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Modeling Future Solar and Wind Energy Source Applications for Power Generation at Public Electric Vehicle Charging Stations in Airport Parking Areas Using HOMER-Grid

Rendy Adhi Rachmanto[1], Noval Fattah Alfaiz[1], Singgih Dwi Prasetyo[1,2], Watuhumalang Bhre Bangun[1], Wibawa Endra Juwana[1], Zainal Arifin[1*]

[1] Department of Mechanical Engineering, Universitas Sebalas Maret, Surakarta 57126, Indonesia
[2] Power Plant Engineering Technology, State University of Malang, Malang 65145, Indonesia

Corresponding Author Email: zainal_arifin@staff.uns.ac.id

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ABSTRACT

Indonesia is generous in renewable energy resources since the country benefits from abundant solar energy. There has been an increase in the energy demand, and thus, it is essential to consider shifting to renewable energy sources to sustain future energy demand. This research looks at how renewable energy could be formed in an airport, specifically alleviating the use of fossil fuel-powered vehicles. Among them is the engineering of a standalone Public Electric Vehicle Charging Station (SPKLU) powered by other energies. The researcher applies a HOMER-Grid simulation approach to design an approximate daily electrical load of 424.25kW. According to the projections made in the simulation, approximately 254,078kWh of electricity will be produced annually from this renewable energy system. The percentage contribution of the energy from this system to the total energy load is 26.11%. Harnessing renewable energy at the airport is about developing a green technology approach, which can reduce the operational carbon footprint efficiency of the airport and help make the operation more sustainable.

1. INTRODUCTION

The primary challenge is the growing need for electrical energy brought on by population expansion and technological development, which increases dependency on fossil fuels and exacerbates environmental issues [1]. Switching to sustainable energy sources, such as solar, wind, hydro, and geothermal, is crucial to combating climate change and global warming [2]. However, renewable energy faces challenges, including high installation and maintenance costs, intermittency, and limited storage capacity, making it relatively expensive [3]. The answer to these problems is the Hybrid Renewable Energy System (HRES) [4]. Many renewable energy sources are integrated with storage technologies in the Hybrid Renewable Energy System (HRES) to increase the reliability, efficiency, and affordability of energy generation [5, 6].

Indonesia is a country located in the southeastern part of the Asian continent. In this country, the use of solar and wind energy is increasingly in demand because it has easier installation compared to other renewable energy sources [7-9]. Optimizing solar and wind energy utilization can help sustainably meet the country's energy demands. Indonesia is ideally suited for developing photovoltaic energy since it is located on the equator and has constant exposure to sunshine throughout the year, with an average intensity of around 4.8 kWh/m^2/day [10]. In addition, with a coastline of more than 81,000 km and favorable geographical conditions, Indonesia has significant wind energy potential, especially in coastal areas and remote islands, with average wind speeds reaching 6-7 m/s in some areas' locations [11]. Building renewable energy infrastructure contributes to the nation's energy diversification, which is essential in lessening the risk of becoming too dependent on a single energy source. It also lowers greenhouse gas emissions and reduces dependency on fossil fuels [12]. Increasing the usage of renewable energy can also improve energy security by lowering the risk of changes in the price of fossil fuels on the international market by supplying a more reliable and sustainable resource [13].

In Indonesia, there is a great potential for renewable energy, which needs to be optimized, especially in the transport sector, where fossil fuels are still primarily used [14]. Indonesia, an archipelago country with a large population and rapid economic development, faces challenges such as air pollution, dependence on foreign energy sources, and the impacts of climate change. Transitioning to electric vehicles is crucial for addressing the country's social, economic, and environmental problems [15]. The two primary sources of pollution in large cities today, air pollution and greenhouse gas emissions, may be decreased by using electric vehicles for land transportation. In addition to saving money on maintenance, electric cars use Indonesia's plentiful renewable energy sources [16]. Apart from that, the air transportation sector also requires serious attention. Airplanes are currently one of the most significant contributors to carbon emissions in the transportation industry [17]. Increasing fuel efficiency and implementing green technology in aviation can significantly reduce the carbon footprint of this sector [18]. Optimizing renewable energy in these sectors helps reduce emissions and improve air quality. It opens significant opportunities for developing domestic technology and renewable energy industries on eco-technology [19].

Air transportation offers unparalleled time efficiency and the broadest geographic reach among modes of transport. Enhancing the facilities and infrastructure supporting aviation is crucial for optimizing operational efficiency [20]. A green energy airport with integrated sustainable infrastructure must be developed to further a low carbon emissions program. With an emphasis on airport settings, this research thoroughly examines investment prospects and the feasibility of implementing hybrid PV-Wind technology for electric vehicle (EV) charging within the aviation sector. The HOMER-Grid optimization approach is utilized in this study to assess how economically viable grid-connected solar photovoltaic systems are for meeting the power needs of electric vehicle charging stations [21-23]. Technical and economic analysis is done to determine the most economical system design. The final technical and financial research highlights include determining the most efficient system layout and estimating the payback period. These studies consider several variables, such as system architecture, renewable energy potential, and load needs [24]. This research offers practical insights for implementing efficient and cost-effective renewable energy solutions at EV charging stations while identifying key opportunities and challenges in advancing renewable energy technologies within the transportation sector.

2. SUBSTANCES AND PROCEDURES

2.1 Local selection

The location chosen for the PLTS design at SPKLU is planned to be located at Adi Soemarmo Airport, Ngesrep, Ngemplak, Boyolali Regency, Central Java, Indonesia (7°31.2' S; 110°44.8' E). Due to its advantageous location close to the city center and residential neighborhoods, this location has the potential to become a central air transportation hub on the island of Java. Its low-lying setting makes it more easily accessible to the general people. To promote sustainable infrastructure development, this airport has to have a Public Electric Vehicle Charging Station (SPKLU) integrated with renewable energy sources, such as solar electricity. The geographic conditions of this hybrid system's installation site are described in detail in Figure 1.

Figure 1. Mapping of location

The SPKLU electrical charging system will be linked to solar panels and wind turbines erected near Adi Sumarmo Airport, supplying sufficient energy to meet the station's needs. The locations of this public electric charging station (SPKLU) were obtained using the NASA POWER program and HOMER-Grid software. Considering different geographic and environmental criteria, the optimal project locations may be found and selected using the HOMER function.

Adi Soemarmo Airport was chosen to construct an EV Charging Station (SPKLU) that uses renewable energy sources, such as solar energy, because of its advantageous natural surroundings. The tropical environment of Central Java, with plenty of sunshine and solar solid radiation all year round, puts the airport in a prime location to use solar energy. The consistent solar exposure, combined with the airport's flat terrain and surrounding open spaces, minimizes shading and the efficiency of solar panel installations. The region's stable climate, featuring low precipitation and predominantly clear skies, further optimizes solar energy generation. Additionally, the airport's flat topography and the absence of obstructions, such as buildings or dense vegetation, provide ideal conditions for solar panel deployment. These favorable environmental factors collectively establish Adi Soemarmo Airport as a prime location for integrating solar energy into the SPKLU infrastructure.

2.2 Model description

The design of a public charging station that integrates solar and wind power necessitates a methodical plan with a defined flow. Figure 2 displays the flow diagram for the On-Grid PLTS system study for Adi Sumarmo airport, which was modeled using HOMER-Grid software. The processes needed for the design process are depicted in this figure, which includes selecting the location, studying the energy resources, integrating renewable energy components, and assessing system performance. Through these diagrams, each stage in the design process can be identified, ensuring that all essential factors are considered to achieve an efficient and optimal energy solution.

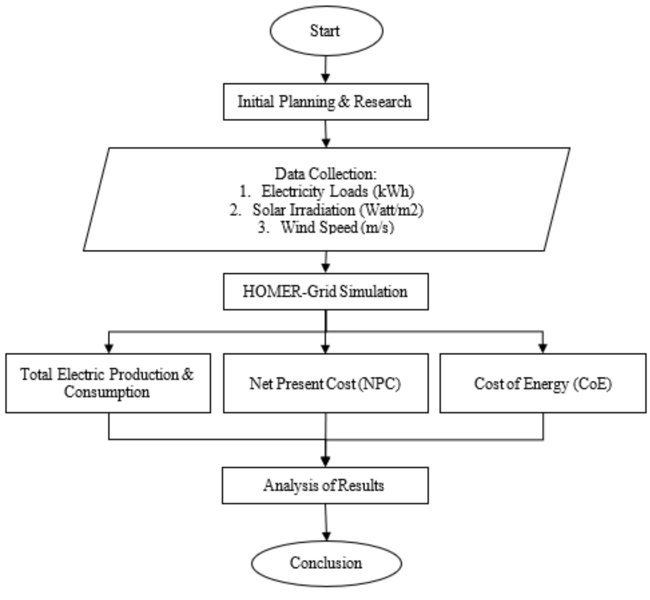

Figure 2. The simulation framework HOMER [25]

A research flowchart is presented in Figure 2, beginning with the design of the proposed Public Electric Vehicle Charging Station (SPKLU) system. The next step involves collecting data that affects the system's performance. The data collected includes solar radiation intensity, daily electrical loads, and wind speed at Adi Sumarmo Airport. This data is crucial for understanding energy demands and assessing the potential of available resources. Following the data collection stage, the HOMER-Grid software runs simulations. HOMER-Grid is an effective analytical tool for planning and evaluating renewable energy projects. Users may use this application to model freestanding (off-grid) and grid-connected (on-grid) power generation systems. The simulation results provide information on electricity generation and consumption, Net Present Cost (NPC), and Cost of Energy (COE). The most economical and efficient system designs are found by comparing these findings across different system configurations.

HOMER-Grid is widely recognized in the renewable energy sector and is frequently used to design and optimize hybrid power systems. This software is regarded as the global benchmark for techno-economic modeling in the energy industry [26]. HOMER-Grid was chosen to run simulations because it offers significant advantages over other software in designing and optimizing renewable energy systems, particularly hybrid systems. This software provides comprehensive technical and economic modeling, allowing users to evaluate system performance and financial feasibility simultaneously. Simulations for both freestanding (off-grid) and grid-connected (on-grid) power-generating systems are supported by HOMER-Grid, allowing for sensitivity analysis and different scenario evaluations. It is the capacity to find the most economical and practical designs by optimizing configurations according to Net Present Cost (NPC) and Cost of Energy (COE) [27]. HOMER-Grid is widely recognized in the renewable energy industry, ensuring reliable and credible results and making it a superior choice for energy project planning.

HOMER-Grid automatically assesses the power consumption requirements for SPKLU operations. This power load profile is adapted to a Rest Area system on toll highways within the HOMER-Grid framework, as illustrated in Figure 3. For each city under study on Java Island, the average daily power consumption is approximately 424.25 kWh, with peak electricity demand reaching up to 49.71 kW. Monthly calculations of electricity usage, as depicted in Figure 4, are conducted to provide a comprehensive analysis. The elements required for the optimal operation of the hybrid wind turbine and solar panel system significantly influence the cost evaluation. Table 1 outlines the types and specifications of the necessary components for this combined system.

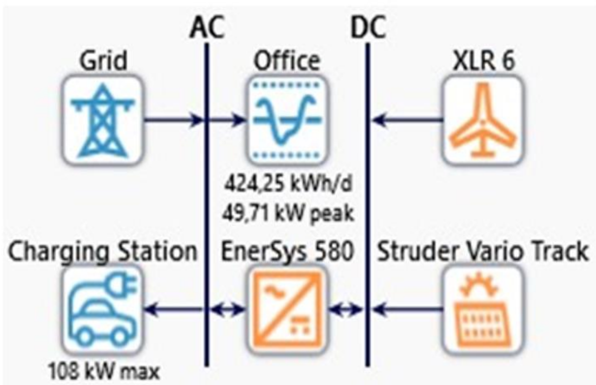

Figure 3. PV-Generator hybrid system configuration scheme

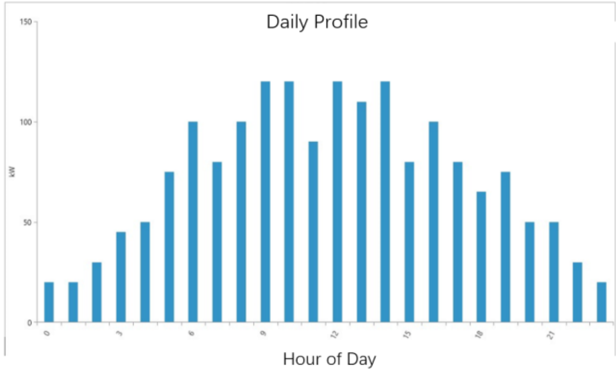

Figure 4. Electrical load in charging station

Table 1. Projections of system components

Parameter	PV	Wind Turbines	Inverters
Name	Struder Vario Track 80-with Generic PV	Bergey Excel 6-R	Sinexcel 150
Rate Capacity (kW)	680	36	150
Capital (IDR)	185,500,000.00	338,500,000.00	46,000,000.00
Replacements (IDR)	168,000,000.00	215,500,000.00	52,728,00.00
O&M (IDR/year)	4,260,000.00	7,250,00.00	1,200,000.00
Lifetime (years)	25	20	10

2.3 Description of the components

a. *PV modules*

Solar panels use the photovoltaic effect to harness light energy into electricity through semiconductor materials [28]. The PLTS system uses a produced Struder Vario Track 80 with a generic PV solar panel. For this solar cell, specific characteristics are given in Table 2.

The total capital cost of this panel will be around IDR 185,500,000.00. Additionally, similar expenses are anticipated if there is a need to replace the wind turbine. We have calculated that the yearly maintenance and operation costs will be IDR 4,260,000.00. It is crucial to consider the system's cover losses, the energy output from the PV module, and the module's nominal capacity of 680 Wp before determining the exact number of solar panels required to power EV charging stations.

Table 2. Details of solar panels

Specifications	Value
Maximum Power (Pmax)	680 Wp
Module Efficiency	19.07%
Derating Factor	80%
Maximum Voltage (Vmax)	45.1 V
Open Circuit Voltage (Vsc)	40.92 V
Maximum Current (Imax)	18.23 A
Short Circuit Current (Isc)	16.81 A

b. *Wind turbines*

Wind turbines convert wind energy into electrical energy via mechanical turbine movement [29]. For this project, we utilized a Bergey Excel 6-R wind turbine with a capacity of 6 kW. The initial capital expenditure is anticipated to be IDR 338,500,000.00. Furthermore, replacing the present wind turbine requires an extra investment of the same amount. On the other hand, we set aside IDR 7,250,000.00 for the cost and yearly operation of the wind turbine. We anticipate this wind turbine will remain active for roughly 20 years. Table 3 lists some critical parameters for the wind turbine system.

Table 3. Wind turbine specifications

Specifications	Value
Output Power	6 kW
Maximum Voltage (Vmax)	230 V
Rotor Speed (RPM)	0-400 RPM
Number of Blades	3
Cut-in Wind Speed	2.5m/s
Furling Wind Speed	4-10m/s

c. *Inverter for AC/DC*

An inverter is a device that has been designed to be of great help in changing the capitalized current from solar energy into alternated current that is findable in most household appliances [30]. The amount of power fed into the inverter's output does not depend on the load size to which the inverter is attached. Still, the output energy is proportional to the amount of power generated during the specific time by the solar panels. Approximately 49.71 kW of electricity are required by the system. For this simulation, a sinexcel 150 kW inverter is employed. The specifications of this inverter appear in Table 4.

Table 4. Details of an inverter

Specifications	Value
Output Power	150 kW
Efficiency	98.2%
Input DC Voltage	100-1500 V
Output Frequency	50/60 Hz

2.4 Environmental parameters

The present study has addressed a broad spectrum of regional geospatial environment factors. Such parameters include the air temperature, wind speed, and sun radiation, which are available in the databases on HOMER. This investigation focuses on one particular section of Adi Sumarmo Airport. Analysis of NASA POWER data within the HOMER framework helps one gain insights into crucial environmental parameters such as air temperature, wind speed, and solar radiation strength. Such information is priceless in understanding and formulating the strategies for sustainable and efficient regional power production systems. This strategy requires that the planning and construction of power plants consider the local geography, thus increasing their effectiveness and reliability.

Figure 5 depicts a graph showing the average monthly temperature of the Adi Sumarmo Airport in degrees Celsius. In October, we witnessed the highest mean temperature of 26.37°C. This is especially true for Figure 6, which shows the average wind speed for each month of the year, with August recording the highest wind speed of 5.14mps. Additionally, Figure 7 portrays the average monthly solar radiation received by the region where, in September, the intensity was recorded at 5,540kWh/m^2/day, which was the highest. The essential information from these numbers is about environmental parameters that affect the working and arrangement of the EV charging system at this airport and its operational capacity.

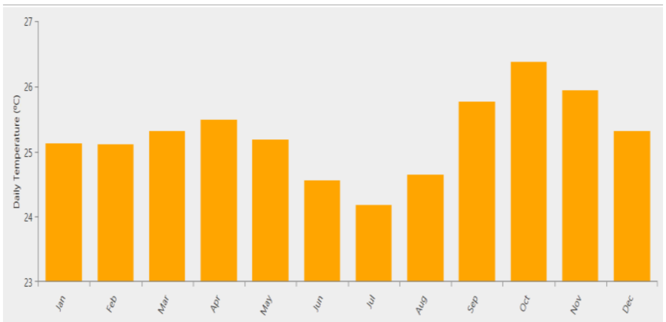

Figure 5. The monthly mean temperature

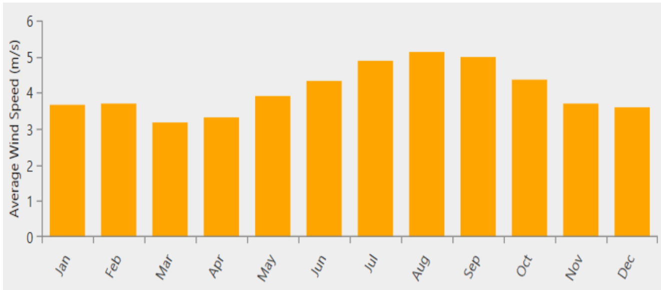

Figure 6. The monthly mean wind speed

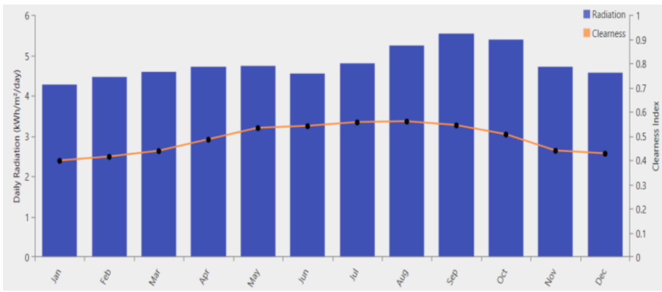

Figure 7. The monthly mean solar radiation intensity

2.5 Economic analysis

The studies on the findings from the HOMER simulation encompassed an economic evaluation, assessing both the costs involved and the power generated. The analysis of power output concentrates on the power from PV panels and wind turbines, whereas the cost analysis highlights the Net Present Cost (NPC) and the Cost of Energy (COE) [31]. The output power of the PV module is determined by using Eq. (1).

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

where,

P_{PV}: The PV module's power generation (Watts);
Y_{PV}: Capacity nominal of PV module (Watts);
f_{PV}: Reduction factor (%);
G_T: Sun radiation in real-time (W/m^2);
$G_{T,STC}$: Solar radiation in reference test scenarios (W/m^2);
T: Real-time temperature (°K);
$T_{c,STC}$: Temperature under standard testing conditions(°K);
α_P: Temperature coefficient of power.

In this hybrid system, the power output generated due to the wind turbine is also worked out. For calculating the output power of a wind turbine, refer to Eq. (2) below.

$$P_{WTG} = P_{WTG,STP} \times \left(\frac{\rho}{\rho_0}\right) \quad (2)$$

where,

P_{WTG}: Power generation of wind turbine (Watts);

$P_{WTG,STP}$: Power generation at ideal condition (Watts);

ρ: The actual air density (Kg/m^3);

ρ_0: The density of air at sea level (W/m^2).

In the HOMER simulation process, the system's operation seeks the optimal system layout with the lowest Net Present Cost (NPC), influenced by economic value. HOMER employs Eq. (3) to calculate NPC [32].

$$NPC\ (Rp) = \frac{C_{ann,tot}}{CRF.i.Rproj} \quad (3)$$

The total yearly cost (IDR/year) is represented by $C_{ann,tot}$; the interest rate is i; the capital recovery factor is CRF; and the age/use period (years) is *Rproj*. The Cost of Energy (COE) refers to the value of electrical energy produced by the system at an average cost per kWh. The formula to calculate COE is Eq. (4) [33].

$$COE = \frac{C_{ann,tot}}{L_{prim,AC} + L_{prim,DC}} \quad (4)$$

$L_{prim,AC}$ and $L_{prim,DC}$ represent the system's AC and DC loads. This technology is predicted to survive 25 years, after which its value is expected to decline, as shown in Figure 8 below.

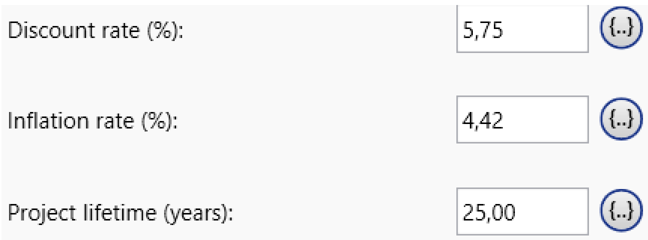

Figure 8. Feasibility system projection

3. RESULTS AND DISCUSSIONS

3.1 HOMER simulation results

These data are the basis for planning and implementing an optimal Public Electric Vehicle Charging Station (SPKLU) system. The information gathered from this data provides a solid basis for determining various essential aspects, such as the right location, required charging capacity, the most appropriate type of technology, and energy management strategies. Using this data, we can identify specific needs and design an efficient and effective SPKLU system according to local environmental conditions and the demands of electric vehicle users. Therefore, using data as a foundation in SPKLU planning can ensure successful implementation and significantly contribute to sustainable mobility in the future, as shown in Table 5.

The most considerable yearly electrical energy output generated by SPKLU is 254,081 kWh, which is split between Struder Vario Track 80 solar panels, Bergey Excel-6R wind turbines, and on-grid consumption. With an annual production of 254,081 kWh, conventional energy dominates this system; wind and solar energy can only generate 51,470 kWh and 17,397 kWh, respectively. At 26.11%, the percentage of energy used from renewable sources is still relatively low. In addition to being used for system operations, the energy generated is also utilized for EV charging services. If extra energy is generated, it can be used for possible resale. Energy use data throughout the year presented in Table 6 shows the importance of evaluating the contribution of each energy source for better planning in increasing the proportion of renewable energy. A deep understanding of energy production and consumption ensures the successful implementation of SPKLU, supports sustainable mobility goals, reduces carbon emissions, and provides long-term benefits for society and the environment.

Surplus electricity is produced when the power generated at any given time exceeds what the system or network needs. Balancing the surplus and deficit of electricity is crucial since the capacity for long-term energy storage in electrical systems is generally restricted. Practical solutions include energy storage, redistributing surplus energy to networks that require it, or employing intelligent automation systems. These strategies can effectively manage the excess generation by smartly redirecting the surplus electricity for other purposes, like charging batteries or heating.

Table 5. The total amount of energy produced annually

Production	**Kwh/Year**	**Percent (%)**
Struder Vario Track 80 with Generic PV	17,397	6.85
Bergey Excel-6R	51,470	20.3
On-Grid	185.214	72.9
Total	254,081	100

Table 6. Total annual energy use

Production	**Kwh/Year**	**Percent (%)**
Primary Load AC	154,851	61.7
Sales Grid	3,770	1.51
EV Charger Served	92,160	36.7
Total	250,781	100

3.2 Cost analysis

Several ideal size factors are established for each key component while functioning autonomously, considering yearly income, capital investment, and operating and maintenance expenses as assessment criteria. As seen in Figure 9, the HOMER-Grid is utilized to examine the outcomes of the same setup at many charging stations. The tool analyzes various variables to help identify the most efficient and profitable solutions for operating electric vehicle charging stations. HOMER-Grid enables in-depth evaluation of the performance of each component and its contribution to the overall system, thereby supporting strategic decisions for charging station optimization. This approach considers current conditions and prepares the system for future changes, ensuring operational efficiency and long-term economic benefits.

Figure 10 displays comparative information on return on costs for every year. Increased returns from the investment are possible when the return on capital is high. Aside from seasonal environmental variations, this profit margin is the primary determinant of the most advantageous site. Greater Return on Investment (ROI) and Internal Rate of Return (IRR) numbers show increased investment profit. Conversely, the payback ratio demonstrates that making payments on time is prioritized. The payback ratio, on the other hand, shows that repaying money is given priority more quickly. As stated differently, ROI and IRR analysis provide an overview of the efficiency and profitability of investments. In addition, the payback ratio assists investors in determining how long it will take to recover their initial investment, allowing them to make better decisions about resource allocation and where to put charging stations for electric vehicles.

The economic growth potential of Adi Sumarmo Airport is very promising, as shown in Figures 9 and 10. With sufficient wind speed and good average monthly solar radiation intensity, this airport offers very supportive environmental conditions, which enable the production of renewable energy with high value. The cost of electrical energy per kilowatt hour (kWh) can vary depending on the amount of power produced, also known as the Cost of Energy (COE). The determining factor in this assessment is the system's total cost over a certain period, or Net Present Cost (NPC), which calculates the system's efficacy. The HOMER algorithm prioritizes optimization discoveries by sorting NPC values from lowest to highest. This ensures that the most cost-effective system design will be found. Table 7 provides a comprehensive overview of the estimated system costs and illustrates the potential benefits and economic viability of implementing a renewable energy system at Adi Sumarmo Airport.

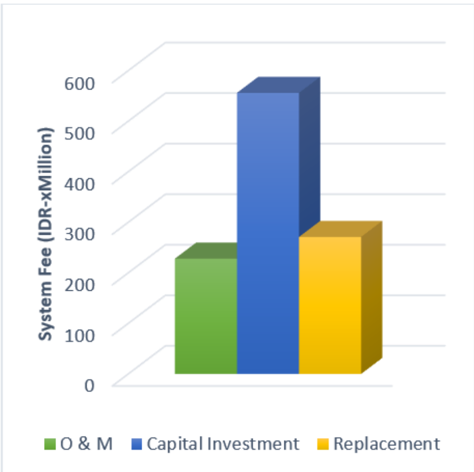

Figure 9. Comparison of system fees

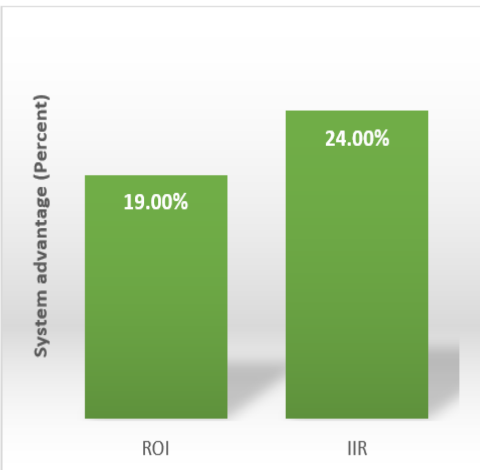

Figure 10. System advantage comparison

Table 7. Cost summary

Type	Cost (IDR)
NPCs	5,411,466,000.00
Initial Capital	555,661,223.38
O & M	228,021,300.00
LcoE	1,922.00

3.3 Electric production monthly

The ability of a solar module to produce power over the course of a month is referred to as its monthly electricity production. This measure is essential for comprehending the system's performance throughout the year. The findings of the HOMER system simulation concerning the monthly output of power are shown in Figure 11. Based on computer models, the system is expected to produce 24 megawatts of power at its peak in August. The month's high level of solar intensity and peak output are correlated. Furthermore, January recorded the highest wind speed, at 5.14 m/s. This wind speed also significantly impacted energy output, particularly at Adi Sumarmo Airport, which was more noticeable. With its potential for solar and wind energy, the airport is in a prime position to make efficient use of renewable energy sources all year round.

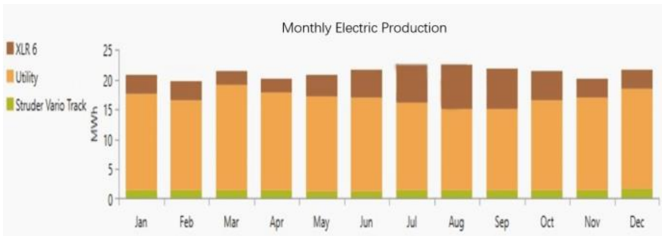

Figure 11. Monthly production

Based on the average monthly electricity production data, the electric grid can be the primary energy source that meets the needs of public electric vehicle charging stations (SPKLU). This is caused by the limitations of the renewable energy system, which still needs to meet overall needs. Electricity production from wind turbines is strongly influenced by regional factors and wind speed, resulting in variations in electricity production. On the other hand, solar panels are considered more reliable because they can provide stable and consistent energy production throughout the year, not being too dependent on external factors such as wind speed. Therefore, solar panels can be a more practical solution for increasing electricity production in areas with high exposure to sunlight. However, in the simulation, the lowest production was obtained from solar panels, caused by using only one set of panels in the configuration. To optimize electricity production, it is necessary to increase the number and capacity of solar panels used to provide a more significant energy contribution to the EV charging station.

4. DEVELOPMENT OF SIMILAR RESEARCH

Techno-economic modeling for public electric vehicle (EV) charging stations using sun-wind hybrid energy sources is crucial for sustainable transportation. Studies show that hybrid renewable energy systems (HRES) combining photovoltaic and wind turbines can meet energy demands, reducing reliance on the grid and fossil fuels. On-grid systems show significantly lower levelized costs of electricity, making them economically attractive. Integrating HRES with EV charging stations can lead to substantial reductions in CO_2 emissions, with one study reporting a decrease of up to 510 tons annually [34]. Renewable energy sources support EV infrastructure and align with global sustainability goals. However, challenges such as initial investment costs and technological adoption remain significant barriers to widespread implementation [35]. Similar research developments are shown in Table 8.

Table 8. Development of similar research

Insights	Methods Used	Findings	Future Research	Reference
"Simulation Model Analysis of Hybrid Renewable Energy Integration in Tourism District" • Showcases economic feasibility and environmental benefits.	The study utilizes a simulation modelling approach to conduct a sensitivity analysis for charging rates.	Using electric vehicles (EVs) in HRES significantly reduces grid pressure and emissions, while charging rates significantly impact project profitability.	The impact of HRES on various regions and the integration of electric vehicles in other sectors.	[34]
"Optimizing On-Grid Hybrid Renewable Energy-EV Charging Stations for BTS Infrastructure" • Lower LCOE with grid connection. • Cost-effective, sustainable solution.	The study evaluates the techno-economic aspects of 26 BTS sites, including sensitivity analysis and carbon emission reduction environmental evaluation.	On-grid hybrid systems have lower LCOE than standalone systems, and adding EV charging stations further reduces average LCOE.	The study aims to conduct a sensitivity analysis of uncertain elements and evaluate the environmental impact of carbon emission reduction.	[35]
"Solar-Powered Charging Station in Indonesia: Economic Viability and Hybrid Technology Integration" • Supports national energy sustainability and efficiency.	The simulation-based approach involves generating financial projections through simulations.	The On-Grid PLTS is projected to yield significant returns, with a profit projection of IDR 374,450,204.39 by the 25th year.	Hybrid technology integration is being used in renewable energy infrastructures to meet national goals for economic efficiency and energy sustainability.	[36]
"Designing Grid-Connected Hybrid Renewable Energy System" • Utilizes solar, wind, battery storage. • Enhances techno-economic perspectives.	The goal of the RB-EMS method is to minimize energy consumption by applying a multi-objective improved arithmetic optimization algorithm (MOIAOA).	With 8 PV modules, 2 wind turbines, and 33 batteries, the ideal system architecture yields an LCOE of 2.66×10^{-2} USD/kWh and a fitness value of 0.1522.	Integrating other renewable sources and optimizing energy management strategies are crucial for sustainable and efficient energy use.	[37]
"Solar Power-Based Hybrid EV Charging Station" • Integrates solar power and battery storage. • Validates effectiveness through simulations.	The study developed a three-stage charging method that combines a PV array, battery bank, and grid electricity using MPPT techniques, PV cell modeling, and charge controller algorithms.	The goal of designing a hybrid electric vehicle (EV) charging station with a 4 kW solar power output is to combine solar electricity with battery energy storage.	The study aims to enhance MPPT techniques for improved efficiency and investigate grid stability in response to increasing EV charging demands.	[38]
Adi Sumarmo Airport Solar Power-Based Hybrid EV Charging Station Research: • Emphasizes hybrid microgrid system for renewable energy. • Analyzes the economic potential of abundant solar and wind resources. • Calls for system enhancements.	The cost-effectiveness of grid-connected solar panels for airport EV charging stations was assessed in the study using HOMER-Grid optimization, considering variables like load requirements and renewable energy potential.	The study reveals that Adi Sumarmo Airport's renewable energy contribution is 26.11%, indicating reliance on conventional sources. Economic viability, system performance, and environmental conditions suggest an on-grid solar power plant as the best option, with potential for improvement.	Future research on renewable energy systems for airports, especially Adi Sumarmo Airport, could include hybrid microgrid systems, advanced simulation tools, economic and policy analysis, technological innovations, environmental impact studies, and integration with electric vehicles to optimize energy management and efficiency.	This research

5. CONCLUSIONS

The simulation results show that renewable energy can only contribute 26.11% of the total need for charging stations. This indicates that improvements are still needed in the renewable energy system to increase the renewable energy fraction. Electricity production from wind turbines is strongly influenced by regional factors and wind speed, which results in variations in electricity production. On the other hand, solar panels are considered more reliable because they can provide stable and consistent energy production throughout the year. However, in this simulation, the lowest production is obtained from solar panels because only one set of panels is used in the configuration. In addition, several technical aspects, such as component specifications, service life, and other operational costs, must be considered when choosing the correct configuration. System design efficiency is assessed through Net Present Cost (NPC). The HOMER program ranks solutions in optimization according to ascending NPC values as they may provide the most cost-effective system design. IDR 5,411,466,000.00 is the ideal NPC size created, and IDR 1,922.70 is the LCOE efficiency.

Continued research is recommended to explore and develop a hybrid microgrid system that could enhance the power supply capacity of SPKLU while maximizing the cost-efficient use of regional renewable energy resources. The proposed method offers several advantages: it allows for the simulation of different setups (disconnected and connected to the grid), conducts a detailed techno-economic analysis of hybrid systems, and fine-tunes costs and performance by utilizing precise environmental information. The HOMER-Grid simulations used to illustrate this approach examine data like Net Present Cost (NPC), Cost of Energy (COE), and system performance indicators to find the most economical and efficient energy options. These simulation results help validate the method's effectiveness by comparing different system configurations under realistic conditions, ultimately providing a robust framework for sustainable energy planning. By adopting renewable energy, Adi Sumarmo Airport can set an example of green technology implementation, contributing to reduced carbon emissions and enhancing the sustainability of its operations.

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