sustainability

MDPI

Article

Analysis of Using Biogas Resources for Electric Vehicle Charging in Bangladesh: A Techno-Economic-Environmental Perspective

Ashish Kumar Karmaker [1,*], Md. Alamgir Hossain [1,2,*], Nallapaneni Manoj Kumar [3,4,*], Vishnupriyan Jagadeesan [5], Arunkumar Jayakumar [6] and Biplob Ray [7]

1 Department of Electrical and Electronic Engineering, Faculty of Electrical and Electronic Engineering, Dhaka University of Engineering & Technology, Gazipur 1707, Bangladesh
2 School of Engineering and Information Technology, University of New South Wales-Canberra, Canberra 2612, Australia
3 School of Energy and Environment, City University of Hong Kong, Kowloon, Hong Kong
4 Sustainable Solutionz, T Nagar, Chennai-600017, Tamil Nadu, India
5 Department of Electrical and Electronics Engineering, Chennai Institute of Technology, Kundrathur, Chennai 600069, Tamil Nadu, India; vishnupriyanj@gmail.com
6 Department of Automobile Engineering, SRM Institute of Science and Technology, Kattankulathur 603203, Tamil Nadu, India; arunkumj1@srmist.edu.in
7 Centre for Intelligent Systems, School of Engineering and Technology, Central Queensland University, Rockhampton, QLD 4701, Australia; b.ray@cqu.edu.au
* Correspondence: ashish@duet.ac.bd (A.K.K.); md.hossain6@student.adfa.edu.au (M.A.H.); mnallapan2-c@my.cityu.edu.hk (N.M.K.)

Received: 25 January 2020; Accepted: 23 March 2020; Published: 25 March 2020

Abstract: The growing popularity of electric vehicles (EV) is creating an increasing burden on the power grid in Bangladesh due to massive energy consumption. Due to this uptake of variable energy consumption, environmental concerns, and scarcity of energy lead to investigate alternative energy resources that are readily available and environment friendly. Bangladesh has enormous potential in the field of renewable resources, such as biogas and biomass. Therefore, this paper proposes a design of a 20 kW electric vehicle charging station (EVCS) using biogas resources. A comprehensive viability analysis is also presented for the proposed EVCS from technological, economic, and environmental viewpoints using the HOMER (Hybrid Optimization of Multiple Energy Resources) model. The viability result shows that with the capacity of 15–20 EVs per day, the proposed EVCS will save monthly $16.31 and $29.46, respectively, for easy bike and auto-rickshaw type electric vehicles in Bangladesh compare to grid electricity charging. Furthermore, the proposed charging station can reduce 65.61% of CO_2 emissions than a grid-based charging station.

Keywords: electric vehicle charging station (EVCS); electric vehicles (EVs); biogas; biomass resources; HOMER; CO_2 emissions; payback period

1. Introduction

Bangladesh is an energy-starved country due to rapid industrialization where the natural gas and petroleum products are the primary sources of energy. These sources are extensively used in electricity generation and transportation sector. However, the scarcity of these resources and concerns of environmental pollution lead the researchers to incorporate renewable energy resources in electricity generation [1–3]. As petroleum resources are significantly decreasing while increasing their cost throughout the entire world, it is essential to consider highly available renewable resources to meet the energy demand for electricity generation as well as the transportation sector [4].

As a developing country, people are using electric vehicles in Bangladesh due to several key benefits including reduction of sound pollution, fumes and GHG emission. On the other hand, the abrupt increase in the number of EVs in Bangladesh needs an additional 500 MW power daily from the national grid [5]. This huge demand creates a burden on the grid and affects the stability & power quality of the grid [6,7]. Moreover, almost all the EVs are charging their batteries from the residential connection which creates unknown variability and stability issues for the grid. Furthermore, the EV owner pays the bill as a residential consumer that leads to the failure of the power sector to reach the profitability margin [8].

Renewable energy-based electricity generation would greatly help to meet up huge energy demand of charging EVs. The EVs charged in renewable-based charging station offers less GHG emission and fewer charging costs than grid-based charging stations [9,10]. Bangladesh has enormous potential for renewable energy resources such as solar, biogas/biomass, wind, hydro, and so on. These renewable resources can be used to charge the EVs that can help to reduce pollution [11]. Currently, a few solar charging stations are established in different cities of Bangladesh. However, these charging stations are not sufficient, and therefore, much of charging stations are required for EV charging by renewables. As it is known, solar energy is available in all over the country to generate electricity effectively for 5–6 h with solar irradiation of 4 to 6.5 kWh/m^2-day [12]. The solar-based charging stations can only work when solar energy is available. However, during cloudy and foggy weather, solar energy is absent which is a significant drawback.

In Bangladesh, necessary wind speed is limited to only coastal and off-shore areas [13]. Hence, wind resources integration for electricity generation throughout the country is not feasible. Different institutions are working jointly with the power sector of Bangladesh to use renewable resources. In addition to this, the electricity generation from solar resources is more expensive than biogas-based electricity generation. Besides, the biogas plant provides digestate which can be used in the agriculture sector as fertilizer [14]. Different research demonstrates that Bangladesh is becoming an oppressive polluted country by making waste on an average of 0.5 kg per day individually [15,16]. Due to having more industry and large populations, the rate of spreading waste is more pronounced in the case of urban cities compared to the rural areas.

A recent study investigated the biomass potential in Bangladesh, and it explored that the total biomass collected from various wastes and residues can generate more than 3447 Peta joules of energy equivalent to 950 TWh [17]. According to waste statistics from the Sustainable and Renewable Energy Development Authority (SREDA) and Waste Concern, Bangladesh, it is found that cow dung, poultry waste, Municipal Solid Waste (MSW) could be a potential source of electricity generation in Bangladesh [18,19]. A study shows that approximately four million biogas plants could be established in Bangladesh which could meet 20% of the total household demand [20].

Various factors, such as biogas potential of feedstock, design of digester, inoculum, nature of substrate, pH, temperature, loading rate, hydraulic retention time (HRT), C: N ratio, volatile fatty acids (VFA), etc. influence biogas production [21,22]. Bangladesh is suitable for establishing biogas plants due to its climate [21,22]. The ideal temperature for anaerobic digestion is 35 °C, where the temperature of Bangladesh varies from 6 °C to 35 °C. The inner temperature of a biogas digester varies from 22 °C to 30 °C which is very close to the optimum requirement [23]. Moreover, the biogas resources are available throughout the country irrespective of location and time. Thus, the proper use of biogas/biomass resources for electricity generation increases the effective operation hours compared to solar and wind potential [24,25]. In this situation, this type of wastes can contribute heavily to produce biogas and further processed for electricity as well as fertilizer.

Several contemporary kinds of research have been made on the issues regarding biogas use in transportation showing better performance than the conventional systems. Furthermore, as EVs need power to charge at any time of the day, it is essential to use available biogas resources for EV charging to increase the effective hour and management of wastes correctly [26]. The design of EVCS using solar and biogas resources can make the system cost-effective and reduces environment pollution significantly [27]. A study in the context of Denmark shows that biogas used for EV charging reduces fuel consumption and GHG emission [28,29]. Biogas can be converted into bio-CNG which is further used for vehicles. Biogas applications in EV charging can be good hope for reducing the use of fossil fuel and GHG emission from the transport sector remarkably [30–32].

To the best of the author's knowledge, no initiative up to date has been taken place to determine the feasibility of biogas/biomass incorporation in EV charging stations in Bangladesh. Therefore, this study carried out to open a new research platform for using available biogas/biomass resources in EV charging. Furthermore, eco-friendly, cheapest, and effective waste management facilities grow up our interest in performing this research on the use of biogas resources for EV charging.

In this paper, the prospects and potentials of biogas/biomass resources are analyzed using the available real data detailed in Section 2. Based on the potentiality of biogas resources, a novel model for the EV charging scheme is proposed in Section 3 which includes system components, mathematical modeling and analysis of the proposed EVCS using solar and biogas resources. Section 4 presents the schematic arrangement of the proposed EVCS. The technological, financial and environmental analysis using HOMER model is presented in Section 5 which also includes the socio-economic benefits of the proposed EV charging station. Finally, Section 6 demonstrates the conclusion with future research directions for sustainable development through the integration of biogas resources for EV charging.

2. Current Status of Electric Vehicles and Biogas Resources

2.1. Electric Vehicle in Bangladesh

Electric Vehicles are now running almost all corners of Bangladesh. There are three types of EVs used in Bangladesh: the Easy Bike carries five passengers, the auto-rickshaw carries two passengers and the electric motorcycle carries two passengers. These EVs can travel for distances ranging from 70–120 km and the energy required per day is about 8–11 kWh. All of these vehicles are charged from the utility grid as a residential consumer. However, the EV charging rate declared by the government is higher than the residential consumer and EV owner treated as a business consumer. Thus, the government is facing difficulties with earning profit from the power sector. Furthermore, lack of EV charging stations as well as load shedding are also issues for the EV industry in Bangladesh. Most recently, the solar energy-based EV charging stations are being built in different points of Bangladesh. However, these charging stations are operational only a few hours a day on average due to lack of effective solar irradiation. Therefore, the government needs a massive plan to establish new charging stations all over the country to reduce the pressure on the grid performance. To charge an EV fully from the grid-based charging station cost 120–150 BDT/day [33]. For a km run, it needs approximately 0.11 kWh and costs BDT. 1.078. Specifications of the EVs used in Bangladesh are given in Table 1.

Table 1. Specifications of Electric Vehicles in Bangladesh.

Parameter	Easy Bike and Auto-Rickshaw	Electric Motorcycle
Power	500–1000 W	1200–2500 W
Voltage	36/48/60 V	60/72 V
Battery	20–30 Ah	20 Ah lead-acid gel battery
Charging time	6–7 h	6–8 h
Maximum speed	30–40 km/h	50–80 km/h
Driving distance	70–100 km	60–80 km

2.2. Potential of Biogas Resources in Bangladesh

Biogas is a source of energy that can be used for electricity generation, cooking, and other heating applications. Typically, it is a mixture of methane and carbon-di-oxide, produced by the breakdown of the organic wastes without oxygen. Biomass is also a resource of bio-energy which consists of wood, crop residues, foods, garbage, and landfill gas.

In Bangladesh, huge potential of biodegradable resources such as animal waste, food substrate, wood and paper, garbage are municipal solid wastes are treated as the primary sources of biogas. The chemical composition of biogas is shown in Table 2.

Table 2. Chemical composition of Biogas [34].

Chemical Parameter	% Content
CH_4	50–75%
CO_2	25–50%
N_2	0–10%
H_2	0–1%
H_2S	0–3%
O_2	0–0.5%

2.2.1. Animal Waste

Animal wastes can be used as a potential biomass resource. In Bangladesh, there are 150,000 poultry farms for chicken and duck. According to the statistics obtained for the fiscal year 2016–2017, waste generation per day from different livestock (i.e., Cattle, buffalo, chicken, duck, and so on) is shown in Table 3. The wastes produced from this livestock can be used to generate power.

Table 3. Waste generation from livestock [35].

Waste Type	No. of Livestock (millions)	Waste Generation (tons/day)
Cattle dung	23.93	179,475
Buffalo dung	1.47	14,700
Chicken waste	275.18	27,518
Duck waste	54.01	5401

2.2.2. Agriculture Residues

Agriculture residues contribute largely to biomass generation. These residues are mainly rice husk, crops, sugarcane bagasse, forest residues, jute, and vegetables. Bangladesh is a major rice-producing country. Rice straw and rice husk are the main residues of rice. Depending on the residue collection period, the crop residues can be categorized as field residues and processed residues. The rice straw and rice husk residue recoverable rate is 35% and 100%, respectively. Sugarcane residue is one of the powerful resources of biomass. In Bangladesh, the volume of sugarcane cultivation reached about 4,434,070 metric tons. The tops and leaves, bagasse residues are used as biomass energy where recoverable residue rate for processed bagasse is 73.42%. Jute is another biomass source in which the recoverable rate is 37.12%. All of these agriculture residues can be a good source of biomass for power generation and also useful in heating applications [36].

2.2.3. Municipal Solid Waste (MSW)

Waste disposal is an emerging problem in almost all of the urban areas. Rapid urbanization and industrialization increase the rate of waste disposal per day. Near about 4200 tons of MSW generates in Dhaka city in every day. The improper management of MSW creates a negative environmental impact, and it appears to be a growing concern at present. The proper management of these wastes can be a tremendous source of energy generation. The government and other stakeholders are thinking about this matter. Recently GIZ and the German development agency performed a detailed feasibility study in collaboration with the Sustainable and Renewable Energy Development Authority (SREDA) in Bangladesh to identify the prospects and potentials of MSW for generating electricity in Keraniganj, Dhaka. The experts recommended dry fermentation technology for the waste to energy project (WTE), Keraniganj. Depending on the suitable waste management, the expert advised to establish 4–5 MW power plants based on organic waste and industrial waste. Bangladesh Power Development Board (BPDB) aim to establish 1 MW unit combined heat and power. Hence, for understanding the electricity generation potentials, it is advised to account for the per capita MSW generation. In Bangladesh, the estimated per capita MSW generation rate is approximately 0.5 kg. The MSW generation scenario in urban areas of Bangladesh is shown in Table 4.

Table 4. MSW generation scenario in urban areas of Bangladesh [18].

Year	Total Population	Waste Generation Rate	Waste Generation (tons/day)
1991	20,872,204	0.49	9873.5
2001	28,808,477	0.5	11,695
2004	32,765,152	0.5	16,382
2015	54,983,919	0.5	27,492
2025	78,440,000	0.6	47,064 (Projected)

Waste generation in Bangladesh is illustrated in Figure 1 according to the type of waste. In Bangladesh, Infrastructure Development Corporation Limited (IDCOL) and Grameen Shakti are working together to develop several biogas plant. They have plant to establish approximately 80,000 small biogas plants. The government of Bangladesh is also aiming to establish 1 MW biomass-based plant and 5 MW of biogas-based plants in different regions [37].

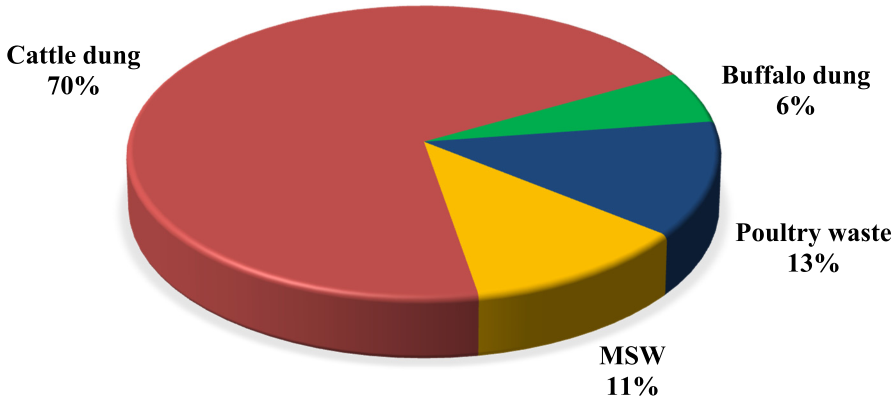

Figure 1. Waste generation per day in Bangladesh.

3. Mathematical Model of System Components

To develop the EV charging stations based on biogas requires information about energy demand, biogas/biomass potential, size of the biogas plant, available space for the plant, initial cost, O & M cost per year and finally, the daily output from the plant. The environmental factors also need to be analyzed before establishing an EVCS. The proposed EVCS will be designed for charging 15–20 EVs which require 20 kW power daily. The design and development phases of the proposed EVCS are detailed below.

3.1. Technical Components

This sub-section provides the details of all technical components of the proposed EVCS.

3.1.1. Energy Required for EVs

Energy required for an EV depends on its battery capacity, State of Charge (SOC) level, and duration of charging, as expressed in Equation (1) [38]. The proposed charging station is open for 24 h daily.

Thus, the total energy demand by an EVCS is the product of the number of EV coming in a day and its energy requirement, as shown in Equation (2) [38].

$$P_{EV} = \frac{Battery_{capacity*}(SOC_{\max} - SOC_{\min})}{Duration \quad of \quad Charging} \tag{1}$$

$$P_{EVCS} = \sum_{n=1}^{N} P_{EV}. \tag{2}$$

3.1.2. Waste Required for the Power Generation

Total waste requirement for electricity generation in an EVCS is an essential parameter for designing biogas-based charging station. Poultry waste, cow dung and MSW are considered to be the biogas/biomass resources for the power generation. However, the energy output will not be the same for different types of wastes. In this study, these wastes are mixed together to ensure effective anaerobic co-digestion for enhancing biogas production capability as well aprocess efficiency [39].

Therefore, for the evaluation of electricity generation from various wastes, Equation (3) is formulated for possible electricity generation.

$$P_E = \frac{W \times B_w}{B_{kw}}. \tag{3}$$

In Equation (3) W, B_W and B_{kW} stand for total waste in kg, biogas production per kg of waste and biogas required for 1 kW electricity generation, respectively. According to different literature, it is assumed that for poultry waste and MSW biogas production per kg of waste is 0.074 m^3 and for cow dung biogas produced per kg is 0.037 m^3 [40,41]. Moreover, the biogas required for 1 kW electricity generation is 0.7 m^3/h is demonstrated in a research [42,43]. Table 5 shows that the different waste requirements for producing 70 m^3 biogas yield. Table 6 shows the cost and available size of the digester in the renewable sectors of Bangladesh.

Table 5. Waste requirement for biogas generation.

Waste Type	Waste Source	Waste Required (kg/day)	Biogas Produced (m^3/day)
Cow dung	50 Cows	500	17.00
Poultry waste	1400 poultries	140	10.36
MSW	200 Families	578	42.77

Table 6. Cost and size of the digester.

Size of the Digester (m^3)	Biomass Required (kg)	Cost of the Digester (USD)
3.2	56	538
4.8	85	650
2.0	35	350

As in this research, the size of the digester is assumed to be 70 m^3 to produce 100 kWh of electricity per day. Therefore, according to the available digester size in the local markets of Bangladesh, we have chosen 4.8 m^3 digester of 14 nos. and a 3.2 m^3 digester for fulfilling the demand of total 70 m^3. This digester will require 1246 kg biomass per day to generate biogas yield of 70 m^3.

3.1.3. Digester Design

An anaerobic digester is the main component of a biogas plant in which biogas is produced after the breakdown of organic waste in the absence of oxygen. The produced biogas can be used for driving transport vehicles and generating electricity. The volume of the digester is the product of the daily substrate input and the retention time which is expressed as Equation (4) [44].

$$V_D = S_i \times t_r \tag{4}$$

Retention time depends upon the temperature. Contemporary research performed on biogas plant reveals that for mesophilic digestion where temperature rises from 30 °C to 42 °C, retention time should be greater than 20 days [42].

Acceptable retention time for anaerobic digestion is 20 days, 40 days, and 60 days. The higher the retention time leads to higher production of biogas yield because of high methane content and acceptable range of p^H values, shown in an experimental study [45]. The design of retention time can be determined by the following well known Equation (5) which is valid for primary sludge digestion on an anaerobic digestion process [46].

$$t_r = \frac{1}{K_d}\left(\frac{1}{\eta \times \sigma} - 1\right). \tag{5}$$

where kinematic co-efficient of anaerobic digestion, $K_d = 0.272 \times 1.048^{(\theta - 33)}$, η = degree of sludge stabilization (0.15), σ = correction factor for raw sludge content (1.0), θ = temperature in the digester, 40 °C. In this research, minimum retention time is assumed as 20 days for the temperature of 35 °C. The substrate input is a combination of waste supplied to a digester and water, as expressed in Equation (6), and the volume of substrate input is expressed in Equation (7).

$$S_i = Waste + Water. \tag{6}$$

$$V_{substrate} = \frac{S_i}{\rho}. \tag{7}$$

where ρ is the density of substrate input.

3.1.4. Gasholder

The gasholder is used in biogas plants to hold the biogas produced by the digester. The design considerations are the rate of biogas generation ($V_{Z,C}$) and the rate of consumption ($V_{C,R}$). It should be designed in such a way so that it can hold a maximum amount of biogas during the zero-consumption period, as expressed in Equation (8) [47].

$$V_g = 1.15 \times \max(V_{C,R}, V_{Z,C}) \tag{8}$$

The digester and gasholder ratio typically ranges from 3:1 to 10:1. However, a 5:1 ratio is the most frequently used in the biogas plants. Different studies explained that the gasholder should be capable of storing 60% of the biogas produced daily [48]. Therefore, the size of the gasholder in this research is calculated as 42 m^3 where the daily biogas production is about 70 m^3.

3.1.5. Biogas Generator

Biogas engine converts biogas energy into mechanical energy. Biogas engine is coupled with an alternator which is driven by the mechanical energy for electricity generation. High efficiency generator maximizes electricity generation and enhances overall biogas plant efficiency. For electricity generation, we have chosen low cost gas pilot injection engine which is suitable for lower heating value of biogas and provides electrical efficiency is approximately about 30–44%. The rating selected for generator is 150 kVA which runs at 1500 RPM.

3.1.6. Converter

It is used to convert the AC voltage into DC for charging EVs. It is assumed that the converter has 90% efficiency. The converter is connected to the charging assemblies where EV is charged.

$$P_{DC} = \eta \times P_{AC}. \tag{9}$$

After this conversion, a DC-DC converter is employed in EV charger for providing fixed DC output voltage for the battery.

3.1.7. Battery

The battery is used to store the excess energy when the EV is unavailable to charge. Therefore, it should be designed very carefully to handle the emergency. It is assumed that the battery bank is designed to store the energy of 50 kWh. The battery capacity is expressed as Equation (10).

$$B_C = V \times Q. \tag{10}$$

where V and Q are the voltage and electric charge respectively.

The charging profile of an EV depends upon the following factors: EVs arrival time, charging level, and time required to recharge the battery. The energy required to charge the battery can be determined by following Equation (11) [49].

$$E^K = \frac{C^K}{\eta^K_{charger}} \times \left(1 - SOC^K\right). \tag{11}$$

where E^K is the total energy required to charge the battery (kWh), SOC^k is the percentage of remaining charge in the vehicle battery, C^k is the battery capacity, and $\eta^k{}_{charger}$ is the efficiency of the vehicle battery charger assumed as 90%.

3.2. Financial Components

3.2.1. Cost of Energy

The EVCS delivers power to the consumer based on power demand and power availability. The cost of charging EVs per kWh is called the cost of energy (COE). In the case othe proposed EVCS, the charging cost can be determined by the following Equation (12) [50].

$$COE = C_{Base} + C_{variable}. \tag{12}$$

The C_{Base} is the base or minimum value of the EV charging cost, and $C_{variable}$ is the variable cost of charging depending on the time. It may vary according to the peak and off-peak periods and thus the charging cost also varies.

3.2.2. Net Present Value

Net present value (NPV) is calculated by subtracting the present values of cash outflows from the present values of cash inflows. Equation (13) describes NPV:

$$NPV = \sum_{t=1}^{N} \frac{R_t}{(1+i)^t}. \tag{13}$$

where R_t = Net cash inflow–outflows during a single period, I = discount rate and t = Project life time in years.

3.2.3. Benefit-Cost Ratio

The Benefit-Cost Ratio (BCR) is a strong financial term which indicates that the project will deliver positive or negative net present value to the investors. This ratio demonstrates overall relationship between relative costs and benefits of a specific project. Equation (14) describes the BCR for any project within a time period.

$$BCR = \sum_{t=0}^{N} \frac{PV_{Benefits}}{PV_{Costs}}. \quad (14)$$

where $PV_{Benefits}$ and PV_{Costs} are present values of benefits and costs respectively.

3.2.4. Payback Period

It is expressed in years after which the investment is equal to its total cash in-flow. It indicates the project will be profitable at the end of the payback period. Equation (15) demonstrates the payback period where the payback period should not be higher than a lifetime in years for a successful project.

$$\text{Payback Period, } PBP = \frac{Total\_investment}{Annual\_cashflow} \quad (15)$$

3.2.5. Profitability Index

It is defined as the ratio of future cash in-flow and cashes outflow. This index determines that the project would be profitable or not. If the project is profitable, the profitability index would be higher than unity. Equation (16) describes the profitability index for the proposed EVCS.

$$\begin{aligned} &\text{Profitability Index, } PI = \tfrac{cash\_in-flow}{cash\_out-flow}; \\ &\text{Or, } PI = \tfrac{Annual\_cash\_flow \times Project\_lifetime}{Total\_investment} \end{aligned} \quad (16)$$

4. Design of the Proposed EVCS

The conceptual design of the proposed biogas-based EVCS where animal and other wastes are collected and processed to recover the energy content is discussed in this section. Animal wastes and MSW are mixed together in order to achieve co-digestion which improves the efficiency of the biogas generation process [39]. The mixer is used to mixing up the slurry which is made by a combination of processed waste and water. The anaerobic digestion depends upon the waste material and temperature in the digester. The biogas generation rate increases with the increase of temperature. In the proposed plant, thermophilic process is chosen due to its benefits over mesophilic and psychrophilic process. The major advantages of thermophilic process over mesophilic are lowering retention time and improving digestion efficiency. In Bangladesh, temperature is suitable for mesophilic operation; however, a thermophilic process can be adopted using the heat produced by the biogas engine itself. After the completion of anaerobic digestion using available fixed dome type digester, biogas is produced. The biogas is stored in a gasholder at the low consumption period which is designed to store 60% of the daily biogas production. The size of the digester is determined by the retention time and daily feedstock/substrate input. The produced biogas is warm and it contains a large amount of water vapor. The gas purification plant mainly removes the H_2S content because it is corrosive with the CO_2 and water. After completion of purification process, the biogas yield goes to the combined heat and power (CHP) system which has an engine, heat recovery system and generator. A biogas generator is coupled with the engine that finally converts mechanical energy into electrical energy. Only 35% of biogas energy is converted into electricity where 55% is converted into heat and 10% becomes system losses. Using CHP unit, the energy efficiency will be increased due to the use of recovered heat as well as fewer environmental pollutions. The heat produced from this plant can be used for many purposes, including domestic use, restaurant hot water supply, and in hospital/medical centers. As the heat demand is not constant, heat storage is used for storing excess heat. On the other hand, the electrical energy produced from the generator can be linked together with EV charger that is responsible for charging EV batteries [51]. In addition, digestate slurry can be used to land and ponds as fertilizer and fish feed. It is important to choose appropriate location for establishing biogas plant based on the availability of the waste materials and water, sufficient area, and so on. With the above discussed features, a conceptual design of the proposed biogas-based EVCS is developed and is shown in Figure 2.

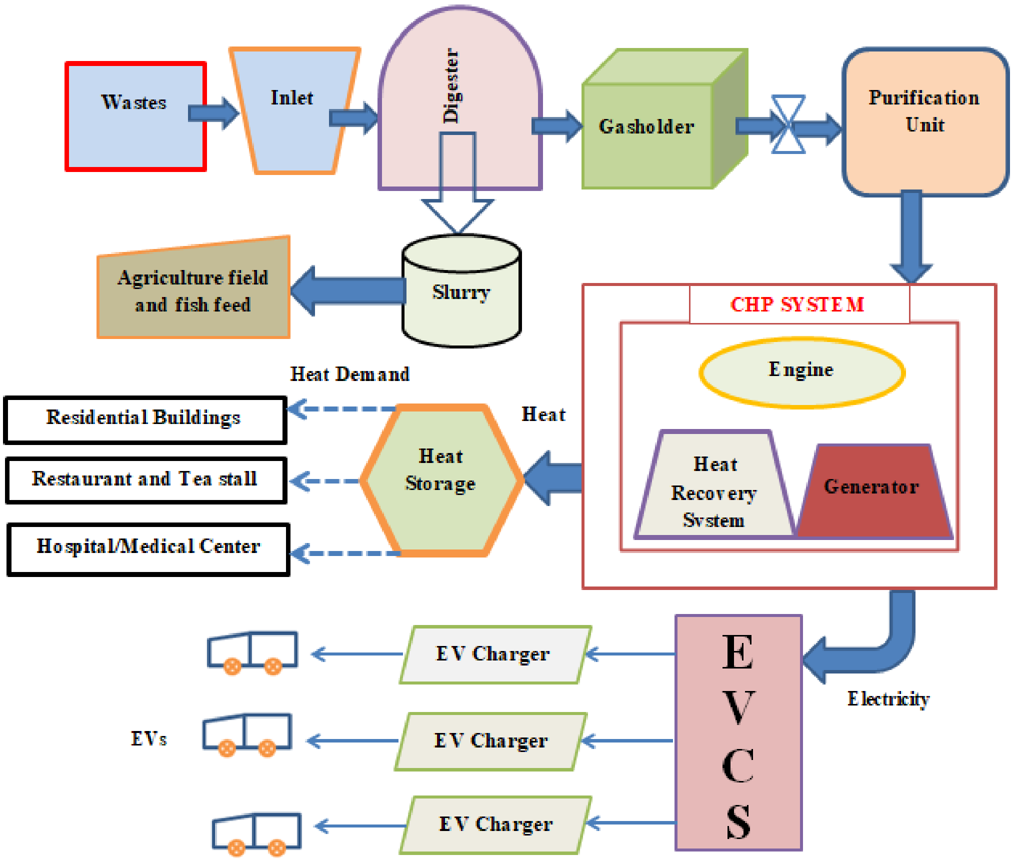

Figure 2. Conceptual diagram of proposed Biogas-based EVCS.

5. Results and Discussion

The load curve in Figure 3 is obtained from the local private EV charging station in Gazipur district, Bangladesh which shows the EV load variation with time.

It is seen from Figure 3 that in the evening period, load gradually increases and at the morning hour load is relatively lower than other times. The scenario of the EVCS is similar to the other EVCS in Bangladesh. The EV demand is almost constant throughout the year for a specific EVCS. However, in case of newly joined EV in the transportation sector causes extra burden to the power system.

In addition to the electricity demand, the proposed biogas plant will be effective for meeting heat demand of the nearby users such as residential buildings, restaurant, tea stall, and hospital/medical center. The heating demand profile is shown in Figure 4 which is derived from the village of Gazipur district in Bangladesh where the planned biogas plant will be established. The maximum heat demand is seen at noon and evening period. However, after the midnight to early morning, the heat demand declines and remains approximately constant.

Figure 5 shows the monthly collection of biomass from the nearby cattle farm, poultry farm, and urban areas of Gazipur district, Bangladesh. All types of wastes are collected from the same village where the proposed EVCS aim to be established. Therefore, the transportation cost for the waste material will be much lower.

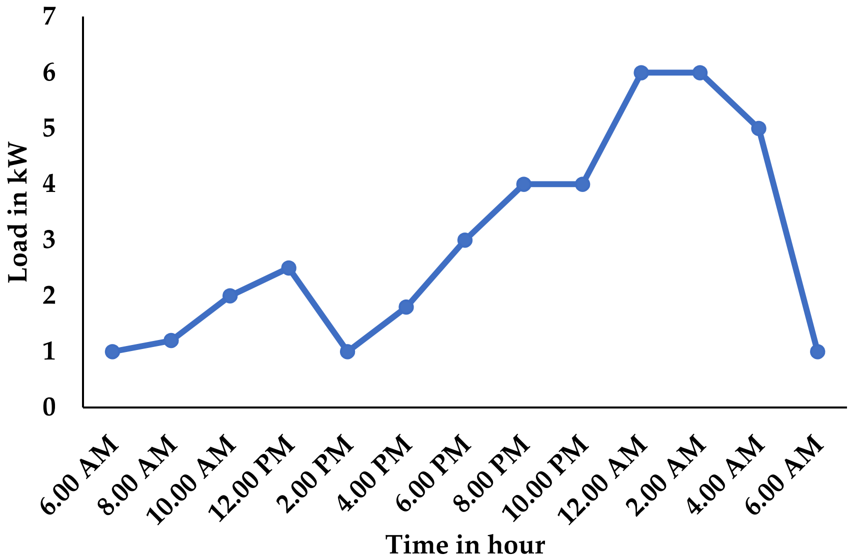

Figure 3. Daily load curve of the proposed EVCS situated in Gazipur, Bangladesh.

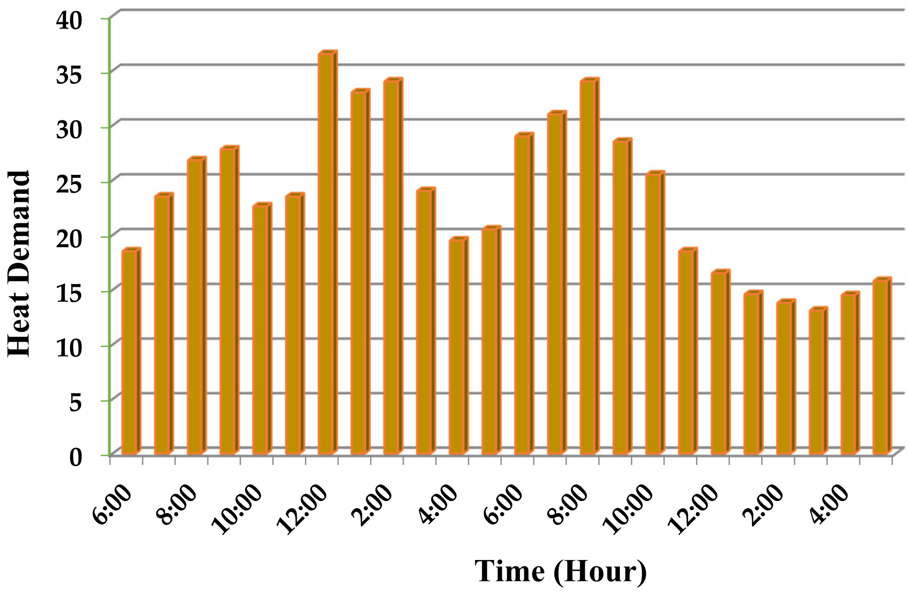

Figure 4. Daily Heat Demand Profile of the proposed area of biogas CHP plant in Gazipur district, Bangladesh.

The proposed EVCS is designed for generating electricity for charging EVs according to the battery SOC. The monthly power generation from the proposed EVCS is shown in Figure 6 where the maximum generation is in July and the minimum in February. It depends upon the biomass collection. The processed biomass is ready for anaerobic digestion in the fixed dome type or floating dome type digester. In accordance with the calorific value of the waste materials, the biogas produces, and thus, electricity is generated.

It is worth mentioning that outputs of a biogas plant are in the form of heat and biogas. Only 35% of the biogas is used for generating electricity but 65% of the output energy is used for mechanical losses and heat [52]. Of the produced heat, 20–30% goes toward heating the slurry of the digester. The heat produced from this plant can be a good source for cooking. One biogas stove requires approximately 19 MJ/hr for daily cooking of a family [53]. In that case, the proposed 70 m^3 biogas plant produces 565 MJ/day which can supply heat water to many places such as residential buildings, restaurant, tea stall, and hospital/medical center. In most of the cases, residential building requires heat to cook foods during morning, noon, and evening period. Besides, hot water is required in restaurants, tea stalls, as well as health care centers.

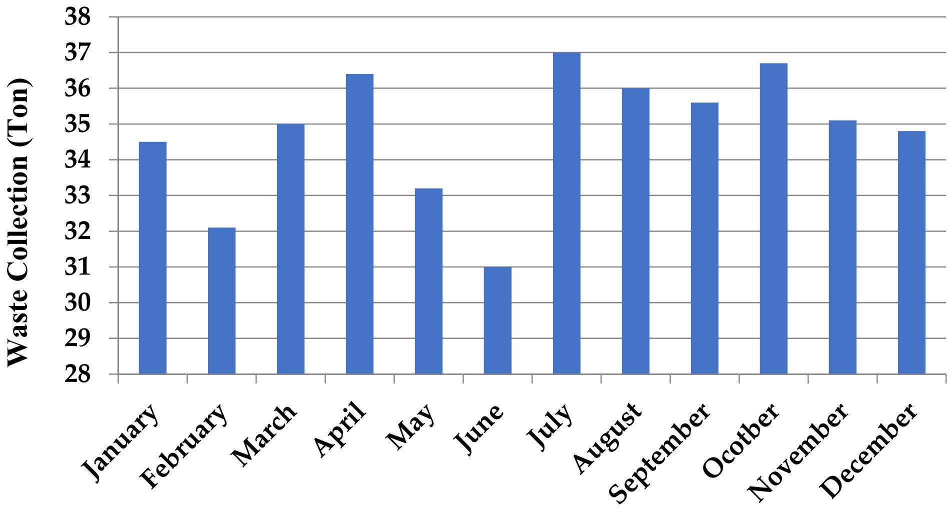

Figure 5. Monthly available biomass collection from a village in Gazipur, Bangladesh.

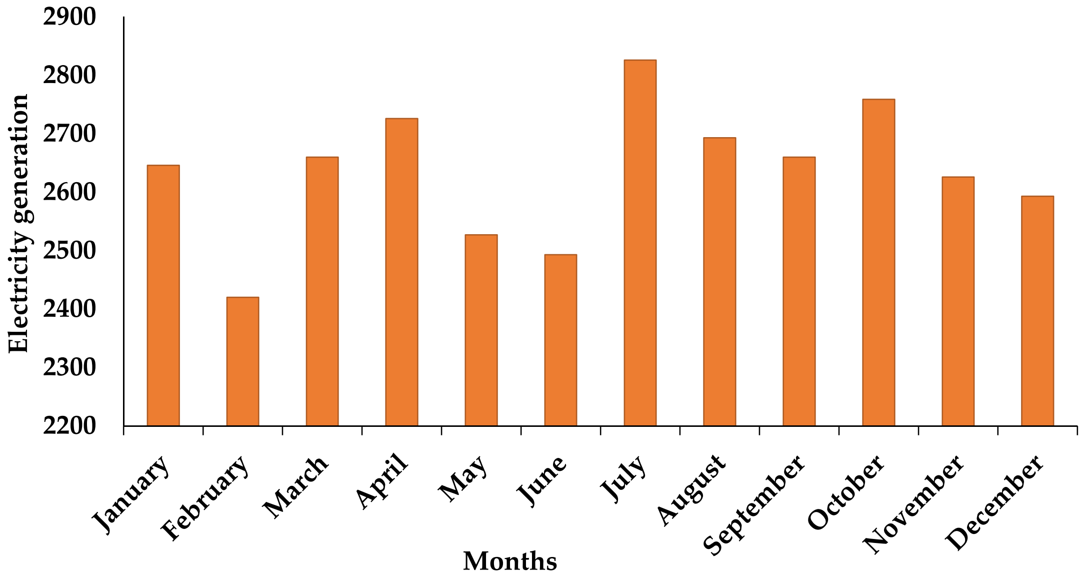

Figure 6. Electricity generation scenario of the proposed EVCS.

In a biogas plant, the production of biogas is not only the output parameter, but digestate produces from the anaerobic digestion is also carries importance. Digestate can be formed as an excellent fertilizer, and selling this bi-product at a minimum rate to the farmer's, the EVCS developer can minimize the running cost of the plant.

The daily electricity required for 15–20 EVs is approximately 100 kWh based on their battery capacity, SOC, and duration of charging. However, if the electricity generation exceeds the demand, then the excess power is transferred to the nearby residential areas for light load applications. This excess power is taken into consideration when calculating economic parameters.

5.1. Cost Analysis of the Proposed EVCS

The economic parameters related to the proposed EVCS consist of initial capital cost, O & M cost, replacement cost, cost of energy, and payback period. These parameters play a vital role in the accomplishment and desired success of the project. Table 7 shows the economic parameters of the proposed EVCS using biogas resources. The O & M cost includes waste transportation cost along with all of the running costs of the plant. It can be minimized by selling slurry as fertilizer at a minimum rate. The HOMER analysis helps to determine the COE, benefit-cost ratio, annual cash flow, payback period and profitability index.

Table 7. Economic parameters.

Item	Cost (BDT.)
Digester	850,000
Gasholder	30,000
Purification unit	20,000
Pipeline	20,000
Biogas generator	500,000
Battery bank	100,000
Charging assemblies	20,000
O & M Cost including waste transportation cost	185,000
Total Cost/investment	1,725,000
Cost of Electricity per kWh	5.56
Gas stove Bill per family per month	500
Digestate Price per kg	1.50
Annual cash flow	381,140

Figure 7 shows the profitable period and payback period of the proposed EVCS where it is observed that after 4.99 years, the project will be profitable. The Benefit-Cost Ratio and profitability index are found to be 1.17 and 2.002 which indicates the proposed project would be economically viable.

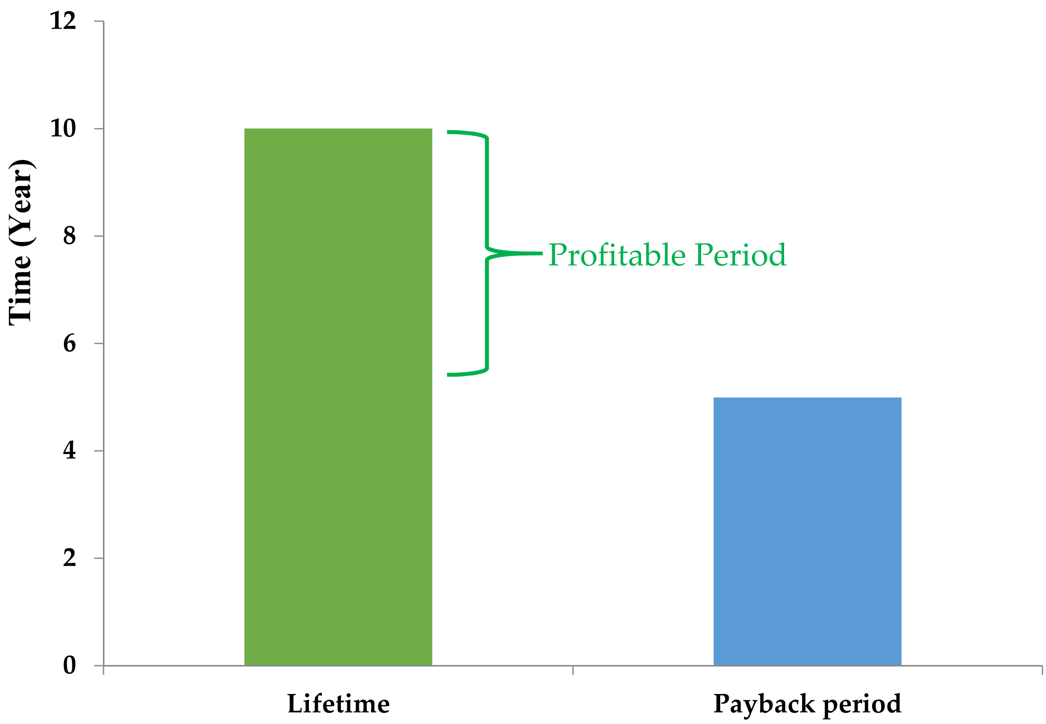

Figure 7. Lifetime and payback period of the proposed EVCS.

5.2. Environmental Aspects of the Proposed EVCS

Electric Vehicles are becoming popular day by day due to their eco-friendly nature. The greenhouse gases (GHG) emission and other pollutants which are noxious to the environment are reduced by using EV. In Bangladesh, the CO_2 emissions are per unit of electricity generation is approximately equal to 640 g [54]. The primary sources of electricity generation in Bangladesh are natural gas and coal. These two resources are limited and producing a large amount of CO_2 emissions. As compared to these resources, renewable resources such as biogas/biomass have more significant advantages of reducing CO_2 penetration from electricity generation purposes.

In this proposed charging station, biogas and biomass are used to generate electricity which will further charge the EVs. Thus, the CO_2 emissions are reduced significantly by using biogas resources.

Figure 8 illustrates the comparison of the CO_2 emissions from the grid-based EVCS and biogas-based EVCS. In the proposed EVCS, yearly CO_2 emissions is about 6653 kg whereas the same demand grid-based charging station produces 19,350 kg of CO_2. Thus, the CO_2 emissions are reduced to 65.61% from the grid-based charging station. This is because the utility grid in Bangladesh mostly depends on fossil fuel which generates more GHG emissions than renewables [55].

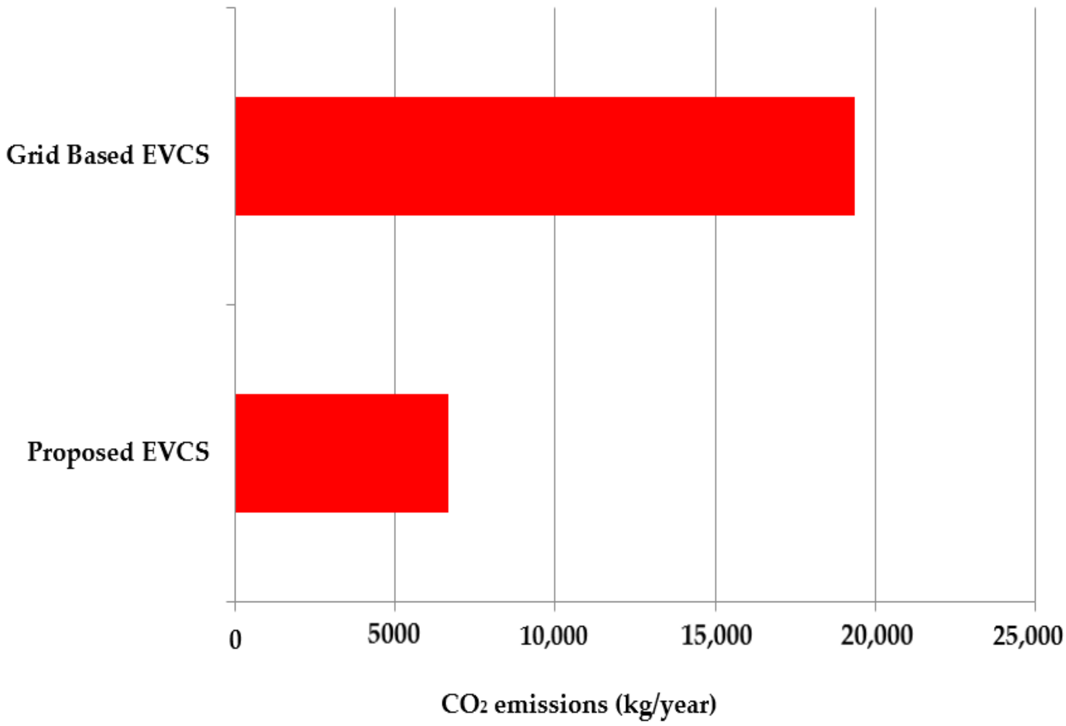

Figure 8. Comparison of CO_2 emissions from grid-based EVCS and proposed EVCS.

Hence, the EV charging from renewables such as biogas energy would be very much promising as it enhances waste management capability as well as reduces environmental pollution with cost. The waste material pollutes the environment and scatters the acrid lousy smell to the atmosphere. Use of this waste saves the environment from pollution and bad smell. Another advantage is that there is much slurry production, which can be used as fertilizer and it makes the atmosphere fresh and clean. The application of slurry improves the physical, chemical, and biological characters of the soil.

5.3. Comparison of Results Between Mathematical Analysis and HOMER Analysis

HOMER analysis provides the result based on inputted renewable resources such as biomass, where the losses associated with the EV charging accessories are not taken into consideration. In the analysis, several other factors, such as variation of biomass collection, uncertainties of weather, and breakdown of charging accessories should be considered when calculating more accurate technological, economic, and environmental parameters.

While economic parameters, such as COE, Net Present Cost (NPC), operating cost, payback period and profitability index are analyzed using the HOMER model to present advantages of power generation from the input resources, the mathematical analysis considers the charging equipment cost and infrastructures for charging five EVs simultaneously. As a result, the economic parameter obtained from mathematical analysis varies from the HOMER results.

GHG emission from biogas-based EVCS is calculated in HOMER software which is only considering the power generation process. However, the GHG emission from EV charging depends on GHG emission from EV charger and battery [56,57].

Furthermore, the EV battery manufacturing process is also responsible for GHG emission. Therefore, the results of HOMER analysis are different from the mathematical calculation.

In mathematical analysis, the loss associated with the EV charging process is taken into consideration. Thus, the kWh generation in mathematical analysis is less than HOMER result. The operating cost in HOMER analysis is greater than the mathematical analysis because the selling digestate minimizes the cost of waste transportation. Table 8 shows the comparison between HOMER results and mathematical analysis.

Table 8. Comparison between results of HOMER Analysis and Mathematical Analysis.

Parameters		HOMER Analysis	Mathematical Analysis
Technological Parameter	kWh Generation	31,680	30,762
Economic Parameter	COE	BDT. 5.56	BDT. 5.72
	NPC	BDT. 1,725,000	BDT. 1,756,790
	Operating Cost	BDT. 178,000	BDT. 68,882
	Annual Cash Flow	BDT. 381,140	BDT. 362,957
	Payback Period (Year)	4.99	5.03
	Profitability Index	2.002	1.99
Environmental Parameter	CO_2 Emissions/Year (kg)	6653	6922

5.4. Socio-Economic Benefits of the Proposed EVCS

Electric vehicle charging infrastructure opens a newly lucrative area of research and application in Bangladesh. Environmental and socio-economic factors are working behind the popularity of electric vehicles. Electric vehicles such as Easy Bikes, Auto-rickshaws and electric rickshaw vans have a high potential of reducing emissions, improving air quality in both urban and rural areas.

An Easy Bike driver in Bangladesh can easily earn approximately $18–$25 where the energy consumption cost of this car is only $1–$1.25 daily which can be a lucrative income option for many as it cuts the physical labor and saves transportation time. The charging cost of an Easy Bike is around $53 per month. It will be lower than the present cost if the proposed charging station charges the EVs.

Table 9 shows the summary of the charging cost in a grid-based system and the proposed EVCS-based system. In addition to the charging cost comparison, the monthly savings by using this EVCS for an EV driver are given in Table 9. The savings are more or less considered as the monthly income for the EV drivers.

Table 9. Cost comparison between grid-based charging station and proposed EVCS.

EV Types	Charging Cost/Month (grid EVCS)	Charging Cost/Month (proposed EVCS)	Monthly Savings
Easy Bike	$53	$23.54	$29.46
Auto-rickshaw	$32	$15.69	$16.31

In a biogas plant, the production of biogas is not only the output parameter, but the digestate produces from the anaerobic digestion is also importance. The digestate can be formed as good fertilizer and selling this bi-product at a minimum rate to the farmers to further minimize the running cost of the proposed EVCS plant.

In this research, the digestate price per kg is taken only in BDT. 1.50 which will inspire the farmers to cultivate using green waste-based composite fertilizer. The Figure 9 illustrates monthly digestate production of the proposed EVCS biogas plant.

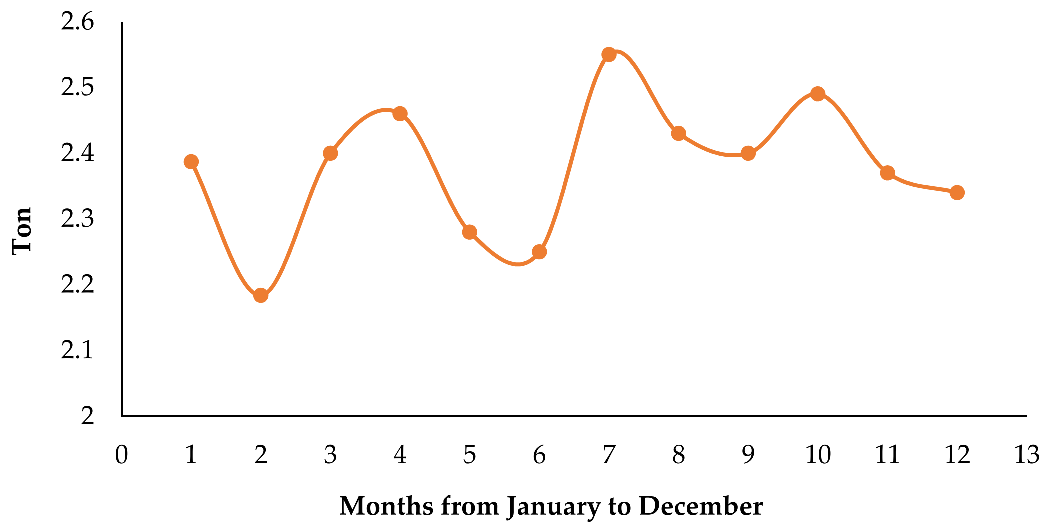

Figure 9. Month wise digestate production from the proposed EVCS.

6. Conclusions

In Bangladesh, almost all the electric vehicle charging infrastructure is operated by grid electricity, leading to rising power demand, cost, and carbon emission. Although few solar charging stations are established by the government but variable duration of solar radiation and high capital cost, it is important to evaluate use of alternative energy resources to establish sustainable energy development. In this context, it would be beneficial to incorporate available renewable energy resources such as biogas to charge electric vehicles. The concept of using biogas/biomass resources for charging battery-driven electric vehicles opens a promising area of research and application in Bangladesh. In this paper, the proposed EVCS is found economically feasible and the investment will be returned after five years. Mathematical analysis provides results of technological, economic, and environmental parameters which are different from HOMER analysis due to the variation in biomass collection, changes in weather and loss associated with the EV charging process. The proposed EVCS saves $16.31–$29.46 per month than grid-based EVCS. In the case of the environmental aspect, the proposed EVCS can reduce GHG emissions remarkably. The efficient use of locally available wastes in the proposed EVCS ensures continuous power supply, stability, and reliability of the charging infrastructure with proper waste management. Besides, strengthening the national grid by reducing extra burdens of electric vehicle charging, the proposed EVCS may also improve reliability and quality service of the energy sector toward sustainable development.

Author Contributions: Conceptualization, A.K.K., M.A.H. and N.M.K.; Data curation, A.K.K., M.A.H. and N.M.K.; Formal analysis, A.K.K. and N.M.K.; Methodology, A.K.K., M.A.H. and N.M.K.; Software, N.M.K. and V.J.; Visualization, A.K.K. and N.M.K.; Writing—original draft preparation, A.K.K., M.A.H. and N.M.K.; Writing—review & editing, M.A.H., N.M.K., V.J., A.J. and B.R. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Liu, G.; Li, M.; Zhou, B.; Chen, Y.; Liao, S. General indicator for techno-economic assessment of renewable energy resources. *Energy conversion and management* **2018**, *156*, 416–426. [CrossRef]
2. Choi, H.; Shin, J.; Woo, J. Effect of electricity generation mix on battery electric vehicle adoption and its environmental impact. *Energy Policy* **2018**, *121*, 13–24. [CrossRef]
3. Leonard, M.D.; Michaelides, E.E.; Michaelides, D.N. Substitution of coal power plants with renewable energy sources–Shift of the power demand and energy storage. *Energy Convers. Manag.* **2018**, *164*, 27–35. [CrossRef]
4. García-Olivares, A.; Solé, J.; Osychenko, O. Transportation in a 100% renewable energy system. *Energy Convers. Manag.* **2018**, *158*, 266–285. [CrossRef]
5. Islam, M.M.; Das, N.K.; Ghosh, S.; Dey, M. Design and implementation of cost effective smart solar charge station. In Proceedings of the 2014 9th International Forum on Strategic Technology (IFOST), Cox's Bazar, Bangladesh, 21–23 October 2014; pp. 339–342.
6. Durante, L.; Nielsen, M.; Ghosh, P. Analysis of non-sinusoidal wave generation during electric vehicle charging and their impacts on the power system. *Int. J. Process Syst. Eng.* **2017**, *4*, 138–150. [CrossRef]
7. Karmaker, A.K.; Roy, S.; Ahmed, M.R. Analysis of the power quality issues in electric vehicle charging station in Bangladesh. In Proceedings of the 2019 International Conference on Electrical, Computer and Communication Engineering (ECCE), Cox's Bazar, Bangladesh, 7–9 February 2019.
8. Ahmed, M.R.; Karmaker, A.K. Challenges for electric vehicle adoption in Bangladesh. In Proceedings of the 2019 International Conference on Electrical, Computer and Communication Engineering (ECCE), Cox's Bazar, Bangladesh, 7–9 February 2019.
9. Pathipati, V.K.; Shafiei, A.; Carli, G.; Williamson, S.S. Integration of Renewable Energy Sources into the Transportation and Electricity Sectors. In *Technologies and Applications for Smart Charging of Electric and Plug-in Hybrid Vehicles*; Springer International Publishing: Cham, Switzerland, 2017; pp. 65–110.
10. Ye, B.; Jiang, J.; Miao, L.; Yang, P.; Li, J.; Shen, B. Feasibility study of a solar- powered electric vehicle charging station model. *Energies* **2015**, *8*, 13265–13283. [CrossRef]
11. Gholami, A.; Ansari, J.; Jamei, M.; Kazemi, A. Environmental/economic dispatch incorporating renewable energy sources and plug-in vehicles. *IET Gener. Transm. Distrib.* **2014**, *8*, 2183–2198. [CrossRef]
12. Anik, D.; Bhuiyan, M.A.M.; Nasir, A. Prospects of solar energy in Bangladesh. *IOSR J. Electr. Electron. Eng.* **2013**, *4.5*, 46–57.
13. Hossain, M.A.; Ahmed, M.R. Present energy scenario and potentiality of wind energy in Bangladesh." World Academy of Science. *Eng. Technol.* **2013**, *7*, 1001–1005.
14. Di Fraia, S.; Figaj, R.D.; Massarotti, N.; Vanoli, L. Corrigendum to "An Integrated System For Sewage Sludge Drying through Solar Energy and a Combined Heat and Power Unit fuelled by Biogas. *Energy Convers. Manag.* **2019**, *185*, 892–893. [CrossRef]
15. Al Tanjil, H.; Akter, S.; Chowdhury, M.S.; Jabin, S.M.; Mintu, A.H.; Ahmed, M.T.; Hossain, M.S. Biogas as an Alternative Energy Source in Rural Areas and Public Awareness: A Case Study in Jessore District. *J. Energy Nat. Resour.* **2019**, *8*, 12. [CrossRef]
16. Rahman, K.M.; Harder, M.K.; Woodard, R. Energy yield potentials from the anaerobic digestion of common animal manure in Bangladesh. *Energy Environ.* **2018**, *29*, 1338–1353. [CrossRef]
17. Hossen, M.M.; Rahman, A.S.; Kabir, A.S.; Hasan, M.F.; Ahmed, S. Systematic assessment of the availability and utilization potential of biomass in Bangladesh. *Renew. Sustain. Energy Rev.* **2017**, *67*, 94–105. [CrossRef]
18. Sustainable and Renewable Energy Development Authority. Available online: www.sreda.gov.bd (accessed on 12 February 2020).
19. Waste concern, Bangladesh. Available online: www.wasteconcern.org (accessed on 12 February 2020).
20. Talukder, N.; Talukder, A.; Barua, D.; Das, A. Technical and economic assessment of biogas based electricity generation plant. In Proceedings of the 2013 International Conference on Electrical Information and Communication Technology (EICT), Khulna, Bangladesh, 13–15 February 2013; pp. 1–5.
21. Kabir, H.; Yegbemey, R.N.; Bauer, S. Factors determinant of biogas adoption in Bangladesh. *Renew. Sustain. Energy Rev.* **2013**, *28*, 881–889. [CrossRef]
22. Biogas Production Technology: An Indian Perspectives. Available online: http://www.iisc.ernet.in/currsci/jul10/articles13.htm (accessed on 12 February 2020).

23. Gofran, M.A. Status of biogas technology in Bangladesh. 2007. Available online: http://www.thedailystar.net/story.php?nid=2631 (accessed on 15 July 2019).
24. Huda, A.S.; Mekhilef, S.; Ahsan, A. Biomass energy in Bangladesh: Current status and prospect. *Renew. Sustain. Energy Rev.* **2014**, *30*, 504–517. [CrossRef]
25. Felca, A.T.A.; Barros, R.M.; Tiago Filho, G.L.; dos Santos, I.F.S.; Ribeiro, E.M. Analysis of biogas produced by the anaerobic digestion of sludge generated at wastewater treatment plants in the South of Minas Gerais, Brazil as a potential energy source. *Sustain. Cities Soc.* **2018**, *41*, 139–153. [CrossRef]
26. Islam, M.S.; Hoque, N.; Beg, M.R.A. *ICMEAS 2017 Feasibility Study of Implementing Renewable Energy on an Institutional Campus in Bangladesh–A Case Study*; Military Institute of Science and Technology: Dhaka, Bangladesh, 2017.
27. Karmaker, A.K.; Ahmed, M.R.; Hossain, M.A.; Sikder, M.M. Feasibility assessment & design of hybrid renewable energy based electric vehicle charging station in Bangladesh. *J. Sustain. Cities Soc.* **2018**, *39*, 189–202.
28. Jensen, S.S.; Winther, M.; Jørgensen, U.; Møller, H.B. Scenarios for use of biogas for heavy-duty vehicles in Denmark and related GHG emission impacts. In *Selected Proceedings From the Annual Transport Conference at Aalborg University/Udvalgte Artikler Fra Trafikdage På Aalborg Universitet*; Aalborg University: Aalborg, Denmark, 2017.
29. Xie, F.; Lin, Z.; Podkaminer, K. Could a bioenergy program stimulate electric vehicle market penetration? Potential impacts of biogas to electricity annual rebate program. *Gcb Bioenergy* **2019**, *11*, 623–634. [CrossRef]
30. Singhal, S.; Agarwal, S.; Arora, S.; Sharma, P.; Singhal, N. Upgrading techniques for transformation of biogas to bio-CNG: A review. *Int. J. Energy Res.* **2017**, *41*, 1657–1669. [CrossRef]
31. Uusitalo, V.; Soukka, R.; Horttanainen, M.; Niskanen, A.; Havukainen, J. Economics and greenhouse gas balance of biogas use systems in the Finnish transportation sector. *Renew. Energy* **2013**, *51*, 132–140. [CrossRef]
32. Ammenberg, J.; Anderberg, S.; Lönnqvist, T.; Grönkvist, S.; Sandberg, T. Biogas in the transport sector—actor and policy analysis focusing on the demand side in the Stockholm region. *Resour. Conserv. Recycl.* **2018**, *129*, 70–80. [CrossRef]
33. Karmaker, A.K.; Ahmed, M.R. Fuzzy Logic based Optimization for Electric Vehicle Charging Station in Bangladesh. In Proceedings of the 2019 1st International Conference on Advances in Science, Engineering and Robotics Technology (ICASERT), Dhaka, Bangladesh, 3–5 May 2019; pp. 1–5.
34. Source: Biogas –Green energy. Available online: http://dca.au.dk/fileadmin/DJF/Kontakt/Besog_DJF/Oevelsesvejledning_og_baggrundsmateriale/Biogas_-_Green_Energy_2009_AU.pdf (accessed on 12 February 2020).
35. Department of Livestock Services, Bangladesh. Available online: www.dls.gov.bd (accessed on 12 February 2020).
36. Halder, P.K.; Paul, N.; Beg, M.R.A. Assessment of biomass energy resources and related technologies practice in Bangladesh. *Renew. Sustain. Energy Rev.* **2014**, *39*, 444–460. [CrossRef]
37. Power cell, Bangladesh. Available online: www.powercell.gov.bd (accessed on 15 July 2019).
38. Shamsdin, S.H.; Seifi, A.; Rostami-Shahrbabaki, M.; Rahrovi, B. Plug-in Electric Vehicle Optimization and Management Charging in a Smart Parking Lot. In Proceedings of the 2019 IEEE Texas Power and Energy Conference (TPEC), College Station, TX, USA, 7–8 February 2019; pp. 1–7.
39. Lee, B.; Park, J.G.; Shin, W.B.; Kim, B.S.; Byun, B.S.; Jun, H.B.; Byun, B.S. Maximizing biogas production by pretreatment and by optimizing the mixture ratio of co-digestion with organic wastes. *Environ. Eng. Res.* **2019**, *24*, 662–669. [CrossRef]
40. Al Imam, F.I.; Khan, M.Z.H.; Sarkar, M.A.R.; Ali, S.M. Development of biogas processing from cow dung, poultry waste, and water hyacinth. *Int. J. Nat. Appl. Sci.* **2013**, *2*, 13–17.
41. Rahman, K.M.; Melville, L.; Edwards, D.J.; Fulford, D.; Thwala, W.D. Determination of the Potential Impact of Domestic Anaerobic Digester Systems: A Community Based Research Initiative in Rural Bangladesh. *Processes* **2019**, *7*, 512. [CrossRef]
42. Teferra, D.M.; Wubu, W. Biogas for Clean Energy. In *Anaerobic Digestion*; IntechOpen: London, UK, 2018.
43. Hasan, A.M.; Khan, M.F.; Mostafa, R.; Kaium, A. Feasibility study on electricity generation from poultry litter based biogas in Bangladesh. In Proceedings of the 2014 3rd International Conference on the Developments in Renewable Energy Technology (ICDRET), Dhaka, Bangladesh, 29–31 May 2014; pp. 1–4.

44. Rennuit, C.; Sommer, S.G. Decision support for the construction of farm-scale biogas digesters in developing countries with cold seasons. *Energies* **2013**, *6*, 5314–5332. [CrossRef]
45. Shi, X.S.; Dong, J.J.; Yu, J.H.; Yin, H.; Hu, S.M.; Huang, S.X.; Yuan, X.Z. Effect of hydraulic retention time on anaerobic digestion of wheat straw in the semicontinuous continuous stirred-tank reactors. *Biomed Res. Int.* **2017**, *2017*. [CrossRef]
46. Arsov, R.V. Sizing of Wastewater Sludge Anaerobic Digesters. In *Urban Water Management: Science Technology and Service Delivery*; Springer: Dordrecht, The Netherlands, 2003; pp. 223–234.
47. Sizing of Biogas Plant. Available online: https://energypedia.info/wiki/Sizing_of_the_Biogas_Plant (accessed on 14 February 2020).
48. Mudaheranwa, E.; Rwigema, A.; Ntagwirumugara, E.; Masengo, G.; Singh, R.; Biziyaremye, J. Development of PLC based monitoring and control of pressure in Biogas Power Plant Digester. In Proceedings of the 2019 International Conference on Advances in Big Data, Computing and Data Communication Systems (icABCD), Winterton, South Africa, 5–6 August 2019; pp. 1–7.
49. Pouladi, J.; Bannae Sharifian, M.B.; Soleymani, S. A New Model of Charging Demand Related to Plug-in Hybrid Electric Vehicles Aggregation. *Electr. Power Compon. Syst.* **2017**, *45*, 964–979. [CrossRef]
50. Jhala, K.; Natarajan, B.; Pahwa, A.; Erickson, L. Coordinated electric vehicle charging for commercial parking lot with renewable energy sources. *Electr. Power Compon. Syst.* **2017**, *45*, 344–353. [CrossRef]
51. Al Zaman, M.A.; Amin, R.; Tanvir, M.M.H.; Ovi, M.K.; Rakhaine, N.J.; Nayem, K.H.; Akhter, T. Prospects of Union Based Biogas Plant Model for the Generation of Electricity in Bangladesh. *Int. J. Biomass Renew.* **2019**, *8*, 1–11.
52. Biogas Calculation. Available online: https://www.wip-munich.de/nachhaltige-waermenutzung-von-biogasanlagen-ein-handbuch/1_2_Handbook-2ed_2015-02-20-cleanversion.pdf (accessed on 14 February 2020).
53. Kurchania, A.K.; Panwar, N.L.; Pagar, S.D. Design and performance evaluation of biogas stove for community cooking application. *Int. J. Sustain. Energy* **2010**, *29*, 116–123. [CrossRef]
54. Das, B.K.; Hoque, N.; Mandal, S.; Pal, T.K.; Raihan, M.A. A techno- economic feasibility of a stand-alone hybrid power generation for remote area application in Bangladesh. *Energy* **2017**, *134*, 775–788. [CrossRef]
55. Karmaker, A.K.; Rahman, M.M.; Hossain, M.A.; Ahmed, M.R. Exploration and corrective measures of greenhouse gas emission from fossil fuel power stations for Bangladesh. *J. Clean. Prod.* **2020**, *244*, 118645. [CrossRef]
56. Küfeoğlu, S.; Hong, D.K.K. Emissions performance of electric vehicles: A case study from the United Kingdom. *Appl. Energy* **2020**, *260*, 114241. [CrossRef]
57. Zheng, Y.; Shao, Z.; Zhang, Y.; Jian, L. A Systematic Methodology for Mid-and-Long Term Electric Vehicle Charging Load Forecasting: The Case Study of Shenzhen, China. *Sustain. Cities Soc.* **2020**, *56*, 102084. [CrossRef]