
Research article

Optimization and cost-benefit analysis of a grid-connected solar photovoltaic system

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Abstract: Growing energy demand has exacerbated the issue of energy security and caused us to necessitate the utilization of renewable resources. The best alternative for promoting generation in Bangladesh from renewable energy is solar photovoltaic technology. Grid-connected solar photovoltaic (PV) systems are becoming increasingly popular, considering solar potential and the recent cost of PV modules. This study proposes a grid-connected solar PV system with a net metering strategy using the Hybrid Optimization of Multiple Electric Renewables model. The HOMER model is used to evaluate raw data, to create a demand cycle using data from load surveys, and to find the best cost-effective configuration. A sensitivity analysis was also conducted to assess the impact of differences in radiation from the solar (4, 4.59, 4.65, 5 kWh/m²/day), PV capacity (0 kW, 100 kW, 200 kW, 300 kW, 350 kW, 400 kW, 420 kW), and grid prices (\$0.107, \$0.118, \$0.14 per kWh) upon that optimum configuration. Outcomes reveal that combining 420 kW of PV with a 405-kW converter and connecting to the utility grid is the least expensive and ecologically healthy configuration of the system. The electricity generation cost is estimated to be 0.0725 dollars per kilowatt-hour, and the net present value is 1.83 million dollars with a payback period of 6.4 years based on the system's 20-year lifespan. Also, compared to the existing grid and diesel-generator system, the optimized system, with a renewable fraction of 31.10%, provides a reduction in carbon dioxide emissions of 191 tons and 1,028 tons, respectively, each year.

Keywords: grid-connected solar system; solar photovoltaic array; HOMER model; life-cycle cost; cost of energy; emissions

1. Introduction

Electricity plays a leading role in our daily lives in homework, industry, transport, agriculture, and so on. The Gross Domestic Product (GDP) yearly growth rate represents any country's socio-economic development. Gross domestic product is heavily influenced by a country's long-term energy supply surety, particularly its direct links to the country's energy market [1]. In order to reach the Sustainable Development Goals (SDG), we need to have affordable, reliable, sustainable, and modern energy that is also easy to use [2]. The most practical type of energy is electricity. Electricity is one secondary type of energy that is created by the energy transition. It can be produced in a variety of ways, including the combustion of gas, oil, or coal and some renewable energy (solar, hydro, wind, tidal, and nuclear energy) resources [3]. The creation of power from nonrenewable energy has a negative impact on the environment by producing greenhouse gases as a result of nonrenewable fuel source burning. Renewable sources of energy have long been considered a form of clean energy creation as a replacement for fossil fuel burning because they can produce nil environmental harm. Fossil fuels are predicted to make up about 80% of the world's primary energy [4]. Each year, the equivalent of 10 billion metric tons of coal was consumed in the mid-eighties of the previous century. Coal consumption is estimated to reach 55 billion metric tons by 2025. This huge use of fossil fuels would deplete non-renewable resources, exposing the Earth to more severe climate change and global warming concerns. To achieve economic development without causing significant changes to the Earth's climate, fossil fuels should be used efficiently, while other clean energy sources must be developed concurrently [5]. For the past few years, energy consumption has grown in every discipline of life globally. It is extrapolated from 2010 to 2030 to increase by 33% and it is expected to rise by 2.3 percent per year between 2015 and 2040 [6,7]. Consumption in growing economies such as China and India are driving global energy demand upwards. These two countries currently account for half of global demand growth, with consumption predicted to treble by 2030 [8]. In the global energy sector, renewable energy generation is gaining traction. This is primarily driven by the need to transition to clean, sustainable energy in order to reduce greenhouse gas emissions and reduce reliance on fossil fuels [9]. Bangladesh has many renewable resource potentials, such as solar, hydro, biogas, biomass, and wind, which can help to achieve the success of the government's February 2000 announcement of a vision and policy statement outlining its plans to supply energy to the entire country in stages through 2020 [10]. By 2020, the Bangladesh government will have provided electricity to 85.6% of the total population [11]. But, compared with all other renewable sources, Bangladesh offers a lot of scope for solar energy gathering due to its geographic location on the planet. It is also the most abundant and permanent source of energy on the planet since the solar power received from the Earth's surface each year per minute is far greater than the total energy used by all people. Solar photovoltaic (PV) technology generates electricity by converting incident solar radiation directly into electricity [12]. As a result, solar energy is being used to generate more electricity around the world. There are already 583.5 GW of operating PV systems around the world, accounting for a significant share of the 2563.8 GW total installed renewable capacity [13]. In Bangladesh, total solar energy production is 500 MW, which contributes to 39.5 % of total renewable energy [14]. However,

about 3.3% of Bangladesh's total generation of electricity is from the renewable energy, which is still on the rise, as the government has established the objective of generating 5% of renewable energy supplies by 2015 and 10% by 2020, and a series of renewable energy programs have been initiated to attain this objective [15].

Bangladesh is one of the world's most extremely populated countries with approximately 1118 people per square kilometer, and it is classified as a lower-middle-income country in 2018 by the World Bank [16]. The country has a population of 162 million people and is ranked eighth among the world's most densely populated countries [17]. Since 1998, it has maintained an annual economic growth rate of more than 6%, with the goal of becoming a country with a high level of income by 2041 [1]. To meet this development goal, net power demand is expected to reach 61 GW by 2041. Bangladesh now has 20,383 MW installed capacity with a total power demand of about 20,000 MW of during peak hours. The maximum peak generation is 12,738 MW, with a growth rate of only 1.26 percent, and electricity generation per capita is expected to be 510 kilowatt-hours [18]. Importing countries' national interests are committed to providing energy access because countries that lead the world in economic growth support small and mid-size businesses, thereby stimulating innovation within organizations, enhancing the competitiveness of products and services, and contributing to a high standard of living that is entirely reliant on electricity accessibility [19,20]. To provide for that electricity demand, Bangladesh has to import energy resources like oil, gas, and sometimes direct electricity. In comparison to all other forms of energy, Bangladesh relies heavily on fossil fuels to generate power. Figure 1 indicates that about 54% of total electricity is produced mostly by natural gas, with the balance being produced by coal, liquid fuel (imported), hydropower, energy imports, and solar photovoltaics [18]. According to estimates, the country's fossil fuel reserves, which are a major source of electricity, will be depleted within the next decade [21]. For this reason, Bangladesh must deploy alternative energy generating systems (such as solar PV systems) to meet the growing demand. Integration of renewable energy sources into both grid-connected and off-grid systems has recently been discovered to be the most efficient and appealing solution from a technical, economic, and environmental standpoint, though there are potential limitations because RE generation is variable and weather dependent [22]. This green power strategy can minimize present dependencies on nonrenewable resources, as well as different imported fuels [1]. This report recommends solar power as an alternate power source to address this energy crisis. Because, from 2010, the cost of power generated by solar photovoltaic plants dropped dramatically. Even though the cost of electricity from non-renewable sources was estimated to range from 0.05 to 0.17 dollars per kWh in 2017, depending on fuel and country, the global total average cost of electricity from utility-scale solar systems has decreased since 2010, to 0.10 dollars per kWh for new ventures deployed in 2017, and it is continuing to fall [23]. Although solar investment costs are often higher than those of fossil fuels, they can be made economically viable by factoring in health hazards, environmental concerns, and lower operating costs.

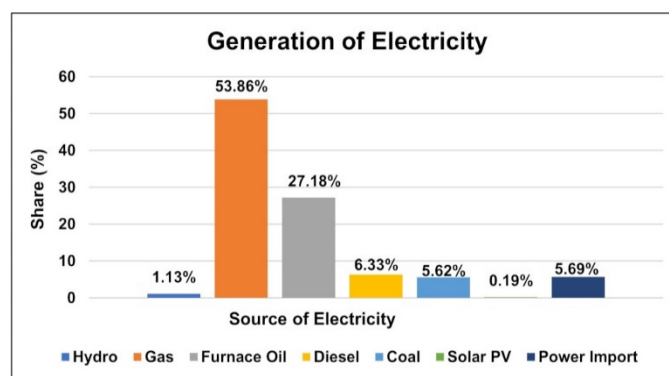


Figure 1. Electricity generation in Bangladesh by fuel type.

Bangladesh lies between 20.30° to 26.38° North latitude and 88.04° to 92.44° East longitudes, which is optimum place to use sun power and the radiation is 4 to 6.5 kWh per square meter per day [24]. Consequently, Bangladesh has a significant solar PV power generation option for making sustainable energy generation by solar PV systems [25]. As a result, grid-tied solar systems are becoming increasingly popular and are widely regarded as a superior option to off-grid solar systems here. Solar energy is widely regarded as one of the most abundant and promising renewable energy sources on the planet [26]. According to International Renewable Energy Agency statistics, grid-connected solar capacity reached 580.1 GW globally and 3.4 GW of off-grid capacity in 2019. With the grid-connection facility, Bangladesh's installed PV capacity has exceeded 370 MW [27].

In this study, an improved and cost-effective technique to synchronize the PV array output with the utility grid using a net-metering scheme is proposed. For this purpose, an optimization and cost-benefit analysis were conducted for grid-tied solar system using HOMER (Hybrid Optimization Model for Electric Renewables) software at Younus Khan Scholars' Garden, Ashulia, Dhaka. To estimate the most feasible system configuration for the study area, the three core capabilities of HOMER: simulation, optimization, and sensitivity analysis [28] are executed. The study's goals are to introduce the technology as a more cost-effective and ecologically friendly replacement to the present grid-only and diesel-generator systems, with the goal of reducing pollution by lowering greenhouse gas emissions and saving money for the Younus Khan Scholars' Garden. In this analysis, initial demand data was acquired using a systematic survey, focus groups, and on-the-ground observations to build elements of a system whose inputs to the HOMER model include technological and economic characteristics. The collected data is used to generate a daily load profile for the HOMER model, which was then used to build the system. As a result, the system delivers the most cost-effective and ecologically friendly alternative for meeting the area's daily electricity consumption. Changes in critical parameters like solar radiation, grid electricity prices, and PV array capacity were considered in sensitivity analyses to determine the feasibility of our proposed system to achieve our paper's economic aim. The study sheds light on how grid-connected systems could help Bangladesh to achieve its development goals by 2041.

1.1. Literature review

In Bangladesh, extensive research has been conducted on grid-connected solar PV system applications, but the majority of studies have focused on hybrid systems, mixed renewable source

assessments and off-grid standalone solar PV system applications. N.K. Das and J. Chakrabarty propose an energy scenario and evaluate Bangladesh's energy mix [29]. The potential for renewable and solar energy in Bangladesh was investigated and presented in Ref. [14]. The Global Oil Market was examined using data from Asian crude oil imports by demand countries and gasoil exports by supply countries, as presented in Ref. [19], where assumptions were made based on the complementary nature of the economies of the Republic of Korea and the Russian Federation, taking into account that both parties are making sufficient effort in the current political climate. Global Solar Atlas 2.4 produced solar resource maps for Bangladesh in December 2020 [24]. According to the study, Bangladesh's yearly average solar radiation is calculated at 4.59 kWh per square meter per day, with a minimum of 4.33 kWh per square meter per day in September and a maximum of 4.95 kWh per square meter per day in April.

In Bangladesh, a study of grid-connected solar systems was conducted without any techno-economic assumptions [30], an optimized PV/Diesel/Pump-hydro system was compared with a battery-based system [31]. The improved configuration has a lower energy cost of \$0.24/kWh and emits 30% less CO₂ than the battery-based system. According to another study in Bangladesh's southeastern region, the grid-connected system's cost of producing one unit of power is USD 0.20 [32]. Another study found that a grid-connected PV system with a USD 0.200/kWh generating cost could meet Bangladesh's electricity demand [33]. Another study used the HOMER model to propose a grid integrated system with PV and battery storage for an 800-household rural residential region in Bangladesh [34]. According to the analysis, the suggested system's levelized cost of electricity (COE) is USD 0.24/kWh. Similarly, the HOMER model was used to depict a hybrid conjugation with an electricity cost of USD 0.0995/kWh [35]. Iqra and Abdul Razaque, compared off-grid with grid-tied solar systems using HOMER [36]. Research about stand-alone hybrid systems for rural electrification also discovered that the generating cost was more than Bangladesh's current rate [37]. Furthermore, a hybrid system analysis of a small town in Bangladesh revealed that the generation cost is 0.47 USD/kWh, with a 10% annual capacity shortage [38]. Another study in Bangladesh found a high cost of generation 0.27 dollars/kWh with a payback period of 8.2 years with a solar-wind-diesel hybrid system in rural regions [39]. In India, Amit and Ashutosh presented an optimization study of grid-connected hybrid systems using HOMER, which resulted in lower levelized COE and emissions [40]. In rural Pakistan, Fahad Ali used HOMER software to examine techno-economics of grid-connected hybrid systems, and the cost of electricity is currently lower than off-grid systems [41]. Also, in Amman, El-Tous investigated the economic feasibility of a grid-connected PV system, as well as the inducement tariff's impact [42], Research by Li et al. of grid-connected PV systems in Hong Kong with an anticipated payback period of 8.9 years has been published [43], Samir & Lin used HOMER optimization to find an economical and environmentally friendly hybrid system in Egypt [44]. Finally, Chouki and Maamar present a hybrid grid-connected system of low levelized cost of electricity with minimal carbon dioxide emissions for a university building in the UAE [45].

Many countries, including Australia [46], India [47], the Maldives [48], Saudi Arabia [49], Zimbabwe [50] and the UAE [51], are doing a lot of research right now to make microgrid-based energy-efficient and reliable power systems for rural areas that are more efficient and reliable. In recent years, there have been a lot of studies on solar photovoltaic systems. Such as, a modified crow search algorithm was used to optimize the operation expenses of a hybrid solar photovoltaic (PV)-diesel-PHS (Pump Hydro Storage) system [52]. A thorough examination of the prospects for wind and solar power systems with PHS was conducted, with the conclusion that PHS could be promising in the future

for long-term storage [53]. Ganesan et al. [54] also constructed a model employing a Wind/PV/Diesel system and discovered that using RE resources reduces the operational cost of DG. A prefeasibility economic and sensitivity assessment in [55] and a feasibility study and comparative analysis of hybrid renewable energy systems in Nigeria in [56] are also presented. Another study of key technology development and applicability analysis of renewable energy hybrid technologies in off-grid areas is presented in [57]. Various researchers have carried out studies on the performance parameters of installed photovoltaic systems in various locations and with different climatic conditions [58–60], as well as research work on solar thermal, solar photovoltaic, solar radiation, and financial analysis of grid-connected photovoltaic system modeling. Furthermore, Elmorshedy et al. [61] provided a combined and conceptual strategy for technoeconomic and dynamic rule-based power control of an off-grid solar—wind renewable energy system with net present and energy costs of \$232, \$423.3 and \$0.3458/kWh, respectively. After that, Al-Sarraj et al. [62] undertook research to determine the economic viability of using a hybrid solar and wind energy system to produce clean electrical power for an Iraqi institution. They used HOMER software to calculate the economic viability of the hybrid system. Finally, a study on the techno-economic analysis of solar energy systems for rural school electrification in Southern Ethiopia [63] presented the most feasible, optimized, cost-effective, and environmentally friendly system with a relatively high net present cost (NPC) of \$32,019 and a cost of energy (COE) of \$0.254/kWh.

Almost all of the studies cited above looked at PV, PV-diesel, PV-wind-diesel, PV-diesel-battery, PV-diesel-hydro, and hybrid systems and concluded that renewable systems are the most viable. Some studies reflect only the feasibility or performance of the systems, while others estimate the data for analysis. Most studies focused on rural electrification or home systems without any unique technique. Still, some are also showing grid-tied PV systems with a high leveled COE or high carbon dioxide emission. Thus, the studies on this topic are less consistent. This research uses surveyed primary energy usage data and updates system component costs for more up-to-date energy system planning and includes a net metering scheme for selling excess electricity from the grid-connected solar PV system at Younus Khan Scholars' Garden, Bangladesh, which will introduce grid-connected solar photovoltaic systems as a more cost-effective and ecologically friendly system, reducing the cost of electricity and greenhouse gas emissions. The sensitivity analysis also scopes the broadness and deepness of the evaluation. The outcome of this study can be applied in any location in Bangladesh where electrification is available from the grid and solar radiation and can offer insights into other fast-emerging Asian countries as well as the world.

2. Materials and methods

To identify Younus Khan Scholars' Garden as a good site for on-grid electricity generation, first we used National Aeronautics and Space Administration (NASA) data for solar potential and temperature. As a consequence of this analysis, the research area offers a lot of solar potential. By getting the support of the administration, the Younus Khan Scholars' Garden is regarded as a model for on-grid electrification.

From September 2020 to April 2021, primary data was gathered from surveys and end-users' questionnaires. The administrative officer also assisted with data collection. Secondary data was mostly gathered via yearly reports, publications, literature, and online searches from relevant organizations. All of this data was entered into the HOMER energy model, which determined that a

grid-connected solar PV system could meet primary power requirements while lowering overall system and power costs. The following is a description of the theoretical formalism of the proposed system components.

2.1. Equation of PV the array

Output from PV arrays mostly depends on array size, derating factor, solar radiation, and temperature. To compute that output, HOMER uses this equation below [64].

$$P_{PV} = C_{PV} f_{PV} (I_T / I_{T,STC}) [1 + \beta_P (t_C - t_{C,STC})] \quad (1)$$

here, C_{PV} is PV array capability (kW), f_{PV} is derating factor of PV panel [%], I_T is in the current time step, solar energy strikes the array in kW per m², $I_{T,STC}$ is in conventional test conditions, incident radiation kW/m², β_P is the heat coefficient of energy in %/°C, t_C is current time step's cell temperature in degree Celsius, and $t_{C,STC}$ is temperature of cells under typical circumstances for testing [25 °C].

2.2. HOMER's cost analysis procedure

The sum of the C_{PV} and converter costs C_{CONV} is the system cost.

$$C_{System} = C_{PV} + C_{CONV} \quad (2)$$

A. Net present cost: Total installation and operation costs over its lifetime, are determined as [65]:

$$NPC = \frac{A_C}{R_F} (i, P_L) \quad (3)$$

where, A_C , R_F , i , and P_L represent total annualized cost, capital recovery factor, interest rate in percentage, and system lifetime in years, respectively.

B. Annualized cost: The sum of all equipment's annualized costs, including capital, operation, and maintenance, including replacement and gasoline costs [65].

$$C_{Annual} = (CCR_F + CO) \quad (4)$$

C. Capital recovery factor: It is a ratio that calculates the present value of equal annual cash flows [65].

$$R_F = (i \times (1 + i)^n) / ((1 + i)^n - 1) \quad (5)$$

where n denotes the length of time and i the denotes yearly real interest rate.

D. Cost of energy: It is the average cost per kilowatt-hour of usable electricity produced by system [65]:

$$COE = A_C / (D_{Pr,(AC)} + D_{Pr,(DC)}) \quad (6)$$

here, $D_{Pr,(AC)}$ denotes primary load of AC and $D_{Pr,(DC)}$ is DC primary load.

2.3. Study site and rooftop illustration

Younus Khan Scholars' Garden is located at 23.5° North latitude and 90.2° East longitude, as illustrated in Figure 2, which is connected to the utility grid through the REB distributor to meet its energy requirements. The geographical location of the location is Daffodil Road, Khagan, Ashulia, Savar, Dhaka, Bangladesh. It is located about 5 km from Ashulia Union Parishad and 19 km from Hazrat Shahjalal International Airport. YKSG has a total area of 10,000 m² and a 2900 m² rooftop area is used to propose a grid-tied solar system to meet its load demand. A manual site inspection and Google Earth online site in satellite mode are used to measure the rooftop areas. The climate in Ashulia, Dhaka is a subtropical monsoon with an annual rainfall of 1595 mm. Bangladesh's rainy season runs from June through September [66].

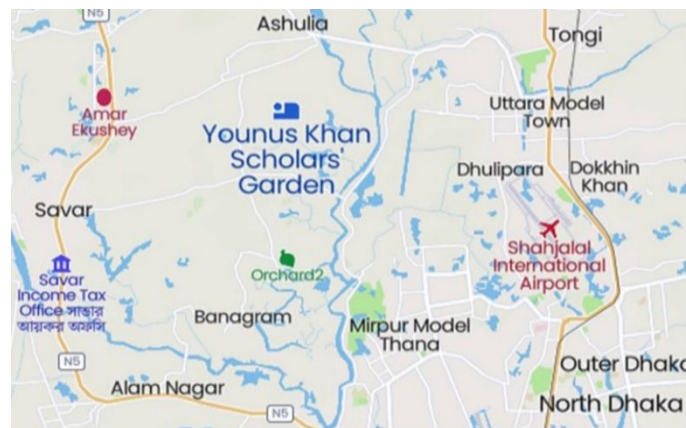


Figure 2. Map showing the location of the Younus Khan Scholars' Garden.

2.4. Electrical load profile of Younus Khan scholars' garden

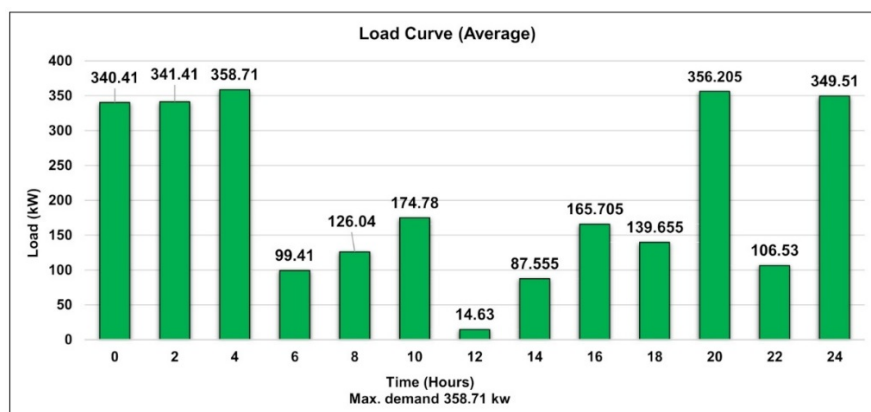


Figure 3. Average electrical load curve of Younus Khan Scholars' Garden.

Younus Khan Scholars' Garden has 400 student rooms, 5 single rooms, 2 office rooms, 2 officer living rooms, 1 canteen, 1 night canteen, 1 mosque, 1 IT server room, and 48 washrooms, according to the survey. The load demand was investigated across the site, and is presented in Table 1. It has a

load of 491 kW and a total of 8240 pieces of equipment. The maximum load demand of YKSG in summer is about 448 kW/day and in winter it is about 286 kW/day. Then the daily average load demand has also been determined, which is depicted in Figure 3.

Table 1. Estimated electrical load in Younus Khan Scholars' Garden.

Appliance	Quantity	Rated power (Watt)	Total power (Kilo Watt)
Light	2540	18	45.72
Fan	1669	100	166.9
Exhaust fan	103	70	7.21
Water filter	27	120	3.24
UV water filter	30	10	0.3
Refrigerator	3	270	0.81
Drinks freezer	4	330	1.32
Desktop	609	220	133.98
Surveillance camera	159	6	0.954
Television	1	75	0.075
Sound box	1	100	0.1
Coffee maker	2	1100	2.2
Microwave oven	2	1150	2.3
Charger	1614	15	24.21
Broadband box	40	15	0.6
Laptop	1005	35	35.175
Halogen light	16	200	3.2
Water pump (1)	2	2238	4.476
Water pump (2)	1	7460	7.46
Pump (submersible 1)	2	2238	4.476
Pump (submersible 2)	2	1492	2.984
Elevator	5	7460	37.3
Air cooler	3	150	0.45
Corridor light	400	13	5.2
Total	8240	24885	490.64

This survey was conducted in two sections. The pressures on these individual sectors are much higher in the summer than in the winter. Since load demands vary by season, this study considers the variations in Younus Khan Scholars' Garden load demands during the summer and winter. Finally, the average load demand calculations were carried out using manual calculations based on the surveyed loads and working schedules of various loads.

2.5. Input parameters of proposed grid-connected system

HOMER is a piece of software made by the National Renewable Energy Laboratory for designing micro-electrical systems. It carries out optimization and determines the technical feasibility and life cycle costs for each hour of the year of a certain system configuration. It also performs multiple optimizations under a variety of input assumptions to assess the impacts of changes in input variables [67]. The

investigated load profile is changed in the HOMER model by defining an average daily demand profile of 10% daily, 15% hourly random variability. As a result, the annual peak load has increased to 718.68 kilowatts, and initial demand has increased at 4945 kilowatt-hour per day. Figure 4 depicts the proposed system configuration that uses a net metering technique to connect to the grid. Figures 5 and 6 display the overall hourly and monthly load profiles, respectively.

To begin designing the system, sunlight and temperature information for the designated study area were acquired from the NASA database. Throughout the year, the average radiation on horizontal surfaces is 4.65 kWh/m²/day. The clearness index is 0.521, which measures the cleanliness of the air. In Ashulia, Savar, the annual average temperature is 25.20 °C. Solar radiation reaches its maximum in April at 5.76 kWh/m² and its minimum in September at 4.02 kWh/m². Table 2 shows the site's monthly solar radiation and temperature data. According to daily solar radiation and temperature data, there is enough sunlight all year to make a lot of PV power.

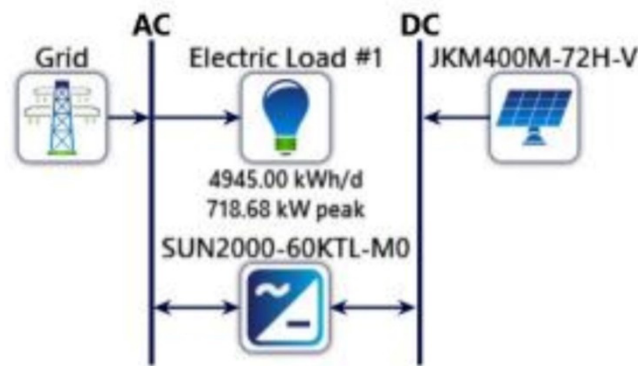


Figure 4. Configuration of the proposed system.

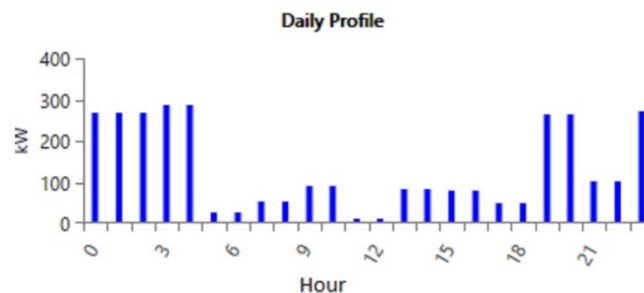


Figure 5. Hourly load profile by HOMER.

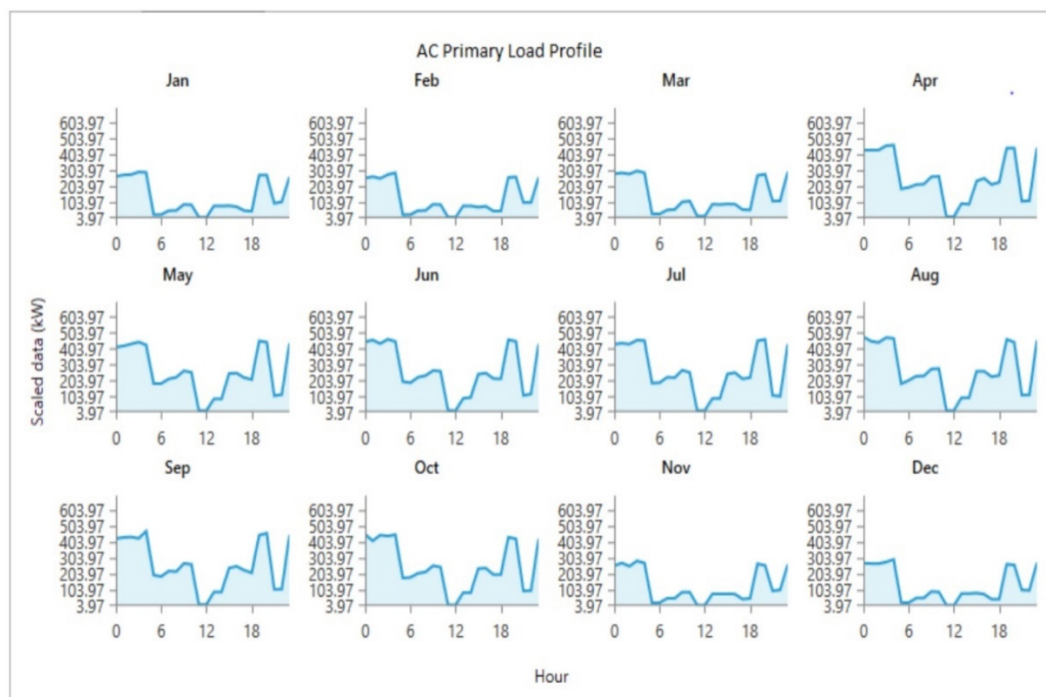


Figure 6. Monthly load profile of Younus Khan Scholars' Garden.

Table 2. Solar radiation (kWh/m²/day) and temperature (°C/day) at Ashulia.

Month	Solar radiation (kWh/m ² /day)	Clearness index	Temperature (°C/day)
January	4.36	0.632	19.74
February	4.92	0.616	23
March	5.59	0.599	26.45
April	5.76	0.552	27.15
May	5.3	0.481	27.65
June	4.53	0.405	27.95
July	4.23	0.382	27.66
August	4.29	0.404	27.61
September	4.02	0.415	27.01
October	4.32	0.517	25.48
November	4.28	0.601	22.5
December	4.21	0.644	20.2
Annual average	4.65	0.521	25.20

2.6. Technical and economic input parameters

PV modules produce DC electricity, which an inverter converts to AC, which subsequently feeds into the grid and supplies the AC load through a net-metering strategy. Because the grid works as infinity storage in a net-metering grid-tied solar PV system, we designed this system without battery storage [68].

A. Photovoltaic modules

The PV array's output is proportional to the amount of solar energy it receives. Like, a panel generates 80 percent of its rated output if solar radiation is 0.80 kilowatts per square meter [69]. In a manual calculation using our rooftop area and PV module dimension values, it was estimated that our study site is capable of arranging a 350–420 kW capacitive PV array on its rooftop. Therefore, this study includes 0-kW, 100-kW, 200-kW, 300-kilowatt, 350-kilowatt, 400-kilowatt, and 420-kilowatt of proposed solar PV arrays. This simulation also takes into account the temperature effect and uses a derating factor of 88% on PV modules having a 19.88% efficiency and a 25-year lifetime. Solar PV's capital and substitution expenses are considered at USD 920/kilowatt, and operation and maintenance costs are USD 0.55/year.

B. Power Converter

The simulation model includes power converter with a 98.6% efficiency and a 15-year lifetime, with capital and substitution costs of \$75 per kilowatt and operating and maintenance (O&M) costs of \$1.60 per year. The converter is used in inverter mode as the grid is to be fed in an alternating way.

C. Grid

The electricity grid benefits from resource complementarity because it helps to smooth out the output of renewable resources that aren't always the same [70]. A grid is deployed as infinite storage of electricity in a net-metering scheme. In this study, power costs are considered at \$0.107/kilowatt-hour for purchasing and \$0.165/kilowatt-hour for selling back to the grid [71].

A nominal discount rate of 8% and a 6% inflation rate were applied in this simulation with both load-following and cycle-charging dispatch strategies [72]. The capacity shortage penalty is not taken into account throughout the planned project's 20-year lifespan. The maximum renewable portion was also determined to be 100%. Based on total NPC, COE, and renewable energy penetration (%), HOMER chooses optimum system configurations. The NPC is the resultant of the current value of all connected expenditures minus the actual value of all earnings during the project's lifetime. This covers initial investment, restoration, operational and maintenance costs, as well as penalties on emissions.

3. Results and discussion

This part displays the HOMER model's optimization results with the results for optimal system power generation, as well as a feasibility evaluation that compares the system to grid-only and diesel generator systems. This section also looks at sensitivity, taking into account data variations for key elements including grid pricing, solar radiation, and PV size.

3.1. Optimized outcome

HOMER assessed simulations, optimizations, and sensitivities according to specified supplies and limitations in order to select the most likely system. The overall optimization outcomes are given in Figure 7 based on the system's NPC, and the optimized model by category is in Figure 8.

Architecture					Cost				System	
	JKM400M-72H-V (kW)	Grid (kW)	SUN2000-60KTL-M0 (kW)	Dispatch	COE (\$)	NPC (\$)	Operating cost (\$/yr)	Initial capital (\$)	Ren Frac (%)	Total Fuel (L/yr)
	420	999,999	405	LF	\$0.0725	\$1.83M	\$111,146	\$416,747	31.1	0
	420	999,999	405	CC	\$0.0725	\$1.83M	\$111,146	\$416,747	31.1	0
	400	999,999	405	LF	\$0.0741	\$1.85M	\$114,266	\$398,347	30.0	0
	400	999,999	405	CC	\$0.0741	\$1.85M	\$114,266	\$398,347	30.0	0
	350	999,999	405	LF	\$0.0785	\$1.91M	\$122,105	\$352,347	27.0	0
	350	999,999	405	CC	\$0.0785	\$1.91M	\$122,105	\$352,347	27.0	0
		999,999		LF	\$0.107	\$2.24M	\$175,748	\$0.00	0	0
		999,999		CC	\$0.107	\$2.24M	\$175,748	\$0.00	0	0

Figure 7. Overall optimized result by HOMER.

Architecture					Cost				System	
	JKM400M-72H-V (kW)	Grid (kW)	SUN2000-60KTL-M0 (kW)	Dispatch	COE (\$)	NPC (\$)	Operating cost (\$/yr)	Initial capital (\$)	Ren Frac (%)	Total Fuel (L/yr)
	420	999,999	405	LF	\$0.0725	\$1.83M	\$111,146	\$416,747	31.1	0
	420	999,999	405	CC	\$0.0725	\$1.83M	\$111,146	\$416,747	31.1	0
	400	999,999	405	LF	\$0.0741	\$1.85M	\$114,266	\$398,347	30.0	0
	400	999,999	405	CC	\$0.0741	\$1.85M	\$114,266	\$398,347	30.0	0

Figure 8. Categorized optimized result by HOMER.

HOMER findings demonstrate that the PV-Grid-Converter configuration, where PV array capacity is 420 kilowatts and a converter capacity is 405 kilowatts with a cycle-charging strategy, is the most cost-effective setup. It has a USD 1.83 million total NPC and a COE of USD 0.0725/kWh, with 31.1% renewable energy penetration. It is not only less expensive, but it also emits fewer CO₂ (953 tons/year) into the atmosphere. The payback period of the system is only 6.4 years, which means approximately 13.5 years of pure income over the system's 20-year lifespan. As a result, it can be regarded as the most reliable, cost-effective, and environmentally friendly system arrangement.

The existing grid-only configuration has an NPC of 2.24 million dollars and a COE of 0.107 dollar/kWh (shown in Figures 9 and 10). From an economic and environmental standpoint, this system is less practical because the overall NPC and COE are somewhat higher and because it emits 1144 tons of CO₂ per year with 0% renewable penetration.

The system with a diesel generator only, which requires a 760-kW diesel generator with a price of diesel \$0.77 per litre, with an annual diesel usage for diesel generator systems of 6,86,578 liters. It gives the worst performance, with COE of 0.53 dollars/kilowatt-hour, a net present cost of 15.8 million dollars (shown in Figures 9 and 10), and CO₂ emissions of 1981 tons per year, which is much greater than the grid-tied PV system.

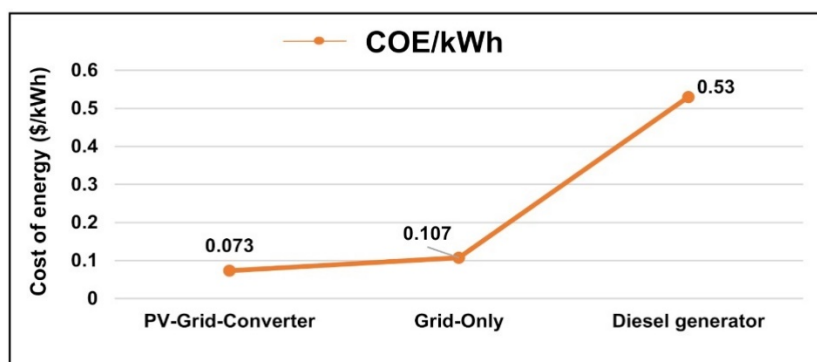


Figure 9. Electricity costs for various systems.

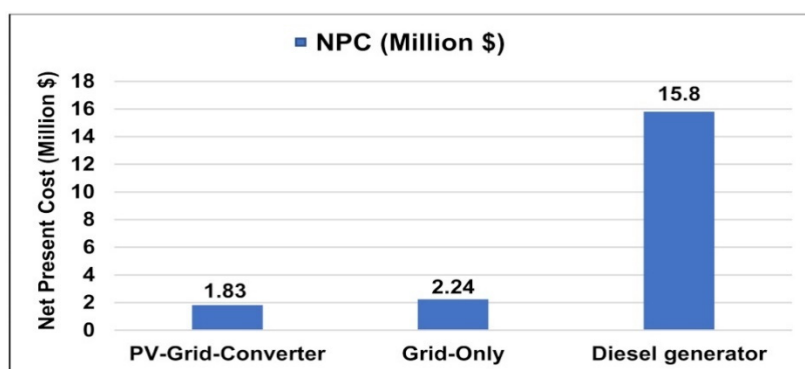


Figure 10. Net present cost for various systems.

In the system with a diesel generator only, COE and NPC are 0.46 dollars per kilowatt-hour and 14 million dollars, respectively and of a grid-only system are 0.035 dollars/kilowatt-hour and 0.41 million dollars higher than that of the solar PV system. With renewable penetration rates of 0%, diesel generators and grid-only systems produce 1028 tons and 191 tons of CO₂ per year more than PV-Grid-Converter systems. As a result, grid-only and diesel generator systems are no longer economically viable or environmentally beneficial due to rising COE and CO₂ emissions.

3.2. Production of electricity

The total electricity generation of our proposed grid-tied solar PV system comes from both PV and the grid, where the PV array and grid provide 31.4% and 68.6%, respectively, with no capacity shortage and 0.0077% of surplus electricity. The monthly average electricity generation of the grid-tied solar PV system is shown in Figure 11. Figure 12 also shows grid-tied solar PV systems' current AC demand and supply for the first 10 days of January.

The operation of the grid depends on the setup of the system. The HOMER simulation determines how much electricity can be bought from the grid or given to the utility. The net operation and energy bills annually of our proposed system reveal that the annual net energy purchases are 1,025,044 kWh where purchases from the grid are 1,368,445 kWh and sold by the grid are 343,401 kWh, which caused the annual energy bill for the Younus Khan Scholars' Garden to be 109,680 USD. Surplus electricity is occasionally sold by the grid during the daytime because of significant solar PV production and

seasonal factors that lead to energy sold to the grid being slightly lower from April to October, which is shown in Figure 13.

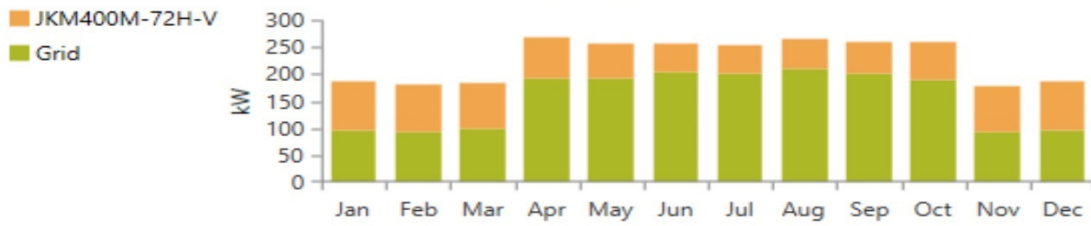


Figure 11. Monthly average electricity production from the system.

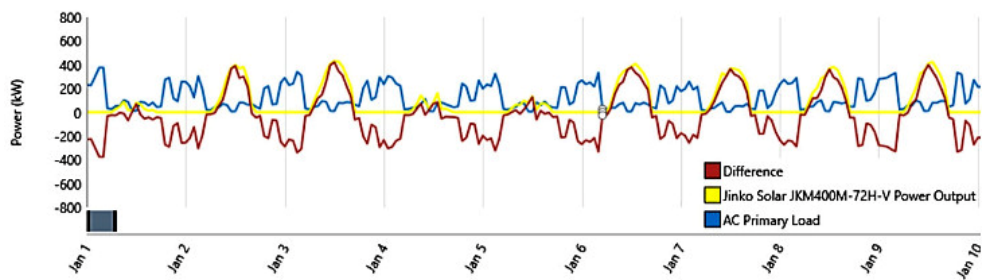


Figure 12. For the first ten days of January, load demand and generation.

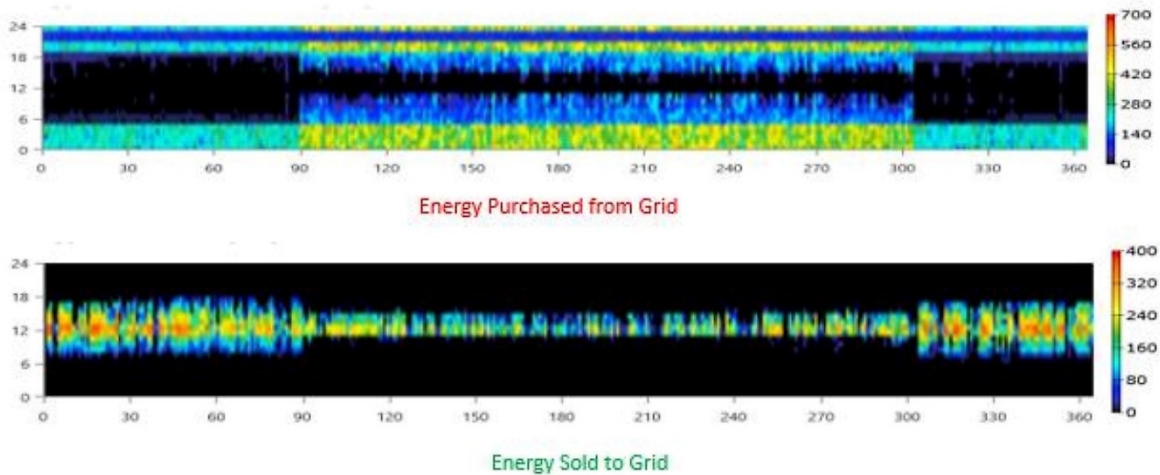


Figure 13. Annual grid operation of the proposed system.

3.3. Sensitivity results

Sensitivity analysis allows us to examine the impact of power price fluctuations as well as variability in key resource components on the total NPC and levelized COE of generation. This section performs sensitivity analysis based on key parameters such as PV capacity (0-kilowatt, 100-kilowatt, 200-kilowatt, 300-kilowatt, 350-kilowatt, 400-kilowatt, 420-kilowatt), grid prices (\$0.107,

\$0.118, \$0.14 per kWh) and solar radiation (4, 4.59, 4.65, 5 kWh/m²/day).

3.3.1. Cases of sensitivity

Sensitivity results for fluctuations in solar radiation and energy prices are shown in Figure 14 with a constant 420 kW PV capacity. The NPC and levelized COE have both decreased significantly, as demonstrated for all energy prices in the scaled average solar radiation and higher electricity prices for all average fixed scaled radiation in the NPC and levelized COE have increased. The figure shows that with solar radiation ranging from 4-5 kWh/m²/day and a levelized COE of 0.072 dollars/kWh to 0.103 dollars/kWh, systems with PV-Grid-Converters become attractive for any grid purchase price.

A sensitivity case with PV derating factor and converter efficiency present in Figure 15 shows that the system with the PV-grid-Converter becomes much more economically advantageous and fascinating if the converter efficiency and PV derating factor are as large as they can be. Since the higher the converter performance and the PV derating factor, the lower the levelized COE of the systems will be.

Also, the sensitivities for varying PV capacity with converter sizes are shown in Figure 16, where solar irradiance is constant at 4.65 kilowatt-hour per square meter in a day. In this situation, increasing PV capacity for any converter size reduces NPC and levelized COE significantly, whereas increasing converter size for any PV capacity increases NPC significantly as well as levelized COE. The figure shows that with any converter size, PV capacity range of 300-420 kW, and COE of 0.072 dollars per kilowatt-hour to 0.085 dollars per kilowatt-hour, a system with PV-Grid-Converter becomes the most cost-effective and ideal system.

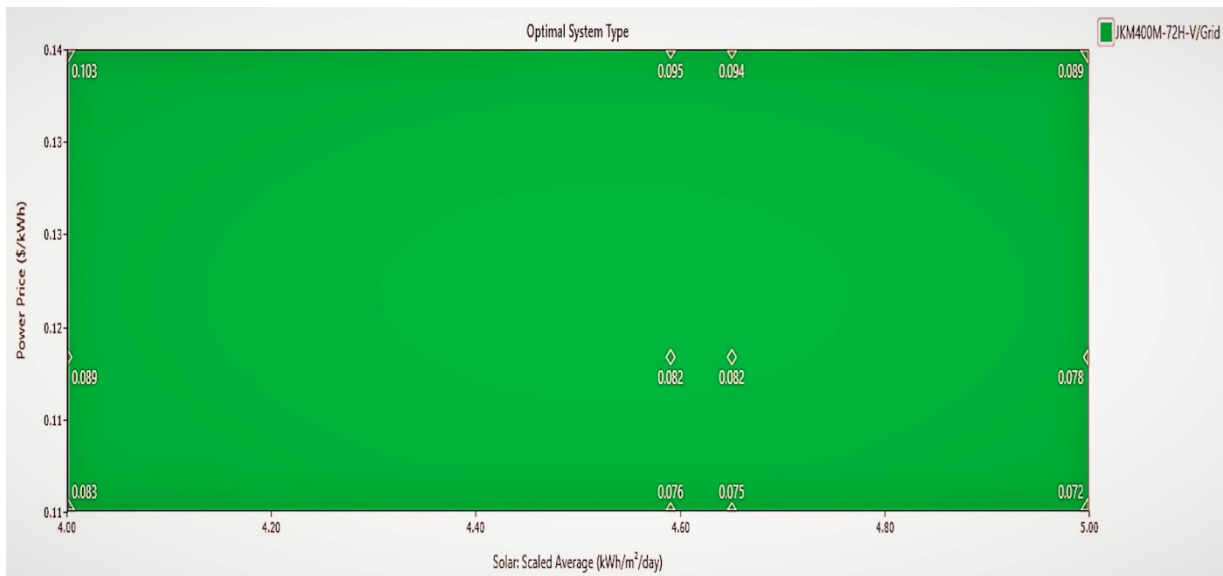


Figure 14. Optimal systems for average solar radiation and power prices at 420 kW PV.

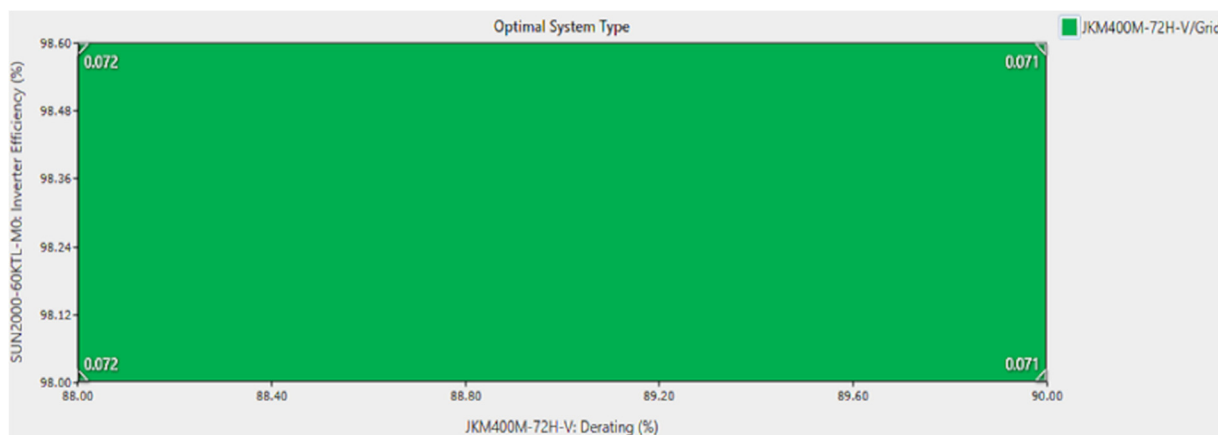


Figure 15. Type of optimal system in terms of PV derating factor and converter efficiency.

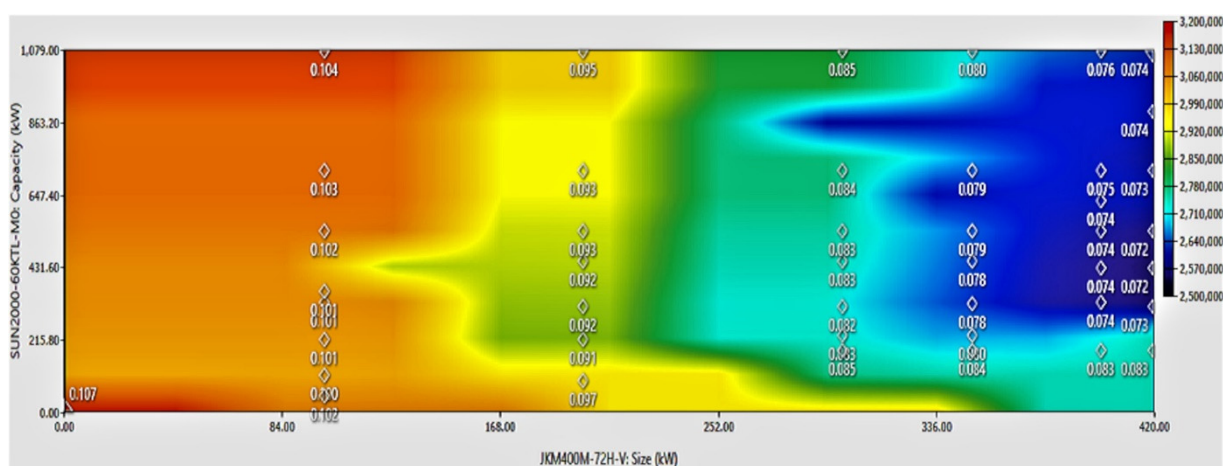


Figure 16. Optimal systems for PV and converter capacity at 4.65 kWh/m²/day solar radiation.

However, a grid-tied solar system with 420 kW PV capacity and a 405-kW converter size emerges financially feasible for all grid pricing and solar irradiance of 4.65 kWh/m²/day for the Younus Khan Scholars' Garden in Ashulia, Dhaka.

3.4. Emission analysis

The grid-connected solar PV system is far more environmentally friendly than the present grid-only and diesel generator systems. Because solar PV provides a substantial amount of energy, the rate of fuel combustion can be reduced, which results in, greenhouse gas release rate into the atmosphere. The emissions of three alternative system configurations for Younus Khan Scholars' Garden are displayed in Table 3.

Table 3 indicates that integrating renewable energy sources into the grid reduces greenhouse gas emissions on an annual basis. So, though the proposed grid-tied solar PV system involves some fuel combustion in the energy generation process, it is a cleaner and environmentally beneficial technology.

Table 3. Emissions of different models.

Components	Amount (kg/yr.) (Grid-only system)	Amount (kg/yr.) (Grid-tied system)	Amount (kg/yr.) (Diesel generator system)
CO ₂	1,038,060	864,857	1,797,196
CO	0	0	11,329
Hydrocarbons	0	0	494
Particulate matter	0	0	68.7
SO ₂	4,500	3,750	4,401
NO _x	2,201	1,834	10,642

4. Conclusions

The optimization and cost-benefit analysis using HOMER Pro simulation of a grid-connected solar PV system for commercial buildings at Younus Khan Scholars' Garden are presented in this paper. The chosen study location is a strong option for the implementation of a grid-tied solar system as it receives significant solar radiation on an annual basis of 4.65 kWh/m²/day, with a daily energy demand of 4945 kWh. The simulation and sensitivity results show that the system with 420 kW PV capacity, 405 kW capacitive converter, \$0.107/kWh (BDT 9.095/kWh) grid power price, average solar radiation of 4.65 kWh/m²/day, and an 88% PV derating factor is the most environmentally and economically feasible system rather than the current grid-only system or a diesel generator system.

The proposed system's energy cost is found at 0.0725 dollars/kWh, its net present cost is 1.83 million dollars, and its initial cost of capital is USD 416,747. With a renewable fraction of 31.1%, the system has a surplus electricity of 343,401 kWh/year. The payback period for the system's life of 20 years is only 6.4 years. The proposed grid-tied solar PV system also emits fewer greenhouse gases: CO₂ of 953 tons, SO₂ of 4.13 tons, and 2 tons of NO_x into the atmosphere per year.

The analysis also shows that in nearly all areas in Bangladesh, there is a suitable candidate for the deployment of one of the grid-tied solar photovoltaic systems because of the favorable solar radiation throughout the country. This study also indicates that future use of the proposed system or similar types would decrease the pressure on grid and increase production from renewable sources, which would reduce the use of fossil fuels and improve energy security with mitigation of greenhouse gas emissions.

Although grid-connected solar PV systems have substantial installation costs, they are highly profitable and environmentally friendly in the long run. With their increased reliability and service quality, grid-connected solar photovoltaic systems can play a major part in Bangladesh's electrification as well as the world.

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Conflict of interest

All authors declare no conflicts of interest in this paper.

Authors' Contributions

Md. Mehadi Hasan Shamim performed conceptualization and methodology of the research, system design with software, writing- original draft preparation and editing; Sidratul Montaha Silmee performed data acquisition and writing- original draft preparation; and Md. Mamun Sikder performed investigation of component cost and writing-reviewing.

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