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An Examination of Hybrid PV-Biogas Power Plants for Electric Vehicle Charging Station Development in Indonesia

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ABSTRACT

Renewable energy is being created to replace traditional energy sources due to the depletion of fossil fuel reserves. Constructing appropriate infrastructure, such as charging stations, is essential to enable the expansion of electric vehicles. Renewable energy sources power the EV charging station. This study assesses the feasibility of constructing PV-biogas hybrid power plants to power EV charging stations in the Indonesian cities of Denpasar, Surakarta, Bekasi, and Semarang. The HOMER program was utilized for simulating and optimizing the Hybrid Optimization Model for Electric Renewables. The research design incorporated an anticipated daily power consumption of 232 kWh and a project lifespan of 25 years. The optimal city is found by considering various factors, including total power output, total power consumption, break-even point (BEP), net present cost (NPC), and cost of energy (COE) figures. Semarang City has demonstrated the highest potential for building a hybrid production system among all cities, mostly due to its better economic advantages. Semarang has the lowest NPC, COE, and slowest return on investment. The initial investment cost for establishing a hybrid generating system is IDR 2,454,489,904.74. In Semarang City, the system design generates 625.88 kWh/year of electricity and consumes 551.03 kWh/year. It has an NPC value of IDR 20,964,400,000.00, a COE value of IDR 1,673.18, and a BEP in year 7.05.

1. INTRODUCTION

In recent years, there has been significant climate change on a global scale due to the effects of greenhouse gases. The demand for renewable energy is increasing every year. It shows that renewable energy will have an essential role in electricity generation in the future because traditional energy sources are quickly running out [1]. Solar energy sources are increasingly receiving attention because their energy potential is quite convincing. In addition, the unlimited of solar energy makes this energy the center of attention for renewable energy development [2]. Converting solar energy into electrical energy is done using solar panels or photovoltaic (PV).

Nonetheless, investigations into solar energy sources reveal that it is unreliable due to its unpredictable existence [3]. A comprehensive analysis of the hybrid renewable energy management sector has been discussed conceptually and empirically by Ciupageanu et al. [4]. Therefore, utilizing a hybrid energy scheme in solar energy is a more efficient and cost-effective approach. An interesting hybrid energy source to be developed is solar biogas because the use of solar energy and biogas as a source of electrical energy is still tiny, even though it has pretty large potential. The research aims to model the most optimal generating system to integrate renewable energy to supply energy needs [5].

Hybrid power generation systems from renewable energy sources are currently one of the most researched areas. Hybrid power plants are designed by combining several energy sources to generate electricity [6]. Previous research regarding the technical and economic analysis of PV-Biogas hybrid power plants was only on a small scale and utilized biogas from animal waste [7]. Rodríguez-Gallegos et al. [8] researched the analysis of the PV-Biogas hybrid power generation system, where the results showed that this hybrid system configuration had better service quality and guaranteed electricity supply than using PV only. Therefore, the development of hybrid energy sources, one of which is solar biogas, is needed to increase efficiency and optimize electrical energy sources.

Biogas is a resulting gas from fermentation activities from organic materials under anaerobic conditions [9]. Biogas is a clean fuel, so it does not produce pollutant fumes, and the high methane content in biogas gives this material excellent combustion power [10]. Biogas has been widely used by people in Indonesia, especially to meet household needs [11]. Several studies have been carried out regarding the further use of biogas. Purnomo [12] utilize biogas as fuel for grass chopper machines, showing high fuel efficiency. Perdana and Wahyuni [13] utilize biogas as an energy source to prime the water pump. Yangsen [14] utilize biogas as a driving force in an electric generator. These many factors allow biogas's ongoing development as an electrical energy source. Based on earlier discoveries, biogas has the potential to be a renewable energy source for the production of power.

The increasingly depleting fossil fuels and worsening climate change due to the effects of greenhouse gases have made electrical energy the center of attention. Currently, electric vehicles have become a widely researched topic. This is because it is the right solution to reduce the negative impact of the greenhouse effect and air pollution and as a substitute for increasingly depleting fossil fuels [15, 16]. Currently, the government is aggressively spreading the use of electric vehicles in Indonesia, so various parties are required to support this program. Among the benefits of electric vehicles over fossil fuel vehicles are their reduced running costs, lack of pollutants, favorable effects on air quality, and environmental friendliness [17, 18]. With the increasing number of electric vehicles used, supporting facilities are also needed in Electric Vehicle (EV) charging stations for charging them.

This study aims to model the use of a hybrid PV-Biogas energy source for providing electrical power at EV charging stations located in four Indonesian cities: Semarang, Surakarta, Bekasi, and Denpasar. This is done to provide affordable, environmentally safe electricity in the future and promote sustainable economic development [19, 20]. By utilizing the Hybrid Optimization Model for Electric Renewable (HOMER) software, this study examines the techno-economic features of a PV-Biogas-based hybrid power generating system that is not connected to the State Electricity Company (PLN), also known as an off-grid system. The HOMER simulation results may be used to examine the variables affecting the cost-effectiveness of designing a hybrid power system [21, 22]. PV systems may be measured, analyzed, and examined using HOMER. The HOMER findings display the best available data from the system design, making them appropriate for optimization. Based on how much power households use, this research can solve issues utilizing a hybrid system between many renewable energy sources. By taking into account several factors, including Net Present Cost (NPC), Cost of Energy (COE), annual electricity production and consumption power, and break event points, this study identifies the city with the most significant potential for system design (BEP).

2. RESEARCH METHODS

2.1 Research flow diagram

Research is carried out in several stages, which must be structured by collecting data and facts from a research object. A research process flow is needed so that the research process can run according to plan [23]. The flow diagram for designing a hybrid PV-Biogas generating system for an EV charging station is shown in Figure 1.

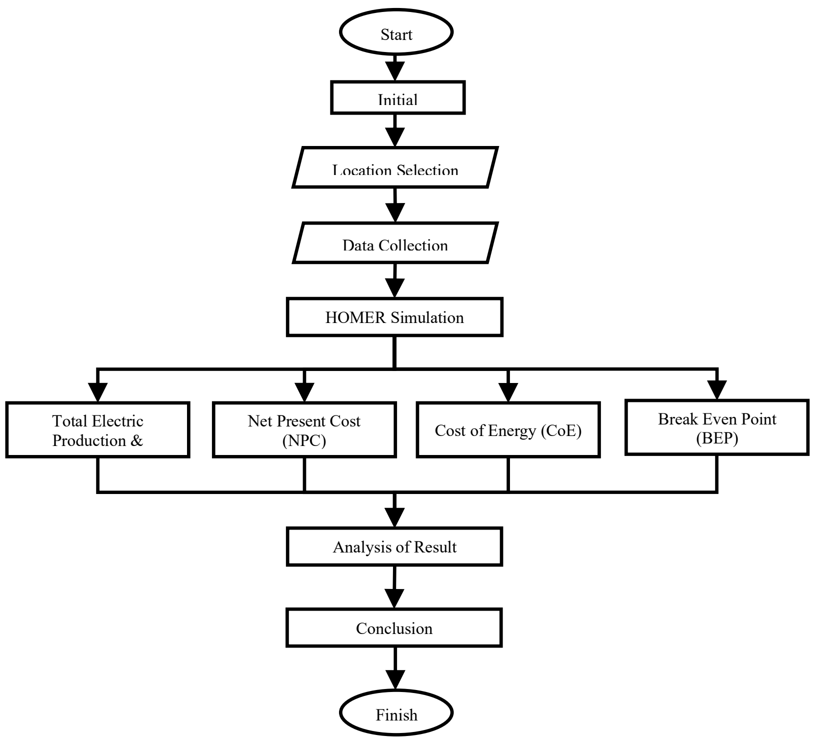


Figure 1. Research flow diagram

2.2 An explanation of the design model for a hybrid PV-Biogas generation system

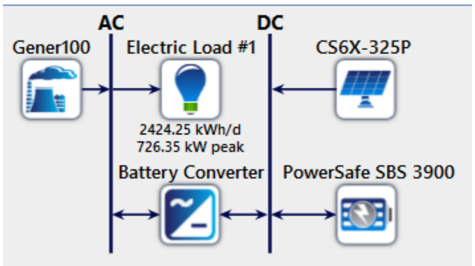


Figure 2. Hybrid PV-Biogas generation system modeling scheme

The EV charging station's hybrid generator system setup is off-grid. To maximize system performance, the planned generating system needs several auxiliary parts. The generating system being designed in this design is modeled using HOMER software. Solar/PV panels, batteries, generators, and converters are necessary. Figure 2 shows the modeling of the hybrid generating system in the HOMER program.

The total daily load of four Hyundai Ioniq 5 prime Standard Range cars, each with a battery capacity of 58 kWh, is around 232 kW, according to the estimation of the electrical load consumption made by the HOMER program. Figure 3 provides an estimated profile of the charging station's electrical load.

Understanding the expenses associated with each component's investment is essential for conducting an economic analysis of this hybrid power plant. Table 1 lists the parts required to assemble a hybrid PV-Biogas EV charging station-producing system.

2.3 Description of location for design of hybrid PV-Biogas generating system

Four cities in Indonesia—Semarang, Surakarta, Bekasi, and Denpasar—will model the design of a hybrid PV-Biogas-producing system for EV charging stations. The simulation aims to identify which of these cities has the most economic potential for EV charging station construction. Figure 4 shows the position of the development plan location.

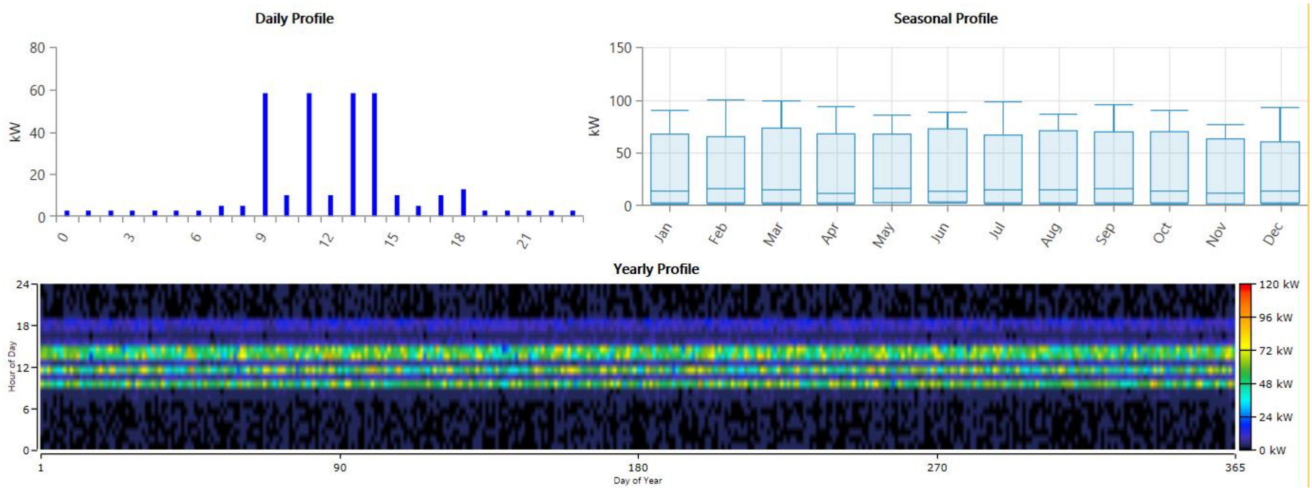
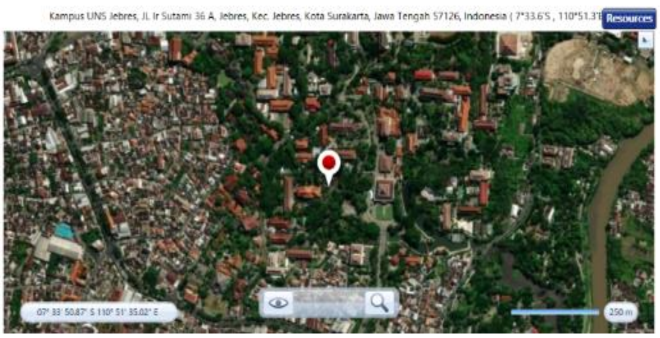


Figure 3. EV charging station electrical load profile

Table 1. Hybrid PV-Biogas EV charging station generator system components

Parameter	Canadian Solar CS6X-325P	Enersys PowerSafe SBS 3900	KEHUA France KF-BCS250K-B	Generac 100kW SD100
Capital Costs	IDR 2,000,000.00	IDR 55,000,000.00	IDR 12,000,000.00	IDR 100,000,000.00
Replacement Cost	-	IDR 55,000,000.00	IDR 12,000,000.00	IDR 100,000,000.00
O&M Costs	IDR 200,000.00	IDR 5,500,000.00	IDR 700,000.00	IDR 20,000.00
Lifetime	30 years	15 years	15 years	15,000 hours

(a) Semarang City generating system design location



(b) Surakarta City generating system design location

(c) Bekasi City generating system design location

(d) Denpasar City generating system design location

Figure 4. Location of Hybrid PV-Biogas generating system design

2.4 Potential use of solar energy

The potential for using solar energy to become a hybrid power plant, which are Semarang City, Surakarta City, Bekasi City, and Denpasar City, can be processed using data regarding the intensity of solar radiation and regional temperature obtained from the NASA (National Aeronautics and Space Administration) website. Table 2 displays information on solar radiation intensity in various cities.

Table 2. Solar radiation intensity data

Month	1	2	3	4
January	2.55	2.50	2.01	3.38
February	2.62	2.63	1.84	3.92
March	3.29	3.21	2.77	4.40
April	3.59	3.51	3.09	5.39
May	4.19	4.05	3.49	5.15
June	4.33	4.31	3.39	5.04
July	4.76	4.76	3.73	4.69
August	5.06	5.10	4.14	5.03
September	5.06	5.08	4.01	5.32
October	4.04	4.13	3.10	5.24
November	3.16	3.11	2.39	4.37
December	2.42	2.59	2.04	3.07
Average	3.76	3.75	3.00	4.58
Minimal	2.42	2.50	1.84	3.07

Note: 1. Semarang, 2. Surakarta, 3. Bekasi, 4. Denpasar. Radiation intensity data is in kWh/m^2 units.

Variability in sun irradiation levels causes a PV system's output power to fluctuate. In order to make up for energy shortfalls during periods of poor solar irradiation, a hybrid system can assist by utilizing biogas. The degree of output power efficiency that the producing system can provide increases with the intensity of solar radiation. The data above indicates that Denpasar City has the highest average solar radiation intensity of 4.58 kWh/m^2, making it the city with the most significant development potential for constructing this hybrid-producing system.

2.5 Potential use of biogas

According to data from research conducted by Santoso et al. [24], in Bali Province, biogas has a capacity to produce 1.16 GWh of electricity per day. The average total livestock population in Bali Province (19,183,779) is used to create this biogas. Based on information obtained from the Directorate General of Animal Health and Husbandry [25], the number of livestock populations in Bali Province is shown in Table 3.

Table 3. Livestock population data for Bali Province

Year	Total Population
2013	17,730,740
2014	18,740,619
2015	20,514,304
2016	20,605,849
2017	18,327,383

Biogas production capacity can be estimated by calculating the amount of feces produced by each type of livestock per day using Eq. (1).

$$Feces\ production = n \times total\ feces\ per\ day \quad (1)$$

where,
n = Total livestock populations
After that, the dry matter content of each type of livestock can be calculated, as shown in Eq. (2).

$$TDMC = feces\ production \times DMC \quad (2)$$

where,
TDMC = Total dry matter content (kg)
DMC = Dry matter content (kg)
The biogas potential can be obtained, as shown in Eq. (3).

$$BP = TDMC \times BL \quad (3)$$

where,
BP = Biogas potential (m^3)
BL = Biogas produced by livestock (m^3/kg)
Biogas potential can be converted into electrical energy using Eq. (4).

$$E = BP \times 4.7\ kWh \quad (4)$$

where,
E = Electrical potential (m^3.kWh)

2.6 Main components of a hybrid PV-Biogas generation system

2.6.1 Daily total load
This concept starts with figuring out the overall daily load

used. The electrical load at charging stations, generally in a range of Solar Home Systems, displayed in Table 4, is the basis for the daily total load data.

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	5	18	13
8	5	19	3
9	58	20	3
10	10	21	3
11	58	22	3
12	10	23	3
13	58	0	3
14	58	1	3
15	10	2	3
16	5	3	3
17	10	4	3
		5	3
		6	3
Total (kW)	287		49
Increase the load by 20%, so the total power (kW)	344.4		58.8
Total load per day (kW)		403.2	

2.6.2 Photovoltaic solar panels

Solar panels convert solar radiation into electrical energy by utilizing the photovoltaic effect on semiconductor materials [26]. The following formula may be used to determine the power generated by the solar panel module without considering the PV's temperature [27].

$$PPV = F_{pv} . Y_{pv} \frac{G_T}{G_{T,STC}} \qquad (5)$$

where,

PPV: Power produced by the PV module (kW)

F_{pv}: PV derating factor

Y_{pv}: PV output power under standard conditions (kW)

G_T: Instantaneous radiation on the surface of the PV module (kW/m^2)

$G_{T,\, STC}$: Instantaneous radiation under standard conditions (1kW/m^2)

This time, the Canadian-made MaxPower CS6X-325P solar panel is utilized in the PLTS system. This solar panel is featured in Figure 5 and contains the specs listed in Table 5.

Table 5. Canadian Solar MaxPower CS6X-325P specifications

Technical Specifications	Mark
Maximum power (Pmax)	325 Wp
Maximum voltage (Vmp)	37 V
Maximum current (Imp)	8.78 A
Open circuit voltage (Voc)	45.5 V
Short circuit current (Isc)	9.34 A
Module efficiency	16.94%
Derating factors	88%

Figure 5. Canadian Solar MaxPower CS6X-325P

2.6.3 Generator

An energy-conversion tool that transforms mechanical energy into electrical energy is a generator [28]. HOMER has various generators, including thermoelectric, fuel cell, thermo-photovoltaic, microturbine, and Stirling engine generators. The generator's fuel consumption may be determined using the following formula, which considers electrical output [27].

$$F = F0 + F1.P_{gen} \qquad (6)$$

where,

P_{gen}: Generator output power (kW)

F: Fuel consumption rate (L/h)

F0: Fuel intercept coefficient curve (L/h/kW)

F1: Fuel curve slope (L/h/kW)

This design uses a Generac 100kW SD100 generator, whose specs are displayed in Figure 6 and Table 6.

Figure 6. Generac 100kW SD100

Table 6. Generac 100kW SD100 specifications

Technical Specification	Mark
Capacity	500 kW
Fuel	2.45 L/h
Load ratio	25%
Lifetime	15,000 hours

2.6.4 Inverter

The direct current (DC) produced by solar panels is converted into alternating current (AC) using an inverter [29]. The KEHUA France KF-BCS250K-B inverter is the one utilized in this setup. Figure 7 depicts this inverter with the specs listed in Table 7.

Figure 7. KEHUA France KF-BCS250K-B

Table 7. KEHUA France KF-BCS250K-B specifications

Technical Specification	Mark
Output power	250 kW
Maximum power	250 kW
Output frequency	50/60 Hz
Input dc voltage	500 – 900 V
Efficiency	98.8%

2.6.5 Battery

The battery stores energy the solar panels produce so that the generating system can run even at night [30]. In this setup, an EnerSys PowerSafe SBS 3900 battery is utilized. This kind of battery is seen in Figure 8 and has the specs listed in Table 8.

Table 8. EnerSys PowerSafe SBS 3900 battery specifications

Technical Specification	Mark
Type	Lead acid
Normal voltage	2 V
Internal holding capacity	0.18 mΩ
Nominal capacity	4300 Ah

Figure 8. EnerSys PowerSafe SBS 3900

2.7 Economy

The design of generating systems heavily relies on the economic sector. The project duration, currency, discount value, and inflation value are the forms in which the input data is presented in the economic window. Due to the project's Indonesian setting, the rupiah is the currency. Data from Bank Indonesia is used to calculate the inflation rate, which is 4.97%, and the discount rate, which is 5.75%. The project has a 25-year duration in mind. The asset value of a project will be impacted by inflation and discount rates. However, if the fluctuation in value is manageable, it will not significantly impact the assets in a project. A sound business strategy is necessary to anticipate fluctuations in interest rates to prevent a decline in asset values.

2.7.1 Net Present Cost (NPC)

HOMER uses the Net Present Cost (NPC) value to display the overall costs required during the project [31]. All project-related expenses, such as component replacement, maintenance, fuel, and interest costs, are included in the total NPC costs. The NPC may be computed using the below formula [21].

$$CNPC = \frac{C_{ann,tot}}{CRF.i.R_{proj}} \tag{7}$$

where,

$C_{ann,\,tot}$: Total annual fee (Rp/year)
CRF: Capital recovery factor
i: Interest rate
R_{proj}: Life of use (years)

2.7.2 Cost of Energy (COE)

The average cost of electricity spent per kWh, or COE, is the result of comparing the yearly operating expenses of a project with the annual energy consumption [31]. Through the COE value, it can be seen whether a designed generating system is profitable or not. COE can be obtained using calculations with the following formula [21].

$$COE = \frac{C_{ann,tot}}{L_{prim,AC} + L_{prim,DC}} \tag{8}$$

where,

$L_{prim,AC}$: AC loads per year (kWh/year)
$L_{prim,DC}$: DC loads per year (kWh/year)

3. RESULT AND DISCUSSION

3.1 HOMER simulation results

The PV-Biogas hybrid generating system's configuration is designed and modeled as part of the simulation process. Following the simulation, HOMER will optimize the design to yield the optimal configuration outcomes. Table 9 shows the results of the energy the system generates annually.

Meanwhile, the electricity consumption per year can be seen in Table 10.

Denpasar City has the highest potential and total power production (633.89 kWh/year) among the cities based on the data in Tables 9 and 10. At 546.25 kWh annually, Bekasi City has the most significant potential and the least total electricity consumed.

Table 11 shows the difference between total electricity production and total electricity consumption. Denpasar City has the most profitable electricity potential compared to other cities, with a net electricity of 80.60 kWh.

Table 9. Electricity production per year

City	Production	Amount of Production Power (kWh/year)	Total Production (kWh/year)
Semarang	PV	427.60	625.88
	Generator	198.28	
Surakarta	PV	397.98	611.30
	Generator	213.32	
Bekasi	PV	404.05	616.71
	Generator	212.66	
Denpasar	PV	434.98	633.89
	Generator	198.91	

Table 10. Electrical power consumption per year

City	Consumption	Total Consumption (kWh/year)
Semarang	AC primary load	551.03
Surakarta	AC primary load	546.97
Bekasi	AC primary load	546.25
Denpasar	AC primary load	553.29

Table 11. Net electricity

City	Net Electricity (kWh)
Semarang	74.85
Surakarta	64.33
Bekasi	70.46
Denpasar	80.60

3.2 Net Present Cost (NPC)

The size of the NPC determines one of the best system setup outcomes. The city with the lowest NPC value has the most significant potential. Table 12 displays the NPC values generated by this arrangement.

Table 12. NPC value

City	NPC
Semarang	IDR 20,964,400,000.00
Surakarta	IDR 22,321,090,000.00
Bekasi	IDR 22,427,140,000.00
Denpasar	IDR 21,241,030,000.00

Semarang, with IDR 20,964,400,000.00, is the most prospective city with the lowest NPC value, according to the visual data above. Odoi-Yorke et al. [32] analyzed a PV-Biogas hybrid power plant in Ghana with a design NPC of IDR 7,852,749,500.00 to create 70 kW of energy per day. It shows that the hybrid system design in Semarang City has a lower NPC value.

3.3 Cost of Energy (COE)

The size of the COE dictates the outcomes of the most optimum system configuration. The city with the lowest COE value has the most promise. Table 13 displays the COE values that were found for each city.

Table 13. COE value

City	COE
Semarang	IDR 1,673.18
Surakarta	IDR 1,794.70
Bekasi	IDR 1,805.59
Denpasar	IDR 1,688.35

Based on the data above, the smallest COE value is obtained for Semarang City, IDR 1,673.18.

3.4 Break Even Point (BEP)

When income and investment value reach zero or there is neither a profit nor a loss, this is referred to as a BEP. To determine the year investors will begin to realize profits, one must know the BEP value expressed in units. Table 14 displays the results of the HOMER system simulation for each city.

Table 14. BEP value for each city

City	Year of BEP Occurrence
Semarang	7.05
Surakarta	8.88
Bekasi	9.13
Denpasar	7.45

Based on the above, Semarang City has the most potential with the lowest BEP point, 7.05 years old.

3.5 Proposed model

The research results show that the city with the most potential in designing a hybrid PV-Biogas generating system for EV charging stations is Semarang City. Semarang City is the most optimal city for this hybrid system configuration because it has a profitable economic value, namely low NPC and COE values, and the fastest return on investment. Monthly electricity production is shown in Figure 9. Figure 9 displays the monthly generation of power. The hybrid solar-biogas system's monthly electric production, which varies in total output from both sources, displays the overall power generated. This variance must be adjusted to biogas production to satisfy energy demands since solar irradiation values cause variations. Table 15 displays the cash flow system utilizing the suggested model.

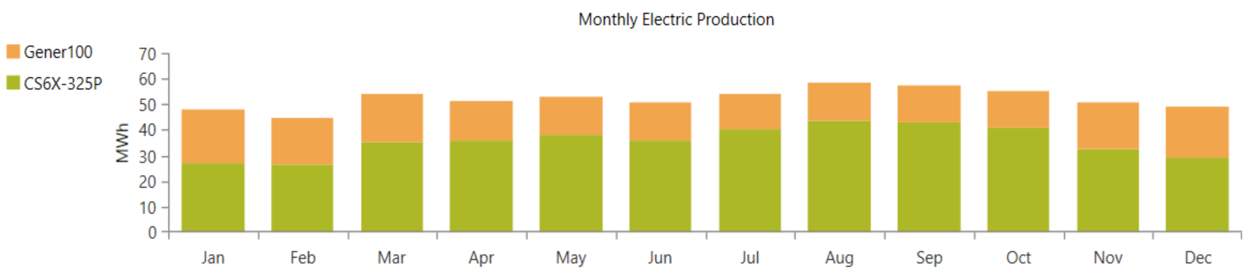


Figure 9. Monthly production of electricity with the suggested model

Table 15. Cash flow system using proposed models

Components	Capital	Replacement	O&M	Fuel	Salvage	Total
Canadian Solar MaxPower CS6X-325P	IDR 1,605,866,226.52	-	IDR 3,651,495,258.87	-	-	IDR 5,257,361,485.39
Enersys PowerSafe SBS 3900	IDR 715,000,000.00	IDR 2,570,917,976.08	IDR 1,625,801,120.28	-	-IDR 418,629,704.95	IDR 4,493,089,391.40
Generac 100kW SD100	IDR 100,000,000.00	IDR 451,603,548.21	IDR 1,471,179,475.27	IDR 9,110,779,981.99	-IDR 50,554,770.47	IDR 11,083,008,235.00
KEHUA Fance KF-BCS250K-B	IDR 4,623,678.22	IDR 8,281,087.64	IDR 6,132,898.44	-	-IDR 1,921,224.58	IDR 17,116,439.71
Other	-	-	IDR 113,826,647.23	-	-	IDR 113,826,647.23
Systems	IDR 2,454,489,904.74	IDR 3,030,802,611.93	IDR 6,868,435,400.09	IDR 9,110,779,981.99	-IDR 471,105,700.01	IDR 20,964,402,198.73

4. CONCLUSIONS

This study undertakes a comprehensive analysis of the layout of PV-Biogas hybrid power generating systems intended for EV charging stations across various Indonesian cities, namely Denpasar, Surakarta, Bekasi, and Semarang. The configured generating system is meticulously optimized and simulated through HOMER software, spanning a 25-year duration. The primary objective is to pinpoint the city exhibiting the most substantial potential for system design, considering parameters such as total electricity production, total electricity consumption, NPC value, COE value, and BEP value. Semarang City emerges as the most promising candidate for the hybrid PV-Biogas EV charging station generating system, boasting a total electricity production of 625.88 kWh/year, total electricity consumption of 551.03 kWh/year, NPC value of IDR 20,964,400,000.00, COE value of IDR 1,673.18, and BEP in year 7.05. The initial investment cost for establishing a hybrid generating system in Semarang City is estimated at IDR 2,454,489,904.74.

This research is envisioned to contribute significantly to future studies, providing a foundation for the refinement of component selection. Enhancing the efficiency of electricity production and minimizing the design costs of hybrid systems can be achieved through the judicious selection of components. The ongoing optimization of component costs aligns with future investment objectives, ensuring the sustained development of hybrid systems. Supportive regulations promoting the continued and expanded utilization of renewable energy sources facilitate the realization of hybrid system designs. This, in turn, has the potential to catalyze numerous advancements in renewable and hybrid energy research.

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