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Analysis Development of Public Electric Vehicle Charging Stations Using On-Grid Solar Power Plants in Indonesia

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ABSTRACT

Indonesia, abundant in solar energy, poses significant potential for harnessing this renewable resource for electricity generation. This study investigates the feasibility of employing photovoltaic (PV) modules, powered by solar energy, for electric vehicle (EV) charging stations in Surakarta, Yogyakarta, Semarang, Surabaya, and Malang. Utilizing the Hybrid Optimization Model for Electric Renewable (HOMER) software, simulations were conducted to assess on-grid Solar Power Plants (PLTS) systems that leverage both PV modules and grid power. This research enhances existing studies on solar energy potential in Indonesia, emphasizing profitable renewable energy business models. Economic evaluations were conducted based on the Net Present Cost (NPC) and the Cost of Energy (COE), integral metrics for determining investment feasibility. Preliminary capital for PLTS development was estimated at Rp 5,399,387,501.00. Results indicate Semarang City as the most promising location for a PLTS system with an NPC value of Rp 23,243,190,000.00 and a COE value of Rp 1,108.11. The designed PLTS system in Semarang City is projected to generate 982.090 kWh/year of electricity, with estimated consumption at 922.467 kWh/year. This study offers novel insights into the potential of solar-powered EV charging stations in Indonesia.

1. INTRODUCTION

Indonesia is a tropical country located right on the equator. Indonesia is located at 6° north latitude-11° south latitude, and 95° east longitude-141° longitude. This can indicate that Indonesia will be illuminated by the sun throughout the year. Therefore, Indonesia has enormous potential for developing solar resources [1, 2]. This abundant solar resource must be balanced with maximum utilization, one of which is as a source of electrical energy. Electrical energy is one of the most needed energy by everyone. Electricity can be used as a benchmark for the level of welfare in an area where the community's welfare can be said to increase if the need for the use of electrical energy increases. The source of electrical energy is still dependent on fossil fuels, whose existence is increasingly depleted [3]. The conventional power plants is a separate problem for certain areas, because of which air pollution is getting worse, fossil fuels tend to be limited, so that fuel prices always go up and cause large investment costs in the future. Therefore, alternative energy sources are needed for electrical energy generation.

Solar energy is an alternative energy that can be used as a source of electricity generation, one of which is for the needs of an electric vehicle charging station [4]. Solar energy is an alternative energy that can be used as a source of electricity generation. Currently, the use of solar energy is still limited to supporting household activities such as drying clothes, as well as supporting industries that require drying activities. The potential of solar energy for electricity generation has not been fully utilized in Indonesia. The solar power plant (PLTS) uses sunlight to generate electricity DC (Direct Curent), which can be converted into AC (Alternating Curent) power [5]. The generation of electricity from the sun can be achieved using solar PV (SPV) systems or through concentrating solar-thermal power (CSP) systems that drive conventional turbines [6, 7]. Even though the initial investment costs are much more expensive in the short term, installing PLTS will provide sustainable electricity cost savings and financial benefits in the long term for up to 25 years [8-10]. In an era of climate change and the need for more sustainable mobility, electric vehicles offer a promising solution for reducing greenhouse gas emissions, air pollution, and dependence on fossil fuels [11, 12]. With ever-evolving technology and growing government support, electric vehicles are becoming attractive for drivers worldwide. To achieve sustainable economic development in the future, we need to secure electrical energy at a minimum cost and be safe for the environment. The main advantage of electric vehicles lies in their environmentally friendly nature. Unlike conventional motor vehicles that use internal combustion engines, electric vehicles do not produce direct emissions. This has a positive impact on air quality, reduces noise pollution, and reduces its contribution to global climate change [13, 14]. In addition, electric vehicles also offer strong performance, fast acceleration, and lower operating costs compared to fossil fuel vehicles.

This research aims to simulate the use of PV as a source of electrical energy for electric vehicle charging stations in several cities in Indonesia, namely Surakarta City, Semarang City, Yogyakarta City, Surabaya City, and Malang City. The research used the Hybrid Optimization Model for Electric Renewable (HOMER) software. The research on the design of solar home systems using HOMER has been carried out to determine the most optimal results in designing Solar Power Plants [15]. The design was carried out in two ways, namely manual design and design using HOMER software. The design using HOMER has more optimal results, although it has a higher cost than manual design. Using HOMER, results can be obtained to review the factors determining the cost-effectiveness of on-grid PV systems [16, 17]. On-grid PV system is an energy source that uses solar radiation to generate electricity. The system is connected to the PLN network by optimizing solar energy utilization through solar or photovoltaic modules to generate as much electricity as possible [8, 18]. Essential factors such as load requirements, renewable energy potential, and the capacity and composition of the power generation system, this research can address challenges related to the possibility of using grid-connected PV systems based on household power demand [19]. The output of this study is to determine the most potential areas for utilizing solar energy for EV Charging Stations by looking at several aspects of value, namely Net Present Cost (NPC), Cost of Energy (COE), electricity production per year, consumption power per year, and the return on investment after the business or break event points (BEP).

2. RESEARCH METHODS

2.1 Model description

The PLTS configuration implemented at the electric vehicle charging station uses an on-grid configuration. In making a PLTS charging station, several supporting components are needed to optimize the performance of the PLTS system. This design uses HOMER software to model the generated generator system. The components needed are PV solar panels, batteries, and converters. The PLTS system modeling in the HOMER software can be seen in Figure 1.

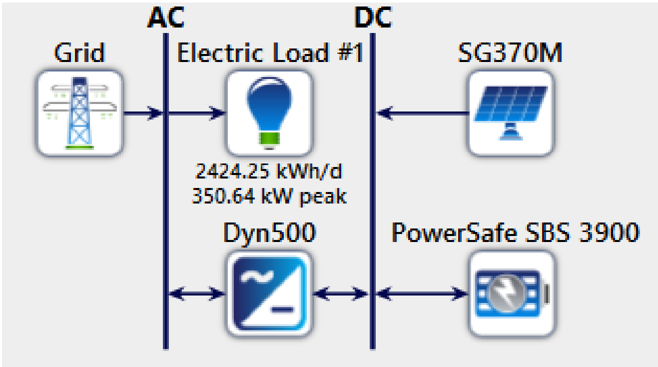


Figure 1. PLTS modeling scheme

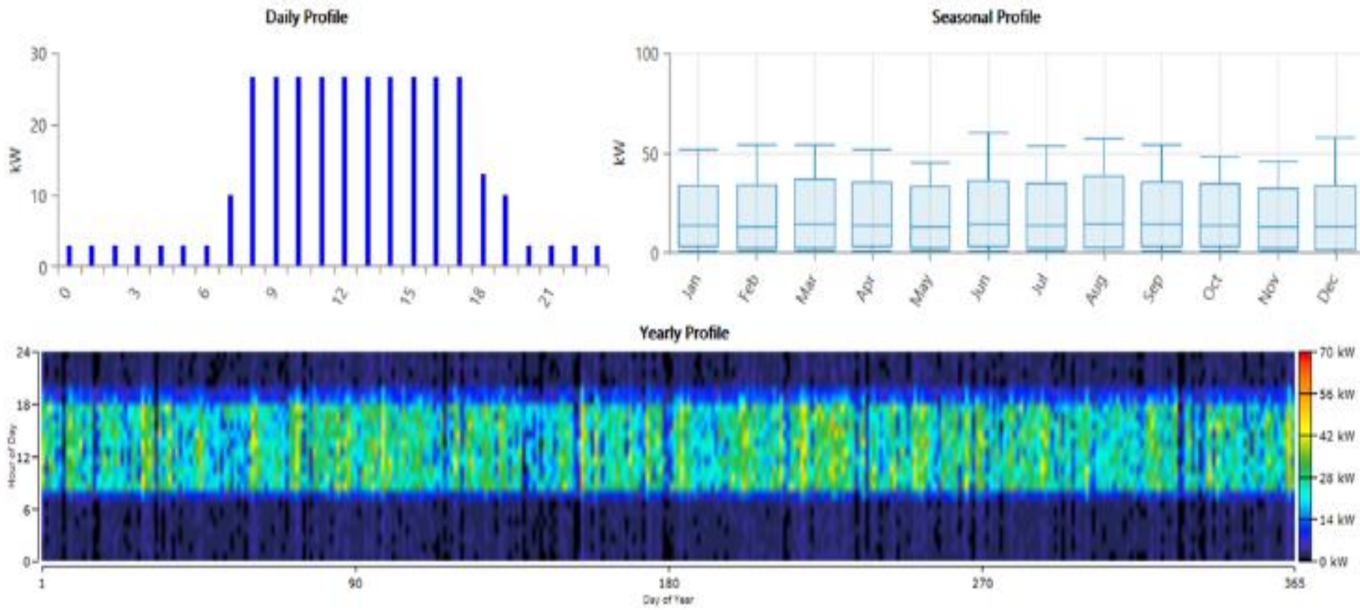


Figure 2. Electrical load profile for charging station

The consumption of the electric load in the HOMER software is estimated using the consumption load for 10 electric vehicles (EV) with a battery capacity of 26.7 kWh each day, so the total daily load is around 267 kW. Details of the electric load profile at the charging station are shown in Figure 2.

The simulated test for charging the Wulling Air-EV Long Range car with a battery capacity of 26.7 kWh and full specifications are shown in Table 1.

To carry out an economic analysis of this PLTS, it is necessary to know the initial investment costs of each component. The initial investment costs required to build a PLTS Charging Station can be seen in Table 2.

Table 1. Willing air-EV long-range specifications

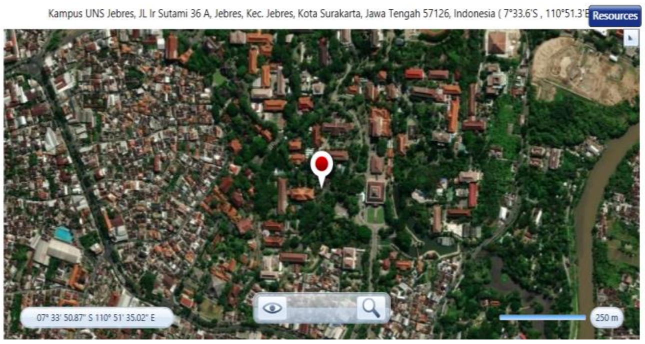
Parameter	Specification
Engine power	30 kW
Engine torque	9.34 Nm
Battery capacity	Lithium Ferro-Phosphate; IP67 Rating 26.7 kWh

Table 2. PLTS initial investment cost

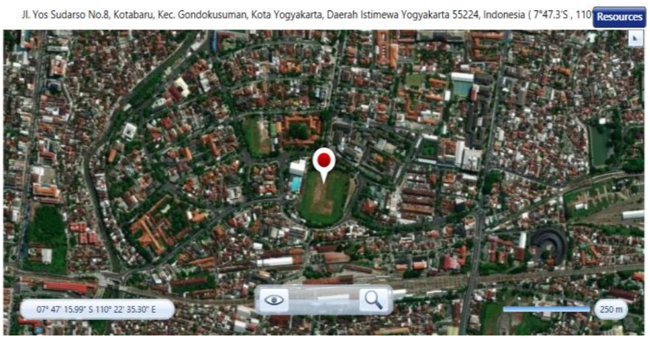
Parameter	Peimar SG370M	Enersys PowerSafe SBS 3900	Dynapower IPS-500
Capital Cost	RP 4,980,000,000.00	RP 412,200,000.00.	RP 7,187,501.00
Replacement Cost	-	RP 412,200,000.00.	RP 7,187,501.00
O&M Cost	RP 5,000,000.00	RP 4,000,000.00	RP 700,000.00
Lifetime	30	15	15

2.2 Description of PLTS design location

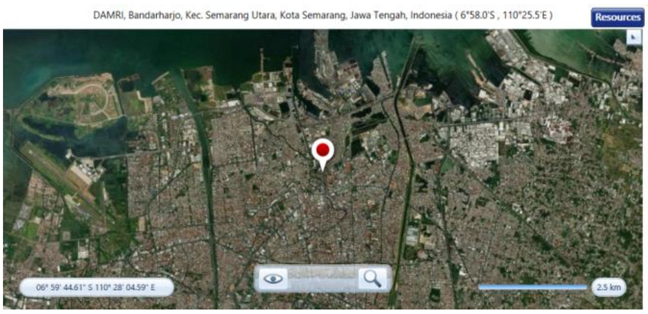
PLTS for this charging station will be simulated in several cities, namely Surakarta City, Yogyakarta City, Semarang City, Surabaya City, and Malang City, to find out which areas have the best economic potential among these cities. The HOMER application has a feature for searching and determining project locations so that from this data, Homer can download the required sources through NASA Prediction of Worldwide Energy Resources (POWER). The location of the installation plan location can be seen in Figure 3.



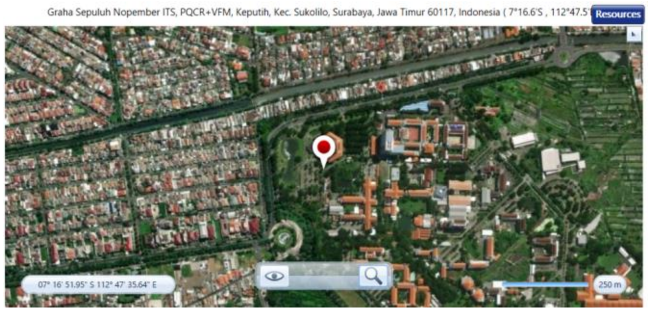
(a) Location of PLTS at Surakarta City



(b) Location of PLTS at Yogyakarta City



(c) Location of PLTS at Semarang City



(d) Location of PLTS at Surabaya City

(e) Location of PLTS at Malang City

Figure 3. Location of PLTS installation

2.3 Potential utilization of solar energy

The intensity of solar radiation affects the level of heat generated. It affects the amount of energy a power plant creates [20]. Data obtained from the NASA (National Aeronautics and Space Administration) website regarding the intensity of solar radiation and regional temperature can be used to process data regarding the potential use of solar energy for PLTS in Surakarta City, Yogyakarta City, Semarang City, Surabaya City, and Malang City. Data on the intensity of solar radiation in several cities can be seen in Table 3.

Table 3. Solar radiation intensity data

Month	1	2	3	4	5
January	2.457	2.622	2.535	2.618	2.758
February	2.596	2.603	2.603	2.827	2.919
March	3.139	3.008	3.266	3.157	3.363
April	3.432	3.365	3.565	3.521	3.839
May	3.960	3.688	4.174	4.385	4.219
June	4.254	3.789	4.327	4.821	4.533
July	4.700	3.814	4.759	5.532	4.640
August	5.018	3.826	5.060	6.144	4.876
September	4.997	3.514	5.059	6.218	5.026
October	4.022	2.958	4.041	5.101	4.320
November	3.029	2.410	3.144	3.379	3.234
December	2.576	2.231	2.400	2.295	2.679
Average	3.682	3.152	3.744	4.166	3.867
At a minimum	2.457	2.231	2.400	2.295	2.679

Notes: 1. Surakarta, 2. Yogyakarta, 3. Semarang, 4. Surabaya, 5. Malang; Radiation intensity data in kWh/m^2 units

The more excellent value of the intensity of solar radiation, the greater the level of output power efficiency that can be produced by the PLTS [21, 22]. Based on the data, it is known that the highest average intensity of solar radiation is Surabaya City, with an average radiation intensity of 4.166 kWh/m^2.

2.4 Design of PLTS component specifications

2.4.1 Methodology limitations

The configured lifespan for the created system is estimated to be 25 years. The types of components used are made same, such as the types of photovoltaic modules, inverters and batteries. The analysis of the projected return on investment is conducted using data provided in HOMER. Input data in the economic window include discount rates, inflation rates, project length, and currency. Due to the project's location in Indonesia, the currency is rupiah, a discount rate of 5.75%, and an inflation rate of 4.97% are obtained through data from Bank Indonesia [23].

2.4.2 Total load

The initial step in this design is to determine the total daily load used. The total daily load data is based on the electrical load at the charging station in general in a Solar Home System circuit in Table 4.

Table 4. Daily total load data

Afternoon (07.00-17.00)		Evening (17.00-07.00)	
O'clock	Load (kW)	O'clock	Load (kW)
7	10	18	13
8	26.7	19	10
9	26.7	20	3
10	26.7	21	3
11	26.7	22	3
12	26.7	23	3
13	26.7	0	3
14	26.7	1	3
15	26.7	2	3
16	26.7	3	3
17	26.7	4	3
		5	3
		6	3
Total (kW)	277		56
30% load increase, so the total power (kW)	285.31		57.68
Total load per day (kW)		342.99	

2.4.3 Solar panels

Solar panels, also known as solar or photovoltaic modules (PV modules), work by using the photovoltaic effect of the semiconductor material in the panel to convert solar radiation directly into electrical energy [24]. This time, the type of solar panel used in the PLTS system is a solar panel with the Peimar SG370M brand. This solar cell has the specifications shown in Table 5; the object can be seen in Figure 4.

Table 5. Solar panel specifications

Technical Specifications	Mark
Maximum power (Pmax)	370Wp
Maximum voltage (Vmp)	40.1V
Maximum current (Imp)	9.23A
Open circuit voltage (Voc)	48.93V
Short circuit current (Isc)	9.81A
Frequency	50Hz
Module efficiency	19.07%
Derating factor	80%

To find out the total capacity requirements of the solar panels to be able to supply the EV charging station, it must first know the losses in the system, the total energy of the PV module, and the capacity of the PV module along with the amount needed if the nominal power of the module is 370 Wp according to the specifications of the PV module. The amount of losses in the system can be seen in Table 6.

Figure 4. Peimar SG370M solar panel

Table 6. System losses

Type of Loss	Percentage
PV module	11.5%
Network inverters	3%
Battery inverters	6%
Wiring	2%
Battery	15%
Total loss at night	37.5%
Total daylight losses	22.5%

So that the capacity of the solar module is obtained as follows.

$$Total\ module\ energy = \frac{Night\ energy}{100\% - losses\ at\ night} + \frac{Daytime\ energy}{100\% - losses\ at\ noon}$$

$$Total\ module\ energy = \frac{57.68\ kWh}{62.5\%} + \frac{285.31\ kWh}{77.5\%}$$

$$Total\ module\ energy = 460.43\ kWh$$

Determination of the number of solar panels based on total load usage per day, total hours per day during peak sun hours of 1000 W/m^2/h through data on average solar radiation potential of 4.80 kWh/m^2/h, and the capacity of the solar panels used is 370 Wp. A simple calculation to determine the number of solar panels is as follows.

$$PV = \frac{Total\ modul\ energy}{Capacity\ of\ solar\ panel}$$

$$PV = \frac{460430}{370} = 1244.4\ or\ 1245\ PV$$

With a 370 Wp solar panel specification, 1245 PV module units are needed to meet the load requirements at the EV charging station. The cost required for 1245 units of 370 Wp solar panels is RP 4,980,000,000.00 with an operation & maintenance cost of RP 50,000,000.00. The PV module has a lifetime of 30 years, so it does not require replacement costs.

2.4.4 Inverters

An inverter is a tool used to convert DC (direct current) generated from solar panels into AC (alternating current) for use by household appliances in general [25]. The inverter output power does not depend on the load's magnitude connected with the inverter. However, it is proportional to the amount of power generated by solar panels at that time [26]. The total of all electrical loads is 342.99 kW, while the inverter used is Dynapower IPS-500. This inverter has the specifications shown in Table 7, and the object can be seen in Figure 5.

Table 7. Dynapower IPS-500 specifications

Types of Technical Specifications	Mark
Output power	500 kW
Maximum power	500 kW
Output frequency	50/60 Hz
Input dc voltage	100-1500 V
Efficiency	98.2%

Figure 5. Dynapower IPS-500

Then the power and the number of inverters needed are:

$$P_{inverter} = \frac{Total\ electrical\ loads \times 125\%}{Maximum\ power}$$

$$P_{inverter} = \frac{342990 \times 125\%}{500000} = 0.857 \text{ or } 1 \text{ inverter}$$

Therefore, the number of inverters to be used in HOMER is one inverter, which has a capacity of 500 kW. The cost required for 1 unit of this type of inverter is Rp 7,187,501.00, with an operation & maintenance cost of Rp 700,000.00. The inverter used has a lifetime of 15 years, so it requires a replacement cost of Rp 7,187,501.00.

2.4.5 Battery

Batteries are components that function as energy storage devices generated by solar panels. The battery aims to store excess electrical energy when the load requirements are low, supply electrical energy when needed at high loads, and supply energy electricity at night [27]. Without a battery, PLTS can only be used during the day or when the sun shines. The battery that will be used in the design of this PLTS system is EnerSys PowerSafe SBS 3900. The battery used is a lead acid-type battery with a voltage of 12 V and a current of 4300 Ah, which has a power capacity of 51.6 kWh. This type of battery has the specifications shown in Table 8; the object can be seen in Figure 6.

Table 8. Energy PowerSafe SBS 3900 battery specifications

Types of Technical Specifications	Mark
Normal voltage	2 V
Internal holding capacity	0.18 mΩ
Nominal capacity	4300 Ah

Figure 6. Energy PowerSafe SBS 3900 battery

The number of batteries to be used is based on the total load per day and the capacity of the batteries used. A simple calculation to determine the number of batteries is as follows.

$$Battery = \frac{Total\ electrical\ loads}{Power\ capacity\ battery \times 80\%}$$

$$Battery = \frac{342990}{51600 \times 80\%} = 8.31 \text{ or } 9 \text{ batteries}$$

Therefore, the number of batteries to be used in HOMER is 9. The cost required for 9 units of this type of battery is Rp 412,200,000.00, with operation & maintenance costs per year of Rp 4,000,000.00. The battery used has a lifetime of 15 years, so it requires a replacement fee of Rp 412,200,000.00.

3. RESULTS AND DISCUSSION

3.1 HOMER simulation results

The simulation process is carried out to get the best system configuration through the optimization process on HOMER. The simulation process models and designs the system configuration specifically, then the optimization process is carried out to determine the best possibility in the system configuration. The system configuration results in the HOMER application having a solar panel with a capacity of 460.65 kW, a total of 9 batteries of 51.6 kWh, a 500 kW converter, and an on-grid type network.

Based on the simulation that has been carried out, the results of the energy produced by the system each year can be seen in Table 9.

Table 9. Electricity production per year

City	Production	Production Power (kWh/year)	Total Production (kWh/year)
Surakarta	PV	515.579	954.959
	Grids	439.380	
Yogyakarta	PV	516.967	959.188
	Grids	442.221	
Semarang	PV	586.287	982.090
	Grids	395.803	
Surabaya	PV	548.088	964.960
	Grids	416.873	
Malang	PV	552.710	972.037
	Grids	419.327	

In addition, there are also results of the consumption of electricity loads per year, which can be seen in Table 10.

Table 10. Electric power consumption per year

City	Consumption	Power Consumption (kWh/year)	Total Consumption (kWh/year)
Surakarta	AC primary load	884.852	908.220
	Grid sales	23.368	
Yogyakarta	AC primary load	884.852	907.722
	Grid sales	22.870	
Semarang	AC primary load	884.852	922.467
	Grid sales	37.615	
Surabaya	AC primary load	884.852	912.890
	Grid sales	28.038	
Malang	AC primary load	884.852	916.099
	Grid sales	31.247	

Based on Table 9, the most potential city with the highest total power production is Semarang City with 982.090 kWh/year. Meanwhile, based on Table 10, the most potential data with the lowest total power consumption is Yogyakarta City, which is 907.722 kWh/year.

3.2 Net Present Cost (NPC)

The most optimal system configuration results are determined by the magnitude of the NPC (Net Present Cost) because NPC is the cost of the entire system over a certain period; for that, Homer sorts the optimization results from the lowest NPC [28]. The total NPC cost includes all costs incurred during the project, consisting of component, replacement, maintenance, fuel, and interest rate costs; the amount of NPC generated by this configuration is shown in Figure 7.

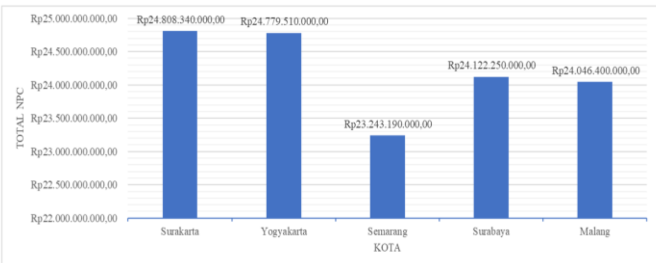


Figure 7. Total NPC per city

Based on Figure 7, the most potential city with the lowest total NPC is Semarang City, which is Rp 23,243,190,000.00. Meanwhile, the largest total NPC is Surakarta City, with a total NPC of Rp 24,808,340,000.00.

3.3 Cost of Energy (COE)

The COE of the system is obtained after knowing the annual cost of the system and the amount of electricity consumption per year [28]. The COE value compares the annual cost and the amount of electricity consumption per year, so the COE value obtained in each city can be seen in Table 11.

Table 11. COE value

City	COE
Surakarta	Rp 1,201.28
Yogyakarta	Rp 1,200.55
Semarang	Rp 1,108.11
Surabaya	Rp 1,162.09
Malang	Rp 1,154.37

Based on Table 11, the most potential city with the lowest total COE is Semarang City, which is Rp 1,108.11, while the most considerable COE value was for Surakarta City, Rp 1,201.28.

3.4 Break event points (BEP)

BEP is a condition where the value of investment and income is at point 0, or it can be said to be in a condition with no losses and no profits [28]. The BEP value in units is needed to estimate in what year investors start to experience profits. The system simulation results using HOMER in each city are shown in Table 12.

Table 12. BEP for each city

City	BEP Occurred Year
Surakarta	11.87
Yogyakarta	11.55
Semarang	10.09
Surabaya	11.07
Malang	10.83

Based on Table 12, the most potential city with the lowest BEP is Semarang City, which is 10.09 years. It shows that Semarang City is a profitable city for the solar energy-based EV charging station business.

The research with the same model has been carried out by Wurangian et al. [15] in Manado City. Through the configuration of the HOMER system, the best possibility is obtained in the configuration of PLTS in Manado City. Therefore, with the same method, the most optimal design comparison can be obtained among several cities studied by considering the total power production, total power consumption, NPC value, COE value, and BEP value.

4. CONCLUSION

This research compares the design of EV charging stations in several cities in Indonesia, namely Surakarta City, Semarang City, Yogyakarta City, Surabaya City, and Malang City. This research uses the Hybrid Optimization Model for Electric Renewable (HOMER) software by comparing several factors, namely total power production, total power consumption, NPC value, COE value, and BEP value. The most optimal design is the city that produces the highest total power production, the lowest total power consumption, the lowest NPC, the lowest COE, and the lowest BEP. Based on the results of the simulation that has been carried out, the city with the highest potential value is Semarang City. The initial investment for PLTS development for the EV charging station is Rp5,399,387,501.00. The design of the EV charging station in Semarang City is capable of producing a total production power of 982.090 kWh/year with a total consumption power of 922.467 kWh/year. This design has NPC value of

Rp23,243,190,000.00, COE value of Rp1,108.11, and the return on investment after the business has been running for 10.09 years. This research is expected to help explore the utilization of solar energy in locations that face challenges in accessing electricity.

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