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Techno-economic feasibility analysis of an electric vehicle charging station for an International Airport in Chattogram, Bangladesh

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ABSTRACT

The transportation system is one of the crucial requirements of day-to-day human life. The car is one of the most attractive modes of transportation system for human beings. The demand for electric vehicles (EVs) has been growing dramatically in the last few years to reduce environmental impacts. This article provides a proposed electric vehicle charging station (EVCS) development with detailed planning and comprehensive analysis for Shah Amanat (CGP) International Airport, Chattogram, Bangladesh. A load profile prediction method is developed by utilizing Fuzzy logic and RNN-LSTM, taking account of climate data, battery state of charge (SOC), vehicle occupancy, and flight schedules. After predicting the load profile, an average load of 10.54 MWh/day is generated as output. This load profile is used in optimization software to optimize the operational and economic performance of the components and determine the most cost-effective design of the EVCS. Four scenarios with different resource combinations were explored, and Scenario-3 (S3): grid-tied Photovoltaic (PV) and wind turbine (WT) configuration was found to be the optimal scenario, with a cost of energy (COE) of $0.041/kWh based on the renewable fraction (84.3 %) and profitability index (5.55). Given these results and a suitable charging tariff ($0.140/kWh), the estimated profit was calculated to be $0.22 M/year. In comparison to the grid-only scenario (Base Scenario), Net present cost (NPC), COE, and emission can be lowered by 84 %, 63 %, and 75 %, respectively. As EVs have yet to enter the country's market, the feasibility research will assist decision-makers in determining the best adoption of integrating EVCS using renewable energy.

1. Introduction

1.1. Background

Sustainability is the ability to meet the needs of the current

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generation without sacrificing the needs of future generations. As the global population is drastically growing, as a consequence, the energy demand is also rising; however, scarce energy resources such as fossil fuels will be insufficient to meet future energy demand. Besides, fossil fuel consumption causes increasing emissions and climate change impacts which need to be reduced. Moreover, policies need to be improved for implementing renewable energy infrastructure to reduce fossil fuel consumption. The major energy consumption sectors are a) households, b) transportation, c) industries, and d) agriculture. Among these sectors, the transportation sector is one of the most impactful sectors for the socio-economic aspect of a country [1]. Nevertheless, the transportation industry is a significant consumer of fossil fuels and contributes to greenhouse gas (GHG) emissions. According to research, globally, 24 % of emissions are caused by the transportation sector, and a significant portion comes from motor vehicles [2].

EVs are becoming more appealing as a viable alternative to fossil-fuel-powered automobiles because of their increased efficiency and zero tailpipe emissions. Moreover, overall car sales significantly decreased during the Covid-19 pandemic; however, three million EVs were sold in 2020, accounting for 4.6 % of global car sales [3]. Furthermore, the United States, Europe, and China currently account for 90 % of the global EV market, though other countries are still trying to improve their overall EV ratio to reduce emissions [4]. Nevertheless, the automotive sector in Bangladesh is heavily reliant on fossil fuels [5]. As per statistics, the number of registered combustion engine automobiles in 2022 was more than 5.3 million [6]. Furthermore, the country's transportation industry significantly contributes to GHG emissions [7]. According to International Energy Agency (IEA) estimates, the transportation sector accounted for around 14.5 % of the country's carbon emissions in 2019 [8].

List of abbreviations

BS	Base Scenario
BEV	Battery Electric Vehicle
CRF	Capital Recovery Factor
CC	Constant Current
CV	Constant Voltage
COC	Cost of Charging
COE	Cost of Energy
ESS	Energy Storage System
EV	Electric Vehicle
EVCS	Electric Vehicle Charging Station
GHG	Green House Gas
GDP	Gross Domestic Product
HEV	Hybrid Electric Vehicle
HOMER	Hybrid Optimization of Multiple Energy Resources
LEV	Lightweight Electric Vehicle
NPC	Net Present Cost
PHEV	Plugin Hybrid Electric Vehicle
RNN	Recurrent Neural Network
RE	Renewable Energy
SOC	State of charge
ToA	Time of Arrival
ToD	Time of Departure

Commonly available vehicles are categorized into five types; the first three types are available in Bangladesh a) Conventional ICE vehicle, b) Hybrid Electric Vehicle (HEV), c) Light Electric Vehicle (LEV), and the rest of the two types are currently unavailable in Bangladesh; those are d) Plugin Hybrid Electric Vehicle (PHEV) and e) Battery Electric Vehicle (BEV). Fig. 1 illustrates the available and unavailable automobile market in Bangladesh. However, HEVs are gradually getting popular in this country. More precisely, BEVs are not introduced profoundly in the country as there is no policy or roadmap for EVs, and charging infrastructures are introduced yet. Although, currently available LEVs in the country have been utilized for short-distance commuting in Bangladesh since 2009 [9]. The prices for these LEVs range from 700$ to 1400$. Furthermore, charging facilities for these LEVs significantly strained the country's power grid. Besides, around 500 MW of electricity (daily average) from the national grid gets consumed to charge these vehicles [9].

1.2. Motivation

Based on academic research and expert assessments, the evaluation index for EVCS site selection was developed primarily from a sustainability standpoint, and it includes economic, environmental, and social factors, as well as eleven sub-criteria by S. Hosseini and M.D. Sarder [10]. S. Mishra et al. highlighted the critical issues to consider while developing charging station infrastructure for EVs [2]. C.T. Ma [11] stated that the most common EVCS configuration is a hybrid system design that incorporates renewable energy-based power generation, different energy storage systems (ESSs), and utility grids. Furthermore, the optimum charging facility and capacity for EVCS's were proposed by H. Mehrjerdi and R. Hemmati [12]. The charging station was designed

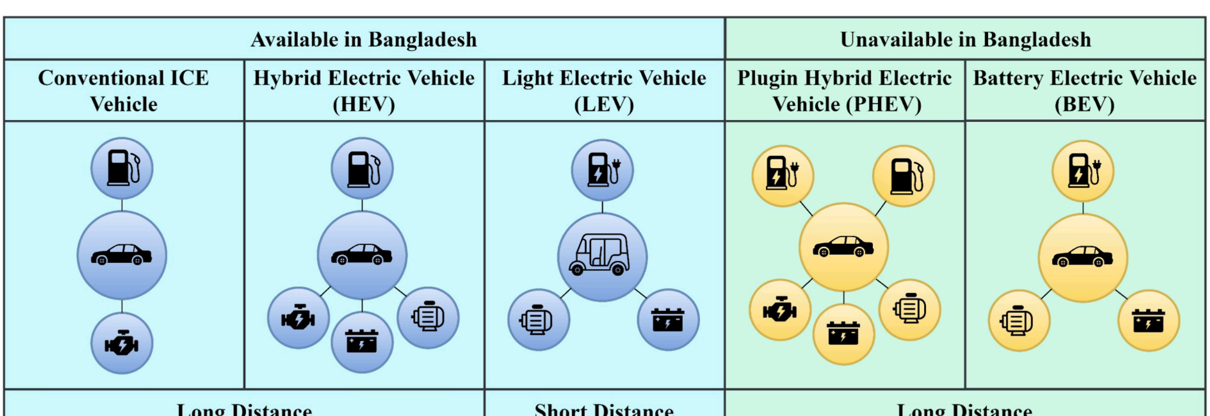

Fig. 1. A glance at the available and unavailable automobile market of Bangladesh.

with fast, midrange, and slow-speed chargers. Moreover, the charging station was connected to the power grid and powered by wind energy and energy storage devices. In another research work [13], S. Deb et al. evaluated the effect of EVCS loads on voltage stability, power losses, reliability indices, and distribution network economic losses. The whole study was carried out using the IEEE 33 bus test system, which represents a conventional radial distribution network, for six distinct situations of EVCS location. In addition, [14] H. Fathabadi designed a grid-connected solar-powered EVCS that incorporates a vehicle-to-grid (V2G) system for charging 15 EVs.

Y. Huang and K.M. Kockelman [15] suggested a design of a charging station. Consequently, the results from Boston show that EVCS's should be concentrated along important roads, which may be a general finding in other urban contexts. Also, another EVCS installation was planned in a radial distribution network superimposed on a road network by A. Pal et al. [16]. Moreover, the effect of EVCS's in Bangladesh on the grid and distribution networks was discussed by A.K. Karmaker et al. [17]. Also, [18] H. Mehrjerdi investigated an advanced approach for microgrid capacity augmentation. The microgrid incorporated renewable energy resources (RES), an ESS, and EVCS, and the extension model was designed with a six-year planning period. In addition, A. Abuelrub et al. [19] proposed a charging/discharging algorithm to determine the number of EV's. However, there are many issues with choosing a suitable location for EVCS that was investigated using a variety of nature-inspired optimization approaches. The optimization algorithm was used to solve four different variations of the charging station location problem by S. Deb et al. [20].

H. Mehrjerdi and R. Hemmati [21] optimized the charging station capacity (number of parking spaces) and network reinforcement level by developing a model. In addition, A. Khaksari et al. [22] enhanced the charging station size models for smart charging capabilities during operation. L. Luo et al. [23] suggested that EVCS should be considered to include many types of charging facilities at the planning stage, and the researcher suggest an optimization model with the goal of reducing the yearly energy cost of the entire EVCS system. Nevertheless, B. Wang et al. [24] proposed a strategy for assessing the electrical safety of large-scale EVCS's when paired with renewable power generation. Moreover, P. Sadeghi-Barzani et al. [25] suggested a strategy for EVCS by considering several factors, including costs of station development, EV energy loss, electric grid loss, and the positioning of electric substations and urban roadways. M. A. Quddus et al. [26] developed a technique for constructing and operating EVCS's that take into account both long-term planning decisions and short-term operational decisions over a pre-specified planning horizon and under stochastic power demand. Furthermore, S. H. Chung and C. Kwon [27] proposed two techniques and created a scenario study utilizing real traffic flow data from the Korean Expressway network. They did not consider the charging time, charging demand, and waiting time for charging.

1.3. Objectives and paper organization

The country's energy generation infrastructure is predominantly based on fossil fuels, with oil and gas contributing 74 % of total generation and renewables accounting for only 3 % [28,29]. The current power infrastructure, which is heavily reliant on fossil fuels, will be insufficient to meet future demand, given the energy requirements of different types of EVs (cars, trucks, etc.). However, it will be more challenging for mainstream EVs to enter the country's automotive market without the implementation of proper charging infrastructure. Furthermore, the proper EV charging facility needs to be regulated for an effective power system to reduce emissions and improve cost-effectiveness. Hence, this article provides a techno-economic analysis of a renewable-based charging station (EVCS) for mainstream EVs in Chattogram, Bangladesh - Patenga (CGP) International Airport, a divisional port city in Bangladesh. The proposed charging station is designed for the city's airport and would use grid-connected solar and wind resources to charge EVs. Furthermore, this paper's literature assessments provide useful insights into renewable energy integration into EVCS, however, significant research gaps remain for integrating EVs into underdeveloped countries. Firstly, there is a requirement for further study into the particular issues related to EVCS infrastructure implementation and integrating renewables in areas where the EV infrastructure has not yet been well established. In addition, there was no reliable dataset for long-term traffic movement and pattern for the selected area which could be a possible gap that needed to be filled. The literature reviews have touched on issues of EVCS tailored for a specific location or region where widespread implementation of EVs has already begun. Aside from implementation, other aspects such as scalability, long-term sustainability, and infrastructure requirements, as well as the impact on electricity pricing, have to be thoroughly examined. Despite the existing literature review, this paper addresses research gaps concerning EVCS, and renewable integration associated with it, proposing a load profile design approach adapted to the needs of the selected location, addressing infrastructure-related challenges, the economic and environmental impact of EVCS, and renewable resources. The key objectives of the study are,

- Designing a potential EVCS for the CGP International Airport.
- Developing a suitable demand prediction approach for modeling charging station load characteristics.
- Designing the optimal system based on the effective utilization of solar and wind resources to power the charging station.
- Providing a detailed economic analysis of the resources and charging station.
- Compare the proposed systems with other possible alternatives and only grid-based options in terms of cost and environmental impact.

The remainder of the paper is organized as follows: Section 2 discusses the methodology, findings are discussed in Section 3, discussion of this research work is described in Section 4, and finally, the concluding remarks are in Section 5.

2. Methodology

2.1. Location assessment

Chattogram is the second-largest city and major seaport of Bangladesh, located on the banks of the Karnaphuli River, which flows into the Bay of Bengal. The population of the city is currently estimated to be 6 million [30]. The city makes a significant contribution to the economy of the country. Chattogram seaport contributes around 12 % of Bangladesh's overall GDP and handles 80 % of the country's total imports [31]. Moreover, the city has one airport named Shah Amanat International Airport, which is also the country's second-largest airport. It is located in Patenga, southwest of the city. The airport (previously known as Chittagong Airfield) was built by the British government during Second World War (WWII) and was used by the US military and air force during the Burma campaign in 1944–45 [32]. Following Bangladesh's independence, the airfield was changed to a domestic airport to allow direct flights between Dhaka and Chattogram. It became an international airport in 1990 [32]. The airport serves flights to several countries such as India, Thailand, the United Arab Emirates (UAE), Saudi Arabia, Oman, and Kuwait. It has a handling capacity of 0.6 million/year passengers and 5700 metric tons of cargo per year [33]. Cars and taxis can easily get to the airport from the city. There are three parking zones, where one zone is dedicated to civilians. The civil Parking zone has an area of 18,400 square meters and can accommodate up to 400 vehicles at a time [33]. The civil parking zone typically gets crowded with cars and micro-buses. The airport's location is depicted in detail in Fig. 2.

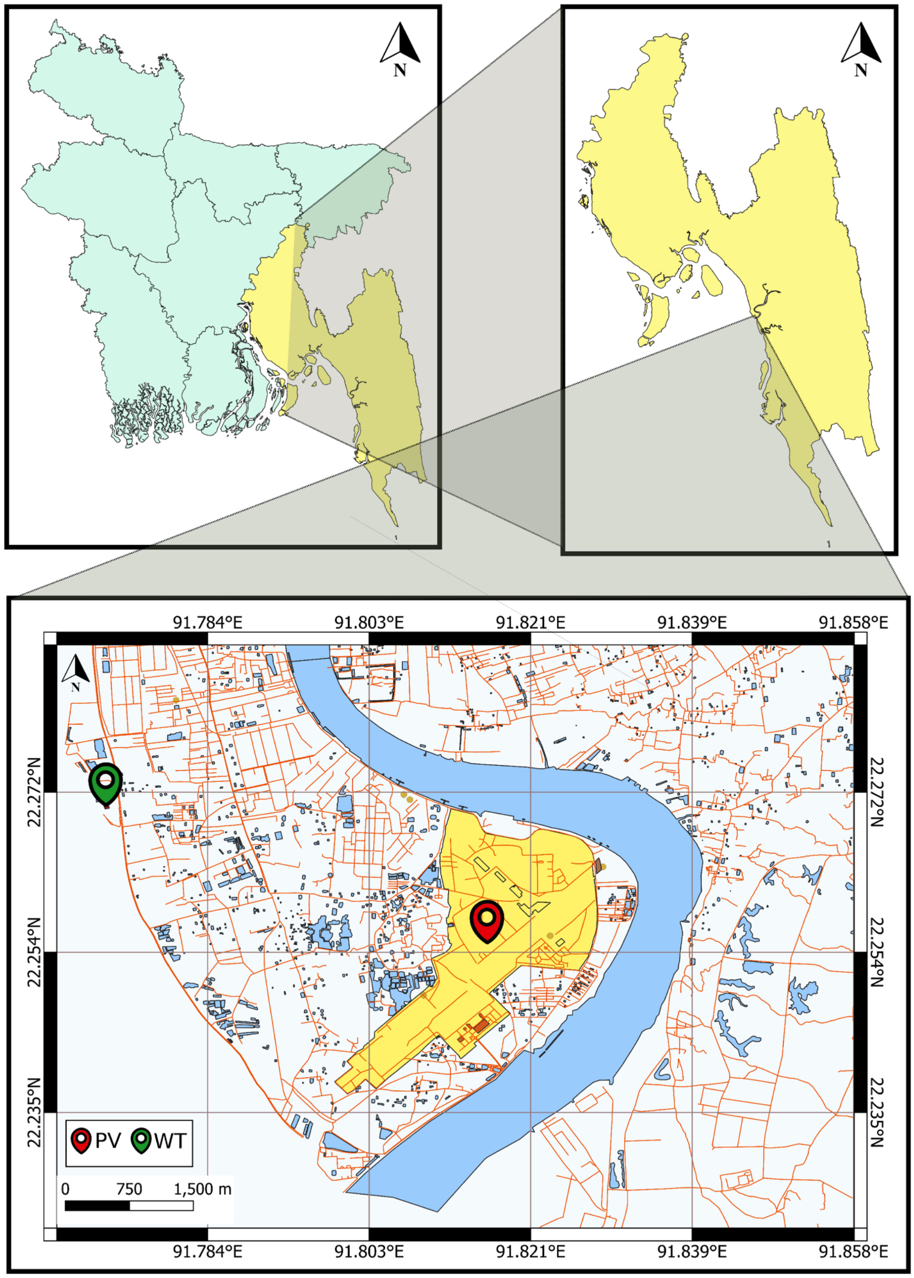

Fig. 2. Detailed view of the airport and resource placement.

2.2. Proposed design of EVCS

A proposed layout of the EVCS in the parking zone is illustrated in Fig. 3**.** Therefore, a portion of the existing parking space is used for EVCS where one lot (Lot-1) is going to be dedicated to the EVCS among nine Lots of public parking areas. More specifically, the selected Lot-1 has a length of 34 m and a width of 13 m, and it can accommodate 28 cars in two rows. Moreover, the EV chargers will be placed on the row divider that has a width of 1 m in the middle of the EVCS. In this public parking space, three entry points are dedicated to vehicle entries, and on the other hand, two points are for vehicle exits. On top of that, two entry points are devoted to human entrance from the airport in the parking space, and one public washroom is also available in the parking lot.

2.3. Resources and system design

For the study, the airport's public parking space was considered for the proposed design of EVCS and a carport PV installation to harvest solar energy. The parking space is indicated by a green marker in Fig. 2. Furthermore, the country's coastal territory has a high potential for wind energy harvesting, and Patenga Sea Beach is conveniently located around 3 km east of the airport. In terms of resources, solar irradiation is abundant at the chosen location. Particularly, wind resource is also a viable option for power generation for the chosen location. Besides, the daily radiation and wind speed of the Shah Amanat International Airport in Chattogram were obtained from the NASA surface meteorological and solar energy database. The average daily irradiation for the location is 4.76 kWh/m^2/day, and the average windspeed is 4.62 m/s. Fig. 4 depicts the hourly incident solar irradiation at the selected site as well as windspeed in the coastal area.

Based on the resources discussed above, the proposed charging station will be a grid-connected system powered by PV panels and wind turbines (WTs). Moreover, the PV panels are going to be installed on the top of the parking lot as a PV carport. Furthermore, the WTs will be

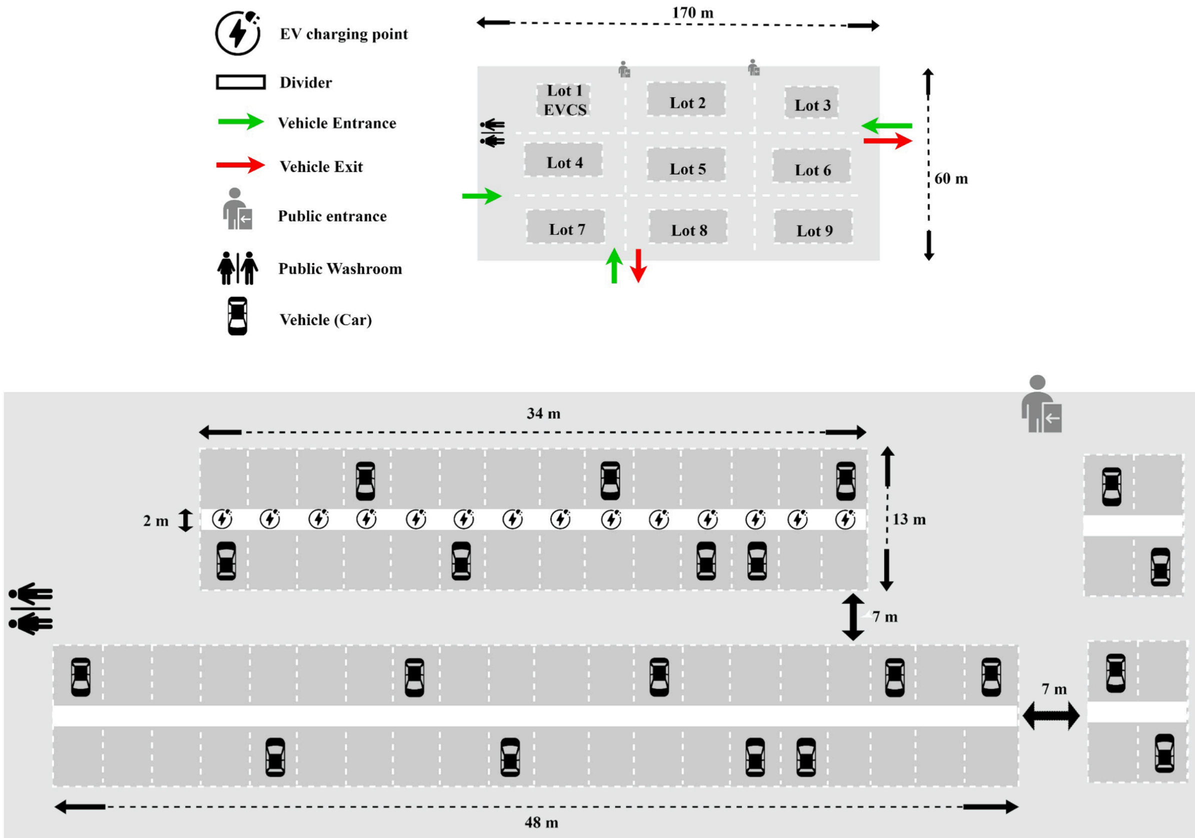

Fig. 3. Parking lot layout of the EV charging station.

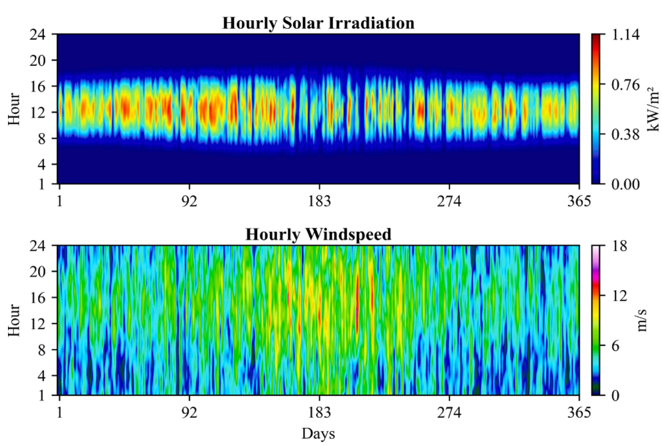

Fig. 4. Average monthly solar irradiation and wind speed in the selected location.

placed at Patenga Beach and connected to the EVCS via a short extension line. However, WTs are placed far from the airport to maintain proper regulations regarding the obstacle height in the airport region. According to Civil Aviation Authority of Bangladesh (CAAB) standards, the maximum permitted obstruction height of 150-500ft falls into the conical surface, which is after the inner horizontal surface (about 4 km radius after transitional surface and runway) [34]. Precisely, commercially available WTs can range in height from 160ft to 430ft when the sum of hub height and rotor diameter is considered as effective height. Therefore, the WTs have to be located 4.5 km-5 km away from the airport. For the above reasons, the most suitable site for these turbines to be placed is near to the coast (shown in Fig. 2 by a red marker), ensuring increased output. In order to connect the WTs to the charging station, an extension line is required, as shown in Fig. 5.

2.4. Input parameters

Global PV generation capacity increased from 17 GW_{DC} to 139 GW_{DC} between 2010 and 2020. Furthermore, the average global price of solar panels has reduced by up to 65 % since 2016 [35]. Continuing the pattern, global wind installation costs are set to decline by 19 % [36]. Concerning all the factors of price deviation in the global market, the prices of the components were carefully chosen. The input of the simulation, along with the component specifications and cost of the component, is shown in Table 1 [37–39] and Table 2.

Solar irradiance, cell characteristics, cell temperature, and temperature coefficient all influence the amount of power generated by solar PV [40–42]. The following is the equation used to calculate the output of

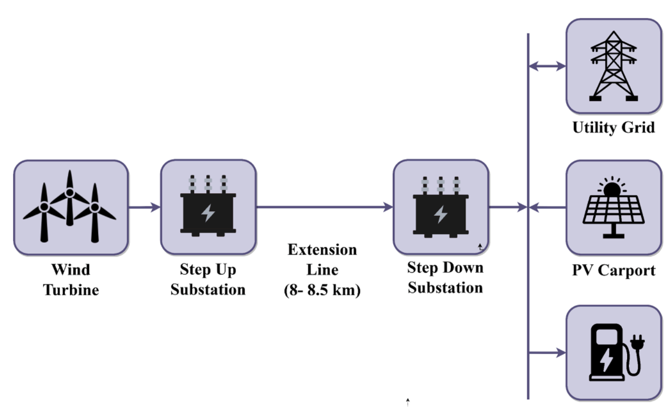

Fig. 5. Proposed grid-tied scheme for the EVCS.

Table 1
Component specifications [37–39].

Component	Parameter	Value
PV	Capacity	500 W
	Efficiency	21.3 %
	Lifetime	25 years
WT	Capacity	500 kW
	Hub height	75 m
	Lifetime	25 years
Converter	Capacity	1 kW
	Efficiency	90 %
	Lifetime	10 years

Table 2
Input parameters for economic assessment.

Parameter	Value	Baseline value	Unit
PV capital cost [45]	1080	1080	$/kW
PV O&M cost [45]	25	25	$/kW/year
WT capital cost [46]	1462	1462	$/kW
WT O&M cost [46]	43	43	$/kW/year
Charger capital cost [47]	425,000	425,000	$
Station setup cost [48]	141,550	141,550	$
Station O&M cost	115,000	115,000	$/year

Discount rate: 10 %, Inflation rate: 5.59 %.

the PV array.

$$P_{PV} = \frac{I_p}{I_s} D_{PV} C_r [1 + \alpha (T - T_s)] \tag{1}$$

Where I_p denotes the solar radiation incident on the site of the PV array; I_s denotes the incident radiation at standard test conditions; D_{PV} denotes the PV derating factor. α is the temperature coefficient of power; T and T_s are the PV cell temperature in operating and standard test conditions, respectively; C_r is the rated capacity of the PV array [43].

The output power from a WT can be calculated by equation (2),

$$P_{WT} = 0.5 \rho A C \eta_s \eta_g \upsilon^3 \tag{2}$$

Where ρ is the wind density, A is swept area by the rotor, C is rotor blade aerodynamic efficiency, υ is turbine speed, and η_s and η_g are gearbox and generator efficiency, respectively [44].

Economic parameters such as net present cost (NPC) and levelized cost of energy are the primary determinants in finding the ideal scenarios from amongst several proposed systems. NPC is the present value of all the expenditures the system incurs, including installation and operation costs for all components throughout its lifespan, deducted from the present value of all the income it makes over its lifetime. Capital cost, replacement cost, operation and maintenance (O&M) cost, fuel costs, and grid power cost are considered expenses. Besides, revenues include salvage value and grid sales revenue. NPC and COE are calculated as:

$$C_{NP} = \frac{C_{TA}}{CRF} \tag{3}$$

Here, the total annualized cost is $C_{TA,}$ and the capital recovery factor is CRF, which is obtained from the equation:

$$CRF = \frac{i(1+i)^n}{1-(1+i)^n} \tag{4}$$

Here, n denotes the number of years, and i is the rate of real interest. COE is computed as the average unit cost of energy generated using the equation.

$$COE = \frac{C_{TA}}{e} \tag{5}$$

Here, C_{TA} represents annualized cost, and e represents annual energy consumption [49]. Because the proposed system is grid-connected, surplus electricity will be sold to the grid, and energy will be drawn from the grid if the system can't generate adequate power. Import or export of energy can be calculated using the following equation,

$$E_{ie} = \sum\nolimits_{t_s=0}^{N} P_{PV} t_s + \sum\nolimits_{t=0}^{23} P_{WT} t - L_s t \tag{6}$$

In this study, the renewable fraction is used to evaluate the environmental performance of the system. Conventional generators and power grids, respectively, are the main sources of air pollution emissions [50]. The renewable energy fraction is the percentage of energy delivered to the load that comes from RES, which can be calculated as follows:

$$F_{re} = 1 - \frac{E_n - H_n}{E_{ls} - H_{ls}} \tag{7}$$

E_n is electricity production from non-renewable, H_n is the production from thermal, E_{ls} is the entire electric load, and the entire thermal load is H_{ls}.

3. Result analysis

3.1. Load profile design

Load prediction or forecasting plays a crucial part in the careful planning required for the proper operation of the power grid and the integration of new resources. In general, load forecasting is required for efficient electricity distribution, cost-effective generation, and proper scheduling. Load forecasting is classified into four categories based on prediction intervals: very short-term load forecasting, short-term load forecasting, medium-term load forecasting, and long-term load forecasting [51]. Among them, long-term prediction is being used to examine the feasibility of new generation infrastructure, strategic planning, and making significant modifications to the transmission and distribution network [52]. So, long-term forecasting is necessary to prevent the uneconomic sizing of charging stations. Load demand prediction of the station depends on different variables like weather, traffic density at the airport, EV battery state of charge, etc. Additionally, the number of cars that arrive at the charging station will be dependent on the weather condition. For instance, on heavy foggy days or during heavy rain, there will be fewer cars on the road. For predicting the cars arriving at the airport, temperature and precipitation data are employed, and fuzzy logic is used. Fuzzy logic is widely used in load prediction, controller design and tuning, and other management and forecasting tasks [53–55]. For this part, the number of cars was assigned to the output membership function, while different climatic conditions were given to the input membership function.

Membership functions for different temperature (in °C) conditions are stated below,

Very cold (VC),

$$VC = \begin{cases} 0, x > 15 \\ \frac{15-x}{5}, 10 \le x \le 15 \\ 1, x < 10 \end{cases} \tag{8}$$

Cold (C),

$$C = \begin{cases} 0, x < 10 \\ \frac{x-10}{5}, 10 \le x \le 15 \\ 1, 15 \le x \le 20 \\ \frac{25-x}{5}, 20 \le x \le 25 \\ 0, x > 25 \end{cases} \tag{9}$$

Warm (W),

$$W = \begin{cases} 0, x < 20 \\ \frac{x-20}{5}, 20 \le x \le 25 \\ 1, 25 \le x \le 30 \\ \frac{35-x}{5}, 30 \le x \le 35 \\ 0, x > 35 \end{cases} \tag{10}$$

Hot (H),

$$H = \begin{cases} 0, x < 30 \\ \frac{x-30}{5}, 30 \le x \le 35 \\ 1, x > 35 \end{cases} \tag{11}$$

Likewise, precipitation (mm/hr.) and the number of cars arriving at the station are given in Table 3 [56].

To find out the number of cars at the charging station every hour based on weather condition, rules of inferences was set and is shown in Table 4. The input and output were mapped based on the surroundings. In short, if the weather becomes very hot, cold, or rainy, the charging station's occupancy will be minimal. For instance, when the weather is really cold and there is no rain, the occupancy in the charging station will be extremely low. Because visibility would be reduced in extremely cold conditions. The same is true for the chilly condition; occupancy would be low. In contrast, given the limited or no rainfall in warm weather, occupancy would be extremely high. In this situation, when rainfall increases, occupancy will decrease. In very hot weather, occupancy will be medium, and when rainfall increases, occupancy will rise. However, in all circumstances, heavy or severe rains will reduce occupancy.

Hourly power consumption by the charging station is dependent on the EV battery state of charge (SOC) and the charger capacity. Moreover, cars arriving every hour will have a random battery SOC. For this assessment, it was assumed that 80 % of all vehicles in the charging station each hour will have a SOC of less than 80 %. However, if the station is fully occupied at a given hour, 20 cars will be charging at constant current (CC) mode, and 5 cars will be charging at constant voltage (CV). Moreover, a 50 kW fast charger is considered for this design. A 50 kW fast charger takes around 72 min to charge the vehicle to cover a range of 200 miles [57]. Average CC charging power is regarded as 44 kW, and CV charging power is considered 22 kW based on empirical data of the charger power consumption at different charging states for Hyundai Ioniq with a 38.3 kWh battery which is shown in Fig. 6 [58].

A load profile is developed based on the hourly load discovered by weather conditions and SOC restrictions. To predict the load profile, the last six years of weather data are used. Utilizing these data through the fuzzy logic and the SOC constraints, the proposed station's hourly demand data for the preceding six years is estimated. The estimated data is then utilized in a recurrent neural network (RNN) based long short-term memory model (LSTM) to predict the yearly load profile. Then, the data is divided into a 5:1 ratio for training and testing purposes, respectively. The LSTM layer consists of 200 hidden units, and the optimum outputs are found running the training at 250 epochs. Accuracy metrics for different epoch ranges are given in Table 5. In this table, Mean absolute error (MAE), Mean absolute percentage error (MAPE), and Root mean square error (RMSE) are compared with different epochs.

The outcome from the RNN prediction is for 24 h, but the number of vehicles at the station will also be dependent on the arriving and departed flights. For instance, during the time of arrival (ToA) of a flight, traffic congestion at the station will be substantial, and the same will be evident during the time of departure (ToD). After sunset, most EVs will be charged at their owners' homes. Based on these factors, a vehicle density weightage (ranging from 0 to 1) is designed in order to reshape the load profile. This will prevent oversizing the system as at a certain time, there won't be any vehicle at the station, though the earlier outcome predicted certain demand of the period. The density weightage is illustrated in Fig. 7 with a comparison of predicted load and reshaped load for a certain day. Fig. 8 summarizes the steps followed for predicting the load profile for the EVCS.

A load profile is developed based on the prediction, and the estimated daily average load is 10.54 MWh, and the peak demand is 1.02 MW based on the load profile. Hourly load demand for each month is illustrated in Fig. 9. The predicted load profile appears to reflect the specified climate conditions after being resized. Load demand is

Table 3
Input and output membership function.

Precipitation	Membership function	EV occupancy at the charging station	Membership function
No rain (NR)	[0 0 0.1 0.2]	Very low (VL)	[0 0 4 5]
Slight rain (SR)	[0.1 0.2 0.4 0.5]	Low (L)	[4 5 9 10]
Moderate rain (MR)	[0.4 0.5 3 4]	Medium (M)	[9 10 14 15]
Moderate shower (MS)	[2 3 9 10]	Dense (D)	[14 15 19 20]
Heavy shower (HS)	[10 11 49 50]	Very Dense (VD)	[19 20 25 25]
Violent shower (VS)	[49 50 200 200]		

Table 4
Fuzzy rules for estimating EV number at the station.

	NR	SR	MR	MS	HS	VS
VC	VL	VL	VL	VL	VL	VL
C	L	VL	VL	VL	VL	VL
W	VD	VD	D	M	VL	VL
H	M	D	D	L	VL	VL

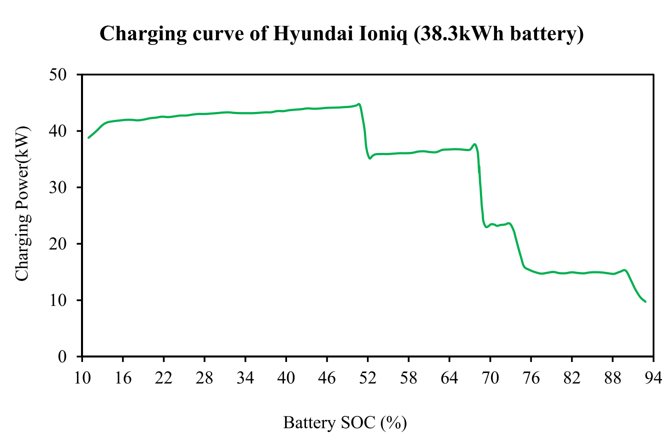

Fig. 6. Charging curve of Hyundai Ioniq using a 50 kW fast charger.

Table 5
Performance metrics at different epochs.

Epochs	MAE	MAPE	RMSE
150	53.24	9.11	68.66
200	42.47	7.74	61.77
250	35.88	6.35	55.18
400	37.75	6.51	55.07

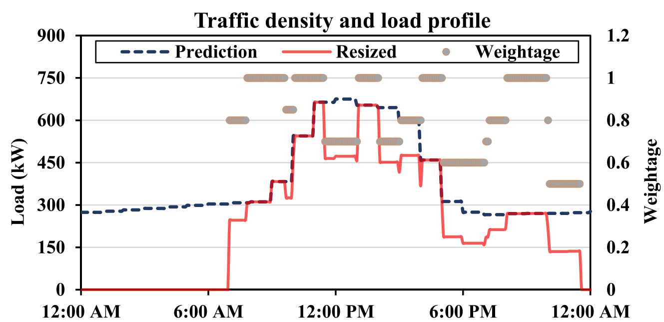

Fig. 7. Load profile shaping based on vehicle density.

moderate during the winter (December-February), but relatively high the rest of the year. In addition, demand is substantially high both before and after landing or takeoff. From 11 a.m. to 5 a.m., the load demand is almost negligible (idle consumption by charger) because there are no scheduled flights at that time, and users are likely to charge their cars at home at that time.

3.2. System sizing

The optimal resource sizing is defined through manual adjustments in tandem with the inbuilt optimizer in HOMER Pro. The preliminary sizing was determined by the auto optimizer, and sizing constraints were set based on resource availability. For instance, the parking space can facilitate around 1600 kW of a PV installation, and the optimizer's upper limit has been set to it. The capacity of different components was manually modified through state space optimization based on the initial results of the simulation, and the procedure was iterated numerous times before the lowest cost and best system sizing were attained. The most efficient capacity values for each component are depicted in Table 6.

Furthermore, three feasible scenarios for microgrid planning were considered for the EVCS and compared with a Base Scenario (BS). In the BS, the designed charging station is connected to the external grid solely. Scenarios 1, 2, and 3 (S1–S3) illustrate that the microgrid is a hybrid design based on renewables and the external grid. S1 includes both the external grid and PV, whereas S2 includes WT along with the external grid. Furthermore, in S3 with an external grid, both WT and PV are considered to use the full potential of renewable sources of the location. All the designed microgrid scenarios have the ability to connect to and draw electricity from the external grid.

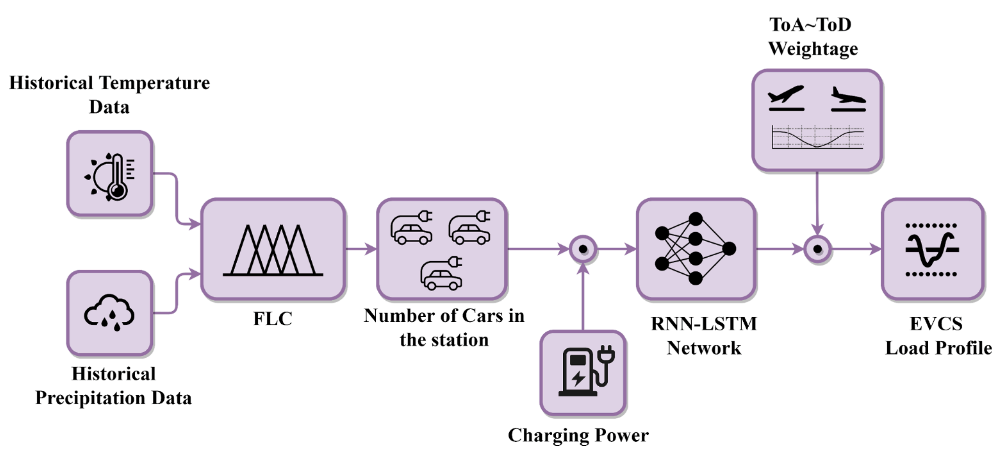

Fig. 8. Procedures followed to obtain Load profile.

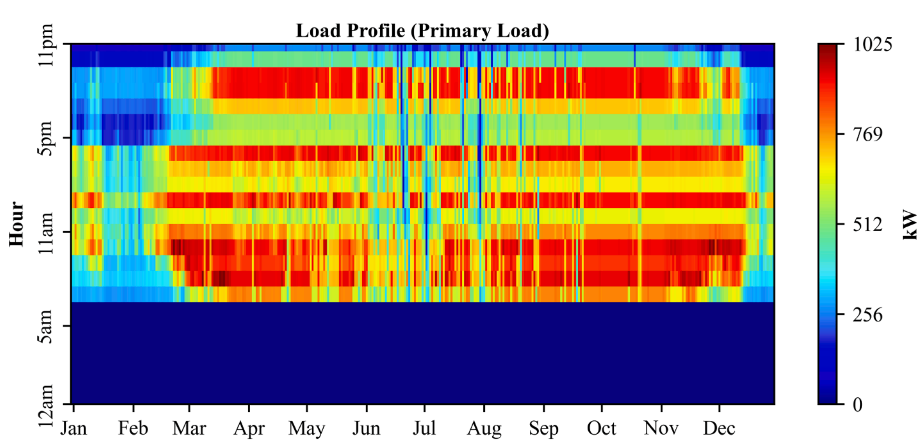

Fig. 9. Load profile of the charging station.

Table 6
Optimized sizing values of each component.

Scenarios	PV Capacity (kW)	WT Capacity (kW)	Converter Capacity(kW)
BS	–	–	–
S1	1400	–	1400
S2	–	1000	–
S3	1400	1000	1400

3.3. Economic analysis

To achieve the primary goal of this study, numerous parameters are taken into consideration. Key highlights findings are shown in Table 7.

For BS, the COE is much higher because energy is directly purchased from the grid. Although because of the renewable fraction, the COE of S1 is 0.098 \$/kWh, close to the BS. S2 and S3 have comparatively less COE than the other two scenarios (BS and S1) because of the lower NPC and production from WT. Besides, COE for S2 and S3 is 0.047 \$/kWh and 0.041 \$/kWh, respectively. The lowest COE is obtained from S3 since both PV and WT are contributing along with the grid.

For the net profit of the system, S3 has the highest annual profit at \$0.22 million; on the other hand, the BS generates no profit as it is purchased from the grid. Besides, the annual energy cost of S3 is much lower than the BS, followed by the operating cost, which results in a change in net profit. Scenarios with the highest renewable fraction have a lower operating cost which causes less COE resulting in higher profit.

NPC of each scenario is illustrated in Fig. 10. In addition, the NPC of the microgrid design is directly obtained from HOMER software. However, the NPC of the charging station for 25 vehicles was calculated, including charger price, electrical cost, civil work cost, maintenance cost, cost of charging (COC), discount rate, and inflation rate. Subsequently, the BS has the highest NPC for both the system and the EVCS. However, the NPC of the system and EVCS is decreasing for S1, S2, and S3 due to the high renewable fraction.

Moreover, operating cost is highest in the BS, which is 0.49 million \$/year, and lowest in S3 with −0.155 million \$/year. Consecutively, for S2, the operating cost is lower than S1 and BS. Nevertheless, S3 has the lowest operating cost for the system and charging station. The operating cost breakdown for each scenario is shown in Fig. 11.

COC is considered at 0.140 \$/kWh for this assessment because the BS offers a COE of 0.111 \$/kWh, and other scenarios still take a significant amount of power from the grid. For the BS, there won't be a payback period for the system, as the station is economically infeasible with the considered COC. However, to generate sufficient profit to break even at 24.6 years a minimum COC of \$0.17/kWh need to be considered for the BS. Also, a similar result was found for S1, but the system payback period for S1 is 17.8 years, the longest among the scenarios. Again, for S2, the minimum charging cost should be set at 0.155\$/kWh to break even, which will occur in 24.8 years. For S2 and S3, the system payback periods are 5.9 and 10.3 years, respectively. For these instances, the lowest COC that would still break even is 0.10\$/kWh and 0.095\$/kWh, respectively. Given these charging tariff rates, the minimum repayment period for S2 and S3 would be 24.8 and 24.4 years, respectively. For S2 and S3, the capital expenditure would be recovered in 3.11 and 2.76 years, correspondingly, considering only the charging station. Fig. 12 illustrates the comparison of payback periods and minimum COC.

Table 7
Key highlights of the assessment.

Scenarios	NPC (total) (million \$)	Capital Cost (million \$)	Cost of Energy (COE) (\$/kW)	Estimated Annual profit (\$)	Profitability Index
BS	8.04	0.57	0.111	−46,479	−1.71
S1	6.99	2.14	0.098	2793	−0.38
S2	1.41	2.03	0.047	198,347	4.91
S3	1.22	3.6	0.041	221,828	5.55

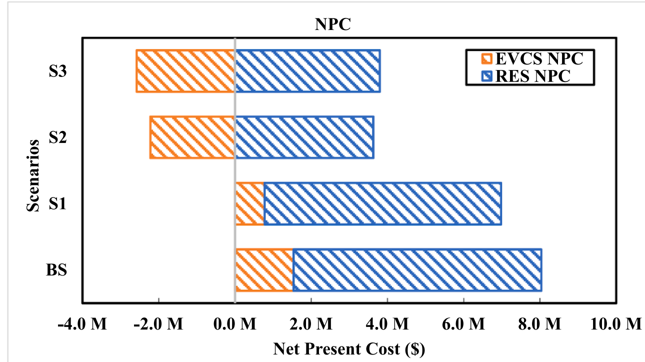

Fig. 10. Net present cost of the energy source and EVCS.

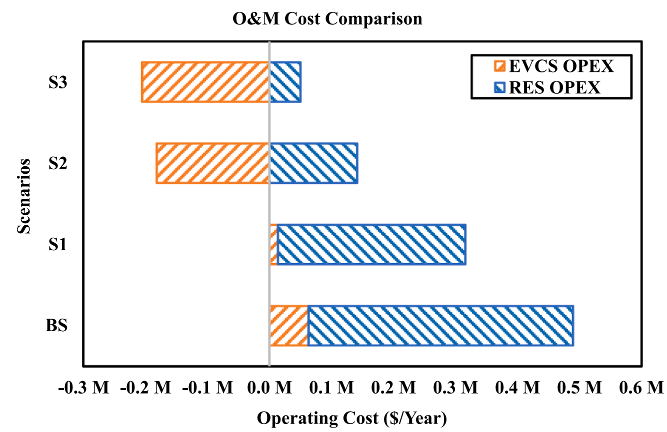

Fig. 11. Operating cost of energy source and charging station.

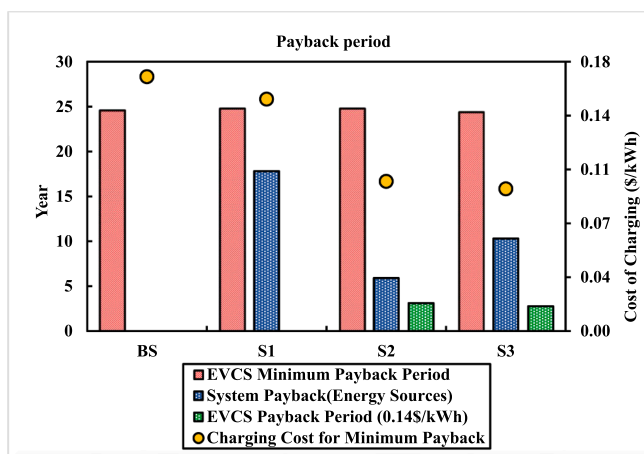

Fig. 12. Payback period comparison of different scenarios.

3.4. Power production and environmental impact

This subsection is dedicated to power production and environmental impact. In the BS, the emission of GHG (tCO_2/year) is highest because of no renewable sources connected. In addition, S3 has the lowest emission as both PV and WT are connected, which also results in an 84.3 % of the renewable fraction. GHG emission is significantly lower compared to BS during the comparison with the other two scenarios. Fig. 13 shows the GHG emission for the considered scenarios.

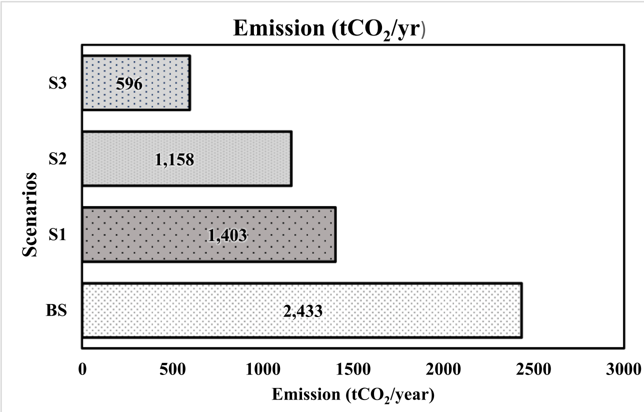

Fig. 13. Annual Carbon emission from different scenarios.

Fig. 14 depicts this annual generation and consumption, as well as sales and purchases in various scenarios. For S3, energy purchase from the grid is comparatively lower, and energy sales to the grid are highest than in other scenarios.

3.5. Comparison of the proposed system using three different WT's

In order to achieve maximum power production, the appropriate component should be selected depending on the resources. For instance, the minimum wind speed at the selected location is 3.5 m/s. A turbine that can operate well at this windspeed should be installed for sufficient power extraction from wind resources. Furthermore, hub height has a significant impact on electricity generation. In Fig. 15**,** three different WT's are compared, and the most efficient one is considered for this assessment.

According to the comparison, the WT with a lower cut-in speed and a higher hub height contributes to maximum power generation in the selected location, resulting in the highest renewable fraction. It is evident that proper component selection is essential for optimal power generation.

4. Discussion

4.1. Main outcomes

This section discussed the main outcomes of this research. In fact, S3 (PV-WT-Grid) is the most feasible scenario considering NPC, COE, renewable fraction, and payback period, which is shown in Fig. 16.

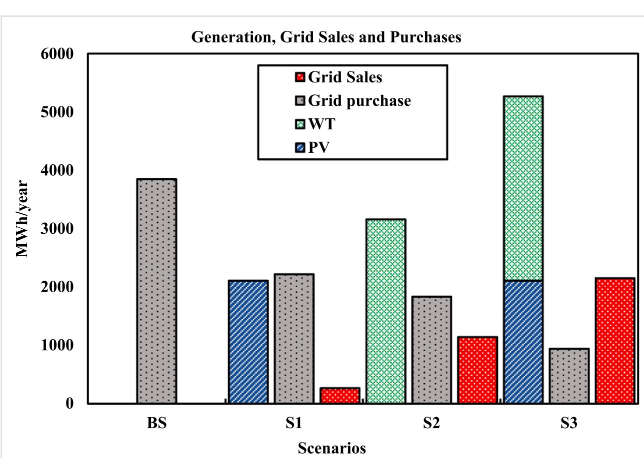

Fig. 14. Energy distribution of different scenarios.

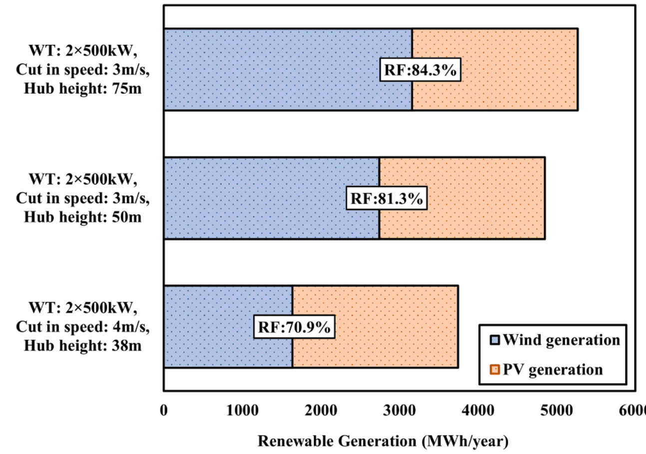

Fig. 15. Output comparison from three different WT's.

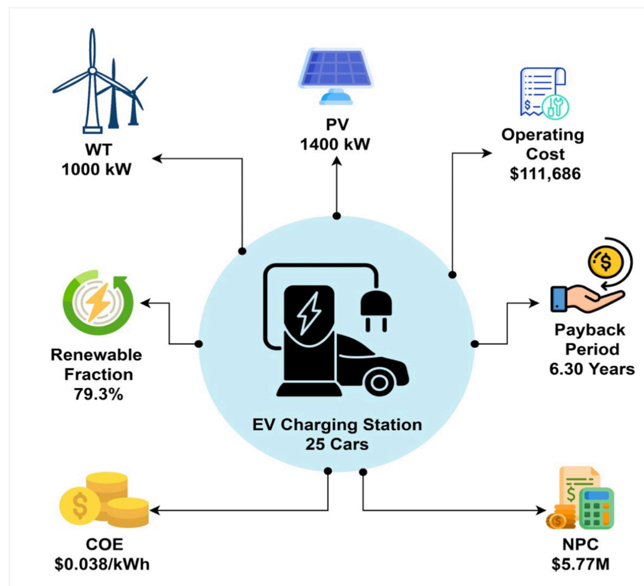

Fig. 16. Outcomes of the proposed EVCS.

Achieved renewable fraction of the microgrid is 84.3 %, whereas the payback period is 6.30 years. NPC of the system is $5.77 million, and the COE is $0.038/kWh. The proposed microgrid will enhance the use of renewable energy sources to the considered location at a considerable cost. Also, the proposed microgrid sells surplus energy to the grid to reduce power outages. The reduction of GHG from EVCS plays a pivotal role in reducing environmental impacts [59].

4.2. Contribution to the literature

This section is mainly focused on contribution to the literature of this research. Previous research works on EVCS [60–62] were based on synthetic or assumed load profiles which doesn't give a clear picture of the day-to-day load variability. Considering this aspect of this research, the load profile was developed with the help of a predictive model. In addition, a detailed plan for EVCS was presented for future urban planners in the context of urban planning, which is also considered another uniqueness of this research work. However, this perspective was not considered in the literature [63–65]. In summary, in this research, several years of historical weather data, ToA-ToD, and RNN-LSTM were utilized as a predictive model to develop the load profile for a certain demand of the EVCS by using fuzzy logic. Besides, this research gives a clear idea about the EVCS of CGP International Airport considering several aspects of proposed planning, predicting load and number of EVs in EVCS, and detailed economic analysis and emission analysis. Without any doubt, this study will assist decision-makers in determining the best adoption of integrating EVCS using renewable energies not only in Bangladesh but also in developing nations.

5. Conclusion

The article proposed a detailed design of grid-connected EVCS for CGP International Airport in Chattogram, Bangladesh. Moreover, fuzzy logic and the RNN-LSTM network are used to forecast the load profile of the EVCS. During this load prediction, various aspects were taken into consideration, including several years of weather data, battery SOC, vehicle occupancy, and airport flight schedules. Among the four scenarios, the S3 (PV-WT-Grid) appears to be the most optimized approach for providing power to the charging station, with an average load of 10.54 MWh/day and a maximum load of 1.02 MW. The factors for selecting the scheme as the best option are summarized below:

- Using both PV arrays and WTs maximizes the use of inherently intermittent renewables. Furthermore, PV arrays can only be utilized during the daytime. Thus, adding WTs would ensure power availability throughout the day.
- The proposed solution offers the lowest NPC, COE, and operating cost for the implemented resources (PV array and WT) and generates maximum profit for the charging station with a reasonable charging cost.
- Similarly, S3 had the lowest GHG emissions among the four scenarios analyzed in this research. S3 reduces carbon emission is reduced by 75 % compared to grid only solution. When comparing S1 and S2 to the BS, emissions can be lowered by 42 % and 52 %, respectively.
- S3 has the highest renewable penetration with an 84.3 % renewable fraction. On the other hand, S1 and S2 have a significantly lower fraction of 46.1 % and 63.3 %, respectively.
- The preferred scenario offers a payback period of 2.76 years for the charging station and 10.3 years for the PV array and WT. However, other scenarios, BS and S1 are not profitable in the long term as there is no payback for the station with the considered charging cost/tariff (0.14$/kWh). For the station to generate profit, the charging cost needs to be increased to 0.17$/kWh for BS and 0.155$/kWh for S1.

Further study scope for the proposed system may include system stability assessment, charging schedule implementation to increase renewable utilization, and investigation of the implementation of the vehicle to grid technology. On top of that, a new design for the EVCS will be implemented in the future for the whole parking area among the nine lots of the airport. The analysis indicates that the renewable fraction of the proposed charging station (25 chargers) ranges from 70 % to 85 %. As a result, if the number of chargers increases in the future, then sufficient electricity will be accessible from renewable sources. By proposing an in-depth EVCS implementation plan and emphasizing the relevance of renewables, this study can be of assistance to policymakers, academics, and stakeholders involved in the transition to a sustainable and renewable energy future.

CRediT authorship contribution statement

Sayeed Hasan: Conceptualization, Methodology, Software, Formal analysis, Investigation, Resources, Writing – original draft, Visualization. **Mohammad Zeyad:** Conceptualization, Methodology, Software, Validation, Investigation, Resources, Visualization, Project administration, Supervision, Writing – original draft, Writing – review & editing. **S. M. Masum Ahmed:** Methodology, Software, Validation, Investigation, Resources, Visualization, Project administration, Conceptualization, Supervision, Writing – original draft, Writing – review & editing. **Dewan Mahnaaz Mahmud:** Software, Formal analysis, Resources, Writing – original draft. **Md. Sadik Tasrif Anubhove:** Software, Formal analysis, Resources, Writing – original draft, Visualization. **Eftakhar Hossain:** Resources, Writing – original draft.

Declaration of Competing Interest

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

Data availability

Data will be made available on request.

Acknowledgments

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