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Analyze the Potential of Hybrid Renewable Energy Systems (HRES) for EV Charging Stations Across Four Provinces in Indonesia: Conduct Energy and Economic Evaluations

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ABSTRACT

This research assesses the feasibility of utilizing alternative energy sources for electric vehicle (EV) charging facilities in four cities representing provinces in Indonesia. The analysis employed HOMER Pro software to optimize PV and wind turbine systems to develop the most efficient hybrid system. This PV-wind hybrid system is considered more environmentally friendly than conventional systems due to its reduced fossil fuel use and increased renewable energy. The data interpretation results indicate that the optimal model for developing the Hybrid PV-Wind system is the best choice and operates effectively in Yogyakarta, with a wind contribution of 32.33% and solar energy accounting for 9.99%. This benefit is mainly attributable to Yogyakarta's favorable geographical and climatic conditions for realizing optimal wind power and solar radiation potential. Out of the four cities studied, the hybrid PV-wind system in Yogyakarta was the most effective regarding renewable energy contribution and financial viability. The hybrid PV-Wind system indeed has a high initial capital requirement. However, operational and maintenance costs are more favorable in the long run than separately installed systems (wind-only or solar-only). This contributes to the long-term efficiency goals in operational costs. Yogyakarta reported the highest Internal Rate of Return (IRR) and Return on Investment (ROI), which signifies a reasonable prospect of higher and faster returns on investment. Moreover, the most remarkable annual energy output was recorded in Yogyakarta, which registered a total production of 987,155 kWh per year and the least LCOE at IDR 1,245/kWh. Nonetheless, the contribution of renewable energy sources in this scheme is still quite limited, around 27% to 42% of the total annual energy requirements. Hence, there still exists a need to buy energy from the conventional grid for the complete requirements of EV charging stations. Oehler et al. highlight the need to deploy renewable energy-based systems in EV charging stations' operation for sustainability and efficiency. In addition, the results of this study also reinforce the urgency of the transition towards a more widespread utilization of renewable energy in the transport sector.

1. INTRODUCTION

In recent years, global trends have shown an increasing awareness of the importance of sustainable energy and pressing environmental issues. Climate change, air pollution, and natural resource depletion have become critical challenges that have forced many countries to find more environmentally friendly solutions [1, 2]. These efforts have led to a transition from using fossil fuels to more environmentally friendly renewable energy. Renewable energy, such as solar, wind, water (hydro), and biomass, are cleaner and more sustainable alternatives to meet global energy needs [3]. As a developing country with rapid population growth and urbanization, Indonesia has experienced a significant increase in energy demand every year [4]. Several global energy problems and environmental issues have made it necessary for Indonesia to take a more efficient and sustainable approach to energy resource management [5].

One of the sectors that contributes the most to greenhouse gas emissions in Indonesia is transportation, which creates a significant challenge in efforts to reduce carbon footprints [6]. The development of Electric Vehicles (EVs) has emerged as a potential solution to reduce emissions and increase energy efficiency in this sector. The adoption of electric vehicles is expected to reduce dependence on fossil fuels and support significant reductions in carbon emissions [7]. However, EV charging station infrastructure must be developed for this transition to be effective, adequate, efficient, and sustainable.

The development of this infrastructure is a critical element in supporting the widespread use of EVs, enabling the transformation of the transportation sector towards a more environmentally friendly system [8]. Most EV charging stations still rely on conventional electricity grids dominated by fossil fuels. This dependence poses a significant challenge to sustainability goals, as emissions from fossil-based power plants can reduce the environmental benefits that should be obtained from adopting electric vehicles [9]. In addition, this dependence on conventional energy sources limits efforts to transition to a clean and sustainable energy system. Therefore, it is essential to develop renewable energy to meet the operational needs of efficient and sustainable EV charging stations [10].

One potential solution that can improve the sustainability and efficiency of energy supply for EV charging stations is the implementation of a Hybrid Renewable Energy System (HRES) [11]. Indonesia has significant potential in utilizing renewable energy, especially solar and wind energy, which can contribute substantially to diversifying national energy sources [12]. Geographically, Indonesia is in the equatorial region, which provides the advantage of high and relatively stable solar radiation levels throughout the year. Based on a study of renewable energy potential, the technical capacity of solar energy in Indonesia is estimated to reach around 207.8 GWp, making it one of the most potential renewable energy sources to be developed nationally [13-16]. In addition, Indonesia's geographical conditions, consisting of islands and varied topography, provide excellent opportunities for wind energy utilization. Wind speeds in these areas are high enough and consistent for the operation of wind turbines so that they can produce significant energy supplies [17, 18]. The combined utilization of solar and wind energy can play a role in reducing dependence on fossil fuels. Integrating these two renewable energy sources will increase national energy security and strengthen Indonesia's steps toward using clean and environmentally friendly energy [19].

Hybrid Photovoltaic-Wind (PV-Wind) system design can be done using the HOMER Energy device. HOMER Energy is a software that models, optimizes, and analyzes hybrid energy systems [20]. HOMER conducts technical and economic feasibility design and evaluation to ensure hybrid energy systems can support sustainable and efficient energy decisions. This software allows solar panel and wind turbine technology to synergize two renewable energy sources continuously [21, 22]. Optimizing the potential of natural resources in various geographic locations will enable users to increase the efficiency and reliability of energy supply for EV charging stations [23, 24]. Integrating the PV-Wind system into the EV charging station electricity network can increase energy independence and significantly reduce carbon emissions. In addition, diversification of energy sources through this hybrid system can also reduce the risk of dependence on one type of resource, increase the stability of the energy supply, and accelerate the transition to the use of renewable energy in the transportation sector [25, 26].

Based on the descriptions above, this study aims to evaluate the potential implementation of the Hybrid PV-Wind system in several cities in Indonesia, focusing on comprehensive technical and economic analysis. Using HOMER Pro simulation software, this study will explore various scenarios to determine the feasibility and performance of the proposed renewable energy system. The evaluation of the economic aspect will involve an in-depth analysis of parameters such as Internal Rate of Return (IRR), Return on Investment (ROI), and Payback Period to accurately assess the potential return on investment. Therefore, this study contributes to developing renewable energy technology at the national level and supports global initiatives to reduce carbon emissions and encourage sustainability in the transportation sector.

2. METHODOLOGY

2.1 Homer energy simulation tool

This study evaluated the energy resources required to design a hybrid PV-Wind system at EV charging stations. This evaluation is an essential tool because of its ability to perform cost-effectiveness analysis and provide insight into the integration of significantly different energy resources. In this study, the analysis was conducted using HOMER Pro software with an interface display, as shown in Figure 1. HOMER Pro provides a comprehensive approach to analyzing various energy scenarios, allowing users to optimize energy resources based on specific needs [27].

Figure 1. HOMER Pro interface

This analysis process requires specific data input for each selected location, such as meteorological data, including global solar radiation (GHI) data, wind data, and temperature data, which vary from one location to another. In addition, other input data include load demand, component specifications (including efficiency and lifetime), component economic data (including capital costs, replacement costs, and operation and maintenance costs), technical data (installed power), inflation ratio, annual discount ratio, and others. All of these data are used to precisely analyze the proposed energy system's efficiency and economic potential [25, 28].

2.2 Description of selected location

Indonesia's climate conditions are very diverse due to its varied landscape. Each region has a different climate, with some areas having a humid tropical climate [29]. This study selected four cities from various provinces of Indonesia for technical and economic analysis. These four cities are administrative cities and financial centers in each province so that they can represent the general needs for Electric Vehicle Charging. Some of the cities selected are Surakarta, Bandung, Yogyakarta, and Surabaya. In addition, the geographic coordinate system for the chosen cities is available in Table 1.

Table 1. Geographical coordinates of the selected location

Province	City	Latitude (ºN)	Longitude (ºE)	Altitude (m)
West Java	Bandung	-6.9147	107.6098	768
Central Java	Surakarta	-7.5743	110.8251	92
East Java	Surabaya	-7.2575	112.7521	5
Yogyakarta	Yogyakarta	-7.7956	110.3695	113

In this analysis, each city's climate and geographical characteristics are considered to assess the potential and efficiency of renewable energy systems, as explained below.

- Surakarta has a humid tropical climate and receives significant sunlight exposure, giving it a high potential for solar energy utilization.
- Bandung is located in a highland area with cooler temperatures and better wind conditions, enhancing its potential for wind energy.
- Yogyakarta has a stable tropical climate, offering a balance between solar and wind energy potential, providing flexibility for implementing hybrid energy systems.
- Surabaya, situated in a lowland area with a hot and humid climate, is more suitable for solar energy utilization due to consistent solar radiation throughout the year.

In addition to climate and topography, infrastructure in each city also plays a crucial role in developing energy systems. For example, the availability of a reliable power grid and accessibility to renewable energy technologies are critical factors in successfully implementing energy systems at each location. By considering technical, economic, and infrastructural factors, this study aims to optimize energy systems in each area according to their local characteristics and potential. The results are expected to provide a comprehensive overview of energy resource utilization across various provinces in Indonesia.

2.3 Meteorological data

a. Annual average global horizontal irradiance (GHI)

Figure 2 illustrates the annual average solar radiation in four major cities in several provinces in Indonesia, namely Bandung, Yogyakarta, Surakarta, and Surabaya. Solar radiation, expressed in kWh/m²/day, shows each city's solar energy potential variation. Surabaya recorded the highest value with 5.17 kWh/m²/day, making it the city with the most significant solar energy potential. Surakarta followed in second place with 4.85 kWh/m²/day, while Bandung and Yogyakarta had almost the same radiation values, at 4.81 kWh/m²/day and 4.80 kWh/m²/day, respectively. This data is essential for planning EV charging stations based on renewable energy systems utilizing solar energy in each city in each province. This data shows that Surabaya has the highest potential for using solar power.

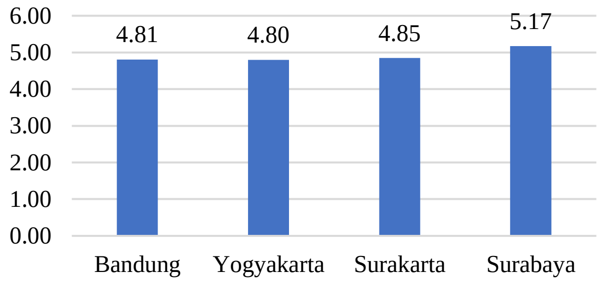

Figure 2. Annual average solar irradiance (kWh/m^2/day)

b. Annual average wind speed data

Figure 3 shows the annual average wind speed in meters per second (m/s) in four major cities in Indonesia, namely Bandung, Yogyakarta, Surakarta, and Surabaya. From the data shown, Bandung has the lowest average wind speed of 3.26 m/s. Meanwhile, Yogyakarta recorded the highest wind speed at 4.24 m/s, followed by Surakarta with 4.06 m/s and Surabaya with 4.05 m/s. Thus, it can be seen that the three cities, Yogyakarta, Surakarta, and Surabaya, have almost comparable wind speeds, while Bandung has a much lower wind speed. The geographical location, topography, and climate conditions in each city can influence this difference in wind speed. This data is also essential to consider the potential for wind energy utilization in each region.

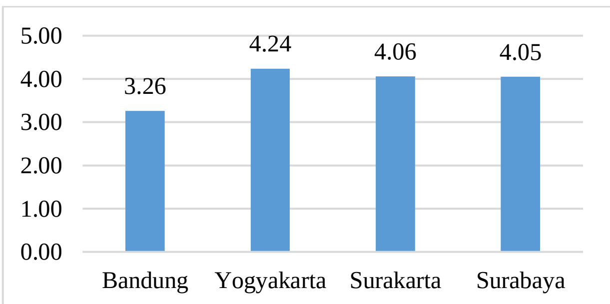

Figure 3. Annual average wind speed (m/s)

c. Monthly average temperature data

Figure 4 shows the monthly average temperatures in four cities in Indonesia, namely Bandung, Yogyakarta, Surakarta, and Surabaya. Bandung, shown with the blue line, has a lower average temperature than the other cities throughout the year, ranging from 22°C to 25°C. Meanwhile, Yogyakarta and Surakarta, shown with the orange and gray lines, show a similar pattern, with temperatures ranging from 24°C to 27°C throughout the year. Temperatures in both cities drop slightly in June and July before increasing again towards the end of the year. Surabaya, shown with the yellow line, has the highest average temperature among the four cities, peaking in October at nearly 29°C. Temperatures in Surabaya are relatively constant between 26°C and 28°C throughout the year, with significant increases in September and October. Overall, Bandung tends to have cooler temperatures than the other cities, while Surabaya is hotter, especially during the middle to late months of the year. This figure helps illustrate the annual temperature variations in these cities, which may be influenced by geographic location, altitude, and local climate factors.

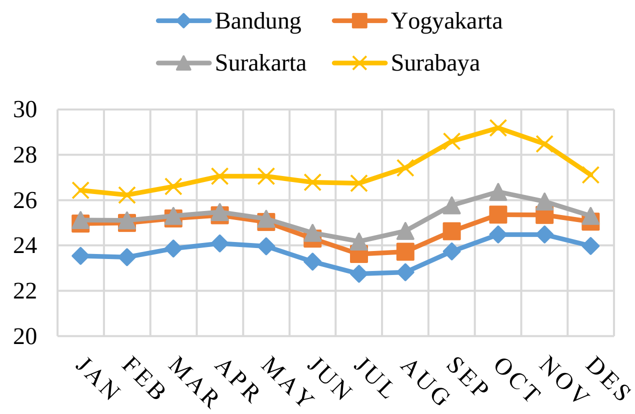

Figure 4. Monthly average temperature

2.4 Load data

Load demand is one of the essential input parameters in HOMER Pro. Unlike the load demand in the industrial and commercial sectors, which is relatively fixed, the load demand for electric vehicle charging stations (EV charging stations) is random and varies over time. This is due to fluctuations in the number of electric vehicles requiring charging, which cannot be predicted with high precision. Therefore, in the context of this research study, a hypothetical load demand has been created, as shown in Figure 5 and Figure 6. This demand model includes a small random element generated to reflect the variation in the number of electric vehicles being recharged each hour of the day.

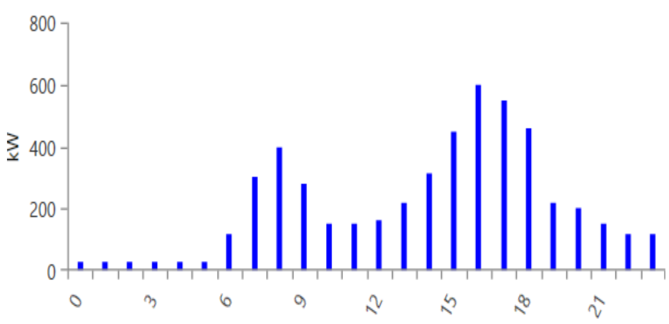

Figure 5. Daily load profile for EV charger station

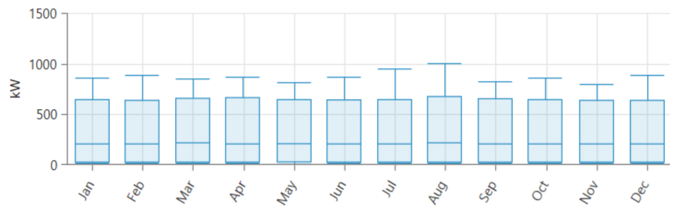

Figure 6. Seasonal load profile for EV charging station

This hypothetical approach is designed to simulate natural conditions that are more representative of the usage patterns of EV charging stations. In a natural system, factors such as user arrival time, charging duration, and variations in user preferences contribute to the uncertainty in load demand. Therefore, the introduction of random elements in the model aims to accommodate variations throughout the day, thus providing a more realistic picture of the challenges in managing load at EV charging stations. Table 2 shows the estimated daily load required to operate the system.

Table 2. Specifications of load demand for the charging station

Province	City
EVs Charged per day	30
EV Charger Capacity	250 kW
Peak Load Demand	473.75 kW
Average Load Demand	101.38 kW
Average Unit Consumption	2424.25 kWh/day

Based on Table 2, the average daily energy consumption is 2424.25 kWh/day, with a peak load demand of 473.75 kW and an average load demand of 225.42 kW. The parameters for day-to-day load variability and time step changes are set at 10% and 20%, respectively, to accommodate random changes in load demand. This approach allows for a more realistic simulation of the energy demand fluctuations at an EV charging station throughout the day. Load demand variability is a crucial component to test the robustness and performance of a hybrid energy system designed to support the operation of an EV charging station. This testing will involve simulations with multiple scenarios, including varying degrees of randomness, to evaluate energy efficiency, operating costs, and their effects on energy storage and renewable resource integration. Figure 7 shows a schematic of the proposed system.

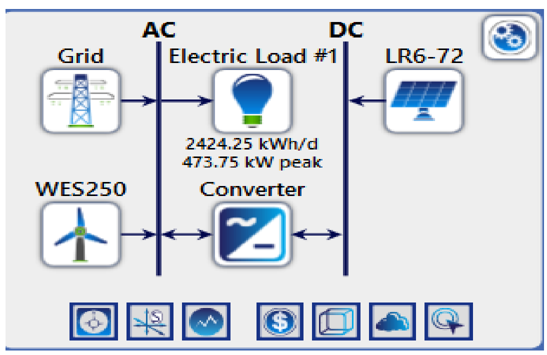

Figure 7. Block diagram of PV-wind hybrid for EV charging station

3. DATA ANALYSIS

3.1 Economic parameters for analysis

The following explains some of the economic parameters commonly used in HOMER Pro to calculate the costs and performance of renewable energy systems.

a. Net present cost (NPC)

Net Present Cost (NPC) is the total cost of an energy system over the project's life, including investment costs, component replacement, operation and maintenance, and fuel costs. NPC is essential to understand the long-term costs incurred to operate the energy system [30].

$$the\ NPC\ (IDR) = \sum_{t=0}^{N} \frac{C_t}{(1+r)^t} \tag{1}$$

where,

Ct: Total cost in year t,

r: Interest rate (%),

N: Project Age (years),

NPC provides an overview of the total cost of a project in present cost terms, allowing comparison between different investment options.

b. Capital recovery factor

Capital Recovery Factor (CRF) is a factor used to calculate a fixed annual payment based on the initial cost of capital and the discount ratio over the life of the project. CRF is beneficial for estimating the annual cost of a system that involves a significant initial investment [31].

$$CRF\ (IDR) = \frac{r(1+r)^N}{[(1+r)^N - 1]} \tag{2}$$

where,

r: Interest rate (%),

N: Project Age (years),

CRF helps divide the total initial cost annually to see how the investment is paid back over time.

c. Nominal interest (discount) rate

The Nominal Interest Rate or discount rate calculates the present value of money invested in energy systems. It is an interest rate that is not adjusted for inflation, which helps determine the future cost of capital [32].

$$r_{nominal} = \frac{1 + r_{real}}{1 + f} - 1 \tag{3}$$

where,

$r_{nominal}$= nominal interest rate (%),

r_{real}= actual interest rate (%),

f: Inflation rate,

The nominal interest rate shows the impact of inflation on the value of money invested in a project.

d. Payback period

The payback Period is the time required to recover the initial investment capital through savings or income generated by the energy system. It simply indicates how quickly an investment will pay off or return capital [33].

$$Payback\ Period = \frac{Initial\ Investment}{Annual\ Savings} \tag{4}$$

where,

Initial Investment = Initial capital costs incurred (IDR),

Annual Savings = Annual savings generated (IDR),

The payback period is used to evaluate the return on investment and provide insight into the financial risk of a project.

e. Levelized cost of energy (COE)

Levelized Cost of Energy (LCOE) is the average cost required to produce one unit of energy over the system's lifetime. LCOE is one of the most important indicators for assessing the economic costs of an energy project and comparing it with other energy sources [34].

$$LCOE = \frac{NPC}{E_{total}} \tag{5}$$

where,

NPC = Total system cost (IDR),

E_{total}= total energy produced (kWh),

LCOE provides an idea of the cost per kWh required to generate energy and is used to evaluate the economic viability of renewable energy projects.

3.2 Energy analysis for system

a. Solar PV

Solar panel modules use the photovoltaic effect of the semiconductor material inside them to convert sunlight directly into electrical energy [35]. Solar PV applications have a capital cost of IDR-9,680,000/kW, a replacement cost, and an annual maintenance cost of IDR-151,250/kW. Solar power generation (PV) systems have a shorter construction time than other renewable energy alternatives. Solar technology has become more competitive in recent years due to its efficiency and significant cost reductions [36]. The output power of a PV system can be calculated in Eq. (6) as follows [37].

$$P_{PV} = Y_{PV} \times f_{PV} \times \left(\frac{G_T}{G_{T,STC}}\right) \times \left[1 + \alpha_P\left(T_c - T_{c,STC}\right)\right] \tag{6}$$

where,

P_{PV}= Output power from PV (Watt),

Y_{PV}= Installed capacity of PV (Watt),

f_{PV}= PV system derating factor,

G_T= Solar irradiation received at a particular time (W/m²),

$G_{T,STC}$= Solar irradiation under standard conditions (1000 W/m²),

α_P= PV power temperature coefficient (%/°C),

T_c= Current PV cell temperature (°C),

$T_{c,STC}$= Cell temperature at standard conditions (25°C).

This equation combines various factors that affect PV, power output, including changes in solar irradiance and the effect of temperature on system efficiency. In this case, the solar panel used in the EV Charging Station energy system is the Peimar LONGi Solar LR6-72 brand. The specifications of this solar cell can be seen in detail in Table 3.

Table 3. Solar panel specifications

Specification	Value
Power Rate	350 Wp
Efficiency	18.1%
Operating Temperature	47°C
Lifetime	25 Years
Capital Cost	IDR- 9,680,000
Re-opening	IDR- 9,680,000
O & M cost	IDR- 151,250

b. Wind turbine

The energy conversion process in a wind turbine begins with the transformation of wind kinetic energy into mechanical energy through the movement of the turbine blades [38]. These blades are designed to maximize wind capture at a certain height; in this case, the turbine hub is at a height of 30 meters, where wind speeds are usually higher and more stable than at ground level [39]. The mechanical energy produced is then converted into electrical energy through an alternator. The output power of the PV system can be calculated in Eq. (7) as follows [40].

$$P_{WTG} = P_{WTG,STP} \times \left(\frac{\rho}{\rho_0}\right) \quad (7)$$

where,

P_{WTG}= Output power from PV (Watt),

$P_{WTG,STP}$= Installed capacity of PV (Watt),

ρ_0= PV system derating factor,

ρ= Solar irradiation received at a particular time (W/m²).

The wind turbine used is the Lagerwey LW30/250 model with a capacity of 250 kW. The estimated system life is 25 years; this turbine offers stable performance with relatively low operational costs. The capital and replacement costs for the wind turbine of IDR-2,781,250,000/250 kW are considered reasonable considering the turbine's ability to generate energy in the long term. The operating and maintenance costs of IDR-19,522,000/year also reflect high-cost efficiency, especially in the context of renewable energy, which often involves lower maintenance costs than fossil fuel systems. The specifications of this wind turbine can be seen in detail in Table 4.

Table 4. Wind turbine specifications

Specification	Value
Power Rate	250 kW
Rotor Diameter	12 M
Hub Height	30 M
No of Blades	2
Lifetime	25 Years
Capital Cost	IDR- 2,781,250,000
Replacement	IDR- 1,568,065,000
O&M Cost	IDR- 19,522,000

c. Converter

The converter used in this system bridges the variable AC output generated by the wind turbine and the DC load requirements [41]. The converter can stabilize the variable AC power generated by the wind turbine, which varies based on wind speed and other operational conditions. After the AC power is stabilized, the converter converts it into DC power through an efficient rectification process [42]. The converter used is the Leonics MTP-413F 25kW, which has a capital cost of IDR-9,680,000 and a service life of 15 years. This converter has the specifications listed in Table 5.

Table 5. Leonics converter specification

Specification	Value
Efficiency	25 kW
Voltage	240 VDC
Lifetime	15 Years
Capital Cost	IDR- Rp4,537,500
Replacement	IDR- Rp4,537,500

4. RESULTS AND DISCUSSION

This study selected four cities that represent the conditions of several provinces for the technical and financial evaluation of on-grid electric vehicle (EV) charging stations. The prioritized renewable energy sources are solar panels and wind turbines to meet the charging energy needs. Different geographical and climatic conditions in each city are the main variables determining system performance. This study evaluates the potential combination of renewable energy to optimize the efficiency and sustainability of EV charging stations in strategic areas in each province.

4.1 Performance of the proposed system

This study uses three system designs in each location: PV on the grid, Wind on the grid, and Hybrid PV wind on the grid. Figure 8 illustrates the comparison between the initial capital cost (ICP) and operation and maintenance (O&M) costs in the three proposed energy generation systems: PV-Wind hybrid system (PV-Wind), grid-connected wind power plant (Wind on Grid), and grid-connected solar (PV) power plant (PV on Grid). The PV-Wind hybrid system has the highest initial capital cost, reaching around 4 billion IDR, but its O&M cost is relatively lower than the capital cost. On the other hand, the wind and PV systems on the grid have a more proportional balance between the initial capital cost and O&M cost. The PV system on the grid shows a lower capital cost but a higher O&M cost than the wind system, indicating a variation in the cost of management and maintenance of each renewable energy generation system.

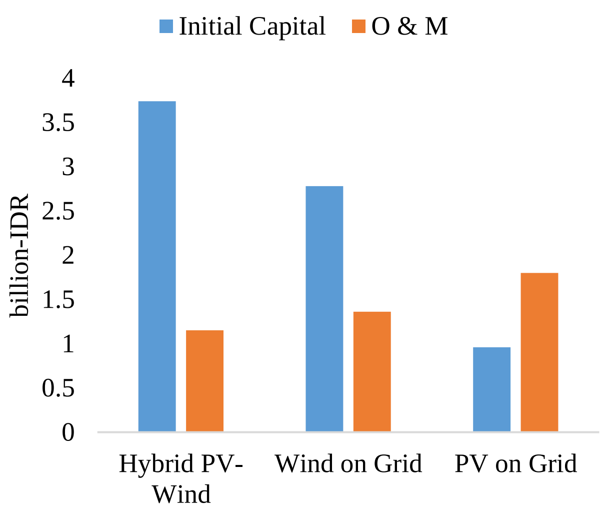

Figure 8. The relationship of costs in each proposed system

Hybrid Energy PV-Wind technology has the highest initial investment cost compared to other systems. This cost is proportional to the proportion of renewable energy generated in four different locations, as shown in Figure 9. Each location shows significant differences in the energy contribution generated from these two sources. In Yogyakarta, the proportion of energy generated from wind reaches the highest figure, 32.33%, while solar energy only contributes 9.99%.

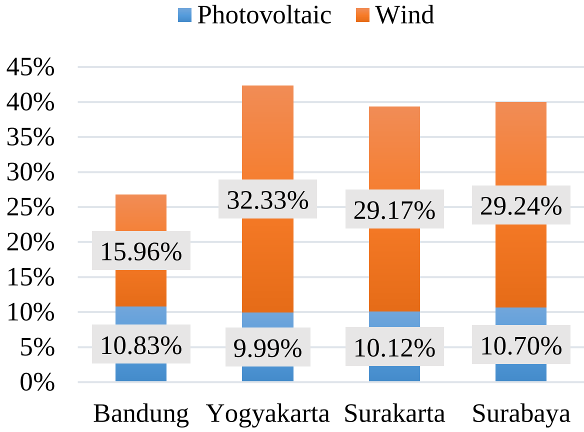

Figure 9. Comparison of the renewable energy fraction generated at each location

In general, wind energy tends to be more dominant across all locations, with proportions ranging from 29.17% to 32.33%, indicating that wind energy sources have more potential to generate electricity than solar panels, which contribute around 10-16%. This analysis is essential in determining the optimal design and location for on-grid EV charging stations, considering that each city has different renewable energy potential and cost characteristics.

4.2 Energy production in four locations

Based on three energy generation systems, namely PV on Grid, Wind on Grid, and Hybrid PV-Wind on Grid. Each city has variations in energy production from each system. Figure 10 shows the total energy produced to meet EV Charging needs. Yogyakarta produces the highest total annual energy, reaching 987 MW/year, with the most significant contribution coming from the Hybrid PV-Wind on Grid system. On the other hand, Bandung has the lowest energy production among the four cities, with a total figure of around 917 MW/year. Meanwhile, energy production from PV and Wind Grid systems is more balanced in each city, although the contribution from the wind system tends to be slightly higher.

Figure 11 shows the classification of energy production produced by each system. The Hybrid PV-Wind on Grid system consistently delivers the highest energy production in all locations, especially in Yogyakarta, reaching 418 MW/year. The Wind on Grid system has a more significant energy contribution than PV on Grid in each area, with production figures varying depending on location conditions. This illustration compares annual energy production based on location and the generating system used. The Hybrid PV-Wind on Grid system is the most efficient for producing renewable energy in four cities. Yogyakarta shows the highest potential, followed by Surabaya and Surakarta, which have similar characteristics.

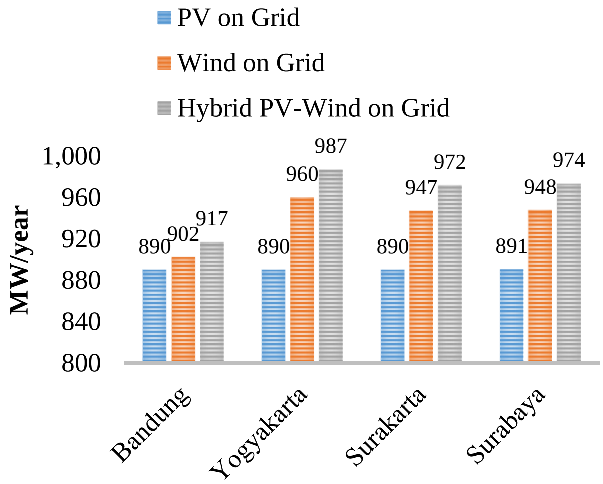

Figure 10. Total annual energy production at each location

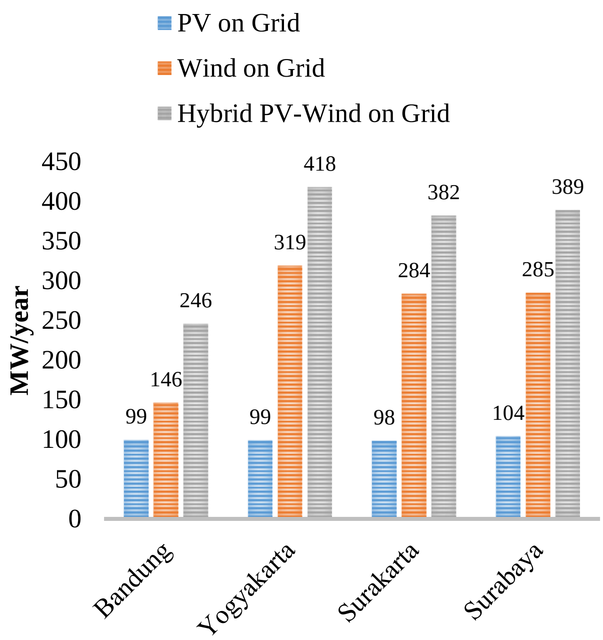

Figure 11. Total renewable energy production in each system

Renewable energy currently needs to fully meet the electricity needs of electric vehicle (EV) charging stations. This can be seen in Figure 9, which shows that the proportion of renewable energy that can be supplied only ranges from 27% to 42% of the total annual energy needs. Utilizing on-grid systems connected to the conventional electricity network must still cover this supply shortage. Table 6 shows the energy deficit needed to be purchased to meet the annual electricity needs.

Table 6. Conventional electricity purchases over the year

Location	**Grid Purchased (kWh)**		
	PV on Grid	**Wind on Grid**	**Hybrid PV-Wind on Grid**
Bandung	791	756	671
Yogyakarta	792	641	569
Surakarta	792	664	590
Surabaya	786	663	585

More effective system optimization is needed to maximize renewable energy production in various regions. This can involve improving the energy conversion efficiency of solar panels and wind turbines and more optimal energy storage management to increase power storage and distribution capabilities. In addition, integrating advanced technologies, such as data-based weather forecasting systems and real-time energy consumption monitoring, are key elements in strengthening predictive capabilities and responding to energy availability and demand fluctuations. Thus, these efforts are expected to reduce dependence on conventional energy and significantly increase the energy independence of EV charging stations, enabling more sustainable and efficient operations. These developments can also accelerate the transition to broader and more sustainable use of renewable energy in the transportation sector.

4.3 Comparison of economic potential in four locations

The economic analysis of the proposed renewable energy generation system in four cities was assessed using a system feasibility study. Some of the parameters used in the assessment are Internal Rate of Return (IRR), Return on Investment (ROI), Investment Value, and Payback Period. Figure 12 shows the classification of each parameter used. Yogyakarta has the highest IRR and ROI values, which means that the potential return on investment in this city is better than that of other cities. On the other hand, Bandung has a lower IRR and ROI, indicating that the economic benefits of investing in renewable energy systems in Bandung are relatively minor. The payback period also differs in each city, with Yogyakarta having the fastest payback period compared to other cities. In contrast, Bandung has a more extended payback period, indicating that the investment is slower to reach BEP (break-even point).

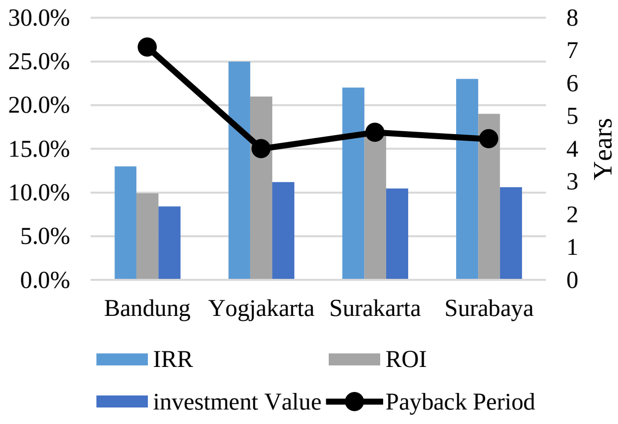

Figure 12. Economic feasibility of the proposed system at each location

In a feasibility study, it is essential to compare the NPC (Net Present Cost) values to determine the total estimated system cost during the project. Figure 13 shows a comparison of the NPC values of three types of proposed renewable energy generation systems: PV on Grid (solar panels), Wind on Grid (wind power), and Hybrid PV-Wind on Grid (a combination of solar and wind panels). The NPC value is measured in billions of IDR for each location. The PV on the Grid system has the highest NPC value in all locations, indicating that the total cost incurred for this system is more significant. In contrast, the Wind on Grid and Hybrid PV-Wind on Grid systems have lower NPC values, indicating a more efficient total cost. The NPC value of the wind system varies in each city, where Bandung has a higher value than other cities, while Surakarta and Surabaya show relatively lower costs.

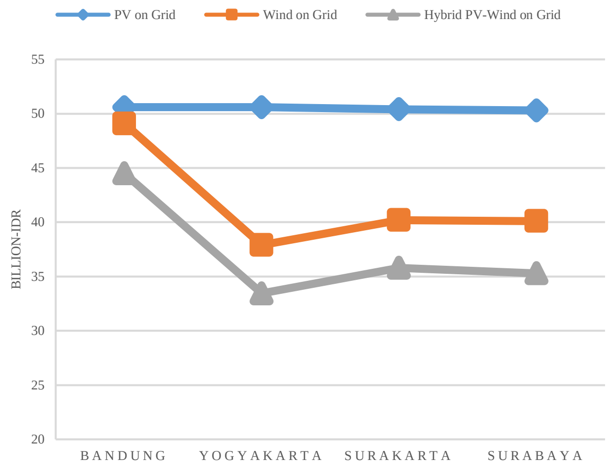

Figure 13. Comparison of NPC values in each proposed system

Figures 12 and 13 illustrate the economic feasibility and cost comparison of various renewable energy generation systems in different locations. This comparison is essential to determine the investment strategy and selection of each region's most economical and effective renewable energy generation system. The economic level of a system can be determined from the Levelized Cost of Energy (LCOE). This LCOE value indicates the cost of energy production per unit (IDR), whereas a lower value indicates a more economical energy production cost. Figure 14 shows the LCOE range of each proposed system in each location.

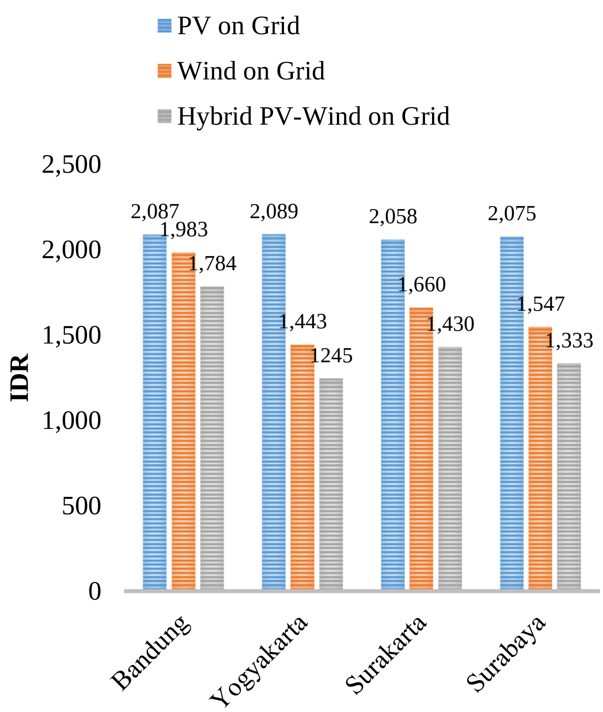

Figure 14. LCOE value at each research location

This figure shows that the PV on the Grid system has the highest LCOE value in all locations, ranging from 2,058 to 2,089 IDR. The Wind on Grid system has a lower LCOE value than PV on Grid, and the Hybrid PV-Wind on Grid system shows the lowest LCOE value, making it the most economical option for renewable energy production. Yogyakarta has the lowest LCOE value for the Hybrid PV-Wind on Grid system, which is 1,245 IDR, indicating the best cost efficiency compared to other locations. These results suggest that the hybrid system has the potential for lower energy production costs and is more efficient than the PV and Wind Grid systems separately in all study locations.

The economic assessment was taken a step further by introducing a sensitivity assessment that investigates the influence of changes in key parameters, namely component prices, interest rates, and electricity tariffs, on the economic viability of the Hybrid Renewable Energy System (HRES). The findings indicate that a change in component prices can have a material impact on the IRR and the payback period, especially in areas such as Bandung, which has a lower IRR. On the contrary, areas like Yogyakarta, which have a higher IRR, are less affected by cost variations.

Moreover, changes in electricity tariffs affect the LCOE at each location, especially in the Surabaya region, where the LCOE rises due to increased electricity tariffs. At the same time, Yogyakarta is more favorable with a lower LCOE as it seeks to attract more clients. This sensitivity analysis gives a better insight into risk and opportunity in the region, hence assisting the investors in making better decisions in the region.

5. CONCLUSION

This study shows that renewable energy systems, especially the combination of solar panels and wind turbines (Hybrid PV-Wind system), have significant potential to meet the energy needs for electric vehicle (EV) charging stations in four cities in several strategic provinces in Indonesia. The analysis results show that the Hybrid PV-Wind system consistently produces the highest renewable energy in all places, especially in Yogyakarta, which has the most significant wind energy contribution. Although the hybrid system has a higher initial capital cost, its operation and maintenance costs are relatively lower than those of separate systems (PV on the Grid and Wind on the Grid). From an economic perspective, Yogyakarta has the highest Internal Rate of Return (IRR) and Return on Investment (ROI), indicating a better potential return than other cities.

The proportion of renewable energy produced ranges from 27% to 42% of the total annual energy demand, creating an energy deficit that needs to be addressed by purchasing electricity from the conventional grid. Therefore, optimizing renewable energy systems is a must to improve energy conversion efficiency and power storage management. This optimization can include implementing more efficient energy conversion technologies, more reliable energy storage strategies, and system integration that allows for dynamic load balancing and energy supply. The results of this study highlight the importance of integrating renewable energy technologies in supporting the sustainability and operational efficiency of electric vehicle (EV) charging stations. These findings also support the urgency to accelerate the transition towards broader adoption of renewable energy in the transportation sector, thereby significantly contributing to reducing carbon emissions and increasing energy independence in the long term.

This study has critical findings that are useful for policymakers and other concerned authorities who deal with sustainable transport planning issues. To promote clean energy technologies in EV charging stations, government-assisted measures such as subsidies and tax facilitates and regulations promoting renewable energy resources are necessary. At the same time, appropriate charging facilities, such as the fast charging networks' reliability and an adequate power grid, must be in place to ensure operational efficiency. The private sector and community collaborations can promote sustainable business models and pilot projects on energy use towards renewable energy in transport. This will reduce dependence on fossil fuels, increase energy security, and contribute to Indonesia's drive towards sustainable transport systems.

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