

## Designing Solar-Powered Electric Vehicle Charging Stations for the Development of Future Green Cities

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### ABSTRACT

This paper presents an overview of the ideas, general design, and preliminary cost estimation for electric vehicle charging stations in planned areas. The selection of a charging station model that integrates solar panels connected to the national grid, having energy storage unit is discussed. This model is suitable for certain urban areas with potential for solar energy usage in electricity generation, contributing to efficient energy use, emission reduction, and decreased electricity consumption from the national grid, aiming towards zero-emission cities and environmental protection. The calculation process is based on the technical specifications of the Vinfast electric vehicle, with a battery capacity of 42kWh. The preliminary estimates of the research indicate that the initial investment cost is very high. However, the potential for capital recovery from the system is quite rapid and feasible upon implementation. The research calculations show that an integrated solar energy electric vehicle charging station system is feasible for the Ba Trø town area in Quang Ngai province. The research results provide a planning orientation for technical infrastructure systems in sustainable and modern urban development in the coming years.

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## 1. Introduction

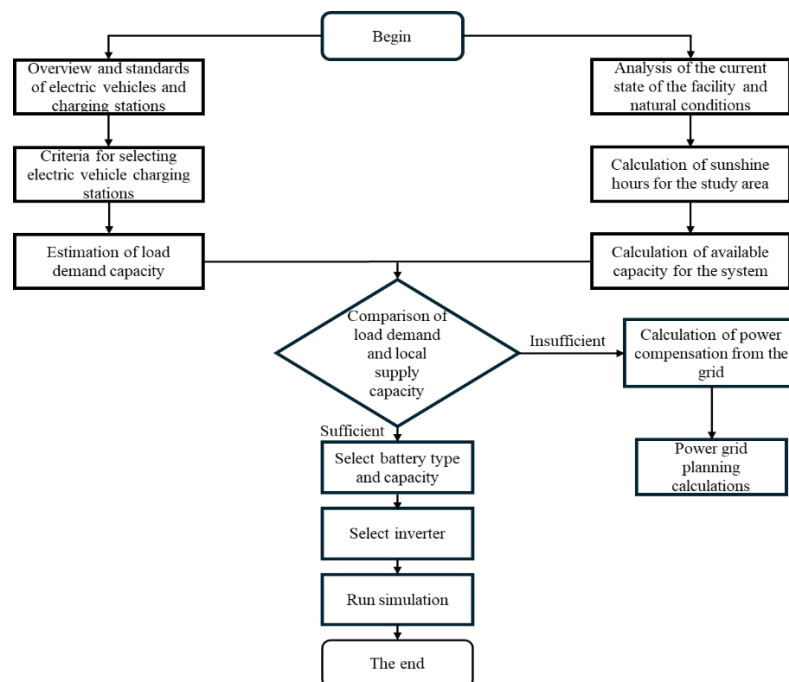
The rapid development of electric vehicles (EVs) is a good solution to energy and environmental issues [1], [2], [3]. Consequently, the demand for electric vehicle charging stations in urban areas is increasing. According to Quang Ngai online news, as of 2021, the province has over 1.24 million people, with more than half owning gasoline-powered vehicles. This contributes to the increase in greenhouse gas emissions. Building a network of EV charging stations within urban technical infrastructure is a crucial step, aligning with the development trend towards smart or green cities in the future. Some previous studies on this topic include [4], which presents a planning model considering the road network structure, vehicle flow information, distribution system structure, and constraints on charging station distribution. The study indicates that the road network and traffic flow directly impact the location of charging stations. The models and methods presented in the paper primarily aim to coordinate the influence of these factors to find the optimal planning scheme. In [5], a model is proposed that considers charging requirements, the economy, and the grid safety of electric vehicles to address the issue of charging station planning using a genetic algorithm in MATLAB. In [6], the design, simulation, and economic analysis of a grid-connected solar energy system for an EV charging station at Thu Dau Mot University are presented. The study estimates the efficiency of the PV system and its potential to reduce CO<sub>2</sub> emissions. Economic issues still exist, resulting in low investment efficiency due to long payback periods. In [7], the technical and economic analysis under different solar irradiation conditions in Vietnam for optimizing PV-powered EV charging stations is presented. The optimal configuration and investment efficiency of PV-powered EV charging stations in each urban area are significantly influenced by the solar irradiation value and the feed-in tariff (FIT) of rooftop solar energy. In [8], Chandra Mouli and the research team compared various EV charging configurations to reduce grid

dependency and maximize the use of solar energy. However, due to seasonal variations in sunlight, the local storage system still cannot completely eliminate grid dependency, with the average daily PV energy production differing fivefold between summer and winter. Jensanyayut [9] presented an analysis of installing solar-powered charging stations within the power distribution system. The content of the paper serves as a practical resource for evaluating and determining suitable values in the design of solar-powered charging stations for electric vehicles within the power distribution system. Muharmamad Akmal and his colleagues [10] presented the design and installation of a solar-powered charging station system for EVs in the UAE environment. The determination of the optimal location for EV charging stations has attracted significant attention from researchers. In [11], [12], authors suggest methods for analyzing approaches, objectives, and constraints to identify the best location for charging stations and assess the impact of charging load on the distribution network. In [13], Ngoc presented a method for calculating the battery system for an electric vehicle, ensuring that the output power is identical to that of the original internal combustion engine vehicle. The vehicle uses only Li-ion batteries, providing a range of nearly 300 km per charge. Additionally, Huynh Quoc Viet in [14] applied fuzzy logic to control traction force to optimize the power management of hybrid electric vehicles (HEVs) and analyzed its effectiveness through several test cycles such as NEDC and UDDS. The HEV model was implemented using Matlab/Simulink, with simulation results showing significant improvements in fuel consumption efficiency. Phap Vu Minh et al. [15] presented a study analyzing the optimal configuration of solar-powered EV charging stations in Vietnam, considering various solar radiation conditions.

This study focuses on designing electric vehicle charging stations integrated with solar power systems, aiming not only to meet charging demand but also to contribute to efficient energy use and environmental protection. The calculation and design process is based on the technical specifications of Vinfast electric vehicles and the solar energy potential in the Ba Tơ town area of Quang Ngai province. This study also emphasizes optimizing the locations of the charging stations, ensuring they are placed in positions that best utilize solar energy and are convenient for electric vehicle users. It contributes to the planning of technical infrastructure systems for sustainable urban development in the future.

## 2. Materials and Methods

The steps to carry out the research process for designing solar-powered electric vehicle charging stations are conducted in stages, from general to detailed interms of planning, economic, and technical issues and shown in Figure 1.



**Figure 1.** Flowchart for the research and calculation process of designing solar-powered electric vehicle charging stations

## 2.1. Electric vehicle and electric charging station analysis

### 2.1.1. Electric vehicle

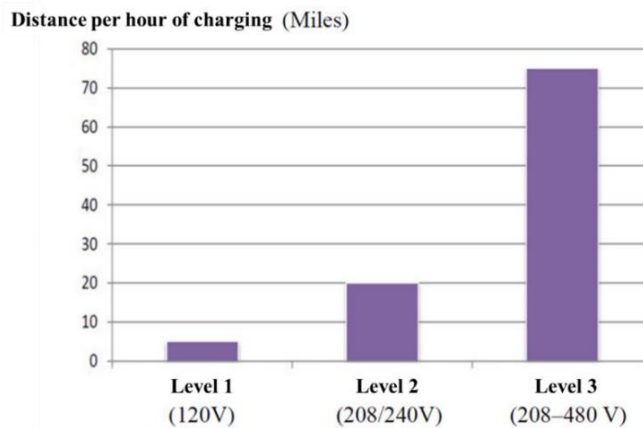
Electric vehicle includes Battery electric vehicles (BEV), Plug-in Hybrid Electric Vehicles (PHEV), Hybrid electric vehicles (HEV) and Extended Range Electric Vehicles (EREV).

### 2.1.2. Modes for electric vehicle charging stations

An overview of the charging levels at electric vehicle charging stations is presented in Table 1. A chart illustrating the distance traveled by the vehicle per hour of charging at charging levels is depicted in Figure 2. The charging levels consider factors such as charging voltage, current type, active power, maximum output power, charging time, and charging connector type.

**Table 1.** Overview of charging levels in electric vehicle charging stations

	Level 1	Level 2	Level 3
<b>Charging voltage</b>	120 V	208/220 V	200 – 450 V
<b>Current type</b>	AC	AC	DC
<b>Active power</b>	1.4 kW	7.2 kW	50 kW
<b>Maximum output power</b>	1.9 kW	19.2 kW	150kW
<b>Charging time</b>	12h	3h	20'
<b>Charging connector</b>	J1772	J1772	J1772 Combo, CHAdeMO and super fast charging



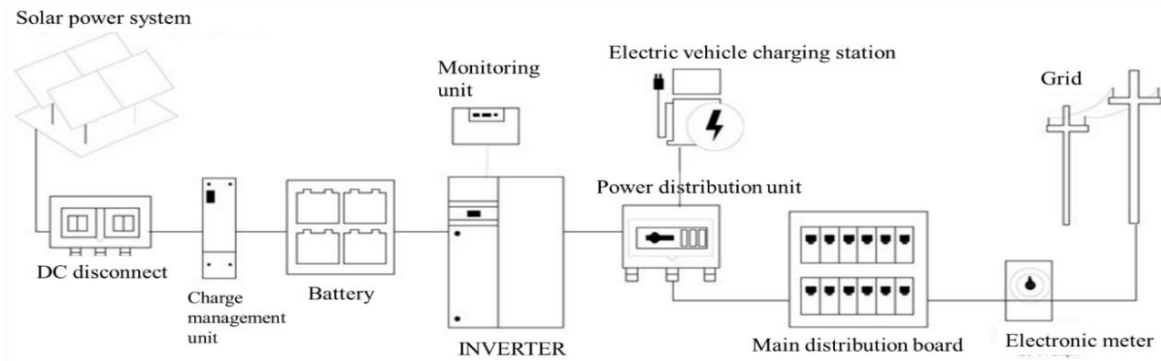
**Figure 2.** The graph of electric vehicle travel distance increases with each hour of charging

## 2.2. Selection criteria for electric vehicle charging stations

Public charging stations are particularly suitable for installation at public toll plazas such as railway station, parking lots, airports, shopping centers, restaurants, hotels, and resorts.

Figure 3 shows the connection diagram of the grid-connected PV system with storage battery. The system includes: solar panels, DC disconnect, charge management unit, storage battery, inverter for DC-AC conversion, electrical cabinet for power distribution to electric vehicle charging stations, main electrical cabinet connected to the electronic meter before connecting to the grid. Electric vehicle charging stations will take electricity from the solar panel system and storage battery through the inverter controller and power distribution unit. In case the solar panel system is not enough to supply, the charging station will take electricity from the local power grid.

### 2.3. Grid-connected solar PV model with backup grid



**Figure 3.** Grid-connected solar PV model with backup grid

### 2.4. Analysis of current status and natural conditions of the project

The design location of the electric vehicle charging station is at the parking lot of the commercial and service project, on the sidewalk of a park belonging to an entity in downtown Ba To town, Ba To district, Quang Ngai province. This area has great potential for solar energy development, with an average annual radiation intensity of 3.489 kWh/m<sup>2</sup>/day. Total annual sunshine hours in Quang Ngai range from approximately 2000 to 2600 hours, with monthly averages of 150 to 200 hours. Based on data from GLOBAL SOLAR ATLAS extracted by coordinates of Quang Ngai province (Latitude: 14.963535°; Longitude: 108.664263°), the following data are obtained: Global horizontal irradiation (GHI): 1652.4 (kWh/m<sup>2</sup>/day), Direct normal irradiation (DNI): 1172.9 (kWh/m<sup>2</sup>/day), Global tilted irradiation for optimized surface (GTI): 1658.3 kWh/m<sup>2</sup>/day, Maximum tilt angle for daily productivity optimization: 8/180°, Potential photovoltaic energy output (PVOUT): 1335.6 kWh/kWp/day.

The location of the electric car charging station is located in the design area integrated into the parking lot of the commercial - service project and the access route to the residential park. It is situated north of prominent landmarks such as Ba To district hospital, Ba To uprising monument, and Ba To museum. This location not only serves the 788 residents living in the area but also welcome over 10,000 neighboring residents and visitors. This paper proposed to use 4-seater electric cars to facilitate transportation for residents, nearby residents, and visitors. The required number of cars is 4 (green park) and 7 (commercial center). Technical specifications of the vehicle (Vinfast E34) is shown in [16].

### 2.5. Design of electric vehicle charging station

#### 2.5.1. Calculation parameters

Based on the technical specifications of the vehicles, the power consumption is equal to the battery capacity of 42 kWh per vehicle. There will be 1 station per vehicle, with each station charging 6 times per day.

Power consumption per day by the load

$$A_{ng-GREEN PARK} = 42 \times 4 \times 6 = 1008 kWh \quad (1)$$

$$A_{ng-COMMERCIAL} = 42 \times 7 \times 6 = 1764 kWh \quad (2)$$

Total DC charging capacity needed to supply stations with charging frequency at each station

$$P_{\Sigma \text{charging}} = (1008 + 1764) \times 0.8 = 2217.6 kW \quad (3)$$

The output of solar electricity generated

$$E = \frac{2278 \times 1134}{1000} \times \frac{22.26}{100} \times 5.48 \times 0.9 = 2836.06 kWh \quad (4)$$

Calculation on the number of sunny hours in a day

- + The average actual sunlight hours per day in Quang Ngai range from 6 to 8 hours/day. Occasionally, sunlight hours can reach up to 10 hours/day with low frequency and different radiation intensity. For long-term calculations and stable conditions, we choose 8 hours/day as the standard sunlight hours.
- + The number of kWh of electricity generated by a 1kWp solar panel system is calculated as follows:

$$1 \text{ kWp} \times 8 \text{ h/day} = 8 \text{ kWh/day} \quad (5)$$

- + This means that there are 8 sunlight hours per day, a 1 kWp generates approximately 8 kWh of electricity per day in average. Therefore, over the course of one month, the solar battery system would produce 180 kWh of electricity.

Therefore, the DC power that the system needs to generate

$$P_{PV.DC} = \frac{2836.06}{8} = 354.51 \text{ kW} \quad (6)$$

From (1) and (2), we establish the following ratio:

$$\Delta P = \frac{P_{PV.DC}}{P_{\Sigma sac}} = \frac{354.51}{2217.6} = 0.16 = 16\% \quad (7)$$

Therefore, solar energy provides 16% (equivalent to 354.816 kW) of the electric vehicle charging demand, necessitating an additional 84% (equivalent to 1862.784 kW) from the grid to ensure the charging process for the charging stations. Hence, we have the load demand for charging stations at the green park and commercial service facilities as follows:

$$A'_{ng-GREEN PARK} = 1008 \times 0.16 = 161.28 \text{ kWh} \quad (8)$$

$$A'_{ng-COMMERCIAL} = 1764 \times 0.16 = 282.24 \text{ kWh} \quad (9)$$

From geographical location data, we have the parameters presented in Tables 2 and Table 3.

**Table 2.** Total solar irradiance in the atmosphere horizontally by month ( $H$ , kWh/m<sup>2</sup>/day).

Province, City	Month											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Quang Ngai	3.95	4.82	6.03	6.54	6.83	6.56	6.71	6.53	5.88	4.97	3.76	3.17

**Table 3.** Conversion factor table for total irradiance  $R$  between a surface tilted 10° facing west relative to the horizontal surface.

Province, City	Month											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Quang Ngai	1.04	1.03	1.02	0.99	0.97	0.96	0.96	0.98	1.00	1.02	1.03	1.03

### 2.5.2. PV capacity

PV capacity in January is as shown below:

$$P_{PV} = \frac{W}{R \times H \times V} = \frac{161.28}{3.95 \times 1.04 \times 0.76} = 51.66 \text{ kWp} \quad (10)$$

Similarly, calculations for the remaining months, the results are presented in Table 4.

**Table 4.** PV power capacity by month

Projects	PV power capacity (kWp)					
	I	II	III	IV	V	VI
GREEN PARK	51.66	42.74	34.50	32.78	32.03	33.70
COMMERCIAL	90.40	74.80	60.38	57.36	56.05	58.97
	VII	VIII	IX	X	XI	XII
GREEN PARK	32.94	33.16	36.09	41.86	54.80	64.99
COMMERCIAL	57.65	58.03	63.16	73.26	95.89	113.74

From Table 4, it can be observed that December has the highest PV power capacity: The PV capacity for GREEN PARK is highest at 64.99 kWp to ensure generation of  $\geq 161.28$  kWh/day all days of the year. The PV capacity for COMMERCIAL is highest at 113.74 kWp to ensure generation of  $\geq 282.24$  kWh/day throughout the year.

### 2.5.3. Option selection

The PV capacity option is chosen equal to the calculated capacity (64.99 and 113.74 kWp) and combined with grid tie.

The average electrical energy generated in January with PV capacity was 64.99 kWp

$$W_{January, AVERAGE} = 64.99 \times (3.95 \times 1.04 \times 0.76) = 202.92 \text{ kWh/day} \quad (11)$$

Similarly, calculations for the remaining months are presented in Table 5 and Table 6.

**Table 5.** Average electricity generated by SOLAR SYSTEM (64.99 and 113.74 kWp) per month

Projects	Electrical energy (kWh/day)					
	I	II	III	IV	V	VI
GREEN PARK	202.92	245.23	303.81	319.81	327.25	311.07
COMMERCIAL	355.10	429.15	531.67	559.67	572.68	544.37
	VIII	VIII	IX	X	XI	XII
GREEN PARK	318.18	316.10	290.44	250.40	191.30	161.28
COMMERCIAL	556.82	553.17	508.28	438.21	334.77	282.24

**Table 6.** Electricity generated by SOLAR SYSTEM (64.99 kWp and 113.74 kWp) throughout the year

Projects	Electrical energy (kWh/day)						
	I	II	III	IV	V	VI	VII
GREEN PARK	6087.45	7356.81	9114.29	9594.41	9817.43	9332.12	9545.51
COMMERCIAL	10653.05	12874.42	15950.00	16790.22	17180.50	16331.21	16704.64
	VIII	IX	X	XI	XII	Whole year	
GREEN PARK	9482.97	8713.30	7512.11	5738.92	4838.40	97133.72	
COMMERCIAL	16595.20	15248.27	13146.19	10043.11	8467.20	169984.01	

#### 2.5.4. Photovoltaic panel selection

Based on the design plan, the selection of photovoltaic panels is carried out. The technical specifications of the solar panels are presented in [17]. Choosing the Jinko Solar panel model JKM575N-72HL4 with a rated power of  $P_{max} = 432, Wp = 0,432 kWp$ , we calculate the number of panels (N) needed to install under normal operating cell temperature (NOCT) conditions.

$$N_{GREEN PARK} = \frac{64,99}{0,432} = 150 \text{ (panels)} \quad (12)$$

$$N_{COMMERCIAL} = \frac{113,74}{0,432} = 263 \text{ (panels)} \quad (13)$$

#### 2.5.5. Selecting the structure and calculating the technical specifications for the inverter.

Due to the large-scale power requirements of the electric vehicle charging station system, a decentralized multi-string inverter structure is chosen, utilizing a three-phase inverter.

DC input power of the inverter:

$$P_{INV.DC-GREEN PARK} = 1.1 \times 64.99 = 71.49 kWp \quad (14)$$

$$P_{INV.DC-COMMERCIAL} = 1.1 \times 113.74 = 125.114 kWp \quad (15)$$

Inverter power factor selection:  $C_{INV} = 1.15$

AC output power of the inverter

$$P_{INV.AC-GREEN PARK} = \frac{67.7}{1.15} = 56.51 kW \quad (16)$$

$$P_{INV.AC-COMMERCIAL} = \frac{113.74}{1.15} = 98.9 kW \quad (17)$$

Choosing the SMA Sunny Tripower Core2 110kW inverter, having the following specifications: Maximum efficiency: 98.6%, Open-circuit voltage:  $V_{OC(mod-t^0min)} = 48.33 V$  at  $45 \pm 2^\circ C$ , Maximum input DC voltage:  $V_{in.IVT} = 1100 V$ , Maximum apparent AC power:  $V_{out.IVT} = 400 VA$ .

The maximum number of modules (solar panels) in a string is calculated as follows:

$$N_{mod.max-CVCX/TMDV} = \frac{1100}{48.33} = 22 \text{ (modules)} \quad (18)$$

Maximum current of the inverter string.

$$I_{max.INV-GREEN PARK} = \frac{56.51 \times 1000}{400 \times 0.986} = 143.28 A \quad (19)$$

$$I_{max.INV-COMMERCIAL} = \frac{98.9 \times 1000}{400 \times 0.986} = 250.76 A \quad (20)$$

The maximum current of each module in a string is taken according to the module specifications. Since the photovoltaic modules are connected in series in a string, we have the following (refer to the catalog according to NOCT):

$$I_{array.max} = I_{module.max} = 11.62 A \quad (21)$$

The number of strings (parallel circuits) in the system is calculated as follows:

$$N_{array.max-GREEN PARK} = \frac{143.28}{11.62} = 13 \text{ array} \quad (22)$$

$$N_{array.max-COMMERCIAL} = \frac{250.76}{11.62} = 22 \text{ array} \quad (23)$$

Conclusion: Installation area 1 – Green park sidewalk: 110 kW inverter, 7 strings connected in parallel, each string consisting of 22 modules connected in series (150 modules in total),  $P_{PV} = 64.8 \text{ kWp}$ . Installation area 2 – Commercial or Trade facility parking lot: 110 kW inverter, 12 strings connected in parallel, each string consisting of 22 modules connected in series (263 modules in total),  $P_{PV} = 113.62 \text{ kWp}$ .

Area required for the system installation

$$S_{sys-GREEN PARK} = [(2.278 \times 1.134) \times 22] \times 7 = 397.82 \text{ m}^2 \quad (24)$$

$$S_{sys-COMMERCIAL} = [(2.278 \times 1.134) \times 22] \times 13 = 738.81 \text{ m}^2 \quad (25)$$

Total DC power of the system

$$\sum P_{DCsys} = 64.8 + 113.62 = 178.42 \text{ kWp} \quad (26)$$

Average monthly electricity generation

$$W = \sum P_{DCsys} \times (R \times H \times V) = 178.42 \times 30 \times (3.95 \times 1.04 \times 0.76) = 16711 \text{ kWh} \quad (27)$$

Table 8 shows the electricity production capability of the solar panel system for each month

**Table 7.** Electricity production capability of the solar panel system

Month	Electricity output of the solar panel system						
	I	II	III	IV	V	VI	VII
	16711.25	20195.87	25020.49	26338.52	26950.75	25618.49	26204.27
Electricity (kWh)	VIII	IX	X	XI	XII	Whole year	
	26032.61	23919.70	20622.20	15754.46	13282.35	266650.95	

### 2.5.6. Energy storage battery selection

Based on the generated electrical energy data and the potential number of vehicles in the area, the selection of storage battery units is carried out with the technical specifications as shown in [18].

### 2.5.7. Calculation and selection of electric vehicle charging stations

From the calculation results in section 5.1, we can also determine the power demand supplied from the grid.

$$P'_{ng-GREEN PARK} = 1008 \times 0.8 \times 0.84 = 677.376 \text{ kW} \quad (28)$$

$$P'_{ng-COMMERCIAL} = 1764 \times 0.8 \times 0.84 = 1185.408 \text{ kW} \quad (29)$$

Calculating the apparent power rating of the transformer station

$$S'_{ng-GREEN PARK} = \frac{677.376}{0.85 \times 1.1974} = 666 \text{ kVA} \rightarrow \text{Choose } S_{TBA-08} = 750 \text{ kVA} \quad (30)$$

$$S'_{ng-COMMERCIAL} = \frac{1185.408}{0.85 \times 1.1974} = 1165 \text{ kVA} \rightarrow \text{Choose } S_{TBA-07} = 1250 \text{ kVA} \quad (31)$$

Power supplied to each charging station

$$P_{Station-GREEN\ PAK} = \frac{677.375}{4} \times 0.5 = 84.67\ kW \rightarrow \text{Choose } 90\ kW\ DC\ (Vinfast) \quad (32)$$

$$P_{Station-COMMERCIAL} = \frac{1185.408}{7} \times 0.5 = 84.67\ kW \rightarrow \text{Choose } 90\ kW\ DC\ (Vinfast) \quad (33)$$

### 2.5.8. Financial analysis

Based on the design results of the above sections, cost calculation statistics from the design solution are given, the results are presented in Table 8.

**Table 8.** Statistical table of cost calculations from design solution

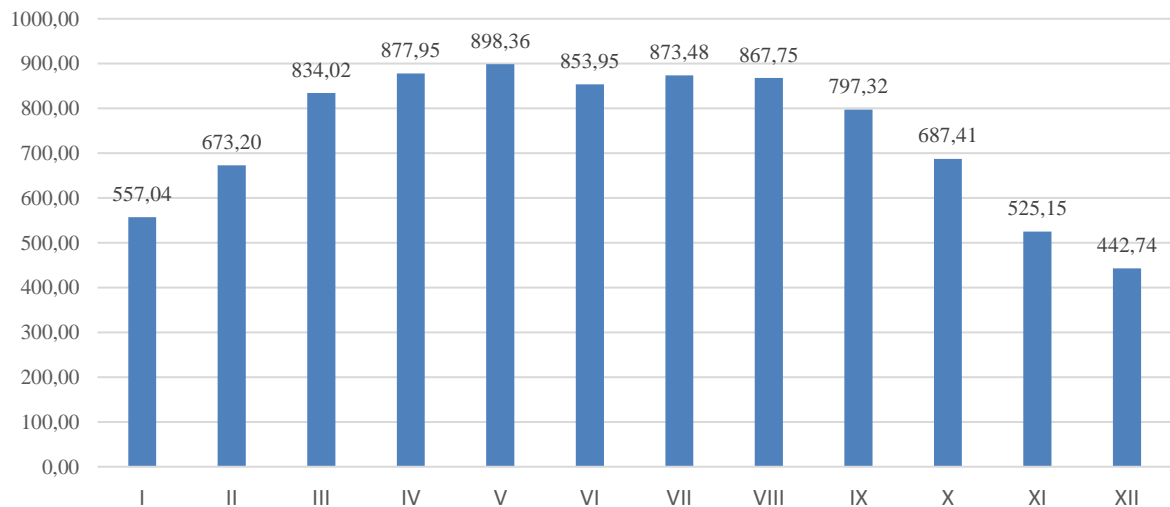
Calculation factors	Results	Units
Prime cost	73 933 402 130	VND
Operating electricity cost	410 109 161	VND
Revenue from selling electricity from charging electric vehicles	45 557 870 952	VND
Payback period	1.62	Year

## 3. Results and Discussion

Based on the calculations presented in Section 2, the results of electricity output from the proposed solution are summarized and presented in Table 9. Simulations of the installation locations for the charging stations at the green park sidewalk (area 1) and at the commercial center parking lot (area 2) are illustrated in Figure 5 and Figure 6, respectively.

**Table 9.** Statistical table of electricity output from the design solution

Interpretation	Results
Electricity output from the PV panel system	$E_{PV} = 740.69\ kWh$
Electricity supplied from the grid	$E_{Gr} = 2352.88\ kWh$
Electricity used by electric vehicles charged from the PV system	$E_{EV.PV} = 443.52\ kWh$
Electricity used by electric vehicles charged from the grid	$E_{EV.Gr} = 2328.48\ kWh$



**Figure 4.** Average electricity output generated from SOLAR SYSTEM during the day

It is suitable to exploit and use solar energy integrated into electric vehicle charging stations as depicted in the urban planning. Hence, implementing the plan for electric vehicle charging stations in Ba To town is both reasonable and should be actively implementation. However, the implementation of planning for electric vehicle charging stations still requires consideration of several factors: technical specifications, the calculated quantity of panels exceeds the limits ( $\geq 150$  per area). The sheer volume of solar panels suggests a need to reassess the entire system to devise a solution for this scenario. Furthermore, the problem does not yet depict the installation locations of the solar panels to calculate technical indices for adjusting the light absorption levels from the panels such as the shade of the panels and the influence of the outside environment, coverage from the surrounding environment, external impacts on the panels, etc. Consequently, it is challenging to determine the specific scale of the system accurately; the calculations thus far only provide a relative estimation.



**Figure 5.** Simulation of charging station installation at Green Park Sidewalk (Area 1) and Commercial Center Parking Lot (Area 2)

This article is based on practical studies conducted in Ba To town to guide the planning of electric vehicle charging stations using solar energy, aiming towards a future green city. However, to implement the specific project, various additional factors need consideration. This article provides only a broad overview of the electric vehicle charging stations in terms of conceptual ideas, overall design, and preliminary cost estimation for the system construction. Therefore, this study serves as a reference and introductory material for future related research.

The future development direction for this project is to propose further research into rooftop solar energy systems, integrated solar lighting systems, and optimizing electric vehicle charging station systems combined with information technology for management and operation, aiming towards a green and smart city in the future.

#### 4. Conclusions

By selecting a model of grid-connected solar panel system with backup, the calculation process is implemented based on the technical specifications of the Vinfast electric vehicle with a battery capacity of 42 kWh, using a single station with 6 charging times per day. The calculated results show that the output of electric vehicles charged from the PV system is 443.52 kWh/day and that of electric vehicles charged from the national grid system is 2328.48 kWh/day (where solar energy accounts for up to 16% of the total system energy). Based on the preliminary estimation from the system scale, the initial investment cost is very large; however, the system's payback period is relatively short, specifically 19.47 months (including all associated costs). The calculations of this study demonstrate that the integrated solar-powered electric vehicle charging station is feasible for the Ba To town area. However, based on the details provided in the paper, the calculations and design are limited to the conceptual and directional stages.

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## Conflict of Interest

The authors declare no conflict of interest.

## Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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