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Simulation of the Photovoltaic System Capacity to Power the Electrical Vehicles under Tropical Climate of Surabaya, Indonesia

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Abstract. This paper presents a simulation study of a photovoltaic capacity to power electrical vehicle under the tropical climate of Surabaya, Indonesia. The study aims to investigate the feasibility of using solar panels as the main energy source for electrical vehicle in a tropical region, where solar radiation is abundant but often accompanied by high temperatures and humidity. The simulation model was developed using "Photovoltaic Geographical Information System" software, which integrates a mathematical model of the photovoltaic panel. The simulation was carried out over a period of one year, with weather data from simulation database. Given that electric cars have an average energy consumption of about 0.15 kWh/km, the daily electrical energy needed falls within the range of 6.0 to 7.5 kWh. Analyzing the specific data on the output energy of photovoltaic systems in Surabaya reveals that a photovoltaic system capacity of approximately 1.7 to 2.0 kWp is required to fulfill this daily energy demand.

1 Introduction

The growing concerns about climate change and the need to reduce carbon emissions have led to increased interest in electric vehicles (EVs) as a sustainable alternative to traditional internal combustion engine vehicles [1]. Studies have shown that EVs have the potential to significantly reduce greenhouse gas emissions, enhance energy efficiency, and improve air quality [2]. However, the environmental benefits of EVs can only be fully realized if the electricity used to charge them comes from renewable and low-carbon sources. This has led researchers to explore various renewable energy options, including solar power, to power EVs [3].

Solar energy is a clean and abundant renewable energy source that has gained significant attention in recent years. Photovoltaic (PV) systems, which convert sunlight into electricity, have become increasingly cost-effective and efficient. The deployment of PV systems for residential and commercial use has expanded globally [4]. Solar panels offer a promising solution to generate clean electricity for EVs, as they can provide a sustainable and decentralized source of power [5].

Several studies have investigated the integration of PV systems with EV charging infrastructure. These studies have explored different aspects, including system design, performance analysis, and economic feasibility [6]. The utilization of PV systems for EV charging can reduce reliance on grid electricity and lower carbon emissions associated with charging EVs [7]. Furthermore, PV-powered charging stations can provide charging options in remote areas or during power outages [8].

Tropical regions, such as Surabaya, Indonesia, pose unique challenges for PV systems due to their specific climatic conditions. High temperatures and humidity can impact the efficiency and longevity of PV panels, leading to reduced energy generation. The performance of PV systems under tropical climates needs to be thoroughly evaluated to assess their feasibility as the primary energy source for EVs in these regions [9].

Simulation studies have been widely used to assess the performance and feasibility of PV-powered EV systems. These studies involve developing mathematical models that incorporate data on solar radiation, weather patterns, PV panel characteristics, and EV charging requirements. Simulation models provide a cost-effective and time-efficient approach to evaluate system performance under different scenarios, enabling researchers to make informed decisions regarding system design, capacity planning, and operational strategies [10].

While numerous studies have explored PV systems for EV charging and their performance under various climates, there is a research gap concerning the specific challenges and feasibility of utilizing solar panels to power EVs in tropical regions. The unique combination of abundant solar radiation and challenging climatic conditions in tropical areas requires an in-depth analysis

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of the potential and limitations of PV systems in this context [11].

The literature highlights the importance of transitioning to sustainable transportation systems and the potential of PV systems to power EVs. However, limited research has addressed the specific challenges and feasibility of PV-powered EV systems in tropical regions such as Surabaya, Indonesia.

This study aims to bridge this research gap by conducting a comprehensive simulation study to assess the performance and feasibility of PV systems as the main energy source for EVs under the tropical climate. The study focuses on evaluating the performance of PV capacity under the specific climatic conditions prevalent in the region. To accomplish this, a simulation model was developed using the PVGIS software, which incorporates a mathematical model of the PV panel. The proposed PV capacity was adjusted to account for energy losses due to equipment such as solar charge controllers, batteries, and cabling systems, ensuring a realistic estimation of the system's capabilities.

By exploring the potential of solar energy for EVs, this study is expected to contribute to the ongoing efforts towards achieving sustainable transportation and reducing greenhouse gas emissions. The findings can serve as a foundation for policymakers, urban planners, and researchers to make informed decisions and develop strategies that promote the widespread adoption of clean and renewable energy sources for EVs.

2 Methods

In this study, a comprehensive examination of Electric Vehicle (EV) specifications and their compatibility with solar energy systems is conducted. The methods employed involve a systematic approach to understanding the power requirements, battery characteristics, and energy needs of electric vehicles. Additionally, the study delves into assessing the feasibility of harnessing solar energy to meet these requirements. The key methodologies are outlined below:

2.1 Electric Vehicle Specifications Analysis

- Power Rate: The power rate of an electric vehicle is crucial for determining its energy consumption and charging needs. This involves a detailed examination of the vehicle's power specifications, which includes its motor capacity and overall power efficiency.
- Energy Needs: An assessment of the overall energy requirements of an electric vehicle, considering factors like daily commuting patterns and charging habits, is conducted. This analysis helps in identifying the energy demands that need to be fulfilled by alternative energy sources.

2.2 Solar Radiation Simulation in Surabaya using PVGIS

Utilizing the Photovoltaic Geographical Information System (PVGIS), solar radiation availability in Surabaya is simulated. This step involves considering geographical factors, weather patterns, and other relevant parameters to estimate the solar energy potential in the region.

2.3 Simulation of PV System Suitability for Electric Vehicles:

Based on the solar radiation data and solar panel efficiency evaluations, a simulation is carried out to determine the suitability of a Photovoltaic (PV) system for meeting the energy needs of electric vehicles in Surabaya. This includes assessing the potential energy generation, taking into account variations in weather conditions and seasonal changes.

By employing these methods, the study aims to provide valuable insights into the feasibility and efficiency of utilizing solar energy to power electric vehicles in Surabaya. The integration of detailed electric vehicle specifications and solar energy assessments ensures a holistic approach to sustainable transportation solutions.

3 Results and Discussions

3.1 Review of Recent Electric Vehicle Specifications

The electric vehicle (EV) landscape is rapidly evolving, with new and exciting models entering the market at an impressive pace. To navigate this dynamic field, staying updated on the latest specifications is crucial. This review delves into the newest EV offerings, dissecting their power rates, battery capabilities, and energy consumption, providing a snapshot of the current state of the art.

EVs are no longer relegated to sluggish acceleration and underwhelming top speeds. The latest crop boasts impressive powertrain outputs. Tesla's Model S Plaid, for instance, delivers a breathtaking 1,100 horsepower (hp) and rockets from 0 to 60 mph in a mere 2.1 seconds [12]. Lucid Air Dream Edition Performance follows closely with 1,111 hp and a 2.5-second 0-60 mph time [2]. For those seeking a balance between performance and affordability, the Hyundai Kona Electric N boasts 275 hp and a respectable 5.2-second 0-60 mph sprint [14].

Battery technology is arguably the backbone of EV performance and range. Recent advancements offer higher energy densities and faster charging times. The aforementioned Lucid Air Dream Edition boasts a staggering 520 miles of EPA-estimated range on a single charge [13]. The Chevrolet Bolt EUV, while offering a more moderate 247 miles of range, can replenish up to 100 miles of range in just 10 minutes at a DC fast-charging station [4]. For city dwellers, the Honda e, with its quirky retro styling and 122-mile range, proves perfect for urban commutes [16].

Ultimately, the true measure of an EV's eco-friendliness is its energy consumption. Expressing consumption in kWh/km (kilowatt-hours per kilometer) allows for clear comparison between models and fuel types. Leading the pack in energy efficiency is the Hyundai Ioniq 6 Long Range RWD, consuming a mere 0.148 kWh/km [17]. The Nissan Leaf e+, while slightly less frugal at 0.160 kWh/km, remains a popular and affordable option [18]. For those seeking a blend of luxury and efficiency, the Mercedes-Benz EQS Sedan 450+ delivers a respectable 0.179 kWh/km [19].

3.2 Site Meteorological and Solar Radiation Data

Surabaya is situated at a geographical position of 07° 19' 17.83" South and 112° 46' 3.19" East, as depicted in Fig 1. The solar path over the course of a year in Surabaya is illustrated in Fig 2. This figure delineates the terrain horizon, module horizon, and active area, accompanied by civil (clock time) and solar time. It is important to note that the module horizon might induce shading effects on solar radiation.

Fig. 1. Geographic position of Surabaya.

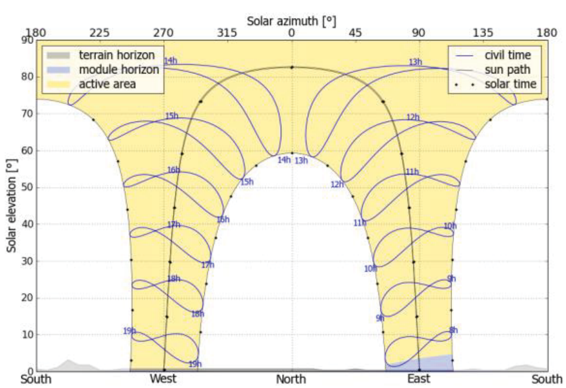

Fig. 2. Path of the Sun over a year in Surabaya.

Fig. 3 illustrates the variation in day length and solar zenith angle throughout the year. The local day length, representing the duration when the Sun is above the horizon, is notably shorter compared to the astronomical day length when obstructed by a higher terrain horizon.

Fig. 4 provides insights into the global horizontal irradiation and air temperature over the course of a year. The global radiation components include direct, diffuse, and reflected radiation. On average, the daily sum of global irradiation on a horizontal surface is approximately 5.54 kWh/m^2 per day, reaching a maximum of 6.81 kWh/m^2 in September and a minimum of 4.82 kWh/m^2 in December. Notably, the diffuse component of radiation plays a significant role, particularly during March to October, while reflected radiation remains relatively low throughout the year. The yearly average of diffuse radiation constitutes about 45% of the total global radiation.

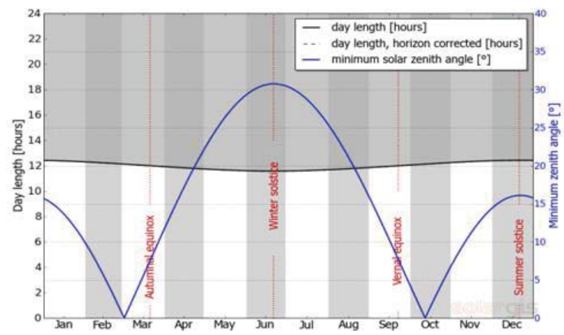

Fig. 3 Day length and minimum solar zenith angle in Surabaya.

Historically, global radiation has exhibited higher values from April to October, coinciding with the dry season in the region. Conversely, lower average solar radiation is observed from December to March, corresponding to the rainy season. However, recent trends suggest an unpredictability in the seasonal periods, prompting further investigation. This unpredictability may be linked not only to photovoltaic (PV) applications but also to broader issues such as

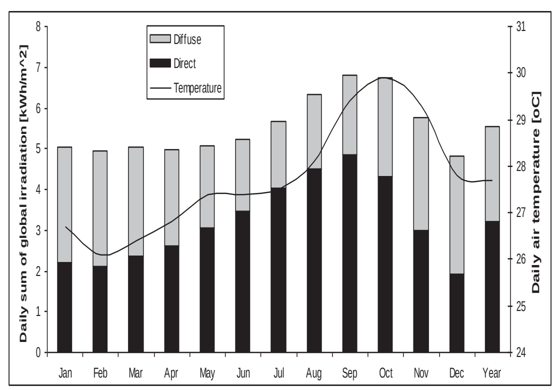

Fig. 4. Global irradiation and air temperature in Surabaya

global warming or climate change. The diurnal air temperature, depicted in Fig. 4, demonstrates variations in ambient temperature in Surabaya ranging from 26 to 30 ^oC.

3.3 PV Specific Energy Production

The summary of the total annual PV system specific energy output in Surabaya, considering different azimuth angles, is presented in Fig. 5. Clearly depicted

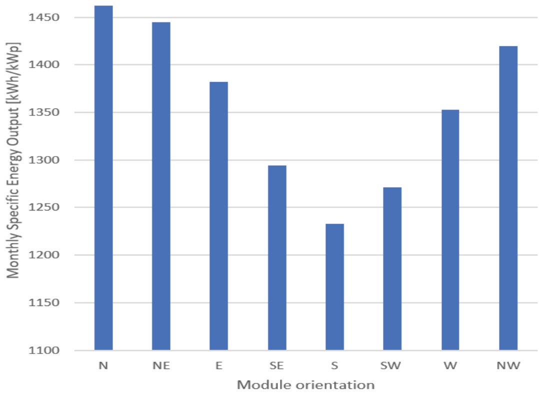

Fig. 5. Specific energy output of PV System in Surabaya

in the figure is the evident peak in specific energy output for a rooftop PV system in Surabaya when the PV system's azimuth angle is around 0°. This implies that, for a fixed installation of a PV system in Surabaya, the recommended orientation for modules is approximately North. A comparative analysis for different locations, particularly within Indonesia, warrants further investigation through subsequent studies to enhance the knowledge base on solar PV performance in the country.

The variation in azimuth angle results in a range of specific energy outputs, spanning from 1,233 kWh/kWp to 1,462 kWh/kWp. Then, the daily average specific energy output is about 3.6 kWh/kWp. The optimal value is achieved when the PV system has an azimuth angle of 0°, reinforcing the recommendation for modules to face North in Surabaya. This valuable information is anticipated to contribute significantly to the advancement of solar PV development in Indonesia.

3.4 The Capacity PV System to Power the Electrical Vehicles

The PV system capacity required to supply energy for electric vehicles depends on various factors, especially:

1. Solar energy potential at the PV installation location expressed in specific output energy
2. The required vehicle mileage is calculated daily
3. Specifications for vehicle electricity consumption, calculated based on kWh/km

According to data, in Indonesia itself, normal use of private cars in a year is usually around 15,000-20,000 km, meaning that car use is an average of 40 – 50 km per day [20]. Referring to the specifications for the average energy consumption of electric cars as discussed previously, namely around 0.15 kWh/km, the electrical energy needed is 6.0 – 7.5 kWh per day. Based on specific data on PV system output energy in Surabaya, to meet the need for 6.0 – 7.5 kWh per day, the required PV system capacity is around 1.7 – 2.0 kWp.

4 Conclussion

The power rate of an electric vehicle is crucial for determining its energy consumption. By exploring the potential of solar energy for electrical vehicle , this study is expected to contribute to the ongoing efforts towards achieving sustainable transportation and reducing greenhouse gas emissions. The capacity of the photovoltaic system needed to power electric vehicles is contingent upon several factors, primarily:The solar energy potential at the installation site, quantified in specific output energ; Daily calculation of the required vehicle mileage; and Specifications outlining vehicle electricity consumption, determined by kWh/km. With an average energy consumption of electric cars at approximately 0.15 kWh/km, the daily electrical energy requirement in is 6.0 to 7.5 kWh. With specific data on photovoltaic system output energy in Surabaya, it is determined that a photovoltaic system capacity of around 1.7 to 2.0 kWp is necessary to meet this daily energy demand.

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