

Development Challenges and Future Prospects of Public Electric Vehicle Charging Infrastructure in Indonesia

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Abstract –The adoption of electric vehicles (EVs) in Indonesia has progressed markedly; nevertheless, public charging infrastructure (SPKLU) remains severely inadequate, with merely 1,081 units installed by end of 2023 against a national target of 32,000 units by 2030. This study presents a quantitative framework for assessing SPKLU development challenges and deployment priorities in Indonesia, integrating market analysis, battery technology evaluation, consumer preference quantification, and spatial optimization. EV market data from January 2026 — totaling 14,908 sales across BEV, HEV, and PHEV segments — were analyzed alongside provincial SPKLU service ratios and battery chemistry efficiency comparisons between lithium iron phosphate (LFP) and nickel manganese cobalt (NMC) technologies. Consumer preferences were quantified through a field survey of 107 respondents using factor analysis, while multi-criteria site selection was conducted via the Analytic Hierarchy Process (AHP) for Probolinggo City as a case study. Intercity SPKLU routing for East Java was optimized using dynamic programming with a 250 km range constraint. Results indicate that BEV sales grew 400% year-over-year, intensifying infrastructure demand; LFP batteries demonstrate superior efficiency at 11.12 km/kWh versus 7.40 km/kWh for NMC; and Sukabumi Gas Station scored highest (4.52) among four candidate locations. The optimal Trans-Java corridor spans six cities across 520 km. The findings provide practical analytical insights for EV charging infrastructure planning and deployment prioritization in emerging economies.

Keywords: Analytic hierarchy process, charging infrastructure, dynamic programming, electric vehicle, SPKLU Indonesia

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I. Introduction

The worldwide advancement of electric vehicles has exhibited a notable increase in recent years, propelled by improvements in battery technology, decreasing production expenses, and governmental policies in several nations focused on mitigating greenhouse gas emissions. Indonesia, as one of the most populous nations globally and with a significant increase in automobile proliferation, is undergoing this transitional momentum. The public's understanding of the environmental consequences of traditional fossil-fueled vehicles, along with the government's dedication to decreasing carbon emissions in accordance with the 2016 Paris Agreement, has emerged as a significant catalyst for electric vehicle adoption in the nation [1] – [2].

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The Indonesian government has affirmed its dedication by issuing Presidential Regulation (Perpres) Number 55 of 2019 for the Acceleration of the Battery-Based Electric Motor Vehicle Program (KBLBB) [3]. This law establishes the legislative foundation for the holistic advancement of the electric vehicle ecosystem, encompassing production and purchasing incentives, technical standards, and the expedited development of supporting infrastructure, including Public Electric Vehicle Charging Stations (SPKLU) [4]. An ambitious goal has been established: by the year 2030, there are approximately 2 million electric automobiles and 13 million electric motorcycles that are expected to be operational [5]. The Ministry of Energy and Mineral Resources (ESDM) anticipates that the demand for SPKLU will reach approximately 32,000 units over the

entirety of Indonesia[6]. This is in order to provide essential services to such a huge population.

Nonetheless, the actual situation poses considerable difficulties. By the conclusion of 2023, the total of installed public charging stations (SPKLU) had hardly attained 1,081 units [7]. This number has nearly tripled compared with the previous year, although it still presents a considerable shortfall in relation to the 2030 target. The existing distribution of SPKLU is markedly inequitable, with over 70% concentrated in Java, leaving other regions in Indonesia deficient in charging infrastructure. This scenario induces user worry regarding range and may impede EV adoption beyond Java[8]. Identifying the optimal SPKLU site is a critical concern in infrastructure planning. Article 26 of Presidential Regulation 55/2019 mandates that SPKLU shall be accessible, possess designated parking, and not disrupt security, safety, order, or traffic flow [3]. Comprehensive research is required to address these factors, encompassing user movement patterns, customer preferences, land availability, electrical connections, and regional connectivity.

Several prior studies have emphasized the challenge of SPKLU infrastructure preparedness in Indonesia. [9], [10] said that SPKLU is still in its early phases of growth and needs substantial policy support and collaboration between several sectors. A study by [11] employed GIS-based spatial analysis to find the best place for SPKLU in Bandung. It stressed how important it is to be close to places where people in the community do things [7]. Nonetheless, research that amalgamates quantitative user preferences with inter-city network analysis and precise placement selection at the municipal level remains scarce.

The main contributions of this study are grounded in a comprehensive quantitative analysis. First, the study provides a data-driven evaluation of the development of Indonesia's public electric vehicle charging infrastructure, known as Stasiun Pengisian Kendaraan Listrik Umum (SPKLU). The analysis examines the current deployment status, identifies key challenges in infrastructure expansion, and outlines future prospects to support the broader adoption of electric vehicles in Indonesia. It also quantifies the gap between existing charging infrastructure and the national development targets for 2030 by incorporating recent market sales data and projected growth of Battery Electric Vehicles (BEV), Hybrid Electric Vehicles (HEV), and Plug-in Hybrid Electric Vehicles (PHEV).

Second, the study employs field surveys and factor analysis to identify and prioritize key consumer preferences related to SPKLU features, producing an empirically derived priority framework for infrastructure development. Third, dynamic programming is applied to determine optimal inter-city routes and priority locations for SPKLU deployment in East Java, enabling feasible long-distance electric vehicle travel. Fourth, a multi-

criteria evaluation using the Analytic Hierarchy Process (AHP) is conducted to identify the most suitable SPKLU placement in Probolinggo City as a case study, with the results ranked and evaluated using weighted composite scoring derived from AHP pairwise comparisons.

Beyond location planning, the study also presents a technical analysis that includes a comparative evaluation of the efficiency of LFP and NMC battery chemistries, an examination of the relationship between battery capacity and driving range, and the development of an energy-constrained vehicle routing model for the Trans-Java network. The findings, supported by simulations conducted using MATLAB, provide analytical insights for infrastructure planning and provide analytical insights for assessing EV charging infrastructure planning in emerging economies.

II. Literature Review

A. *The Development of Electric Vehicles and Charging Infrastructure in Indonesia*

The number of electric vehicles in Indonesia has grown quickly in the last several years. As of October 2023, there were about 20,414 electric cars and 74,988 electric motorcycles on the road [12]. This rise is because there are more car models to choose from, battery prices are going down, and the government is giving people incentives like lower import customs and luxury goods sales tax (PPnBM) [3]. But even with this growth, electric vehicles still only make up about 1.47% of the market, which shows that widespread use still has a long way to go.

The Indonesian government wants to have 2 million electric automobiles and 13 million electric motorcycles on the road by 2030. This goal needs a lot of supporting infrastructure, especially Public Electric Vehicle Charging Stations (SPKLU) [13]. Research by [14] found that the shortage of charging stations and range anxiety were two of the biggest reasons why people in Indonesia don't want to buy electric cars. Research conducted by [15] identified analogous challenges, underscoring that inadequate charging infrastructure and elevated beginning expenses are significant determinants affecting consumer choices.

The best number of vehicles to public charging sites changes from country to country. But in general, to get a lot of people to use them, there should be at least one fast charging point for every 10 to 20 cars [16]. If we assume this, the goal of having 32,000 fast charging stations by 2030 [5] is a realistic one, even though it is quite ambitious since only around 3% of that goal has been attained so far. Table I compares the rise of electric cars and fast charging stations in Indonesia over the past few years.

TABLE I
GROWTH OF ELECTRIC VEHICLES AND PUBLIC CHARGING STATIONS IN INDONESIA

Year	Electric Cars (units)	Electric Motorcycles (units)	Total Public Charging Stations (SPKLU)
2022	7,000	25,000	438
2023	20,414	74,988	1,081
2030 (Target)	2,000,000	13,000,000	32,000

B. Electric Vehicle Charging Technology

International standards, including IEC 61851, categorize electric vehicle charging into many modes. These modes can be categorized into three tiers according to their power and velocity [17] – [19].

There are generally three levels of electric vehicle (EV) charging infrastructure, based on how much power it can provide and what it may be used for. Level 1 charging, sometimes called slow charging, uses alternating current (AC) with a power output of less than 5 kW, usually between 1.4 and 3 kW. This charging method uses a standard household electrical outlet and is primarily intended for residential use, particularly for overnight charging. Level 1 charging can provide you an extra driving range of about 5 to 10 kilometers per hour in normal conditions.



Fig. 1. Comparison of electric vehicle charging levels

Level 2 charging, which is often called "semi-fast charging," also uses alternating current (AC) but works at a larger power range of about 5 kW to 20 kW. To use this charging technique, you need a separate charging unit, like a wall-mounted charger or charging station. Level 2 chargers are often found in offices, stores, shopping malls, and public parking lots. They usually provide you an extra driving range of about 20 to 50 kilometers per hour.



Fig. 2. Common electric vehicle charging connector types

Level 3 charging, often called fast charging or DC fast charging, uses direct current (DC) to charge the car battery at much greater power levels, usually above 50 kW and up to 350 kW in ultra-quick charging systems. The power conversion equipment is outside the car in this setup (off-board charger). Level 3 charging can fill an EV battery to about 80% of its capacity in 20 to 40 minutes. This makes it great for long trips on highways.

One of the biggest problems with building charging stations for electric cars is that there are so many different types of connectors. The Combined Charging System (CCS), CHAdeMO, and the Tesla Supercharger are some of the most prevalent connector standards. CCS is the most used standard in Europe and North America. It has an alternating current (AC) charging connector, like Type 1 or Type 2, and two extra pins for fast charging with direct current (DC). CHAdeMO, on the other hand, is a standard that was created in Japan and is widely utilized by car makers like Nissan and Mitsubishi. It is specifically made for quick charging using DC power. Tesla also created its own charging infrastructure called Tesla Supercharger, which has started to let electric cars from other companies use it in some regions. To support the several types of electric vehicles that are available in Indonesia, the Public Electric Vehicle Charging Station (SPKLU) infrastructure usually has a variety of connections or multi-standard systems, such as CCS2, CHAdeMO, and AC Type 2 [20], [21], [22].

The duration needed to charge an electric car is contingent upon the charging station's power output and the vehicle's battery capacity. The fundamental relationship of power, energy, and time can be articulated using a straightforward equation:

$$t = \frac{E_{battery}}{P \cdot \eta} \tag{1}$$

Where, t represents charging time (h), E denotes battery energy capacity (kWh), P represents charging power supplied by the charger (kW), and η denotes charging efficiency. Charging duration is determined by the battery energy capacity, the charging power supplied by the charger, and the charging efficiency of the system. Charging efficiency accounts for energy losses that occur during the charging process, typically ranging from 0.85

to 0.95 depending on the charging technology and system conditions.

$$v = P \cdot e \quad (2)$$

In addition, the effective charging speed can be expressed in terms of the additional driving range obtained per hour of charging. Where, S represents the effective charging speed (km/h), P denotes charging power (kW), and e represents vehicle energy efficiency expressed in kilometers per kilowatt-hour (km/kWh). This value depends on the energy consumption characteristics of the vehicle, commonly represented by vehicle efficiency in kilometers per kilowatt-hour (km/kWh). For most modern electric vehicles, the average efficiency generally ranges between 6 and 8 km/kWh, although this value may vary depending on the vehicle model, driving behavior, and operating conditions.

TABLE II
COMPARISON OF CHARGING TIME AND CHARGING SPEED FOR VARIOUS AC CHARGING METHODS

Charging Method	Power (kW)	Time 1 (h)	Time 2 (h)	Speed 1 (km/h)	Speed 2 (km/h)
Wall Plug (2.3 kW)	2.3	36.5	29.0	10	15
1-phase 16A (3.7 kW)	3.7	22.5	18.5	20	25
1-phase 32A (7.4 kW)	7.4	9.5	8.5	30	45
3-phase 16A (11 kW)	11	8.5	6.5	45	70
3-phase 32A (22 kW)	22	4.5	4.5	65	68

Table II presents a comparison of charging time and charging speed for several AC charging methods based on typical data reported in previous studies [23], [24]. The table illustrates two different scenarios, which may represent vehicles with different battery capacities or variations in charging conditions. These scenarios are indicated as “Time 1” and “Time 2” for charging duration, and “Speed 1” and “Speed 2” for the corresponding charging speeds.

The data indicate a clear relationship between charging power and charging performance. As the charging power increases, the required charging time decreases while the effective charging speed increases [25]. For example, charging using a conventional household wall plug with a power rating of 2.3 kW may require up to approximately 36 hours to fully charge a large-capacity battery. In

contrast, a three-phase charging system with a power rating of 22 kW can reduce the charging time to around 4.5 hour

C. Fast Charging Technical Challenges

A primary technical problem in the implementation of fast charging for electric vehicles pertains to the constraints of the battery's electrochemical properties. The charging procedure involving elevated currents or voltages can initiate several harmful side reactions in lithium-ion battery cells. Lithium plating on the anode or the emergence of new phases in the cathode material may occur if charging conditions are inadequately regulated. These interactions may result in a permanent reduction in battery capacity and expedite the deterioration of battery lifespan [26] – [27]. Consequently, comprehending battery operational factors is essential in the rapid charging process. A crucial metric frequently employed to characterize battery status is State of Charge (SoC), indicating the amount of energy stored in the battery in relation to its overall capacity. The State of Charge (SoC) can be mathematically expressed as follows.

$$SoC(t) = SoC_0 + \frac{1}{C_{nominal}} \int_0^t I_b(\tau) d\tau \quad (3)$$

The initial state of charge (SoC₀), the battery's nominal capacity in ampere-hours (Ah), and the charging current used during the charging process are some of the most important factors that define the State of Charge (SoC). Where, SoC(t) denotes the battery state of charge at time t, SoC₀ represents the initial state of charge, I denotes charging current (A), τ represents charging duration (h), and dτ denotes nominal battery capacity (Ah). The baseline capacity is the maximum charge that the battery can hold under normal conditions. The charging current is the amount of energy that is sent to the battery per unit time. Each of these factors affects the rate at which the battery gets close to being fully charged.

The Constant Current–Constant Voltage (CC–CV) method is often used to charge batteries because it reduces the chance that the batteries will lose power while they are being charged. In this method, the charging process starts with a phase of steady current, during which a fairly high current is sent to the battery until a certain voltage level is reached at the terminals. When this voltage limit is reached, the charging mode changes to a constant voltage phase. During this phase, the voltage stays the same while the charging current slowly drops until the battery is fully charged. This plan makes charging safer and lasts longer while also putting less stress on the battery[28].

Fast charging stations (Level 3) with high power ratings, usually between 50 and 350 kW, can put a lot of

strain on local energy distribution networks. Total Harmonic Distortion (THD) is a common way to test the electrical performance of charging systems. It shows how much harmonic currents affect the main current component. Power electronic converters used in fast chargers can cause high amounts of harmonic distortion, which can impact the overall quality of power in the distribution system [29]. When several charging events happen at the same time, the total load might cause voltage changes, higher peak demand, and more harmonic distortion in the network.

$$\rho c_p \frac{\partial T}{\partial t} = \nabla \cdot (k \nabla T) + q_{gen} \quad (4)$$

Also, the real power factor of a charging system depends on both the displacement power factor and the amount of harmonic distortion in the current waveform. A high THD number might lower the overall power factor, which makes power delivery less efficient. Smart charging and demand response are two ways that have been suggested to lessen these effects. They control charging schedules so that they don't happen during times of high demand. Also, more and more charging stations are using Battery Energy Storage Systems (BESS) to help balance power demand and make the grid more stable [29] – [30]

$$\%THD = 100 \times \frac{\sqrt{\sum_{h=2}^{\infty} I_h^2}}{I_{s1}} \quad (5)$$

$$PF = \frac{I_{s1}}{I_s} (DPF) = \frac{DPF}{\sqrt{1 + THD^2}} \quad (6)$$

The displacement power factor, which is the difference in phase between the input voltage and the basic input current. To keep charging times in check and avoid overloading, we need the idea of smart charging and demand response. Where, ρ denotes battery material density (kg/m³), c_p represents specific heat capacity (J/kg·K), T denotes temperature (K), t represents time (s), k denotes thermal conductivity (W/m·K), and q_{gen} represents internal heat generation within the battery cell (W/m³). To lessen this effect, SPKLU is also starting to use local energy storage (Battery Energy Storage System/BESS) [31].

Vehicle-to-Grid (V2G) technology lets electric cars and the energy grid send and receive power from each other. This system lets electric cars not only consume power from the grid to charge, but also send power back to the grid when they need to. You can figure out how much power a fleet of electric cars can send to the grid by looking at how much power each car can discharge and how well the bidirectional power converter works. This relationship can be written as:

$$P_{V2G} = \sum_{i=1}^n \eta_i \cdot P_{d,i} \quad (7)$$

where $P_{d,i}$ represents the discharge power from the i -th vehicle and η_i denotes the efficiency of the bidirectional power converter. In practical applications, this capability allows electric vehicles to support grid operations, such as frequency stabilization, peak load management, and the provision of reserve power. Consequently, V2G technology offers significant potential for facilitating the integration of intermittent renewable energy sources and enhancing the overall reliability of power system [32] – [33].

III. Determining the Location of Public Electric Vehicle Charging Stations Methods and Criteria

The identification of suitable locations for public electric vehicle charging stations (SPKLU) is a multifaceted issue that encompasses numerous factors and diverse stakeholders. A multitude of strategies have been suggested in the literature to tackle this problem. A study by [34] – [35] offers an extensive review of prevalent methodologies, emphasizing the amalgamation of Geographic Information Systems (GIS) with Multi-Criteria Decision Making (MCDM) techniques, including the Analytic Hierarchy Process (AHP), Fuzzy AHP, and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) for the selection of electric vehicle charging station locations. [35] implemented a comparable methodology, creating a five-step GIS–MCDM framework that assesses fourteen criteria across four primary dimensions: environmental, transportation, social, and technology.

Various analytical techniques are frequently utilized to identify appropriate sites for SPKLU. geographical analysis of Geographic Information Systems (GIS) is essential for the integration and examination of geographical datasets, including population density, road networks, land use patterns, and electrical substation locations, to determine prospective places for charging stations. Prior research by [36] highlights that GIS is extensively utilized for spatial visualization, overlay analysis, and land suitability mapping in infrastructure design.

The Analytic Hierarchy Process (AHP) is a prevalent multi-criteria decision-making method that assigns weights to qualitative and quantitative factors. The reliability of pairwise comparison judgments in AHP is assessed by the Consistency Ratio (CR), calculated as follows:

$$CR = \frac{CI}{RI}, CI = \frac{\lambda_{maks} - n}{n - 1} \quad (8)$$

where CI denotes the Consistency Index, λ_{max} represents the maximum eigenvalue of the comparison matrix, n is the matrix size corresponding to the number of evaluation criteria, and RI is the Random Index whose value depends on n (for n = 7, RI = 1.32). A CR value below 0.1 is generally considered acceptable, indicating that the pairwise comparison judgments are sufficiently consistent.

Network optimization is another frequent method used in planning EV charging infrastructure. Its goal is to make sure that the infrastructure expenses are as low as possible while still covering a large area. Dynamic programming and the set coverage problem (SCP) are two optimization methods that are often used to find the best position for a station. These methods are especially useful for planning charging infrastructure between cities, when the goal is either to cut down on the number of charging stations needed or to increase the network's travel coverage [37]. To minimize the number of designated station locations, the objective function in the set covering formulation can be expressed as:

$$\text{Min} \sum_{j \in J} x_j \tag{9}$$

$$\sum_{j \in J} a_{ij} x_j \geq 1, \forall i \in I \tag{10}$$

$$x_j \in \{0,1\}, \forall j \in J \tag{11}$$

where x_j is a binary decision variable that shows whether candidate site j is chosen (1) or not (0), a_{ij} is a binary parameter that shows whether location j can meet demand point i, I is the set of demand points, and J is the set of candidate station locations.

When choosing excellent locations for public EV charging stations, people usually think about more than just optimization methods. According to a study by [38], the most important factors that affect how happy users are with PLN charging stations are how easy it is to get in touch with service staff, how clear the user instructions are, how reliable the service is, and how affordable the prices are. Location selection criteria can be classified into various categories, including demand-related factors (traffic density and electric vehicle population), accessibility factors (proximity to major roads and parking availability), technical factors (availability of electrical power), economic factors (investment and operational costs), and user comfort and safety considerations.

This study employs a mixed-methods approach, integrating literature reviews, quantitative surveys, and optimization modeling. The area of study is East Java Province, with Probolinggo City as the main emphasis. A study was carried out with 107 respondents who were either owners of electric vehicles or prospective users of

such vehicles in East Java. The purpose of the poll was to gain an understanding of consumer preferences for SPKLU features. With the help of a Likert scale ranging from 1 to 5, the questionnaire was developed to assess the significance of a number of different characteristics. Charging price.

To evaluate the reliability and validity of the questionnaire data, several statistical tests were conducted prior to factor analysis. Internal consistency reliability was assessed using Cronbach's alpha coefficient. The questionnaire achieved a Cronbach's alpha value of 0.81, indicating good internal consistency among the evaluated variables.

Sampling adequacy for factor analysis was evaluated using the Kaiser-Meyer-Olkin (KMO) test. The obtained KMO value was 0.76, which exceeds the minimum acceptable threshold of 0.50, indicating that the dataset was suitable for factor analysis. In addition, Bartlett's Test of Sphericity produced a statistically significant result ($p < 0.05$), confirming sufficient correlation among the variables for factor extraction.

These results indicate that the survey instrument and collected responses were sufficiently reliable and statistically appropriate for multi-variable analysis and priority assessment. Charger type availability (compatibility), distance or location of SPKLU, quantity or availability of units, supporting amenities (toilets, cafes, etc.), charging speed, and location security were on the list of characteristics that were evaluated.

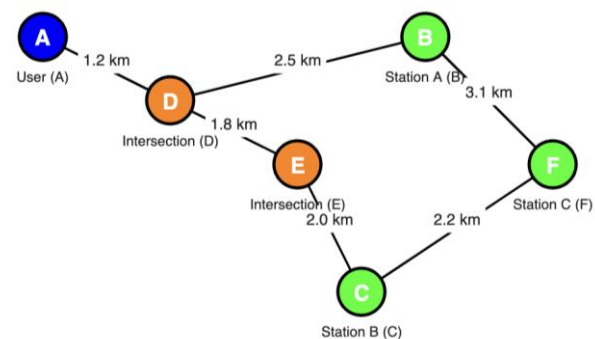


Fig. 3. Electric vehicle charging station network graph

The information that was gathered was then subjected to a factor analysis, which was used to categorize these characteristics into key components and establish the relative importance of each of them. This study employed Dynamic Programming with a backward recursive technique to determine priority cities for SPKLU placement along the primary highways of East Java. The goal of this optimization was to discover a way to get from Ngawi in Central Java to Banyuwangi in Bali. It is assumed that each city chosen along the ideal path will serve as a strategic site for SPKLU growth. This model's objective function can be expressed using the recursive

equation:

$$f(i) = \min_{j \in S(i)} \{1 + f(j)\} \quad (12)$$

$f(i)$ is the smallest number of segments needed to get from city i to the ultimate destination. $S(i)$ is the set of cities that can be visited directly from city i in one trip segment that does not exceed the average range of an electric vehicle (around 200–250 km). We got the distance data between cities from the national road network map. This network optimization strategy is comparable to those talked about in the literature, where problems like the set covering issue are employed to make sure that the best geographic coverage is achieved, especially for transit between cities [39].

The Analytic Hierarchy Process (AHP) was used to find the best place for a public electric vehicle charging station (SPKLU) in Probolinggo City. AHP is a way to make decisions based on more than one factor. It lets you break down complicated situations into a hierarchical model with a goal, assessment criteria, and several options.

A pairwise comparison matrix based on the Saaty scale (1–9) was used to figure out how important each condition was. The main eigenvector of the comparison matrix gives the priority weight of each condition. The Consistency Index (CI) and Consistency Ratio (CR) were used to see how consistent the paired judgments were.

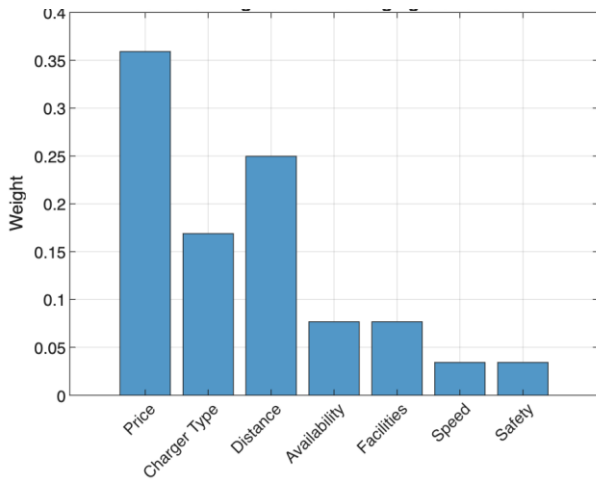


Fig. 4. AHP criteria weights for EV charging station

Fig. 4 shows the outcomes of the AHP weighting method. The study shows that price, how far away the charging station is, and whether the charger type is compatible are the most important factors in choosing the best site for SPKLU. These characteristics show what EV users are most worried about, especially when it comes to accessibility, cost, and technological compatibility.

$$S_k = \sum_{j=1}^m w_j \cdot x_{kj} \quad (13)$$

where S_k represents the final score of alternative location k , w_j denotes the weight of criterion j , and

x_{kj} represents the performance score of location k under criterion j . The location with the highest S_k value is selected as the most suitable site for SPKLU deployment.

IV. Result and Discussion

The study of electric vehicle market data for January 2026 shows that more people in Indonesia are buying EVs faster than ever before. Total sales of electric vehicles (EVs) reached 14,908 units [40]. These included Battery Electric Vehicles (BEVs), Hybrid Electric Vehicles (HEVs), and Plug-in Hybrid Electric Vehicles (PHEVs). This shows that the market is still growing, thanks to more models becoming available and government incentive programs set up by Presidential Regulation No. 55/2019.

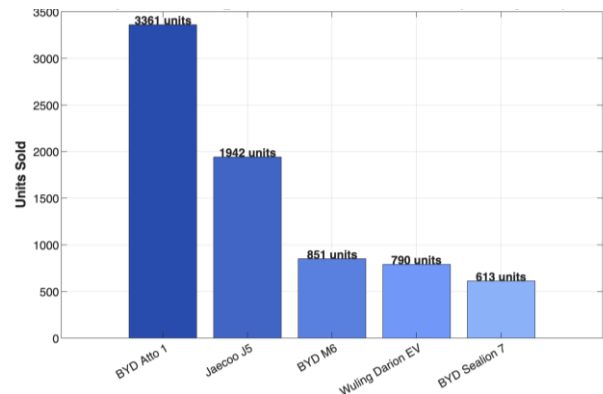


Fig. 5. Top 5 best-selling electric vehicles in Indonesia

The market was led by the BYD Atto 1, which sold 3,361 units. The Jaecoo J5, which sold 1,942 units, and the BYD M6, which sold 851 units, came in second and third, respectively. The Wuling Dairion EV and the BYD Sealion 7 each got 790 and 613 units. The fact that Chinese-made cars are so popular shows that there is a structural change toward affordable, long-range BEVs, with price becoming the main consumer driver. This result fits with the AHP criteria weight analysis in Section III, which showed that price was the most important of the seven factors that were looked at.

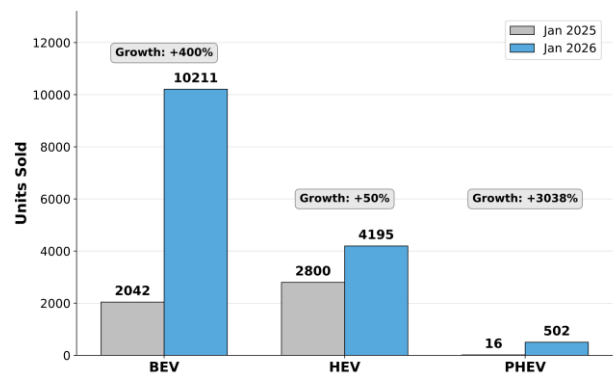


Fig. 6. Year-over-year EV sales comparison

Fig. 6 shows the growth in sales from one year to the next. The most dramatic rise was in BEV sales, which went from 2,042 units to 10,211 units, a 400% increase. From 2,800 units to 4,195 units, HEV sales grew by +50%, and PHEV sales grew by +3,038%, from 16 units to 502 units. The 400% growth rate for BEVs is much higher than the national goal, which suggests that the 2030 goal of 2 million electric cars might be attainable if SPKLU rollout can keep up with fleet growth.

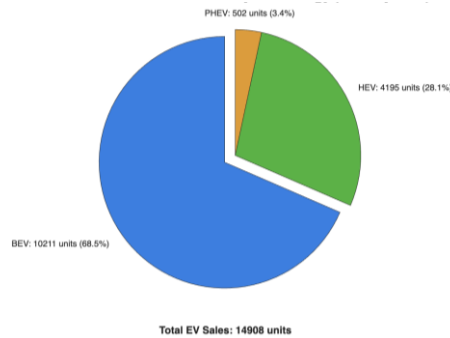


Fig. 7. Electric vehicle market share by technology

Fig. 7 shows that BEVs make up 68.5% (10,211 units) of total sales, HEVs make up 28.1%, and PHEVs make up 3.4%. This BEV-dominant composition has direct effects on the demand for charging infrastructure. Unlike HEVs, which employ regenerative braking and don't need to be charged from the outside, BEV users depend totally on SPKLU being available. Because the BEV share is 68.5%, it is even more important to speed up the deployment of public charging stations, especially in provinces where the service ratios are currently low, as shown in sub-section II-C.

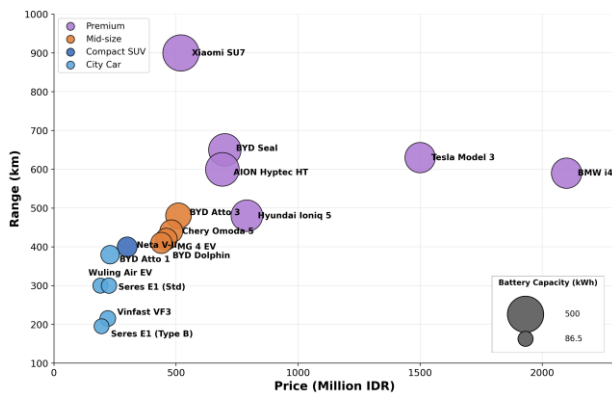


Fig. 8. Electric vehicle models in Indonesia: range vs price

Fig. 8 shows that price and range are related in a good way. The premium car that costs the most (Rp 400 million) has the best range (500 km), while the city car that costs the least (Rp 250 million) only has a 350 km range. According to technical specs, higher-segment cars usually have batteries with more storage space. This finding fits with that.

The range difference between groups is up to 150 km, which means that people who drive city cars will need to plan to charge their cars more often when they go on long trips. This means that charging stations should be put closer together in places where there are a lot of city cars, like city centers and areas with lots of people. The type of battery is one of the technological factors that might influence the preferences and charging requirements of consumers.

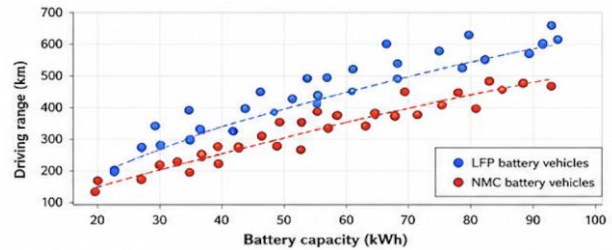


Fig. 9. Electric vehicle models in Indonesia: range vs battery capacity

The correlation analysis presented in Fig. 9 illustrates the relationship between battery capacity (kWh) and driving range (km) for EV models currently available in the Indonesian market. The regression result shows a strong positive correlation with an R2 value of 0.889, indicating that approximately 88.9% of the variation in driving range can be associated with differences in battery capacity. This result supports the 200–250 km range constraint adopted in the dynamic programming model presented in Section III. The findings suggest that battery capacity is one of the dominant factors influencing vehicle driving range, although other parameters such as vehicle efficiency, weight, aerodynamic characteristics, and driving conditions may also contribute to overall performance.

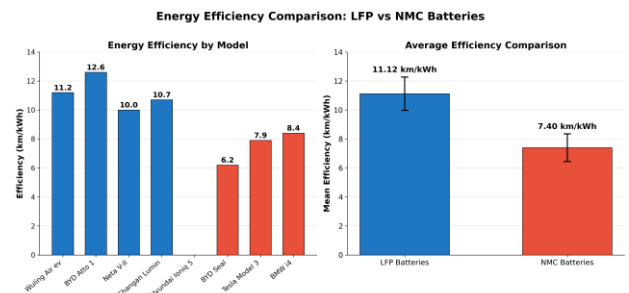


Fig. 10. Energy efficiency comparison between LFP and NMC battery electric vehicles

There is a big difference between LFP (Lithium Iron Phosphate) and NMC (Nickel Manganese Cobalt) battery types. Because they have a higher volumetric energy density, NMC-equipped vehicles (red data points) tend to have better range per kWh. On the other hand, LFP vehicles (blue data points) tend to have lower range values for the same capacity. This difference is very important for

people who plan infrastructure, because LFP-dominant fleets need charging stops more often along long-distance routes. This means that the East Java routing model needs more SPKLU nodes.

Compared the energy efficiency of LFP and NMC batteries. LFP batteries (exemplified by the Viking Jet EV, BYO Aero, and Idea 1/3 models) demonstrated an average efficiency of 11.12 km/kWh, but NMC batteries (Charger Linea, Hybrid Linea, and NEO Soul) attained just 7.40 km/kWh. This conclusion aligns with the literature indicating that LFP exhibits greater efficiency despite its reduced energy density. Vehicles equipped with LFP batteries necessitate less energy to cover equivalent distances, hence alleviating the strain on the power system.

Fig. 4 shows the results of utilizing AHP to weight the criterion. The most important factors are the price of charging (0.36), the distance to the charging station (0.25), and the type of charger (0.17). These findings indicate that electric vehicle users prioritize low operational costs, accessibility, and charger compatibility when selecting charging locations. On the other hand, things like supporting amenities, charging speed, and security have relatively low weights, which means that these things are important to users but not the most important when choosing a place.

We used these weighting results to come up with four other places in Probolinggo City where charging stations (SPKLU) could be set up: Sukabumi Gas Station (A1), East Probolinggo Toll Road Rest Area (A2), Gas Station Mayangan (A3), Parking Lot in the City Center (A4). Each alternative is evaluated based on the seven criteria utilizing field observation data and other information. The ultimate score for each possibility is determined using equation 13.

TABLE III
SCORES AND RANKING OF CANDIDATE SPKLU LOCATIONS IN
PROBOLINGGO CITY BASED ON AHP

Code	Alternative Location	Latitude	Longitude	Total Score	Rank
A1	Sukabumi Gas Station	-7.76437	113.22831	4.52	1
A2	East Probolinggo Toll Road Rest Area	-7.73550	113.16820	3.95	2
A3	Gas Station Mayangan	-7.74890	113.21570	3.21	3
A4	Parking Lot in the City Center	-7.75620	113.21140	2.58	4

The results indicate that the Sukabumi gas station received the highest score (4.52) and was the most recommended site. This location offers several

advantages, including its strategic position along the Pantura (North Coast) route, close to the toll gate, ample land area, and integration with existing service station amenities like as bathrooms and a minimarket. In contrast, Parking Lot in the City Center earned the lowest rating (2.58) owing to restricted capacity and possible congestion in the vicinity. To evaluate the robustness of the AHP-based decision framework, a sensitivity analysis was conducted by varying the three dominant criteria weights charging price, charging distance, and charger compatibility within a reasonable variation range of $\pm 10\%$.

The analysis showed that the overall ranking order of candidate SPKLU locations remained unchanged under all tested scenarios. Sukabumi Gas Station consistently retained the highest ranking position, indicating that the proposed decision framework is relatively stable against moderate weighting uncertainty. These findings suggest that the AHP-based prioritization results are sufficiently robust for practical infrastructure planning applications.

The stability of the ranking outcome strengthens the reliability of the proposed SPKLU site selection approach under varying stakeholder preference assumptions. For the purpose of ensuring that traveling over long distances in an electric car is viable, it is necessary to determine the most efficient routes connecting the cities in East Java. The road network graph shown in Fig.11 includes the distances between each node.

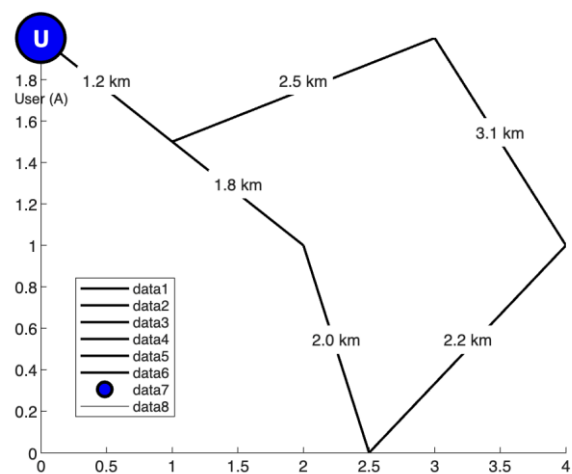


Fig. 11. SPKLU node graph for candidate route evaluation

The network graph illustrates the candidate routing structure used in the dynamic programming optimization. Using a range constraint of 250 km for electric vehicles, an optimal route was identified connecting the cities of Ngawi, Madiun, Jombang, Mojokerto, Probolinggo, Jember, and Banyuwangi.

All segments of the route fall within the 250 km threshold, making the corridor feasible for electric vehicle travel without requiring unexpected intermediate charging

stops. These findings provide a basis for prioritizing the development of public charging stations (SPKLU) in the selected cities, aligning with the average driving range of mid-segment battery electric vehicles (BEVs) identified in the market analysis.

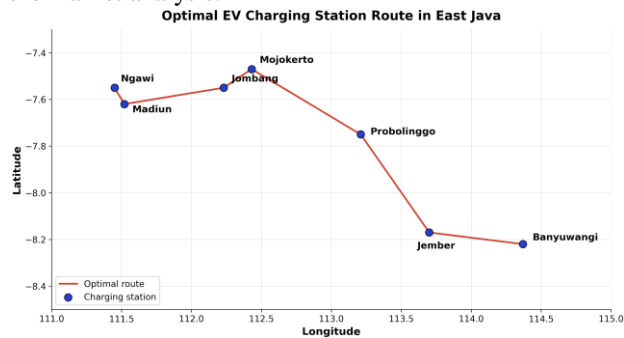


Fig. 12. Dynamic programming based EV charging route network

As can be seen in Fig. 8, the provinces of Bali and DI Yogyakarta have the highest indices, with 4.7 and 4.3, respectively. On the other hand, West Java had the lowest index, which was reported at 2.6. Another possible explanation for this disparity is that West Java has a disproportionately large number of electric vehicle. The ratio of SPKLUs to vehicles in the province is lower, despite the fact that the total number of SPKLUs in the province ranks quite high. On the other hand, provinces that are located outside of Java and have a smaller population of electric vehicles tend to have higher indices. This is due to the fact that each SPKLU serves a smaller number of vehicles.

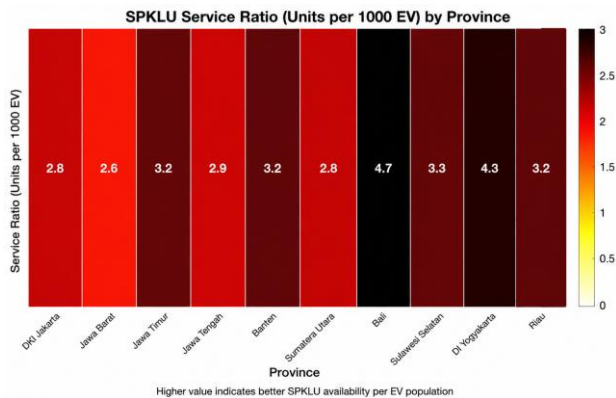


Fig. 13. SPKLU service ratio by Province

The importance of equitable infrastructure distribution is brought to light by this conclusion. This distribution is measured not only by the total number of SPKLUs but also by their proportion to the total population of electric vehicles. It is recommended that areas with a low index, such as West Java, be given priority for the installation of SPKLUs in order to prepare for the rise in the number of electric vehicles and to alleviate potential user concern, also known as range anxiety.

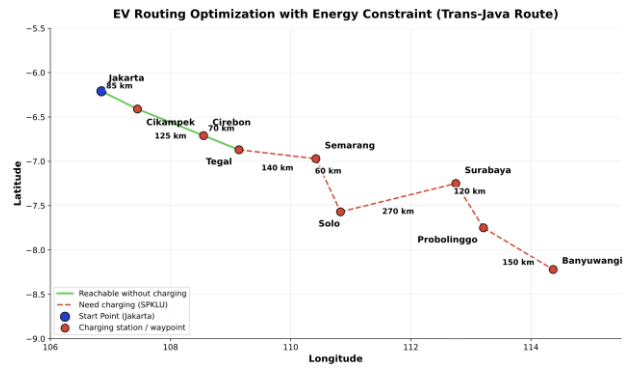


Fig. 14. EV routing optimization

This route optimization model has major consequences for real policy, and those implications are considerable. It would be more efficient to prioritize the construction of charging stations in six specified corridor nodes, which are as follows: Ngawi, Madiun, Jombang, Mojokerto, Probolinggo, Jember, and Banyuwangi. This would be a more effective strategy than establishing charging stations evenly throughout all cities. The implementation of this strategy makes it possible to drive across Java in an electric vehicle with a minimal investment in infrastructure. The use of the set-covering method results in a direct reduction in building costs while simultaneously increasing geographic reach. By doing so, it will be possible to more effectively address the economic hurdles that have prevented the growth of charging stations outside of the Java-Bali corridor.

The results show that building SPKLU infrastructure in Indonesia needs a multi-layered approach. First, high-service-ratio provinces need to be targeted for immediate expansion based on the provincial heatmap analysis. Next, corridor-based fast charging needs to be put in place, along with dynamic programming routing for inter-city connectivity. Finally, charger specifications need to be adjusted to the battery chemistry composition of the fleet to get the best charging speed and station utilization rates. This study uses market growth data, battery technology analysis, spatial optimization, and customer preference quantification to create a framework for analysis that can be used in other emerging economies where EV adoption is growing quickly.

V. Conclusion

This study provides analytical insights into Indonesia's SPKLU infrastructure challenges through the integration of market analysis, consumer preference assessment, and spatial optimization. Rather than proposing a fundamentally new optimization model, the study demonstrates the practical application of established analytical approaches for EV charging infrastructure planning in emerging economies. The results indicate that BEV sales reached 10,211 units in January 2026,

representing a 68.5% market share and 400% year-over-year growth, yet national SPKLU deployment remains below 4% of the 2030 target of 32,000 units. Consumer survey analysis identifies charging price (36%), location distance (25%), and charger compatibility (17%) as the three dominant site selection criteria. The dynamic programming model identifies an optimal six-node Trans-Java corridor — Ngawi, Madiun, Jombang, Mojokerto, Probolinggo, Jember, and Banyuwangi — enabling full inter-city EV travel across 520 km with minimal infrastructure investment. Battery efficiency analysis confirms LFP superiority at 11.12 km/kWh versus 7.40 km/kWh for NMC, supported by a strong capacity-range correlation ($R^2 = 0.889$), with direct implications for charger specification along identified corridors. Provincial service ratio analysis reveals critical disparities, with West Java recording the lowest ratio at 2.6 units per 1,000 EVs, underscoring the need for targeted expansion beyond the Java-Bali axis.

This study has several limitations that should be considered when interpreting the results. The AHP weighting process relies on subjective pairwise comparisons that may vary depending on stakeholder perspectives. Although a sensitivity analysis was conducted to evaluate ranking stability, uncertainty associated with future EV adoption patterns and charging demand growth was not explicitly modeled. In addition, the optimization framework employed simplified range constraints and static routing assumptions without incorporating real-time traffic conditions, stochastic charging behavior, or renewable energy integration. Future studies may extend the present work by incorporating probabilistic demand forecasting, larger survey datasets, and advanced optimization techniques for nationwide SPKLU planning.

Conflict of Interest

The authors declare no conflict of interest in the publication process of the research article.

Author Contributions

Author 1 was responsible for conceptualizing the study, performing the analysis, interpreting the results, and preparing the original manuscript draft, along with contributing to the review process. Author 2 provided research supervision, participated in the investigation, and contributed to manuscript review and editing. Author 3 assisted in the investigation and contributed to editing and reviewing the manuscript. Author 4 and Author 5 contributed to reviewing and editing the manuscript.

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