.8                     |
| X-ray machine          | 1        | 1000      | 1000            | 1             | 1                       |
| TV                     | 2        | 70        | 140             | 4             | 0.56                    |
| Laptop                 | 1        | 60        | 60              | 6             | 0.48                    |
| Computer               | 12       | 100       | 1200            | 5             | 6                       |
| Printer                | 12       | 10        | 120             | 1             | 0.12                    |
| AC                     | 7        | 1000      | 7000            | 4             | 28                      |
| Water pump (mini)      | 4        | 750       | 3000            | 1             | 3                       |
| Water pump             | 1        | 2250      | 2250            | 1             | 2.25                    |
| GeneXpert Machine      | 1        | 190       | 190             | 1             | 0.19                    |
| Water heater           | 1        | 1000      | 1000            | 0.1           | 0.1                     |
| Pulse oximeter         | 3        | 20        | 60              | 8             | 0.48                    |
| Diathermy              | 1        | 100       | 100             | 0.5           | 0.05                    |
| Autoclave              | 1        | 1000      | 1000            | 0.5           | 0.5                     |
| Anesthetic machine     | 3        | 100       | 300             | 3             | 0.9                     |
| Total                  |          |           | 22,760          |               | 81.88                   |
data. The HOMER Powering Health Tool is a free online tool for developing initial electrical power system designs for healthcare centers that lack a particular energy source or have grid energy available for a set number of hours each day (Nouridine and Saad 2021). The HOMER Pro (∗64 3.24.5) microgrid software developed by HOMER Energy is the industry standard for enhancing microgrid designs in all fields, from village electricity and island utilities to grid-connected campuses and military locations (Aisa et al. 2022). Along with HOMER Health Tool and HOMER Pro, the PVsyst (v7.2.5) program has been utilized in this assessment, especially for determining the proposed system’s performance ratio and actual AC power.

**Economic Model**

The economical perception of HOMER Pro software is as follows:

1. Net present cost (NPC): The net present cost of a cost analysis remark component taking into account all costs and revenues incurred over the project's lifespan. The total NPC is determined by the formula (Aziz et al. 2020),

\[
NPC = \frac{C_{tot,ann}}{CRF(i, T_p)}
\]  

where \(T_p\) is the project warranty (year), \(C_{tot,ann}\) is the total annualized cost ($/year), \(i\) is the real interest rate (percent), and \(CRF\) is the capital recovery factor that is obtained by

\[
CRF(i, n) = \frac{i(1 + i)^n}{(1 + i)^n - 1}
\]

where \(n\) refers to the number of years (Lau et al. 2018).

2. Cost of energy (COE): COE is the average price per kWh of the total quantity of electricity a certain energy system produces.

\[
COE = \frac{C_{tot,ann}}{E_{tot,ann}}
\]

where \(E_{tot,ann}\) represents the total annual electricity generated (Aziz et al. 2020).

**Design Specification**

The microgrid hybrid system comprises 400 Wp capacity panels, a module racking system, a 25 kW three-phase inverter, a diesel generator, a utility grid, and related accessories. The detailed specifications of the Trina Solar made PV module (Model no: TSM-EN-2020-PA3) have been presented in the following Table 2. The monocrystalline module comprises 120 cells with 20.8% photoconversion efficiency.

**Results and Discussion**

HOMER Powering Health Tool has simulated climatic, technical, and environmental results. The annual average solar irradiance and ambient temperature of the selected...
area have been simulated as 4.86 kW/m²/day and 25.5 °C, respectively. The maximum power output from the microgrid system has been estimated as 51,467 KWh or 51.467 MWh, and the operation hours as 4377 h annually. The HOMER tool simulated a set of results, as shown in Fig. 4.

**Simulation Results**

Based on the inputs inserted into the HOMER Health Tool, the HOMER Pro program suggested a list of configurations as shown in Fig. 4.

The options generated from the tool elucidated the technical and economic perspectives for each system architecture. The simulation revealed the optimum configuration of the proposed hybrid system (consisting of solar panels, converter, generator, and grid) for the healthcare center was a 32.3 kW photovoltaic system that was connected with a 500 kW grid line, 22.6 kW converter and 28 kW generator as shown in the sky-blue frame into Fig. 4. In this hybrid solar system, a net meter is used to calculate the amount of electricity shared with the national grid. Based on the simulation results, the design perimeters of the microgrid PV system have been proposed. For reliable and uninterrupted electric power supply, the proposed energy system could be comprised of a 32 kW rooftop PV system (where total of 80 solar panels of 400 Wp are racking on the mounting system), a 25 kW grid-tied inverter, an electric grid, a 28 kW diesel generator, a net meter, distinctive diameter wires, and a mounting system those are presented in Table 3.

Figure 4 and Table 3 present the initial capital cost, net present cost, and levelized cost of energy of the hybrid system, has been estimated as US$ 36,036, US$ 33,818, and US$ 0.022, respectively.

**Load Profile**

The Gangachara sub-district hospital complex is a state-own healthcare center comprised of medical facilities, administrative wings, and residential facilities for the doctors and support staff. The medical facilities cover both 24-h emergency services and general wards facilities, as well as 8-h outpatient services, operation, and analytical

![Fig. 4 The different configurations of hybrid energy systems for the hospital are generated by the HOMER Pro](image)

**Table 3** The design specification and prices of the component of the microgrid hybrid photovoltaic system

| S/N | Components          | Specification                                           | Quantity | Price in USD |
|-----|---------------------|---------------------------------------------------------|----------|--------------|
| 1   | Solar panel         | 120 cell 400 Wp mono-crystalline panel having 20.8% efficiency | 80       | $ 19,068     |
| 2   | Grid tied inverter  | 25 kW 3 Phase inverter with 98.6% efficiency            | 1        | $ 3167       |
| 3   | Generator           | 28 kW generator                                        | 1        | $ 4480       |
| 4   | Net meter           | 3 phase 4 wire, 3 x 230 V/3 x 240 V, 50 Hz              | 1        | $ 1000       |
| 5   | Connecting Wire     | Required diameters                                     |          | $ 1200       |
| 6   | Mounting system     | 4 sets                                                 |          | $ 2500       |
| 7   | Others              | Transport, meters, connectors                          |          | $ 4621       |
|     | **Total**           |                                                         |          | **$ 36,036**  |
services. Besides, for security purposes, a large number of lights are lit at night. Moreover, different wings, such as hospital offices, outpatient units, operation theatres, etc., are open at 8 AM and closed at 5 PM. So, maximum electric loads are ON at that time, so these hours consume the highest amount of electricity, as shown in Fig. 5.

The Gangachara region experiences an average daily solar radiation of 4.86 kWh/m²/d, and due to the seasonal variation, this parameter is different. So, for the seasonal variation, load demands are varied from January to December and from summer to winter. Figure 5 illustrates the daily, seasonal, and yearly load profile variation of the healthcare’s hybrid PV system. The figure shows the maximum load demand for July and the minimum for January and May. Besides, being the peak 25 kW demands, the proposed PV system for the hospital was designed for 32 kW. So, the system will produce excess renewable electricity most of the day all over the years shown in the above Fig. 5.

**Techno-Economic Assessments**

The techno-economic feasibilities of the hybrid system have been performed using the HOMER Pro and PVsyst simulation programs. The following sections demonstrate the technical and economic assessments of the microgrid PV system.

**Assessments of the Solar Panel Performances**

The most important electric power generation tool of the proposed hybrid system is its generic flat plate photovoltaic modules.

It has already been mentioned that the microgrid PV system is designed based on peak demand, so most electricity comes from solar panels to power the hospital. Figure 6 shows the HOMER Pro simulated photovoltaic power output. The required maximum estimated PV size was 32.3 kW. The mean output of the system was 5.85 kW, total production was 51,221 kWh/year or 51.221 MWh/year, and hours of operation were 4377 h/year. The maximum hourly output was 31.7 kW, and the PV penetration to the grid was 173%. The simulated PV output revealed its competency to appreciate the investor implementing this system.

**Assessments of the System Converter Performance**

The inverter of the proposed design could function as the DC to AC–conversion device or converter. The HOMER Pro software simulated a 22.6 kW capacity converter requirement, whose mean output was 5.31 kW. The annual inverter output and rectifier output are also presented in Fig. 7. It has been seen that the operation hours of the SMA inverter are 7620 h in a year. Therefore, the inverter received a total of 49,000 kWh DC electricity and generated 45,550 kWh AC electric power for loads of the hospital, and due to the inversion loss factor, 3450 kWh of the power accounted for the loss.

**Assessments of the Auto-Size Genset Performance**

Besides the PV module and utility grid, the diesel generator is considered a vital component for uninterrupted power supply to the hospital. Without a battery bank, the generator is the only option in the hybrid system during the grid supply, or PV electricity is unavailable. The HOMER Pro tool is capable of simulating the performance of the generator. The simulated results of the component are presented in Fig. 8.

From the above figure, it has been found that the contribution of this source was meager, with only two operation hours in 1 year. The mean electrical output was only
7 kW, electrical production was 14 kWh/year, and fuel consumption was only 6.43 L. The hybrid system only burns 6.43 L of oil, generating an insignificant amount of greenhouse gases. Since the hospital consumes 99.5% green electricity and can sell excess electricity to the grid, the system is beneficial for both financial and environmental aspects.

Assessments of the Grid Performance

The national grid is the major contributor to the hybrid system for uninterrupted electric supply when sunlight is unavailable. Usually, in the daytime, excess PV electricity feeds to the grid using a net meter, and in nighttime or bad weather situations, when sunlight is not sufficient to meet the system requirement, the grid supplies the required electricity. In this simulation, the microgrid system supplies 16.819 MWh to the grid annually, as shown in Fig. 9. In addition, the energy purchased and sold to the grid scenarios were also demonstrated.

The grid is the prime contributor to electricity and functions as the energy storage device in this hybrid system. The above demonstration shows that the hospital will purchase only 232 kWh of electricity annually, whereas selling 17,051 kWh of electricity to the grid.
kWh of power is possible. Therefore, the proposed microgrid will be capable of powering the hospital even after increasing the number of beds or medical facilities.

Assessments of the Electrical Performance

In the technical investigation, the electrical output of the microgrid system is an important performance parameter. The HOMER Pro performed simulation results for the electrical output power of the hybrid system is shown in Fig. 10. From the simulated results, it has been seen that 99.5% of the total output comes from solar panels. In contrast, the auto-size generator and grid line contributed only 14 and 232 kW annually, accounting for only 0.5% of power production. Among the total 51,221 kWh of electricity, the AC load consumption is 29,602 kWh, and an excess of 17,051 kWh of electricity is available for sale to the grid annually.
The annual generated DC power is 51,221 kWh; therefore, 4568 kWh of electricity will be lost due to various factors. Hence, the amount of AC electricity is estimated as 46,653 kWh. Among this AC electric power, the Gangachara subdistrict hospital consumes 63.5%, and 36.5%, accounting for 17.05 MWh, which could sell to the grid.

**PVsyst Analysis for Photovoltaic Module Performance Evaluation**

Based on the HOMER simulations, it has been determined that to obtain the maximum power output of 32.3 kW from the hybrid system, a minimum 22.6 kW inverter and a 28 kW generator need to connect to the electric grid and PV system. HOMER Pro has simulated that the maximum annual power generation is 51,467 KWh or 51.467 MWh.

To evaluate the actual system output of the hybrid PV system for real-world electricity supply, the performance ratio (PR) is a crucial indicator. PR is the measurement of the quality factor of a photovoltaic plant. This ratio measures the relationship between a power plant’s actual and theoretical energy outputs. For PR calculation, the availability of the grid, the minimum level of irradiation needed to generate electrical energy, and irradiation levels at a given period have been considered. In measuring the PR ratio, usually, 1 year is considered for the optimum analysis period.

In this assessment, the PVsyst program has been utilized to determine the actual power production from the proposed system. In addition, the same technical and climatic inputs for identifying the 32 kW hybrid PV systems using the HOMER tool were also considered for PVsyst simulation. As a result, the program determined the 37.00 MWh annual power production with a 71.68% performance ratio, as shown in Fig. 11. The PR is the essential parameter to realize the total power output, per unit generation cost, payback period, etc., for a PV plant for its entire 25 years lifetime.

**Fig. 10** The annual electric power production and consumption scenario of the hybrid system

**Fig. 11** PVsyst analysis for the solar system
Per-Unit Cost Estimation

The per unit electricity generation cost has been determined using the net present value (NPC), annualized cost for the entire plant lifetime, and actual output power using the following formula:

\[
\text{Cost per unit} = \frac{\text{Net Present cost} + (\text{Annualized cost}) \times 25}{\text{Actual PV output of 25 year}}
\]

\[
= \frac{\$33815 + (\$1035) \times 25}{925000}
\]

= $0.065

The NPC and annualized cost have been utilized from the HOMER tool. The actual power output of the microgrid plant has been determined from the PVsyst for 25 years. The cost per unit of electricity generation cost has been estimated as US$ 0.065. In fact, this result is a decent lower than the present per unit electricity production of US$ 0.096 in Bangladesh (Bangladesh Electricity Prices, Accessed 28 July 2022). Like most countries, Bangladesh possesses a co-generative energy mix. Therefore, the per-unit electric power generation varies based on power systems, raw materials, and fuels. Moreover, even the generation could vary in the identical sources, such as diesel-based power generation costing, due to the locations and contract with the investors. However, according to Bangladesh Power Development Board (BPDB), the country generates more than 50% of its electricity from mining natural gas. In this case, the per-unit generation cost is ~US$ 0.02; in contrast, the per-unit generation cost based on imported fuels such as HSD and HFO is very high, ranging from US$ 0.15 to US$ 0.27. Furthermore, the tariff for PV electricity lies between US$ 0.105 and US$ 0.2. Hence, the proposed hybrid system’s estimated per-unit ($/kWh) electricity generation cost is competitive with the gas-based power plants and significantly lower than the imported fueled-based electricity production.

System Description with Financial Analysis

The financial parameters of the renewable energy system, such as investment cost, interest rate, internal rate of return, etc., play a crucial role in the investors’ successful installation, operation, maintenance, and profitable business operation. The selected hospital is grid-connected, so the microgrid system does not need further investment for the grid connection, but during the PV installation, it needs to expand due to the net-metering mechanism and commissioning. Therefore, the state-run hospital authority or other agency, such as (the Department of Public Health Engineering) is the investor in implementing the power system. However, the two vital components, such as solar module and inverter, need to import as Bangladesh does not manufacture these. So, the cost for these components was estimated twice compared to their producer website price. Besides, other components could be arranged from the local market paying the regular price, including the VAT and TAX according to PPR-2008.

The initial cost for the system installation is the cost of the components, their integration, and commissioning. The system’s capital cost or initial investment cost (CAPEX) was estimated to be US$ 36,036. The power system needs to be maintained regularly to ensure proper operating conditions. The frequently used term for the operation and maintenance cost is OPEX. The OPEX depends on the employee’s salary, maintenance, replacement, reparation, cleaning modules, and other components. The HOMER Pro simulated OPEX of the system was US$ 1036. The energy system’s interest rate is the rate imposed on the investor or authority when they take a loan to implement the system. This essential parameter could vary from country to country or even in a nation’s boundary due to different schemes and subsidies.

The financial assessments of the hybrid system revealed that the return on investment was 9.8%, and the internal rate of return was 12.7%, as shown in Fig. 12. The internal rate of return (IRR) defines the amount of profit gained by investing in an energy system. HOMER Pro–simulated IRR for the studied system was 12.7%, indicating that there is a possibility to make a 12.7% profit annually on the capital invest US$ 36,036 of the proposed project. The return on investment of 9.8% indicates that the system will generate power whose price is equal to 9.8% of the capital cost annually, estimated as US$ 3,447, leading to earning US$ 86,171 in 25 years system lifetime.

The above figure shows the simple payback period of the hybrid system as 7.53 years. However, the HOMER Pro tool also simulated the discounted payback period for calculating actual years that need to get back its initial investment. In fact, during the simple payback period, the time value of money does not consider. Hence, the discounted payback period of the rooftop microgrid PV was simulated as 6.95 years. So, the actual years for returning the initial investment is 6.95.

Importance of the Work

The sub-district hospitals play a crucial role in serving the village settlements and limited-income urban dwellers. A significant number of patients regularly take the medical facilities from this hospital. For example, more than 700 patients attended doctors using the outdoor treatment facility daily, and more than 50 patients received residential medical facilities after admitting to the 50-bed Gangachara Hospital. So, a reliable power supply is a mandatory criterion for serving this enormous number of patients daily. Each of the 495 sub-districts of Bangladesh has at least one 50-bed hospital.
As mentioned earlier, these hospitals are facing severe power rationing due to a power generation shortage, especially during the working day’s daytime office hours. So, the demand for electric power is high, especially in the daytime. Hence, implementing a hybrid rooftop photovoltaic system would be an immediate solution for a long-term reliable power supply. The proposed hybrid PV system can supply green electricity daily, especially in the daytime.

Photovoltaic technology is a reliable technology for sustainable energy generation, but the initial investment for the system is still significantly higher than most other power generation technologies. This high capital cost creates financial constraints for public and private investors and power consumers, especially in developing and emerging countries. Besides being a densely populated country, land demand and price are always prime factors for Bangladesh. So, the land cost further enhances the PV installation. Microgrid PV system offers the opportunity to avoid the expense of battery banks, charge controllers, and related accessories, and installing the system on the available rooftop space could discard the land price, which significantly reduces the capital cost. So, the studied techno-economic assessments could assist the hospital authority in implementing the rooftop microgrid system for healthcare centers using competitive economic investment. Though the case study for PV integration in Bangladesh is a novel phenomenon, the earlier mentioned literature review section revealed the high capital cost of such medical applications. So, the present techno-economic evaluation would be a catalyst for implementing a hybrid microgrid system for sub-district level hospitals in Bangladesh and similar-sized hospitals in other countries.

The simulated results obtained from the programming tools ensure the practical implementation of the power system on the rooftop of the Gangachara hospital. Moreover, from the above-mentioned techno-economic assessments, it has been elucidated that the proposed system would be effective for uninterrupted power supply for rural healthcare centers because of its cost-effectiveness, technical soundness, and environmental friendliness. So, the microgrid hybrid photovoltaic system would be a better and more sustainable solution for providing continuous medical facilities to rural settlements in Bangladesh and developing nations.

**Load uncertainty and Sensitivity analysis**

The uncertainty investigation for long-term large-scale photovoltaic (PV) systems is a critical parameter for maximum PV generation and sustainability (Thevenard and Pelland 2013). Besides, sensitivity analysis is another essential task to understand the advantages of any techno-economic assessment. All the sensitive parameters such as interest rate, diesel price, climatic resources viz. irradiances and temperature, tariff rate, and cost of PV modules, inverter, etc., have been studied. As mentioned earlier, the load data collected from the selected healthcare center is a state-owned hospital. According to the Public Procurement Rules (PPR 2008), the government of Bangladesh shall be financed for any government establishments; therefore, the capital cost for the hospital must be arranged from the government fund. Thus, the interest rate will not be imposed for...
this case, so this is not a sensitive parameter in this case study. Again, the hospital will be powered by PV electricity; in the absence of this source, the grid will supply the required power, and healthcare rarely uses a diesel generator. This source is kept only for emergency cases. As a significantly lower amount of diesel is supposed to be used, the diesel price is not considered a sensitive parameter. Besides, climatic resources would be a critical sensitive parameter. The simulation has been performed using the NASA satellite database and NREL climate resources. Because the considered hybrid system is only 32 kW in range, the results for the technical and financial parameters were found close for both climatic conditions. Likewise other developing and emerging nations, the price of goods heavily depends on the diesel price and dollar rate in Bangladesh. However, with the diesel and dollar price fluctuation, the prices of the goods are varied and adjusted, so the cost of the power system component and tariff rate is also adjusted accordingly.

**Future Prospects**

The data collection for different electric load from the large-sized state-owned and private hospitals are progressing, where the sensitive parameters will be automatically incorporated. Furthermore, future work will analyze the uncertainties of the demand and sensitive parameters for those hospital power systems using these field data. Besides, the ultimate aim of the study is to implement the proposed energy system on the hospital’s rooftop soon and make a comparative analysis of that experimental demonstration with the present techno-economic evaluation.

**Conclusion**

This paper presents an optimal hybrid power system design of a remotely located sub-district hospital situated in Gangachara, a northwestern region of Bangladesh, using the HOMER Powering Health Tool. This design’s techno-economic evaluation has been performed using HOMER Pro and PV syst tools. The assessment has elucidated that this microgrid system would be the cheapest and most sustainable in comparison with the existing power supply. This design’s techno-economic evaluation has been performed using HOMER Powering Health Tool. The assessment has elucidated that this microgrid system would be the cheapest and most sustainable in comparison with the existing power supply. The summarized conclusion is as follows:

1. The annual average solar radiation and ambient temperature of Gangachara are 4.86 Kwh/m²/day and 25.5 °C, respectively, which indicate the excellent potential for a higher amount of electricity production from solar energy for the selected healthcare center.
2. The actual electricity generated by the PV system during a 25-year period will be estimated as 925 MWh, exceeding the Gangachara health complex’s 25-year electricity consumption. The extra 16.819 MWh of electricity produced annually by the solar system may be sold to the national grid or other organizations or facilities.
3. The simulated capital cost, net present cost, annualized cost, and levelized cost of energy of the microgrid hybrid system are estimated as US$ 36,036, US$ 33,818, US$ 1,035, and US$ 0.022, respectively.
4. The return on investment, internal rate of return, discounted payback, and payback time are estimated as 9.8%, 12.7%, 6.95 years, and 7.53 years, respectively. The payback period is one-third of the estimated lifetime of the hybrid solar system. So, it is evident that the system is highly effective and productive.
5. The simulated renewable electricity percentage (99.5%) of the hybrid system ensures the environmentally benign feature of the proposed system.
6. The per unit electricity production cost of the hybrid solar system is US$ 0.065. This ($/kWh) cost would be higher or lower depending on the energy system size, component price, AC output generation, national tariff, etc. Usually, the higher the total AC PV generation, the less per unit cost for a large-scale power system or vice versa.
7. These economic parameters demonstrate the significant reduction of installation, operation and maintenance, and per-kilowatt-hour generation cost, and environmental beneficial features assure the state-run and private-owned hospital authorities to install the hybrid PV system in LDC and developing countries, including Bangladesh, where installation cost will be a prime commodity.

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**Data Availability** All data generated or analyzed in this study are available from the authors on request.

**Declarations**

**Conflict of interest** The authors declare no competing interests.

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