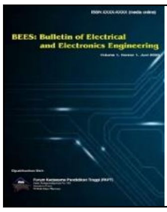

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Techno-Economic Analysis of Integrated Solar-Wind System for EV Charging Station

Eki Juana, Nurul Hiron, Linda Faridah*

Faculty of Engineering, Electrical Engineering, Siliwangi University, Tasikmalaya, Indonesia

Email: [1]ekijuana@gmail.com, [2]hiron@unsil.ac.id, [3,*]lindafaridah@unsil.ac.id

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Email: lindafaridah@unsil.ac.id

A B S T R A C T

This study aims to comprehensively evaluate the potential, technical, and economic feasibility of implementing a hybrid solar-wind power generation system as a sustainable energy solution to support the operation of Electric Vehicle Charging Stations (EVCS) in Pangandaran Regency, Indonesia. Through simulations using HOMER Energy software, this research analyzes the renewable energy resource potential in the region, with an average solar radiation of 5.03 kWh/m² and an annual wind speed of 5.03 m/s. The simulation results show that the optimal system configuration consists of 335 solar panels (113.9 kWp) and 6 wind turbines (9 kW), capable of generating 177,791 kWh of annual electricity, which is sufficient to meet the energy needs of the EVCS with a reasonable margin. The economic analysis conducted indicates that although there is a significant initial investment cost, the hybrid system has a Net Present Cost (NPC) of IDR 5,825,862,785 with a Cost of Energy (COE) of IDR 2,245/kWh, demonstrating that this investment offers long-term economic benefits. Furthermore, the sensitivity study performed shows that the system is relatively robust to changes in environmental conditions and other system parameters. The results of this research provide strong evidence that the hybrid solar-wind power generation system is technically, economically, and environmentally viable for supporting the development of electric vehicle charging infrastructure in areas with high renewable resource potential, such as Pangandaran. The implementation of this system is expected to reduce dependence on fossil fuels, lower greenhouse gas emissions, and promote the transition towards clean and sustainable energy in Indonesia

Keywords: Economic Analysis; Electric Vehices; Homer Energy; Solar; Wind

1. INTRODUCTION

The increasing impact of global climate change has driven many countries to shift towards cleaner and more sustainable energy sources [1] [2]. This shift has made renewable energy, such as solar and wind power, a central focus in efforts to reduce greenhouse gas emissions [3]. Indonesia, with a population of over 250 million, has significant potential for renewable energy development [4]. The implementation of hybrid systems combining solar and wind power not only has the capability to meet rising energy demands but also reduces dependence on fossil fuels and enhances the reliability of electricity supply [5]. A significant transformation is also occurring in the transportation sector with the emergence of electric vehicles (EVs) [6]. EVs offer tremendous potential for reducing greenhouse gas emissions and reliance on fossil fuels [7] [8]. However, widespread adoption of EVs must be supported by adequate charging infrastructure [9]. Indonesia, as an archipelagic country with abundant renewable energy resources [10], has a great opportunity to lead the development of electric vehicles. The high solar and wind energy potential across various regions in Indonesia presents an attractive solution to addressing the energy supply challenges for electric vehicle charging stations (EVCS). Integrated solar-wind power systems, which combine solar panel technology with wind turbines, are designed to generate electricity simultaneously [11] [12]. The integration of these two energy sources can enhance system reliability and efficiency while mitigating the power fluctuations commonly associated with each energy source when used independently [13] [14]. Additionally, the use of energy storage systems, such as batteries, can help address the intermittency issues of renewable energy and ensure a consistent energy supply for electric vehicle charging.

In line with global commitments to combat climate change, the Indonesian government has set ambitious targets to increase the share of new and renewable energy (NRE) in its energy mix to 23% by 2025 [15]. This commitment is reflected in various policies, including Presidential Instruction No. 7 of 2022, which specifically promotes the development of the electric vehicle ecosystem. With strong policy support, Indonesia has the potential to become a leader in the energy transition within Southeast Asia. While research on the utilization of solar and wind energy for various applications has been extensive, studies specifically analyzing the techno-economic aspects of integrated solar-wind power systems for EVCS in Indonesia remain limited. Most existing studies focus more on the technical feasibility and potential of these systems, while comprehensive economic analyses, including investment costs, operational expenses, and return on investment (ROI), are still lacking [16] [17].

The development of electric vehicle infrastructure in Pangandaran Regency, Indonesia, can be optimally supported through the expansion of renewable energy systems. Given the urgency of mitigating global climate change and reducing carbon emissions, the use of renewable energy sources such as solar and wind power has become increasingly crucial [18]. Pangandaran, as a coastal region with abundant natural resources, experiences an average solar radiation of 5.03 kWh/m² and an annual wind speed of 5.03 m/s, making it an ideal location for the implementation of hybrid energy systems [19] [20]. A hybrid solar and wind power generation system is an excellent choice to meet the energy needs of electric vehicle charging stations [21]. EVCS powered by renewable energy systems can contribute to the decarbonization of the transportation sector and support more sustainable national energy policies [21]. By combining solar and wind energy, this system is not only efficient in generating electricity but also provides a sustainable and environmentally friendly solution. Previous studies have shown that the combination of these two energy sources can enhance the reliability of electricity supply and reduce dependency on depleting fossil fuels. Moreover, economic analyses indicate that the initial investment in such hybrid systems will pay off in the long term through operational and maintenance cost savings [21].

This research aims to comprehensively analyze the technical and economic feasibility of implementing an integrated solar-wind power system as the energy source for EVCS in Pangandaran. The analysis will include system performance evaluation, investment and operational cost calculations, simulation model development, and environmental impact assessment. Additionally, this study will examine the system's technical potential in meeting EVCS energy needs, conduct a sensitivity analysis on various economic parameters, and formulate policy recommendations that promote the development of renewable energy-based EVCS in Indonesia. The findings are expected to contribute significantly to the advancement of renewable energy in Indonesia, particularly in the transportation sector. This research will also provide a scientific basis for sustainable energy policies and offer valuable insights for the industry and the public regarding the adoption of electric vehicles and the development of sustainable charging infrastructure in Indonesia

2. RESEARCH METHODOLOGY

This study employs a comprehensive research methodology to evaluate the technical and economic feasibility of an integrated solar and wind power generation system for electric vehicle charging stations (EVCS). The methodology consists of several key steps:

2.1 Literature Review

The research begins with a thorough literature review to collect relevant data and insights on solar and wind power systems, electric vehicle charging technologies, and hybrid energy systems. This comprehensive review draws from a variety of sources, including academic journals, government policies and regulations, and technical manuals for solar panels, wind turbines, and energy storage systems. Additionally, existing studies on the implementation of renewable energy systems for electric vehicle charging stations (EVCS) are also consulted. This review provides foundational knowledge and helps identify potential challenges and solutions in renewable energy system implementation.

2.2 Site Identification and Data Collection

The research site is selected based on geographical and environmental factors in Pangandaran Regency, Indonesia, with a focus on areas suitable for both solar and wind power generation. The data collection process includes:

1. Geographic Analysis: Utilizing topographic and geological maps to understand the physical characteristics of the area.
2. Solar Radiation Data**:** Gathering solar radiation information from sources like NASA and Solargis, with an average solar radiation of 5.03 kWh/m² per day.
3. Wind Speed Data: Collecting wind speed data from meteorological sources, with an average annual wind speed of 5.03 m/s.
4. Energy Demand Data: Estimating energy demand for EVCS based on vehicle usage patterns and charging requirements.

2.3 System Design and Configuration

The next step in designing a hybrid renewable energy system involves several key activities. Firstly, component selection is crucial, where suitable components are identified for the system. This includes:

1. Solar panels: The Canadian Solar MaxPower CS6U-340M, which boasts an efficiency of 17.49%.
2. Wind turbines: Horizontal Axis Wind Turbines (HAWT) with a capacity of 1,500 W.
3. Energy storage: 24 units of Polarium SLB48-150-146-2 batteries, each with a 20-year lifespan.

Following component selection, mathematical modeling is essential. This involves developing models for each component to calculate energy output, efficiency, and overall system performance. These models help in understanding how each component will contribute to the overall efficiency and reliability of the hybrid system.Lastly, system topology needs to be defined. This includes determining the arrangement of solar panels, wind turbines, converters, and their interaction with the energy storage system. The topology must be optimized to ensure maximum energy production and efficient use of the stored energy. By carefully planning these aspects, the hybrid system can be designed to maximize its potential in providing clean and reliable renewable energy.

2.4 Simulation Using HOMER Energy Software

HOMER (Hybrid Optimization of Multiple Energy Resources) Energy software is used to simulate the performance of various system configurations and optimize their design. The key inputs for the simulation include component specifications such as solar panels, wind turbines, converters, and batteries, along with solar radiation and wind speed data from the research site. Additionally, energy demand data for Electric Vehicle Charging Stations (EVCS) and economic parameters like capital cost and maintenance cost are also considered. The software simulates different scenarios, taking into account variations in solar radiation, wind speed, and system size, to determine the optimal configuration that meets the energy demand at the lowest cost.

2.5 Economic Analysis

An economic analysis is conducted to evaluate the financial feasibility of the system, focusing on several key metrics. First, the Net Present Cost (NPC) is calculated to determine the total cost of the system over its lifetime, which includes the initial capital, operational, and maintenance costs . Next, the Cost of Energy (COE) is estimated to determine the cost per kilowatt-hour (kWh) of electricity generated by the system. Additionally, the Levelized Cost of Electricity (LCOE) is determined, which represents the overall cost per unit of energy, accounting for all capital, operational, and maintenance costs throughout the system's lifespan . Lastly, the Return on Investment (ROI) is calculated to estimate the time required to recover the initial investment, based on the energy savings and potential revenue generated from electric vehicle (EV) charging

2.6 Sensitivity Analysis

A sensitivity analysis is conducted to evaluate the robustness of the system in response to changes in environmental conditions and economic parameters. The key variables tested include fluctuations in solar radiation and wind speed, variations in component costs, and changes in energy demand for Electric Vehicle Charging Stations (EVCS). This analysis is essential for identifying the most critical factors that influence the system's overall performance and its economic viability.

2.7 Performance Evaluation

The system's performance is evaluated based on the simulation results, focusing on the following aspects:

1. Energy Production: Estimating the total annual energy generation from the hybrid system (PLTS and PLTB), with a target of 177,791 kWh/year.
2. System Efficiency: Measuring the efficiency of each component and the overall system, with a target absorption rate of 92%.
3. Battery Storage Performance: Analyzing the performance of the energy storage system, including capacity, charge/discharge cycles, and degradation over time.
4. Peak Load Management**:** Assessing the system's ability to handle peak loads and ensure continuous energy supply for EV charging.

2.8 Environmental Impact Assessment

An environmental impact assessment (EIA) is conducted to evaluate the potential environmental benefits of the hybrid system, including several key aspects. Firstly, the EIA assesses the reduction in greenhouse gas emissions resulting from the reduced reliance on fossil fuels. This is a significant benefit as it contributes to mitigating climate change and improving air quality. Additionally, the EIA focuses on minimizing the environmental impact from the construction and operation of the solar and wind power systems. This involves evaluating the potential for habitat disruption, noise pollution, and other ecological effects during both the installation and operational phases of these renewable energy sources. Lastly, the assessment examines land use efficiency and potential impacts on local ecosystems.

2.9 Policy Recommendations

Based on the research findings, several recommendations are proposed for policy-makers and stakeholders in Indonesia to effectively promote renewable energy infrastructure for Electric Vehicle Charging Stations (EVCS). These recommendations emphasize the need for a comprehensive and supportive policy framework to encourage the integration of renewable energy sources in the country's transportation sector.

First, it is recommended to implement financial incentives to attract investments in renewable energy projects. This could include subsidies, tax breaks, low-interest loans, or grants aimed at reducing the high initial costs associated with the installation of solar panels, wind turbines, and energy storage systems. By lowering the financial barriers to entry, these incentives would significantly encourage private sector involvement in the development of clean energy solutions for EVCS.

Second, the creation and enforcement of policies that promote the widespread adoption of electric vehicles is crucial. These policies could involve offering subsidies for EV purchases, establishing stringent emission regulations for conventional vehicles, and providing public awareness campaigns about the benefits of electric vehicles. By increasing the demand for EVs, there will be a corresponding need for a reliable and sustainable charging infrastructure powered by renewable energy.

Lastly, a targeted effort is recommended for the development of renewable energy infrastructure, particularly in rural and coastal areas. These regions often have abundant renewable energy resources, such as ample sunlight and consistent wind patterns, making them ideal locations for solar and wind power generation. Investments in these areas would not only support EVCS but also promote regional development and energy independence.

3. RESULT AND DISCUSSION

The research was conducted in Parigi District, Pangandaran Regency, with an area of 1,660 m². This study focuses on the construction of Solar Power Plants (PLTS) and Wind Power Plants (PLTB) for charging electric vehicles through an integrated system show in **Figure 1**.

Figure 1. Research Location

3.1 System Configuration

3.1.1 Solar Power Plant (PLTS)

The area available for solar modules is 681 m². The solar modules used are monocrystalline types with an efficiency of 17.49%. The solar panels used are Canadian Solar MaxPower CS6U-340M, with a maximum power output of 340 Wp and a panel efficiency of 88% at a maximum operating temperature of 47°C. In one day, a single solar panel can produce 1,376 kWh of electricity. The total energy that can be generated from an area of 681 m² is 45,939 kWh/day using 335 solar panels.

Figure 2. PLTS Farm

3.2.2 Wind Power Plant (PLTB)

The wind turbines used are of the Horizontal Axis Wind Turbine (HAWT) type with an average wind speed of 5.03 m/s. Each turbine has a maximum power output of 1,500 W with an efficiency of 18%. The total electricity generated by one turbine in one day is 527.425 Wh. With 6 turbines installed in an area of 1,094 m², the total energy generated is 316 kWh/day.

Figure 3. PLTB Farm

3.3.3 Converter

The converter used is the SCU EVSS with a maximum output power of 100 kW, an input voltage of 380 V, an output current of 250 A, and an output voltage between 50-1000 V. This converter is capable of efficiently handling electric vehicle charging. Charging is carried out using level 3 charging, which can charge electric vehicles from 20% to 85% battery capacity, with a full cycle reaching 146 charges per day for a total power of 46,255 kWh. Charging at 50 V takes 25 hours, while at 1000 V, it only takes 72 minutes. The total battery capacity used in this study is 18,833 kWh using 24 Polarium SLB48-150-146-2 batteries. These batteries have a lifespan of 20 years and a working voltage of 504 V. This system can generate 177,791 kWh of electricity per year, with PLTS contributing 158,127 kWh/year (88.9%) and PLTB contributing 19,665 kWh/year. The system's energy absorption rate reaches 92%, allowing for high efficiency in charging electric vehicles. These results demonstrate that the integration of PLTS and PLTB is effective in providing sufficient energy for electric vehicle charging in the research area, with potential for wider implementation in the future.

3.2 Technical Analysis

This research was conducted to analyze the performance of the power generation system through the integration of Solar Power Plants (PLTS) and Wind Power Plants (PLTB) to charge electric vehicles. The following are the results of the technical system analysis. With a peak load of 200 kW from HOMER energy optimization, which modifies the load profile to be more realistic for future scenarios, the components in the topology are explained as follows Figure 4. Technical Analysis This system is capable of generating a total of 177,791 kWh per year. Of this amount, the largest contribution comes from the Solar Power Plant (PLTS), generating 158,127 kWh per year or 88.9% of the total energy produced. This indicates that the solar system plays a major role in energy generation.

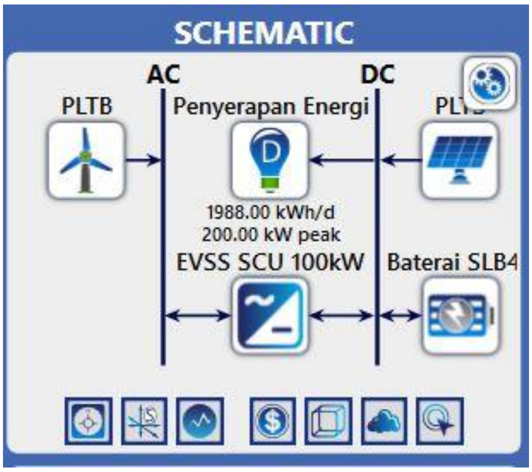

Figure 4. System Topology

Additionally, the Wind Power Plant (PLTB) contributes 19,665 kWh per year or 11.1% of the total energy produced. Although the contribution of PLTB is smaller than that of PLTS, PLTB still provides important support, particularly in weather conditions less favorable for solar power. Out of the total energy generated, the system successfully absorbs 163,590 kWh per year, covering 92% of the total energy produced. This demonstrates a very efficient energy absorption and utilization rate.

3.3 Economic Analysis

An economic analysis was conducted to assess the long-term financial feasibility of this system, covering initial costs, operational costs, and evaluation of the cost of generated energy. Based on this analysis, the Net Present Cost (NPC) of the system is recorded at IDR 5,825,862,785, which includes all initial investment costs, operational and maintenance costs, and equipment costs over the project's lifetime. The initial capital required to build the system amounts to IDR 2,229,391,755, which includes the purchase and installation of key components such as solar panels, wind turbines, batteries, and converters. Annual operational and maintenance costs are estimated at IDR 3,406,966,019, which includes maintenance for solar panels, wind turbines, and storage systems. The Cost of Energy (COE) produced by this system is IDR 2,245 per kWh, reflecting the cost per unit of energy generated during system operation. However, the Levelized Cost of Electricity (LCOE), which considers all energy generation costs throughout the system's operational period, still needs to be further calculated.

3.4 Storage System Performance

Energy storage systems are crucial for ensuring stable power availability, especially when solar or wind energy sources are insufficient. The storage system used has a nominal capacity of 181 kWh, sufficient to meet electric vehicle charging needs in certain situations. The storage system's bus voltage reaches 403.2 V, designed to meet the system's operational needs efficiently. With an autonomy of 7.03 hours, this system can ensure a continuous power supply during this period, even when no energy is being generated. Additionally, the storage wear cost is estimated at IDR 574/kWh, which is an additional cost due to the degradation of storage capacity over time.The results of this study provide a comprehensive overview of the technical and economic feasibility of integrating PLTS and PLTB for electric vehicle charging, as well as the performance of the energy storage system in supporting the system's daily operations.

4. CONCLUSION

This study demonstrates that the integrated solar and wind power generation system (PLTS and PLTB) in Pangandaran Regency can provide a sustainable energy solution for electric vehicle charging stations (EVCS). Utilizing 335 solar panels and 6 wind turbines, this system is capable of generating 177,791 kWh of electricity per year, with solar power contributing 88.9% and wind power contributing 11.1%. The system shows high efficiency, with an energy absorption rate of 92%. Furthermore, despite the significant initial investment cost, the economic analysis reveals a cost of energy (COE) of IDR 2,245/kWh, indicating long-term economic benefits. The implementation of this system not only meets the energy demands of EVCS but also has the potential to reduce reliance on fossil fuels, lower greenhouse gas emissions, and support the transition towards clean and sustainable energy in Indonesia. Additionally, the integration of solar and wind power sources provides a more reliable and resilient energy supply for EV charging stations, reducing the risks associated with energy shortages and fluctuations in power availability. The system's design can be tailored to accommodate varying energy needs, making it adaptable for use in other regions with different renewable energy potentials. This research not only highlights the technical feasibility and economic viability of using renewable energy for EVCS but also underscores the environmental benefits that accompany such a transition. By promoting renewable energy adoption in the transportation sector, the study contributes to Indonesia's broader goals of energy independence and carbon neutrality. This research provides a solid foundation for further development of renewable energy infrastructure in the transportation sector, especially in regions with high renewable energy potential, such as Pangandaran.

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