

Article

Feasibility Assessment of Hybrid Solar Photovoltaic-Biogas Generator Based Charging Station: A Case of Easy Bike and Auto Rickshaw Scenario in a Developing Nation

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Abstract: The popularity of electric vehicles (EVs) is increasing day by day in the modern world. The charging of EVs from grid-connected charging stations causes a considerable power crisis in the grid. Integrating renewable energy resources (RESs) with conventional energy sources in the power grid is now considered feasible to reduce peak power demand and the inevitable emission effect. Hence, this paper presents an energy solution for EV charging with two RESs, namely, solar photovoltaic (PV) and biogas. HOMER software is utilized to analyze the potency and functionality of solar PV and biogas-based EV charging stations. The proposed system consists of a solar PV system, two biogas engine generators, and a bidirectional converter with battery storage. The variation of different costs, such as net present cost (NPC), initial cost, and cost of energy (COE) for different solar PV systems (3 kW, 4.5 kW, 6 kW, and 9 kW), are analyzed in HOMER software. The 4.5 kW solar PV system is finally selected as the NPC, initial cost, and COE are \$93,530, \$19,735, and \$0.181, respectively, which is efficient. The system's lifetime is 25 years, where an initial 12 years is required to overcome the system cost, and the remaining 13 years will provide financial benefits. The study also illustrates the effect of solar irradiance, biomass, and the change in the load of the energy management system. The techno-economic analysis shows that the proposed scheme can be an effective energy solution. The emission of greenhouse gases (GHGs), such as CO₂, CO, SO₂, and NO_x, is reduced considerably compared to other existing techniques. The study is expected to be beneficial in renewables-based EV charging systems with techno-economic and environmental feasibility.

Keywords: electric vehicles; EV charging station; renewables for EV charging; solar PV-based EV charger; biogas for EV; net present cost; cost of electricity



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1. Introduction

The world is moving forward, and the electricity demand is increasing day by day. The fossil fuel (coal, gas, and oil)-based energy generation system produces electricity to meet the load demand, but the storage of fossil fuels is limited. Moreover, fossil fuels emit greenhouse gases (GHGs) that are responsible for the long-term environmental crisis, including global warming and acid rain. Hence, researchers are developing alternative power resources that can contribute to conventional sources to meet the power demand and reduce emissions [1,2]. Integrating renewable energy sources (RESs) with traditional energy sources facilitates the power grid to meet the peak demand [3,4]. Among them,

electric vehicles (EVs) are considered a future wave because of their zero tailpipe emissions, low noise, and higher propulsion efficiency [5,6]. The environmentally friendly features and efficient energy management have made EV technology an alternative to the world transportation system. Many countries have already launched EV transportation systems to achieve an optimized energy solution. The global EV utilization is increased to 160% in 2021 compared to 2020, where 2.6 million EVs are sold in 2021 [7]. Tesla, Volkswagen Group, SGMW, BMW Group, and Stellantis are the top five global EV manufacturing companies. Bangladesh also utilizes EV technology to move towards a carbon-free transportation system. EV utilization in Bangladesh is increasing dramatically because of its environmental and budget-friendly features. Two types of EVs (auto-rickshaw and easy bike) are commonly available in Bangladesh, as shown in Figure 1.

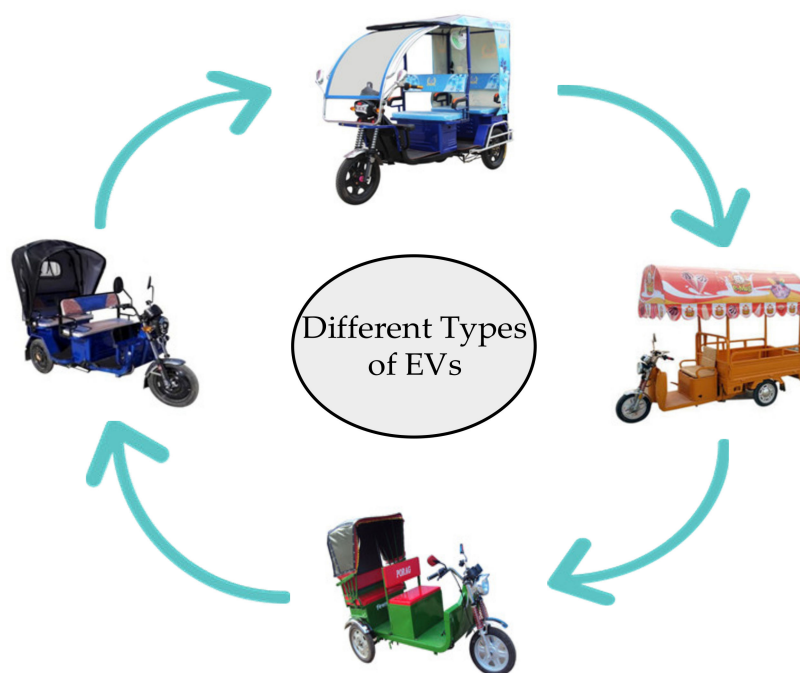


Figure 1. A schematic representation of different types of EVs.

Specifications of the two types of EVs are demonstrated in Table 1. According to the Bangladesh Road Transport Authority (BRTA), the total number of auto-rickshaws and easy bikes in Bangladesh from 2011 to 2020 is 330,338 [8]. The increasing rate of auto-rickshaws in Bangladesh is impressive, as shown in Figure 2.

Table 1. The specifications of two types of EVs: easy bike and auto-rickshaw. Data from ref. [9].

Parameters	Easy Bike	Auto Rickshaw
Battery Number	5	4
Battery Specification	12 V/80 Ah	12 V/80 Ah
Voltage	60 V	48 V
Power	800 W (Approximate)	500 W (Approximate)
Power Consumption	8–11 kWh	3.0–4.5 kWh
Load Bearing Capacity	300–400 kg	150–250 kg
Charging Time	7–8 h	6–8 h
Continued Trip Mileage	80–100 km	50–60 km
Maximum Speed	35 km/h	25 km/h

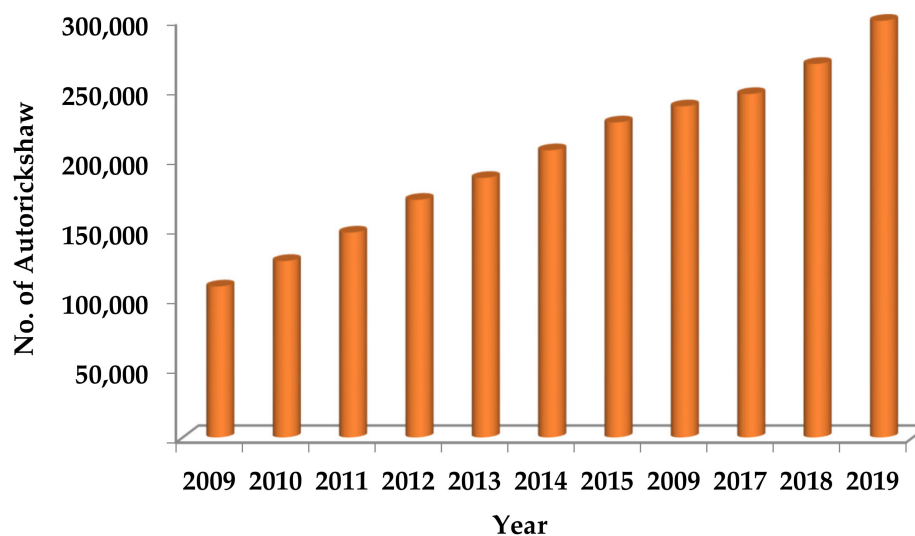


Figure 2. The number of auto-rickshaws in Bangladesh in recent years. Data from ref. [8].

In Bangladesh, approximately 900,000 EVs are charged through the main supply of electricity [10]. Around 9000 MWh (9,000,000 kWh) energy is used daily from the supply grid to meet EV charging demand, resulting in more energy crises and load shedding in Bangladesh [10]. To overcome the ongoing energy crisis and support the EV system in Bangladesh, RESs will be the most promising alternative and energy-efficient sustainable solution.

The solar photovoltaic (PV) system is a sustainable and developed technology with low retainment costs. The off-grid solar system is prevalent in Bangladesh, especially in rural areas, where electricity is unavailable. According to the World Economic Forum, over 4 million households and about 20 million people in rural areas, approximately one-eighth of the country's population, receive electricity support from small-scale solar home system projects [11]. In urban areas, people use the PV system to meet their electricity needs during the load-shedding period. Due to the increasing rate of using the PV system, the government of Bangladesh (GOB) has introduced the net metering system to the public, contributing to the national grid through the PV system. Moreover, Bangladesh is blessed with several biomass fuels and agriculture residues. According to Live Animal data of the Food and Agriculture Organization Corporate Statistical Database (FAOSTAT), about 102.6 million tons of cow dung from 25.5 million cows and buffaloes, 12.9 million tons of poultry waste from 291.5 million chickens and ducks, and 8.65 million tons of municipal waste are produced in Bangladesh per year that can be used to produce electricity [12]. Hence, solar PV and biogas can be the most probable solution for charging EVs.

A considerable amount of research has been conducted for developing EV charging stations using RESs. An EV charging model is proposed in [13] that analyzes the effect and load profile for different levels of EV penetration in both conventional sources and RESs such as wind and solar PV. The analysis claims that the integration of 15 EVs increases the load by 2%, whereas the increment is 7% for 50 EVs. A genetic algorithm and particle swarm optimization (GA-PSO)-based and RESs-integrated EV charging station is demonstrated in [14], which focuses on achieving optimal system sizing. The study aims to reduce power loss, voltage fluctuations, energy supply costs, and car battery maintenance costs. A queuing model for a stochastic optimization problem is presented in [15] that integrates RESs with EV charging. The study also introduces an optimization technique that minimizes the charging cost and time delay. A grid-connected and solar PV-based EV charging station with vehicle-to-grid (V2G) technology is presented in [16], where a 24 kW PV array is integrated into the DC bus through a unidirectional DC/DC converter with a maximum power point tracking (MPPT) controller. An idea of designing and managing the power of an EV charging station for solar PV and battery energy storage systems (BESS)

with an AC grid is proposed in [17]. The system has been formulated, designed, and validated using MATLAB/Simulink. A solar PV, battery, and diesel generator (DG)-based EV charging station is implemented in [18], where a single voltage source converter is used to combine the solar PV array, a storage battery, the grid, and a DG set. A solar charging station with storage backup that includes a solar PV module with rated power 280 W, battery voltage 12 V, and capacity 130 Ah is designed in [19]. The research aims to provide an efficient EV charging platform in urban cities with zero emissions. An automated switching system-based solar battery charging station is introduced in [20] that introduces a charging 48 V battery set with two 200 W solar panels. The project aims to provide clean energy for rural and urban perspectives. The automated switching system can shift the power connection from the RESs to battery backup when there is uncertainty in RESs. The feasibility of another solar–biogas-based EV charging station using HOMER Pro software is demonstrated in [9], which focuses on establishing several RESs-based EV charging stations to provide an efficient energy system.

Based on the above analysis, numerous research has been conducted to enhance renewable resource-based EV charging efficiency. This paper provides biogas and solar PV-based EV charging solutions (as shown in Figure 3) with techno–economic and environmental feasibility.

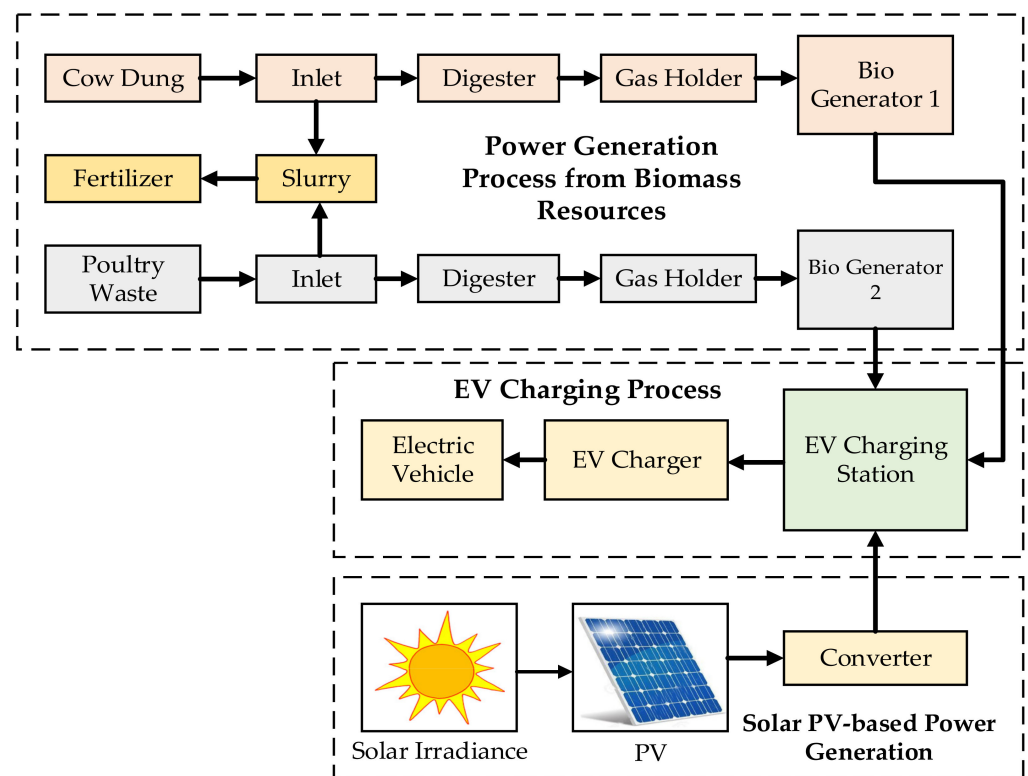


Figure 3. A schematic representation of power management of different resources of the proposed system.

The main objective of the research work is to eliminate the dependency on the grid and to fully utilize the RESs for EV charging purposes. The major contributions of the proposed scheme can be expressed as follows:

- provides biogas and solar-PV-based efficient energy solution for EV charging purposes;
- determines the most financially viable hybrid EV charging system for the selected area regarding various financial and technical parameters;
- investigates the designed system's performance due to the uncertain variation of the input key variables by sensitivity analysis;
- analyzes the environmental benefits in comparison to the existing system in terms of emission of GHGs (CO_2 , CO, SO_2 , and NO_x); and

- discusses the policy aspects of the proposed standalone hybrid charging system to highlight its significance towards reducing the stress of the national grid.

The paper is organized into six sections. Section 1 includes the introductory analysis and relevant information of the proposed system. Section 2 presents the policy of solar PV and biogas taken by the GOB to the EV adoption and EV charging infrastructure in Bangladesh. Section 3 demonstrates the location, resources, and load demand assessment of the proposed approach. Specifications and mathematical modeling of technical, economic, and environmental components are presented in Section 4. Section 5 presents the result and discussion for the technical, economic, and environmental outcomes, followed by sensitivity analysis and validation with existing literature. The summary and concluding remarks are presented in Section 6.

2. Favorable Policies

Bangladesh is a fast-growing developing country with a potential economy. Economic enhancement can be achieved by developing industrial infrastructure that requires a vast amount of electricity. The increasing electricity demand creates pressure on conventional energy resources (oil, coal, and natural gas). The integration of RESs into the national grid can be an effective solution for peak power demand. Therefore, the GOB undertakes various policies to develop the power sector and meet the energy demand.

In 2008, the Ministry of Power, Energy, and Mineral Resources (MoPEMR) of Bangladesh made Renewable Energy Policy for the first time. It characterized its objective to generate 5% and 10% of the total generated power from the sustainable power source by 2015 and 2020, respectively. However, the GOB plans to expand the 10% sustainable focus by 2041 after 2020—though this is not stipulated in the current arrangement [21]. In the most recent power advancement plan, by 2041, Bangladesh needs above 56,000 MW of energy generation. Moreover, the GOB should introduce about 5600 MW of sustainable energy to fulfill the 10% target. Bangladesh may experience issues in meeting this objective by keeping in mind its sustainable potential. However, the policy target can be met if a cross-border power exchange is possible. For instance, having approximately 5000 MW hydropower from neighboring countries and about 4000 MW local, sustainable energy generation can help to fulfill the policy target [21].

According to the sustainable and renewable energy development authority (SREDA) of Bangladesh, the present renewable energy installed capacity in Bangladesh is 764.88 MW [22]. Solar PV provides 69.4% of total energy, and the remaining 30.6% is provided by wind, hydro, biogas, and biomass [22]. The statistic implies that solar energy is the best and most promising energy source compared to other renewable resources. Solar energy has become popular in recent times as it provides electricity in remote areas. The GOB has planned a National Solar Energy Roadmap, 2021–2041, to achieve a sustainable energy solution from solar energy. The roadmap mainly focuses on three scenarios: business as usual (BAU), medium, and high solar PV development scenario. In the BAU scenario, the roadmap will follow the existing infrastructures, policy, and facilities. Both the public and private sectors can contribute to the energy generation process. The cumulative amount of electricity generation in the timespan under the scenario can be predicted as 6000 MW. The medium scenario will focus on upgrading existing policy, risk management, and facilities. The cumulative energy generation of the medium scenario can be predicted as 20,000 MW. The high scenario will introduce advanced technology to maximize energy generation and develop an economic infrastructure to enhance the national grid. The scenario will contribute 30,000 MW of solar energy by 2041. Figure 4. presents a graphical representation of the National Solar Energy Roadmap, 2021–2041 for solar charging stations based on previously described scenarios. The cumulative capacity of electricity of the solar charging station for BAU, medium, and high scenarios are 80 MW, 101 MW, and 226 MW, respectively.

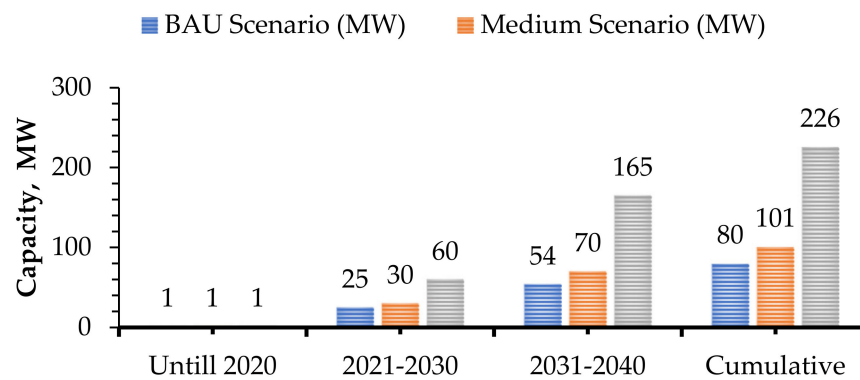


Figure 4. A graphical representation of the National Solar Energy Roadmap, 2021–2041 illustrating three scenarios for solar charging stations: business as usual (BAU), medium, and high solar PV development scenario.

Biogas is geographically an essential source of electricity in Bangladesh. However, the GOB does not yet take a specific policy for biogas-based power generation. The first biogas plant was established in Bangladesh Agricultural University, Mymensing [23], for research purposes. The domestic potential of the biogas system in Bangladesh can be expected to be 9 million m³/yr. The potential outcomes of biogas power plants can be estimated as 380 MW, where the GOB targets 5 MW of output power, as shown in Figure 5 [24]. The generation of biogas power in Bangladesh in recent times is less than 1 MW. Several barriers exist in establishing biogas power plants: technical, economic, social, policy, and market barriers [25]. The lack of proper waste management and storage platform, land, investment and financial support, policy, social awareness, social awareness, market strategy, technical experts, user demand, and so on are the reasons that hinder the development of the biogas-based power generation systems.

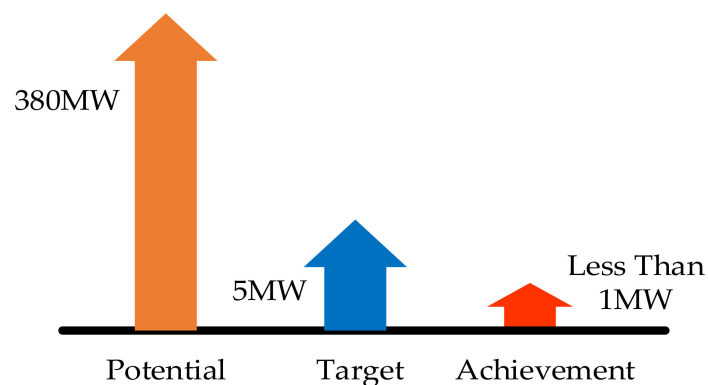


Figure 5. A representation of current statistics of biogas power plants in Bangladesh.

Although there are a significant number of solar charging stations in Bangladesh, there is not a single charging station with combined biogas and solar PV system. However, there is an urgency to utilize the RESs for reducing the stress on the power grid during the charging of increasing EVs, and appropriate policies have been developed. Hence, the hybrid EV charging station with the solar PV system and biogas will be the crucial solution for solving the charging problem of EVs while keeping the power grid stress-free.

3. Materials and Methods

This section presents the primary materials, i.e., location of the studied region, available resources, and load demand of the proposed system. Moreover, the step-by-step methodology of performing the research work is also discussed below.

3.1. Study Region

The proposed research work has been carried out in Fatullah, Narayangonj, Bangladesh. The longitude and latitude value of this origin is $23^{\circ}39.0' N$, $90^{\circ}29.3' E$. The geographical view of the research origin is presented in Figure 6. According to Banglapedia, Fatullah is a small union with 117,863 people [26]. Most of the people of this region are educated and employed; hence, vehicles such as EVs are used as transport to reach their destination daily. There are approximately 120–150 EVs in this region, and there are 10 garages where these EVs are kept and charged. According to the garage owner's perspective, the charging price is high as the EVs are charged through the grid's electricity. Hence, this research work presents a standalone system, such as a solar biogas-based EV charging station, to mitigate the charging price.

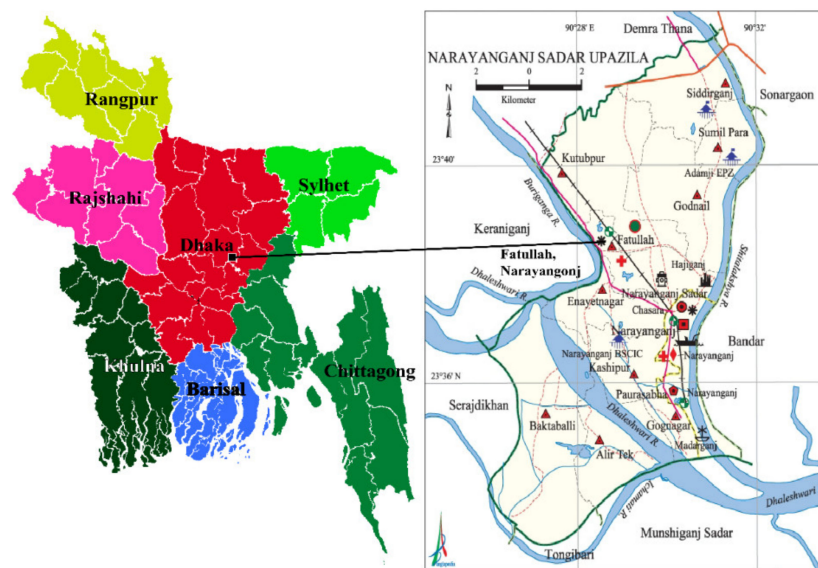


Figure 6. The geographical view of the research origin (Fatullah, Narayangonj). Adapted and redrawn from ref. [27,28].

3.2. Resources Assessment

In Bangladesh, solar radiation remains at its peak level from March to September. Solar radiation is also available in the winter season but not at its peak level. Hence, solar radiation is considered an excellent energy source because of its feasible characteristics. The variation of solar irradiance and temperature of the selected origin throughout the year are shown in Figure 7. The clearness index, which is the fraction of the solar radiation transmitted through the atmosphere, is also demonstrated in Figure 7. It can also be defined as surface radiation divided by extraterrestrial radiation. The proposed research work incorporates two types of biomass energy resources: poultry dumping and cow dung. There are 10 cow farms and 5 poultry farms in the selected region, where enough waste is produced every day. Energy production from these biomass resources will be comparatively easy and cost-effective. Hence, the biomass fuel generator can be used for EV charging in peak hours.

3.3. Load Assessment

In the proposed research work, the three-wheeler EVs are considered as the load of the system. In a three-wheeler, four to five 12 V lead-acid batteries with a capacity of either 160 Ah or 180 Ah are used. When the 12 V and 180 Ah battery is considered, the theoretical energy of the battery is found to be 2.2 kWh. Generally, a 12 V lead-acid battery can be charged up to 90% of its rated capacity. Hence, the energy of the battery would be 1.94 kWh. For four 12 V battery vehicles, i.e., auto-rickshaws, the accumulated energy consumption would be 7.8 kWh. Again, considering the 15% transmission loss of the

system, the total energy consumption is found to be 9 kWh. Hence, for every three-wheeler, energy consumption per day is approximately 9 kWh. The research findings show that the annual average energy is 72.51 kWh/d and average power is 3.02 kW, where peak load is 13.17 kW, and load factor is 0.23. A graphical representation of the daily profile of the electric load of EV is shown in Figure 8.

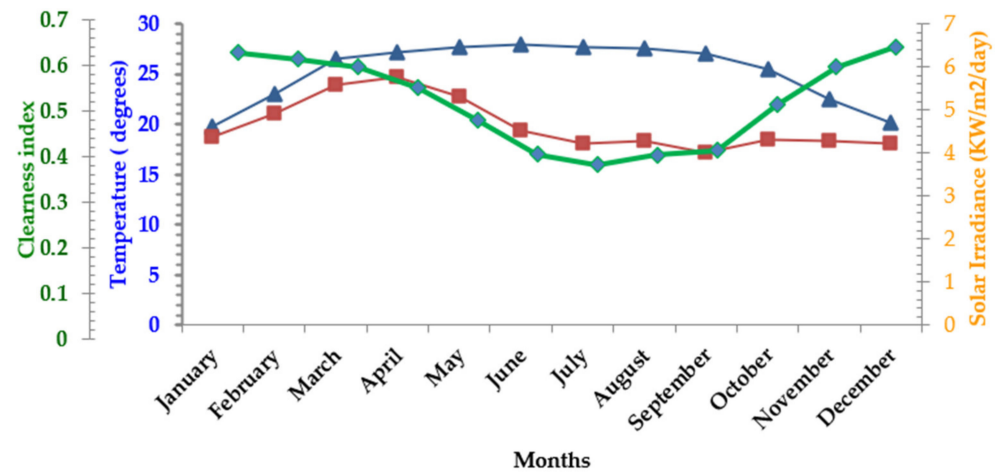


Figure 7. A graphical representation of the variation of solar irradiation and clearness index throughout the whole year of the selected origin. Data from ref. [29].

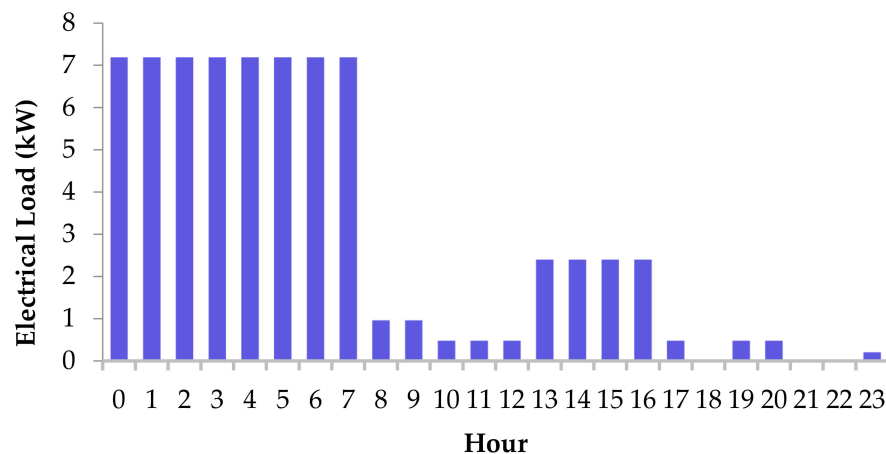


Figure 8. A graphical representation of the daily profile of electric load of EV.

3.4. Simulation Procedure

The selection of the studied location is the primary requirement for the proposed EV charging station. Solar PV and biomass (poultry dumping and cow dung) energy are considered as the system's energy sources. For load assessment, a three-wheeler is introduced that requires 9 kWh energy per day. The site selection, resource assessment, load estimation, and parametric value initialization act as input terms in the simulation proceedings, as shown in Figure 9. The biogas and solar PV-based EV charging station are implemented in the HOMER software to evaluate the financial, technical, and environmental aspects of the proposed system. The financial analysis suggests that the 4.5 kW solar PV system is the most optimized one in terms of COE, initial cost, and NPC. The reason behind it is explained in Section 5.2. The technical outcome evaluates the load demand of EV, the energy generation of solar PV, and biogas plants. The feasibility of power generation in the system is visualized in the simulation process. The amount of GHGs that emit from the proposed system is evaluated and compared with the existing systems. In the post-design analysis, the outcomes found from the proposed system are compared with the existing EV charging stations in terms of system configuration, economic aspects, technical feasibility,

and environmental benefits. The policy that the GOB takes for solar PV and biogas is also investigated. Future directions to continue research for the solar PV and biogas-based charging stations are also demonstrated.

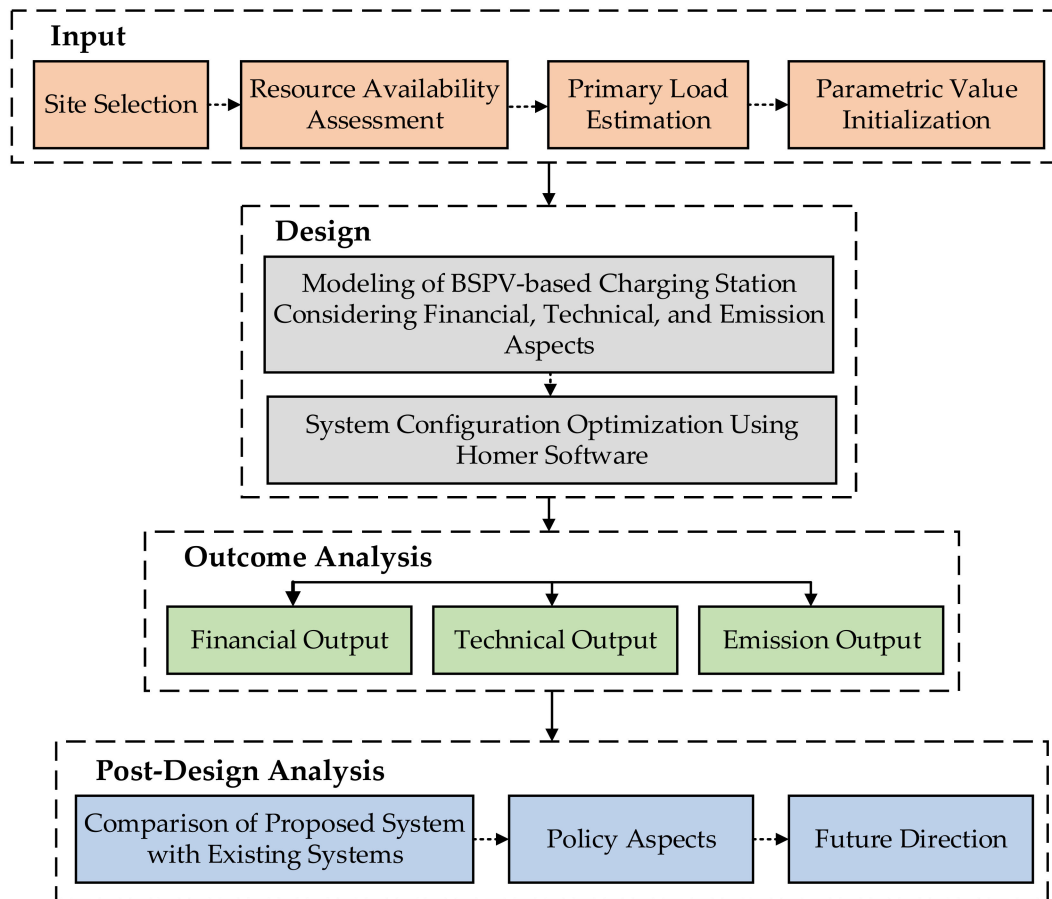


Figure 9. An illustration of the methodology for the proposed system design and analysis.

4. Data Collection and Mathematical Modelling

The system configuration is visualized in Figure 10, consisting of a PV panel, two biogas engine generators, and a bidirectional converter with battery storage. Two biogas generators and an electric load are connected to the AC bus. The PV module and battery storage are associated with the DC bus. Moreover, the converter is connected to the DC and AC buses. Different technical, financial, and emission components utilized in the system are described in the following sub-sections.

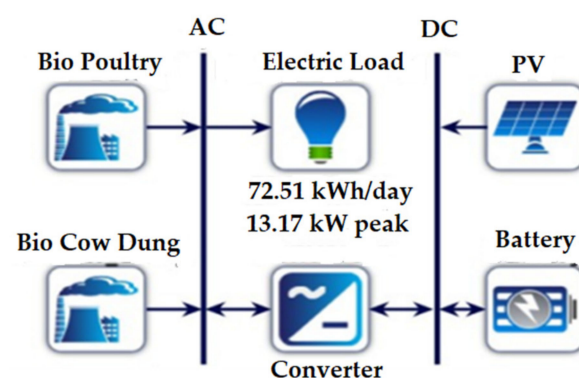


Figure 10. The proposed solar and biogas-based hybrid EV charging system.

4.1. Charging Station's Distributed Energy Components Modelling

Identification of all the system components, such as the PV module, biogas generator, digester, converter, and battery with the necessary mathematical terms, is demonstrated in this section.

4.1.1. Solar Energy Conversion System

A flat plate-type solar PV module having an efficiency of 17.33% is utilized in the research work. The system maintains the temperature coefficient, derating factor, and the nominal operating cell as -0.41 , 88% , and $45\text{ }^\circ\text{C}$, respectively. The detailed specification of the utilized PV module is given in Table 2.

The solar PV output according to the HOMER energy site can be expressed as [30]

$$P_{PV} = Y_{PV} \times f_{PV} \times \left(\frac{G_T}{G_{T,STC}} \right) \times [1 + \alpha_f(T_c - T_{C,STC})] \quad (1)$$

where P_{PV} symbolizes the PV array output, Y_{PV} is the PV arrays rated capacity in kW, f_{PV} is the PV module derating factor (%), G_T is the solar radiation incident on the PV array (kW/m^2), $G_{T,STC}$ refers to the incident radiations at STC (kW/m^2), α_f is the temperature coefficient of power ($\%/^\circ\text{C}$), T_c is the PV cell temperature in the current time step ($^\circ\text{C}$), and $T_{C,STC}$ represents the PV cell temperature under STC ($^\circ\text{C}$).

The energy production from the PV system can be calculated as [31]

$$E_{PV}(t) = G(t) \times \eta_{PV} \times A \quad (2)$$

where $E_{PV}(t)$ refers to the energy produced by the PV array, $G(t)$ represents the hourly irradiance in kWh/m^2 , η_{PV} represents the efficiency of the PV array, and A is the area of the PV array.

Table 2. Specifications of the utilized solar PV module (Canadian solar Dymond CS6K-285M). Data from ref. [32].

Parameters	Value	Parameters	Value
Cell Type	Monocrystalline 6 inch	Max. System Voltage	1500 (IEC) or 1000 V (UL)
Cell Arrangement	60 (6×10)	Max. Series Fuse Rating	15 A
Nominal Max Power (P_{max})	285 W	Temperature coefficient (P_{max})	$-0.41\%/K$
Operating Voltage (V_{mp})	31.7 V	Temperature coefficient (V_{oc})	$-0.12\text{ V}/K$
Operating Current (I_{mp})	8.98 A	Temperature coefficient (I_{sc})	$-0.053\%/K$
Open Circuit Voltage (V_{oc})	38.6 V	Operating Cell Temperature	$45\text{ }^\circ\text{C}$
Short Circuit Current (I_{sc})	9.51 A	Module Efficiency	17.22%
Parallel String	11	Series Connected Modules	2

4.1.2. Biogas Generator

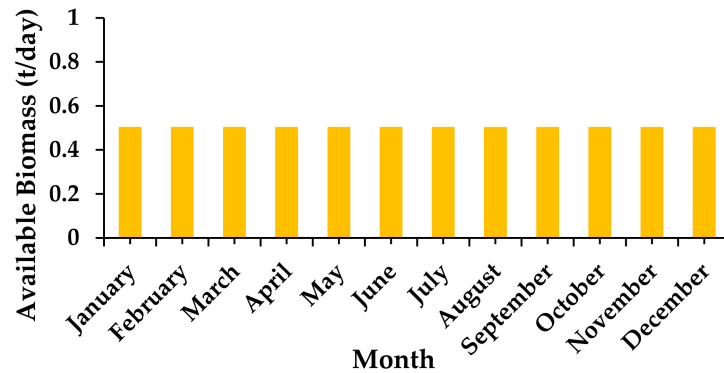
Two 5 kW biogas generators are used in the system. The specifications of the generators are given in Table 3. The two generators utilize biogas as fuel and convert mechanical energy to electrical energy. The amount of waste needed for each bio-generator is calculated considering the amount of biogas production from 1 kg poultry waste and cow dung and the amount of biogas required for 1 kW electricity generation, which is 0.074 m^3 and 0.71 m^3 , respectively [33]. Hence, the amount of biogas needed to produce 5 kW electricity is 7.0423 m^3 and the amount of waste needed is 93 kg. Approximately 200 kg of waste is required to produce biogas to run each generator. The collection of 200–250 kg waste may not be a problem as cow dung and poultry dumping are available in the research origin.

The monthly amount of cow dung and poultry waste for the proposed system is provided in Figure 11a. The operating schedule of the biogas generators is 8 h, mainly from 12 a.m. to 7 a.m., and they are kept off and in optimized condition for the rest of the day

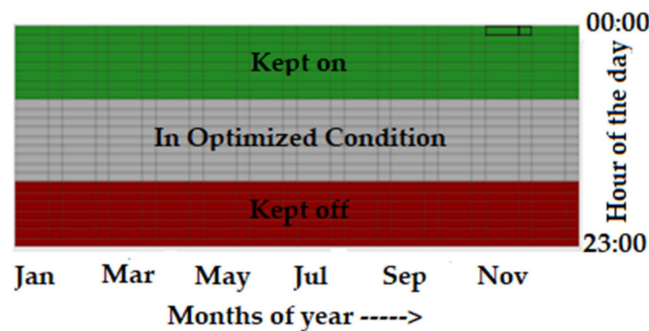
during weekdays and weekends (as shown in Figure 11b). The biogas generators' output power, P_{bio} , can be calculated as follows [34]

$$P_{bio} = \frac{B \times C_{VBG} \times \eta_{BG} \times \eta_{Gas}}{3600} \quad (3)$$

where B represents the amount of biomass, C_{VBG} refers to the calorific value of biogas (kJ/kg), η_{BG} refers to the efficiency of the biogas generator, and η_{Gas} refers to the efficiency of gasification of the gasifier.



(a)



(b)

Figure 11. (a) Available cow dung and poultry waste biomass resource input and (b) the annual biogas generator operating schedule. Note: The green, ash, and red color in the generator schedule denote forced on, optimized, and forced off conditions of the generator, respectively.

Table 3. Specifications of the utilized bio-generator (ELEMEX SH5300EX Generator). Data from ref. [35].

Parameters	Specifications
Model	ELEMEX SH5300EX Generator
Rated Power	6.3 kW @ 3600 rpm
Generator AC Output	4.7 KVA@ 220 V, 50 HZ
Ignition System	Transistor
Continuous Operating Hours (h)	12 h
Fuel Tank Capacity	28 L

4.1.3. Digester

Two 500 L biogas digesters for two types of waste (cow dung, poultry dumping) are used in the research work, costing USD 17 each. The volume of the digester can be

calculated by the product of the daily waste input and the retention time and can be expressed as

$$V_D = S_i \times t_r \quad (4)$$

$$S_i = \text{Waste} + \text{Water} \quad (5)$$

where V_D is the volume of digesters, S_i is the daily substrate/waste input, and t_r is the retention time.

The volume of the substrate input, $V_{\text{substrate}}$, can be expressed as

$$V_{\text{substrate}} = \frac{S_i}{\rho} \quad (6)$$

where ρ represents the density of the substrate input.

The retention time, t_r , can be expressed as [36]

$$t_r = \frac{1}{K_d} \left(\frac{1}{\eta \times \sigma} - 1 \right) \quad (7)$$

$$K_d = 0.272 \times 1.048^{(\theta-33)} \quad (8)$$

where K_d is the kinematic coefficient of the anaerobic digestion, θ is the temperature of the digester, and η and σ are the degree of sludge stabilization and correction factor for the content of raw sludge, respectively.

4.1.4. Converter

A bidirectional converter is mainly utilized in the research work. This type of converter can operate as an inverter and a rectifier according to the system's needs. The utilized converter is a grid following type converter with a maximum DC charge, rated dc voltage, and maximum discharge current of 125 A, 700 V, and 250 A, respectively. It is a dedicated central inverter with 96.3% conversion efficiency. The model number of the utilized converter is GTP500 125 KW, manufactured by Leonics. The considered size of the converter is 14 kW. The capacity of the converter, P_{con} , can be presented as [37]

$$P_{\text{con}} = \frac{E_{L(\text{max})}}{\eta} \quad (9)$$

where $E_{L(\text{Max})}$ represents the maximum energy demand and η is the converter efficiency in percentage (%). The energy output of the bidirectional converter system can be represented as below [31]

$$E_{\text{ac-dc}}(t) = \eta_{\text{rec}} \times E_{\text{bio_sur}}(t) \quad (10)$$

$$E_{\text{dc-ac}}(t) = \eta_{\text{inv}} \times E_{\text{bat_load}}(t) \quad (11)$$

where the hourly energy input and output of the rectifier and inverter can be represented as $E_{\text{ac-dc}}(t)$ & $E_{\text{dc-ac}}(t)$, respectively. η_{inv} is the inverter efficiency, η_{rec} is the rectifier efficiency, $E_{\text{bat_load}}(t)$ refers to the hourly energy output of the battery to supply load, and $E_{\text{bio_sur}}(t)$ refers to the surplus energy produced hourly from biogas generators.

4.1.5. Battery Bank System

The battery is utilized as an energy storage system in the proposed approach to store the excess energy from the PV system and the biogen system when necessary. A charge controller system is introduced to prevent the overcharging of the battery. A Trojan SAGM 06 220 Deep Cycle Solar AGM battery with a maximum capacity of 241 Ah is chosen from the HOMER database in this configuration. The battery capacity can be calculated as follows

$$B_c = V \times Q \quad (12)$$

where B_c is the battery capacity, V is the battery's voltage, and Q is the electrical charge. The total energy required to charge the battery (kWh), E_k , can be expressed as [36]

$$E_k = \frac{C_k}{\eta_{\text{charger}}^k} \times (1 - \text{SOC}_k) \quad (13)$$

where C_k is the battery capacity, η_{charger}^k is the efficiency of the battery charger, and SOC_k is the state of charge (SOC) of the vehicle battery in percentage (%).

The instantaneous SOC of the battery can be calculated as follows [34]

$$\text{SOC}(t) = \text{SOC}(t-1) \times \left(1 - \frac{\sigma \times \Delta t}{24}\right) + \left(\frac{I_{\text{bat}(t)} \times \Delta t \times \eta_{\text{bat}}}{C_{\text{bat}}}\right) \quad (14)$$

where $\text{SOC}(t-1)$ represents the SOC at $(t-1)$ hours, σ is the self-discharge rate of the battery, $I_{\text{bat}(t)}$ is the battery current at time t , η_{bat} is the battery charge efficiency, and C_{bat} refers to the capacity of the battery bank. The technical and economic parametric value of the above-mentioned technical components is presented in Table 4.

Table 4. Technical and economic parameters of the utilized technical components of the system.

Component Name	Size	Lifetime	Capital Cost (\$)	Operations & Maintenance (O&M) Cost (\$)	Replacement Cost (\$)
PV Module	1 kW	25 years	1000	0	1000
Bio Generator -1	5 kW	20,000 h	1500	0.3	1500
Bio Generator -2	5 kW	20,000 h	1500	0.3	1500
Converter	1 kW	20 years	650	0	650
Battery	321 Ah	10 years	98.45	22	98.45

4.2. Economic Modelling

This section presents the mathematical model of the different economic components: the cost of energy (COE), net present cost (NPC), payback period (PP), annual real interest rate, and salvage cost.

4.2.1. NPC

NPC refers to the difference between the current cost during the installation and operation process and the current revenue from the system's lifetime. The NPC can be determined by the following equation [38]

$$\text{NPC} = \frac{C_{TA}}{F_{CR}(i, T_P)} \quad (15)$$

where C_{TA} is the total annualized cost, which refers to the annualized value of NPC, F_{CR} is the capital recovery factor, i is the annual real interest rate, and T_P is the project lifetime.

The capital recovery factor is utilized to determine the present value of the annual cash flow and can be expressed as [39]

$$F_{CR}(i, T_P) = \frac{i(1+i)^{T_P}}{(1+i)^{T_P} - 1} \quad (16)$$

4.2.2. COE

The COE represents the per-unit cost of electrical energy generated from the system, which can be calculated as below [38]

$$\text{COE} = \frac{C_{TA}}{E_{P_AC} + E_{P_DC}} \quad (17)$$

where E_{P_AC} and E_{P_DC} are the AC primary load and DC primary load, respectively.

4.2.3. PP

The *PP* refers to the amount of time required to recover the cost of an investment. It indicates the profitability of a project. The *PP* should not be higher than a lifetime in years for a successful project [40].

$$PP = \frac{C_{Total}}{E_{Demand} \times C_{Unit} \times 365} \text{year} \quad (18)$$

where C_{Total} is the total cost, E_{Demand} is the energy demand per day, and C_{Unit} is the per-unit cost of energy.

4.2.4. Annual Real Interest Rate

The annual real interest rate (i) considers the yearly and one-time costs that can be expressed as [38]

$$i = \frac{i_N - F}{1 + F} \quad (19)$$

where i_N is the nominal interest rate and F is the nominal inflation rate.

4.2.5. Salvage Cost

Salvage cost is the value of a product when the project's useful life is over or the project is ended. The equation of the salvage cost can be expressed as [34]

$$\text{Salvage Cost, } C_{sal} = C_{rep} \times \frac{T_{Rm}}{T_P} \quad (20)$$

where C_{sal} is the salvage cost, C_{rep} is the component replacement cost, T_{Rm} is the remaining life of the components, and T_P is the project lifetime.

4.3. Emission Modelling

It is necessary to minimize CO₂ emissions from power generation systems to maintain a sustainable and friendly environment. Conventional power plants (oil, gas, nuclear, and diesel) emit a massive amount of GHGs such as CO₂, CO, SO₂, and NO_x. Renewable resources cause no emissions and provide a solution to maintain an environmentally friendly power generation system. The maximum mitigation of CO₂ emissions from a renewable energy-based power plant can be expressed as [41]

$$Mit_{CO_2} = E_g \times f_e \quad (21)$$

where Mit_{CO_2} is the mitigation CO₂ emissions in CO₂/MWh, E_g is the annual energy generation in MWh, and f_e is the emission factor released per MWh. The amount of CO₂ emission can be calculated as

$$Emission_{CO_2} = E_g \times \text{Emission per kWh} \quad (22)$$

where $Emission_{CO_2}$ is the CO₂ emissions in CO₂/KWh. Hence, the net reduction of CO₂ can be expressed as

$$\text{Net CO}_2 \text{ reduction} = Mit_{CO_2} - Emission_{CO_2} \quad (23)$$

5. Results and Discussion

This section demonstrates the financial analysis, technical analysis, and environmental analysis of the proposed PV and biogas-based EV charging scheme. The study is based on the simulation outcomes implemented in the HOMER software.

5.1. Energy Analysis

Figure 12 illustrates the 24 h profile of meeting the AC primary load (EV) demand by PV, two biogas generators, and battery storage. At night (0 to 5 h), PV output power is zero as sunlight does not exist at that time. Two biogas generators generate the required power output to meet the load demand. In the morning, when the sunlight exists, PV power starts to generate power, and the biogas generators stop their activity. The load power demand then entirely depends on PV that produces power during the whole day. The backup battery discharges power whenever necessary during the EV operation. Figure 10 demonstrates the simulation outcomes from HOMER software that implements the yearly (365 days/24 h) energy production of PV and biogas generators.

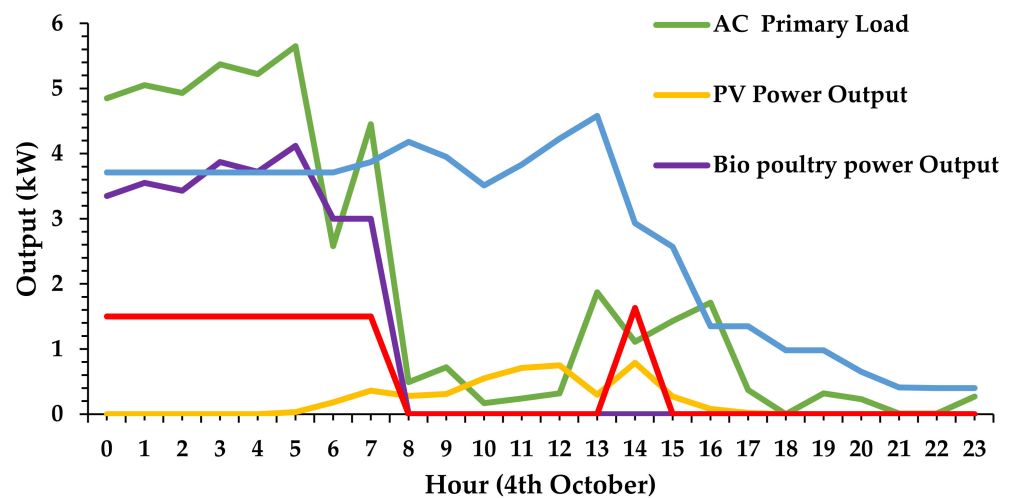


Figure 12. 24 h profile of meeting ac primary load (EV) demand by PV, two biogas generators, and backup battery.

Figure 13a signifies the generation of PV power during daylight, whereas Figure 13b,c illustrate that the biogas generators generate power at night. Figure 13d,e show the yearly and seasonal variation of output power and SOC of the inverter and storage system, respectively. The inverter is connected to the PV unit as PV generates DC power. Hence, the inverter operates during the operation of PV, as shown in Figure 13d. The biogas generators generate AC power and, therefore, an inverter is not required. The variation of the SOC of the storage system is at its maximum in February, March, and April, whereas the minimum SOC level occurs in June, July, and August, as shown in Figure 13e.

Figure 14 demonstrates the monthly electricity production from a solar PV system and two biogas generators and shows that most of the electricity has been produced by the bio poultry generator. The summary of the annual electricity production is shown in Table 5. Figure 15 provides a relative view of the annual electricity production of the three resources. The highest electricity produced annually from the bio_poultry generator is around 12,488 kW/year, which is 55% of the total electricity production by the whole designed system. The electricity generation is 5455 kW/year from the solar PV system, which is 23.9% of the total electricity production. The bio cow dung generator can produce 4860 kW/year, which is 21% of the total electricity production by the proposed system.

Table 5. The annual electricity production from PV, bio_poultry, and bio_cow_dung.

System	Electricity (kWh/yr)
PV	5455
Bio_Poultry	12,488
Bio_Cow_dung	4860
Total	22,803

5.2. Economic Analysis

The solar PV system and the biogas system are utilized to meet the EV load demand in the proposed work. The proposed method mainly focuses on the available biomass resources in the studied region. Therefore, it is assumed that the biofuel system primarily meets the EV demand, and the solar and battery will act as the backup. For this reason, firstly, the appropriate size of the solar PV system is determined by using financial analysis. Figure 16 illustrates a graphical representation of the variation of *NPC*, initial cost, and *COE* for different solar PV system size (kW). When solar PV is 3 kW, the *NPC* and the initial cost become USD 97,402 and USD 18,125, which causes a high *COE* (as shown in Figure 16). The solar PV size of 4.5 kW provides the *NPC* and the initial cost of USD 93,530 and USD 19,735, respectively, which causes a *COE* of USD 0.181. Again, when solar PV is 6 kW, the *NPC* and initial cost become USD 93,143 and USD 21,255, which causes a *COE* of USD 0.182. The *NPC* and the initial costs are USD 94,957 and USD 247,305, respectively, when the solar PV size is 9 kW. From the analysis, 4.5 kW solar PV is selected as the *NPC*, and the initial cost remains moderate with a good value of *COE*.

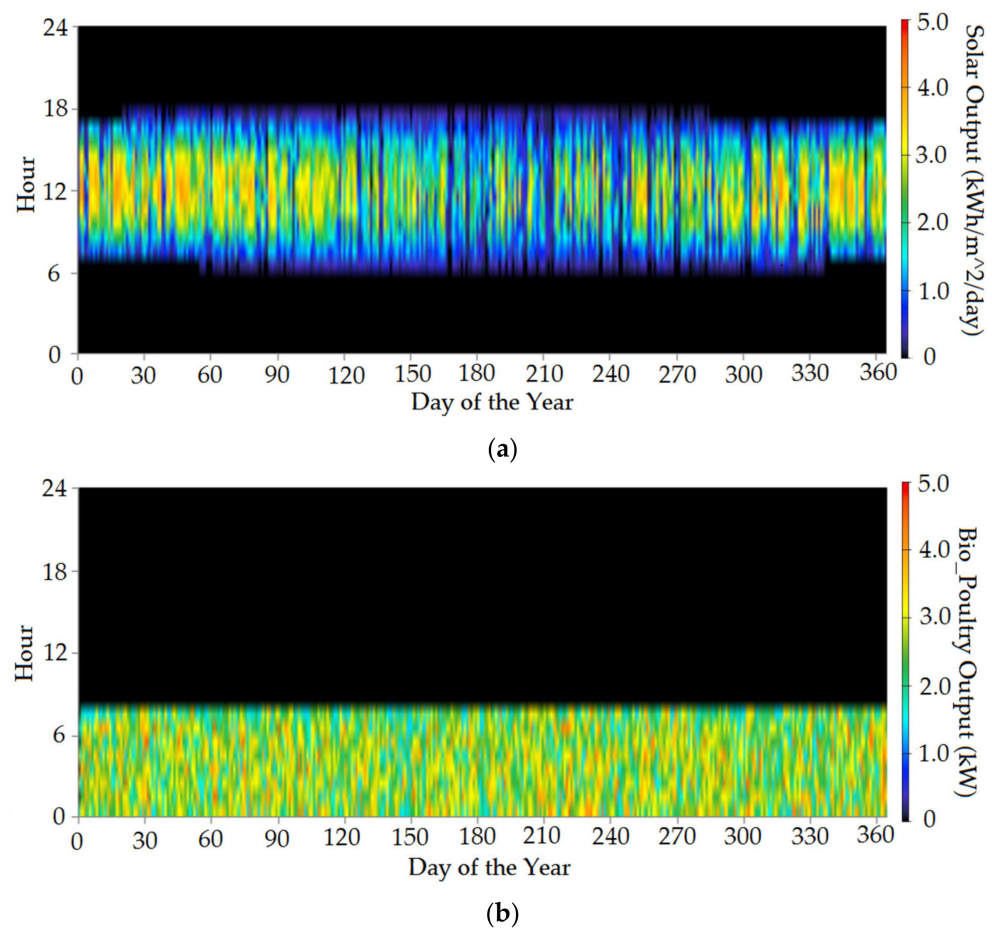


Figure 13. Cont.

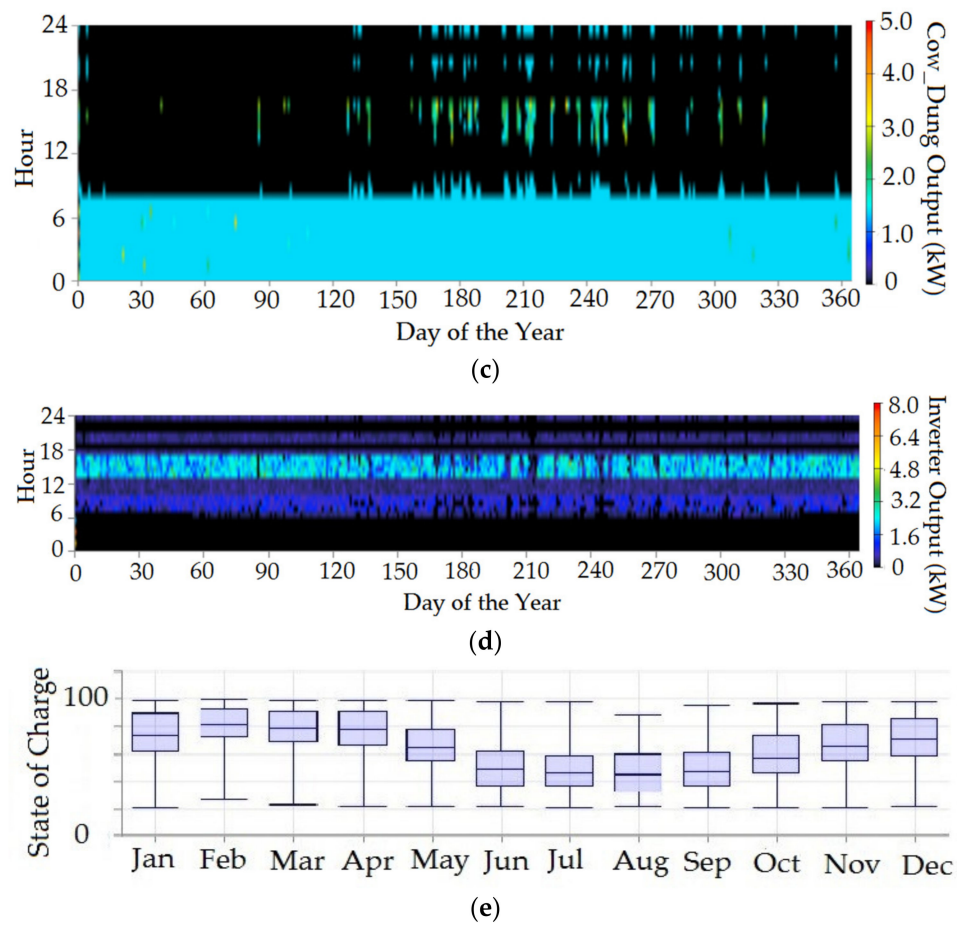


Figure 13. Yearly (365 days/24 h) energy production from (a) PV, (b) bioenergy generator using poultry wastes, and (c) bioenergy generator using cow dung. Yearly and seasonal variation of output power and state of charge of the (d) inverter and (e) storage system. Note: The left y-axis denotes the output of the solar irradiance in kWh and the other generators (bio poultry and cow dung) and inverter in kW.

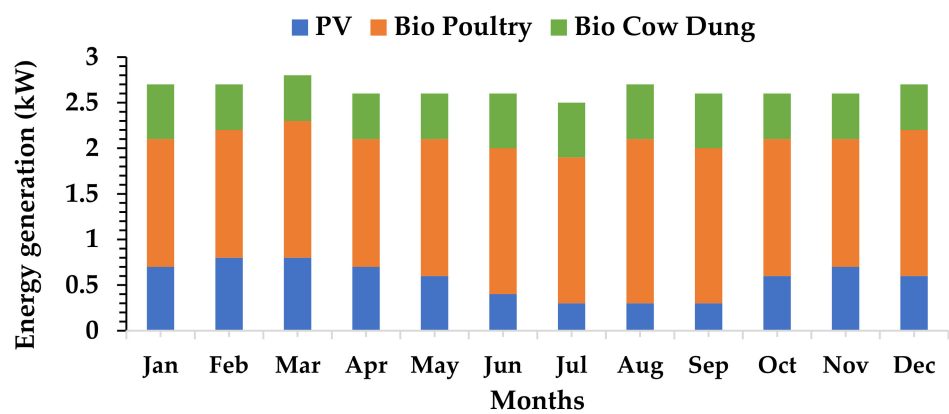


Figure 14. The monthly electricity production from the solar PV and biogas generators (bio_poultry and bio_cow_dung).

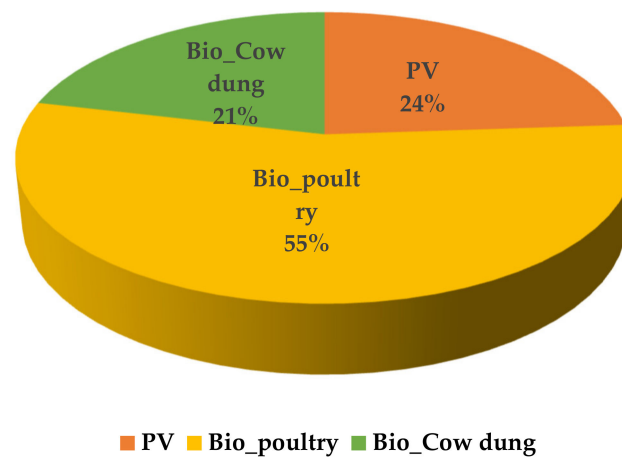


Figure 15. A relative view of the annual electricity production of the three considered resources (solar PV, bio_poultry, and bio_cow_dung).

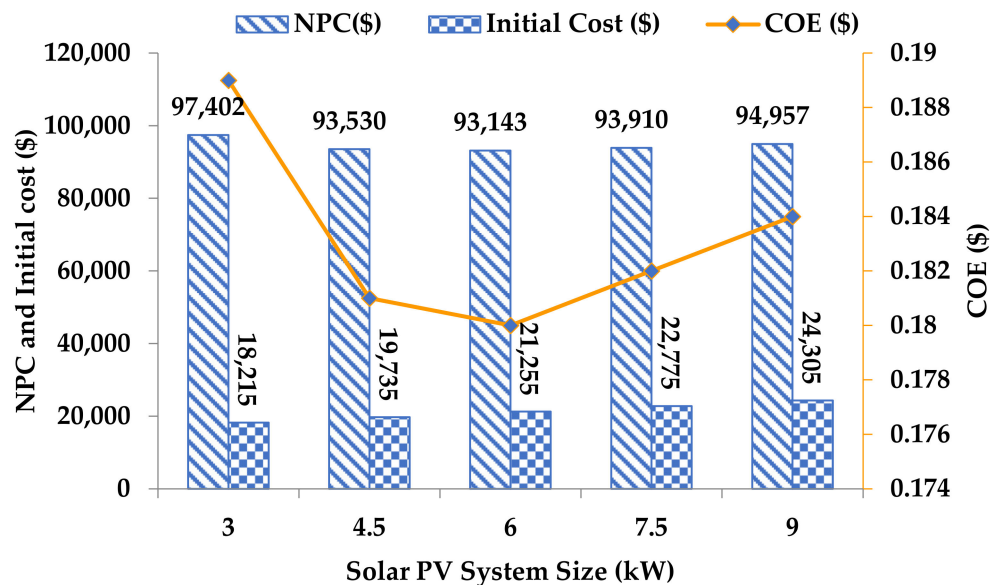


Figure 16. A graphical representation of NPC, initial cost, and COE for different solar PV system sizes (kW).

Table 6 depicts the different types of system configurations with economic characteristics. The grid-only system provides an impressive financial condition, but it produces high CO₂ emissions. Moreover, other hybrid systems collaborating with the grid have less NPC but high CO₂ emissions. On the other hand, the hybrid system without a grid has a high value of NPC and initial cost with fewer emissions. This type of system is costly because it includes a battery as an energy backup system. A battery system is needed here to stabilize the whole system configuration. Since the main target of the proposed work is to reduce the stress on the national grid and utilize the available local RESs to reduce CO₂ emissions, the PV/biogas/battery system is selected for the studied region.

Table 6. An illustration of different types of system configuration with economic characteristics.

Various Configuration	COE (\$)	NPC (\$)	Operating Cost (\$)	Initial Cost (\$)	CO ₂ Emission (kg/h)
Grid	0.15	77,486	3970	0	16,727
Biogas/Grid	0.0488	53,719	2522	4500	7274
Biogas/Battery/Grid	0.0656	72,256	2924	15,175	7272
PV/Biogas/Battery	0.181	93,530	3781	19,735	6.93
PV/Biogas/Battery/Grid	0.0601	71,384	2646	19,735	6359
PV/Biogas/Grid	0.112	84,415	2823	18,160	1114

The different costs of the system component and the overall system cost are presented in Table 7. Two biogas generators, a converter, PV, and battery cost mainly suppress the total capital cost, whereas two biogas generators cover approximately 23% of total capital cost, which is USD 4500. The capital cost of the converter is high among all system components that suppress 46% of the total capital cost, which is USD 9100. The battery cost is USD 1575.20, which is low, costing only 8% of the total capital cost. The lifetime of the proposed system is 25 years, whereas the generator's lifetime is 7–8 years. Hence, the two biogas generators must be removed three times, which will cost USD 12,651.21—53.2% of the total replacement cost. On the other hand, the converter and battery replacement costs are USD 8250.64 and USD 2885.48, respectively. The solar PV replacement cost is zero. The fuel cost is zero as fuel is available in the research area, and it will cost nothing to use. Two biogas generators' salvage cost is USD 4.98 and USD 955.50, respectively, where the converter's salvage cost is expected to be high, at USD 6038.24—approximately 73% of the total salvage cost. There is no salvage cost expected for the PV system, but the salvage cost of the battery is USD 1280.33. The per-unit COE is selected as USD 0.181 in the research work, as shown in Figure 14. One EV needs 9 units of energy to charge the battery, hence, the charging cost of one EV will be USD 1.63 per day, and the total annual charging cost will be USD 8924.25. The total profit of the system will be USD 8000 per year after deducting the O&M cost from the total charging cost. Calculations show that the profit rate can be achieved after 12 years, as shown in Figure 17. Approximately 12 years are required to overcome the project cost, and financial benefits can be achieved for the next 13 years.

Table 7. A representation of the different costs of the system.

Component	Capital (\$)	Replacement (\$)	O&M (\$)	Fuel (\$)	Salvage (\$)	Total (\$)
Bio_Cow_Dung	\$1500.00	\$4233.77	\$22,512.04	\$0.00	\$4.98	\$28,240.83
Bio_Poultry	\$3000.00	\$8417.44	\$41,010.36	\$0.00	\$955.50	\$51,472.29
Converter	\$9100.00	\$8250.64	\$0.00	\$0.00	\$6038.24	\$11,312.40
PV	\$4560.00	\$0.00	\$0.00	\$0.00	\$0.00	\$4560.00
Battery (Trojan SAGM 06 220)	\$1575.20	\$2885.48	\$8262.16	\$0.00	\$1280.33	\$11,442.50
System	\$19,735.20	\$23,787.32	\$71,784.56	\$0.00	\$8279.05	\$107,028.03

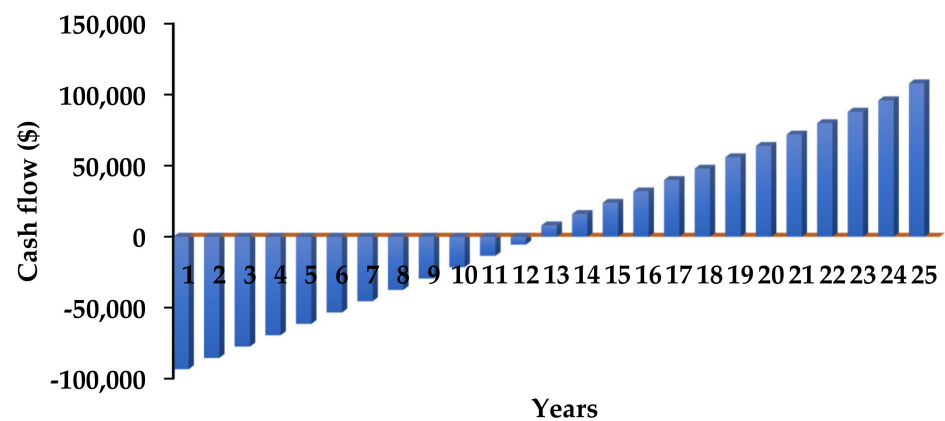


Figure 17. A representation of the cash flow during the proposed system's lifetime, which indicates a 12 years of recovery time after the installation.

The 25 years cash flow of the system is shown in Figure 18, which includes the initial capital and replacement cost of each component of the system, such as PV, bio_cow_dung generator, bio_poultry generator, converter, and battery. The lifetime of each component of the system is given in Table 4. It is seen that some components of the system need to be replaced during the 25 years of operation (project lifetime) of the system, apart from the solar PV system. For instance, both the biogas generators should be replaced three times during the 25 years of operation, as the lifetime of both the generators is 20,000 h. Similarly, the cash flow of the system shows that the battery should be replaced after 11 years and 21 years of operation of the system as the battery has a lifetime of 10 years. The converter needs to be replaced after 20 years, and hence converter replacement cost is added in the 20th year of the operation. The cost will be restored after 25 years, and profit can be achieved.

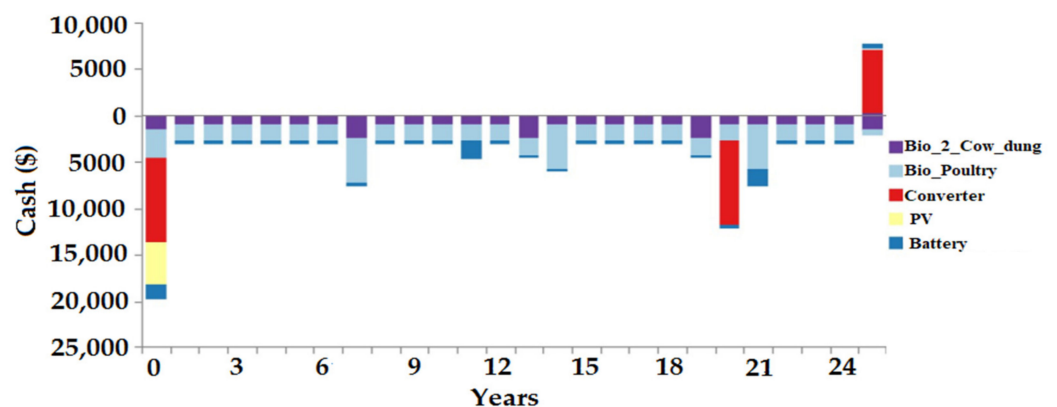


Figure 18. A graphical representation of the cash flow of the system showing the initial investment and replacement cost for each resource.

5.3. Emission Analysis

Renewable resources present environmentally friendly and sustainable energy solutions for the world's energy demand. It is necessary to analyze the environmental benefits to obtain the optimum system configuration [42]. The proposed system considers different GHGs such as CO₂, CO, SO₂, and NO_x to estimate environmental feasibility [43]. The average grid emission factor is considered to be 0.67 tons of CO₂ per MWh, and the lifetime is 25 years. Table 8 illustrates that the existing system emits CO₂ as 16,727 kg/h whereas the proposed system's CO₂ emission is 6.93 kg/h. Again, the proposed system emits a small amount of CO, which is 0.726 kg/h, where the existing system demonstrates zero CO emissions. The proposed approach has zero SO₂ emissions. The emission of NO_x for the existing and proposed system are 35.5 kg/h, and 6.48 kg/h, respectively. It is seen

that the existing system emits 81.74% higher NO_x than the proposed system. The analysis emphasizes that the proposed approach has greater environmental feasibility than the existing system.

Table 8. A representation of different GHGs from the existing and the proposed systems.

Emission (kg/h)	Existing System	Proposed System
CO ₂	16,727	6.93
CO	0	0.726
SO ₂	72.5	0
NO _x	35.5	6.48

5.4. Sensitivity Analysis

Biomass is considered as a variable parameter in the research work that can be increased or decreased with other parameters. The surface plot in Figure 19 portrays the change of the total NPC and COE with the variation of the nominal discount rate (NDR) and average biomass resources.

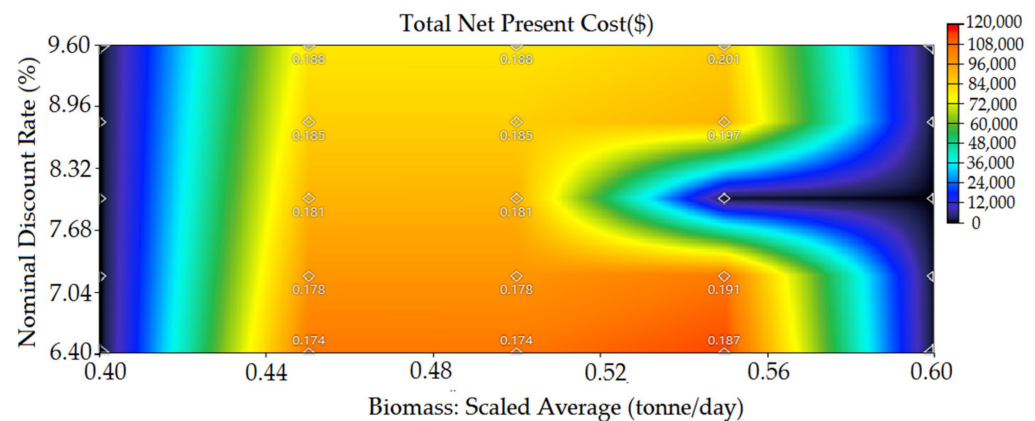


Figure 19. A surface plot illustrating the change of the total NPC and COE with the variation of nominal discount rate and average biomass resources. Note that the COE value is superimposed on the value of total NPC.

It is seen that when the amount of biomass is less than 0.4 tons/day and higher than 0.55 tons/day, the total NPC will be zero, i.e., the system is not feasible. Hence, the higher and lower amounts of biomass turn the system into an impractical position. Besides, the total NPC is higher for the lower value of biomass resources. A higher NPC causes a longer payback period that will make the system imbalanced. Again, the quantity of biomass above 0.56 ton/day increases the value of COE with the increase of NDR, making the total system unfeasible. Consequently, an acceptable trade of points should be selected. Hence, when the amount of biomass of 0.50 ton/day is chosen, the outcome is USD 0.181 COE, approximately 8% of the NDR, and a stable NPC (USD 84,000 to USD 96,000), making the overall system feasible.

Figure 20 demonstrates a surface plot that presents the relation between solar irradiation, total NPC, COE, and NDR. When solar irradiance varies from 3.72 to 5.58 kWh/m²/day, it slightly affects the total NPC. It is evident that the total NPC changes are inversely proportional to the NDR, where the COE changes proportionally. The COE reduces with the increasing value of solar irradiance. As a result, a static value of solar irradiance and NDR is necessary, where the total NPC and COE will be optimized. Figure 20 shows that for solar irradiance, 4.84 kWh/m²/day and 8% NDR, the most optimized COE is USD 0.181.

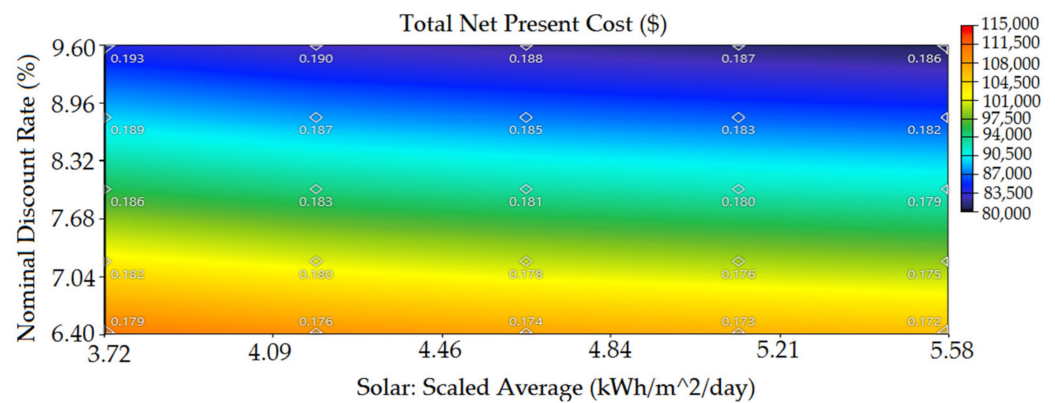


Figure 20. A surface plot illustrating the change of the total *NPC* and *COE* with the variation of nominal discount rate and scaled average solar resources. Note that the *COE* value is superimposed on the value of total *NPC*.

The surface plot in Figure 21 demonstrates the effect of the electric load and NDR changes over total *NPC* and *COE*. The total *NPC* and *COE* vary for the electric load and NDR from high to low values. In this system, when the electric load rises above 80 kW/day, the total system will collapse as it is designed for specific load demand (only 15 EVs). The *COE* increases proportionally with the increment of NDR. However, the *COE* has an inversely proportional relationship with electrical load. The total *NPC* remains almost unaffected by the variation of electrical load and NDR. Consequently, 72.5 kW/day is taken as the trade-off point to achieve the optimized value of *NPC* and *COE*, which keeps the system stable and fully functional.

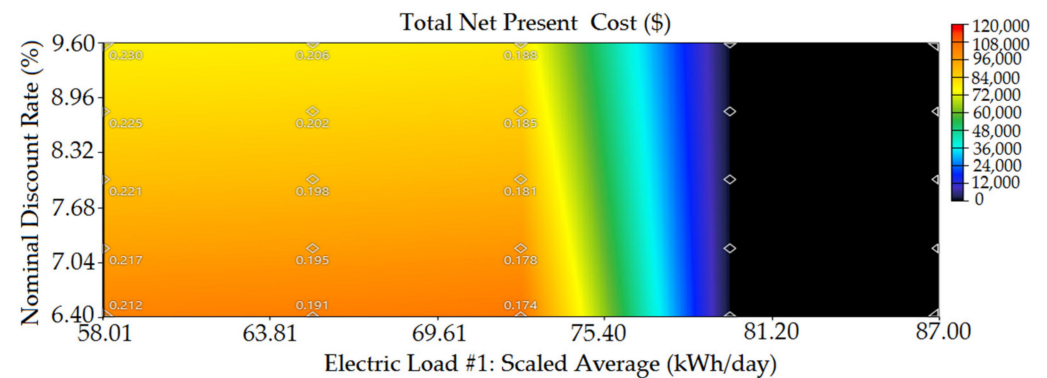


Figure 21. A surface plot illustrating the change of the total *NPC* and *COE* with the variation of nominal discount rate and scaled average electrical load. Note that the *COE* value is superimposed on the value of total *NPC*.

Figure 22 presents a line graph that portrays the relation between total *NPC*, *COE*, and NDR. The *COE* rises proportionally with the NDR in the line graph, where the total *NPC* decreases when the NDR increases. However, the point where the *COE* and *NPC* line graphs intersect is assumed to be the fixed point. According to that point, the NDR should be kept at approximately 8.6% to keep the system feasible.

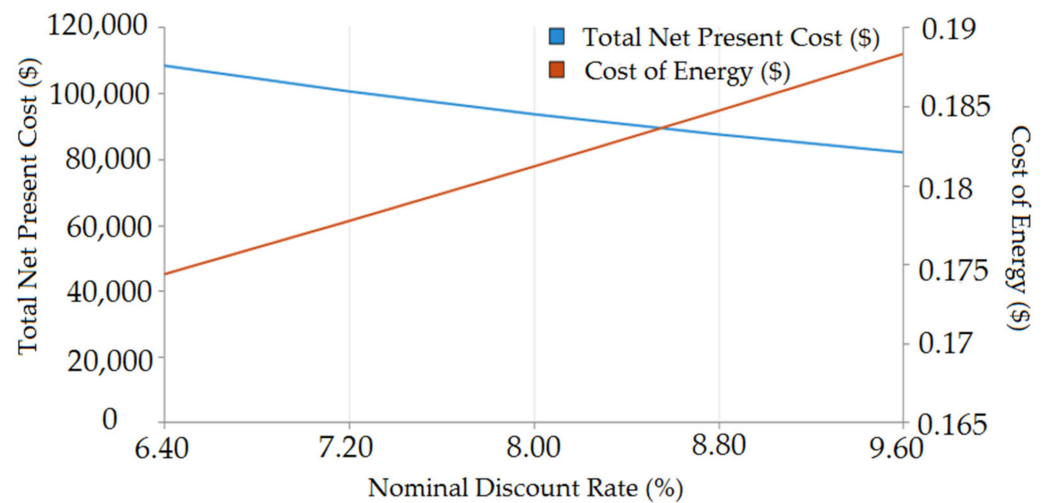


Figure 22. An illustration of the line graph between *NPC*, *COE*, and *NDR*.

5.5. Validation with Existing Literature

Table 9 illustrates a relative comparison among existing literature on EV charging stations integrated with RESs. The table implies that most of the literature based on the context is simulated in HOMER software. Technical terms such as system configuration and the amount of generated energy are illustrated. Moreover, financial terms such as capital cost, initial cost, cost of energy, and operation cost are presented. The paper signifies the environmental benefits for power generation and EV charging operations. Hence, the amount of emission of GHGs for the existing literature is demonstrated. The capital cost and initial cost are kept in a single column. The EV charging system in [30] integrates the fuel cell with the PV and wind for operation backup. A study in [44] illustrates a PV-powered EV charging station in Vietnam that analyzes the technical and economic feasibility in three regions: Hanoi, Da Nang, and Ho Chi Minh. The simulation results for each 50 kW PV system are demonstrated in Table 9 for Scenario 1 at each location. The experimental study in [45] is evaluated in Brazil for three scenarios: S1, S2, and S3, where S1 is only for the grid and others for hybrid renewable systems. The table demonstrates two charging stations in Bangladesh that effectively reduce CO₂ emissions and sustain cost efficiency. Most of the existing literature incorporates grids with renewables, where the proposed system is a standalone renewable-based EV charging station that integrates battery as power backup. The amount of energy production and the economic benefits seem feasible for the proposed scheme compared to others. Environmental analysis suggests that the proposed method reduces GHGs emissions considerably.

Table 9. A relative analysis of different existing research on EV charging in different countries.

Ref.	Location	Year	Simulation	System Configuration	Energy Production (kWh/Year)	Life Cycle	Capital/Initial Cost	Financial Cost			GHG Emission (kg/Year)	
								NPC	COE	O&M		
[9]	Gazipur, Bangladesh	2019	HOMER + MATLAB	PV + Biogas	40,170	10.10 Y for PV	Not Mentioned	\$56,202	\$0.1302	\$2720	CO ₂ = 8837.40	
[30]	Ayvalik, Turkey	2020	HOMER	PV + Wind + Battery + Fuel Cell	27,385	25 Years	\$43,776	\$69,221	\$0.685	Not Mentioned	Zero	
[36]	Gazipur, Bangladesh	2020	HOMER	Biogas + Battery	31,680	4.99 Year	Not Mentioned	BDT. 1,725,000	BDT. 5.56	BDT. 178,000	CO ₂ = 6653	
[44]	Vietnam	Hanoi	2021	HOMER	PV + Utility Grid + Battery	100,255	25 Years	\$62,550	\$113,462	\$0.0992	\$4396	Minimum CO ₂
		Da Nang	2021	HOMER	PV + Utility Grid + Battery	105,290	25 Years	\$62,550	\$100,748	\$0.0841	\$3299	
		Ho Chi Minh	2021	HOMER	PV + Utility Grid + Battery	106,872	25 Years	\$62,550	\$97,227	\$0.0800	\$2995	
[45]	City of Niteroi, Rio de Janeiro Brazil	Scenario1 (S1)	2020	HOMER	Only Grid	Not Mentioned	25 Years	\$0.00	\$7,505,534.25	0.14 \$/KWh	\$300,221.37 /Year	Not Considered
		Scenario2 (S2)	2020	HOMER	Grid + Solar PV + Wind	525,477	25 Years	\$504,221.37 /Year	\$8,616,347.95	0.16 \$/KWh	\$324,489.59 /Year	
		Scenario3 (S3)	2020	HOMER	Grid + Solar PV + Wind	2,428,072	25 Years	\$897,232.88 /Year	\$6,958,162.19	0.12 \$/KWh	\$242,437.26 /Year	
[46]	Shenzhen City, China	2015	HOMER	PV + Grid + Battery	2,627,953	Not Mentioned	\$180,907	\$3,579,236	\$0.098/kWh	\$23,687	CO ₂ = 461,206 SO ₂ = 1266 NO _x = 619	
[47]	North Central Region, Bulgaria	2016	Not Mentioned	PV + Battery	Not Mentioned	20 Years	1300,22 EUR/KW	EUR 18,949.32	Not Mentioned	1180 EUR/kWh	Not Considered	
[48]	Shanghai, China	2019	MAPSO algorithm	PV + Battery + Utility Grid	Not Mentioned	25 Years	10,000 Yuan/unit	Not Mentioned	0.623 Yuan/kWh	15 Yuan/year	Not Considered	
Proposed	Fattullah, Bangladesh	2021	HOMER	PV + Biogas + Battery	22,803	25 Years	19,735.20	\$93,530	\$0.181	\$71,784.56	CO ₂ = 6.93 CO = 0.726 SO ₂ = 0 NO _x = 6.48	

6. Conclusions and Future Works

The RESs act as an alternative to conventional energy resources with low emission and energy sustainability. The paper presents a solar PV and biogas-based EV charging station that focuses on attaining an energy solution for EV charging to reduce the stress on the main grid. The techno-economic models are developed and analyzed along with the emission factor of the system. The system configuration is implemented in HOMER software considering certain essential factors: *COE*, initial cost, *NPC*, and emissions. The effects of solar irradiance, biomass, and load changes are analyzed to verify the efficacy of the proposed approach. The significant findings of the proposed system are summarized as follows:

- The variations in *NPC*, initial cost, and *COE* are evaluated for different PV system configurations (3 kW, 4.5 kW, 6 kW, and 9 kW), which identify the 4.5 kW PV system as feasible due to its reasonable *NPC* (USD 93,530), initial cost (USD 19,735), and *COE* (USD 0.181).
- The lifetime of the system is 25 years. The cost summary claims that 12 years is required to overcome the system cost, and the rest of the 13 years will provide the financial benefits.
- The sensitivity analysis for the variation of biomass resources and NDR demonstrates that the system is stable for biomass of 0.50 ton/day, a *COE* of USD 0.181, and a stable *NPC* (USD 84,000 to USD 96,000).
- The sensitivity analysis for the variation of solar irradiance claims that the system is efficient with a *COE* of USD 0.181 and NDR of 8% when solar irradiance is 4.84 kWh/m²/day.
- The sensitivity analysis for the load changes illustrates that the system is stable and fully functional with optimized values of *NPC*, the initial cost, and *COE* when the load changes are 72.5 kW/day.
- The environmental analysis demonstrates that the emission of CO₂ is much lower (6.93 kg/h) than the existing grid-only system (16,727 kg/h).

Future research can focus on integrating different energy storage systems (fuel cell, battery, and supercapacitor) with EV charging technology. Research on the wireless EV charging technique can also be an excellent contribution.

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