Strategic Planning of Public Electric Vehicle Charging Stations Using AHP and GIS to Support Sustainable Mobility in West Java, Indonesia

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Abstract. The transition toward sustainable and low-emission transportation in Indonesia has accelerated the adoption of electric vehicles (EVs), especially in densely populated provinces such as West Java. Despite this progress, the distribution and capacity of Public EV Charging Stations (EVCS) remain uneven, creating significant gaps between vehicle growth and infrastructure readiness. This spatial imbalance threatens to slow down EV adoption and limit the effectiveness of national decarbonization targets. Addressing this challenge requires an integrated, evidence-based planning approach that combines spatial analysis and multi-criteria decision methods. This study aims to determine strategic priority zones for the development of EVCS infrastructure across West Java using a Geographic Information System (GIS) framework integrated with the Analytical Hierarchy Process (AHP) and Weighted Overlay methods. Five spatial criteria were used to evaluate site suitability, including proximity to city centers, main roads, industrial zones, fuel stations, and PLN (state electricity company) networks. The analysis results show that Bekasi City, eastern Bekasi Regency, Depok City, and central Bogor Regency represent areas with very high potential for EVCS expansion due to their dense population, strong industrial base, and robust electrical network. The resulting spatial model produces a data-driven priority zoning map that supports evidence-based policy formulation and regional planning. This research provides strategic insights for policymakers and energy planners to enhance infrastructure accessibility, optimize resource allocation, and accelerate the electric mobility transition in West Java.

1 Introduction

The transportation sector has long been recognized as one of the largest contributors to global greenhouse gas emissions, particularly in rapidly urbanizing regions where private vehicle ownership continues to rise. According to international energy and climate assessments, road transport alone accounts for a significant share of carbon dioxide

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emissions, air pollution, and fossil fuel consumption. In response to these challenges, electric vehicles (EVs) have emerged as a key technological pathway to reduce emissions, improve urban air quality, and support long-term energy sustainability [1]. However, the effectiveness of EV adoption is not determined solely by vehicle technology, but also by the availability, accessibility, and reliability of supporting infrastructure, particularly Public Electric Vehicle Charging Stations (EVCS).

Globally, countries that have successfully accelerated EV adoption have demonstrated that charging infrastructure development must proceed in parallel with vehicle deployment. Beyond infrastructure, adoption is shaped by a combination of perceived usefulness, total cost of ownership, social context, and policy incentives, meaning that charging expansion should be planned alongside demand-side measures and ecosystem readiness [2], [3]. Insufficient or poorly distributed charging stations can create range anxiety, reduce user confidence, and ultimately slow the transition toward electric mobility [2]. Consequently, strategic EVCS planning has become a central concern for policymakers, urban planners, and energy authorities.

In Indonesia, the government has formally committed to promoting electric mobility through Presidential Regulation No. 55 of 2019, which emphasizes the development of a comprehensive EV ecosystem encompassing manufacturing, incentives, and charging infrastructure. Within this national context, West Java Province plays a particularly strategic role. As the most populous province in Indonesia and a core industrial and logistics hub, West Java exhibits high daily mobility demand and rapid growth in EV ownership. Official statistics indicate that the number of electric vehicles in West Java increased sharply from approximately 1,430 units in 2023 to more than 5,600 units in 2024, reflecting strong market momentum. As EV penetration grows, charging demand may create localized pressure on the electricity system and require proactive planning to avoid bottlenecks and reliability issues [4].

Despite this growth, the spatial distribution of EVCS in West Java remains highly uneven. Existing charging stations are largely concentrated in selected urban centers, while many industrial corridors, suburban areas, and intercity routes remain underserved. Similar infrastructure imbalances have been observed in other developing regions, where EV adoption progresses faster than charging infrastructure deployment [5]. In Indonesia specifically, studies identify persistent barriers such as technology readiness, regulation, and ecosystem coordination, which can amplify the consequences of uneven charging availability [6], [7]. This mismatch poses a risk to long-term adoption and may lead to inefficient investment if new stations are developed without a systematic spatial strategy. Recent reviews also emphasize that criteria selection and method transparency are essential to ensure EVCS placement decisions remain defensible under stakeholder scrutiny.

Previous studies suggest that effective EVCS planning requires multi-criteria decision-making approaches capable of integrating technical, spatial, economic, and behavioral factors. Methods such as the Analytical Hierarchy Process (AHP), when combined with Geographic Information Systems (GIS), have proven effective in translating expert judgment into spatially explicit suitability maps, particularly for regional contexts that require transparent criteria weighting and interpretable spatial outputs[8], [9]. However, empirical applications at the provincial scale in Indonesia remain limited, and there is a lack of comprehensive frameworks tailored to regional planning contexts.

This study addresses this gap by proposing an integrated AHP–GIS framework for strategic EVCS location planning in West Java Province. The main objectives of this research are: (1) to identify and weight key spatial criteria influencing EVCS suitability, (2) to generate a priority zoning map for EVCS development using GIS-based Weighted Overlay analysis, and (3) to provide evidence-based recommendations to support sustainable mobility policies at the provincial level. By doing so, this research aims to contribute both methodologically and practically to the growing body of literature on EV infrastructure planning in developing regions.

2 Literature Review

In addition, the Indonesian mobility transition literature highlights that infrastructure decisions should account for broader adoption conditions, including regulatory and market barriers that shape the pace of diffusion and infrastructure utilization.

2.1 Electric Vehicle Charging Infrastructure and Sustainable Mobility

Electric vehicle charging infrastructure is widely recognized as a critical enabler of sustainable mobility systems. The availability of accessible and reliable EVCS networks directly influences travel behavior, user confidence, and adoption rates of electric vehicles. Empirical studies across multiple contexts consistently show a positive relationship between public charging availability, user awareness, and EV purchase consideration, reinforcing the role of infrastructure visibility and accessibility in accelerating adoption. Conversely, inadequate infrastructure coverage often leads to underutilization of EVs and discourages potential users. Empirical work also suggests that consumer awareness of available public charging can be as important as the actual density of stations, reinforcing the need for visible, well-sited infrastructure [10].

From a sustainability perspective, EVCS planning is closely linked to broader decarbonization strategies in the transportation and energy sectors. Research has shown that integrating EVCS development with renewable energy sources, such as photovoltaic systems, can further enhance environmental benefits and reduce lifecycle emissions. In Southeast Asia, where electricity generation mixes vary significantly across regions, spatial planning of EVCS must also consider grid capacity and energy supply reliability.

In developing countries, EVCS deployment faces additional challenges related to land availability, institutional coordination, and financial constraints. In Indonesia, these challenges are closely linked to market economics and affordability considerations, including comparative ownership costs and break-even dynamics between battery EVs and conventional vehicles. Studies in Indonesia highlight that charging infrastructure development often lags behind policy targets due to fragmented planning, grid readiness constraints, and ecosystem coordination challenges [7]. These findings underscore the importance of adopting structured, data-driven approaches to EVCS location planning. Indonesian evidence on public charging development also highlights practical constraints and implementation challenges (e.g., permitting, investment coordination, and operational considerations), which strengthens the case for systematic, criteria-based site prioritization at the provincial level.

2.2 Multi-Criteria Decision-Making and the Analytical Hierarchy Process

Multi-criteria decision-making (MCDM) methods have been extensively applied in infrastructure planning to address complex decision problems involving multiple, often conflicting criteria. Among these methods, the Analytical Hierarchy Process (AHP) is one of the most widely used due to its conceptual simplicity, transparency, and ability to incorporate expert judgment. AHP decomposes complex problems into hierarchical structures and derives relative weights through pairwise comparisons, allowing decision-makers to prioritize criteria systematically.

Numerous studies have applied AHP to EVCS site selection with promising results. Recent evidence from Indonesia and comparable contexts shows that integrating criteria weighting with spatial analysis can support practical EVCS placement decisions based on accessibility, activity centers, and infrastructure feasibility [11]. AHP is particularly suitable for contexts where quantitative demand data are limited but expert knowledge is available, because it provides an auditable weighting procedure and consistency checking that can be communicated to policy stakeholders.

Recent methodological advances include the use of fuzzy AHP to address uncertainty in expert judgments and hybrid approaches combining AHP with machine learning or optimization techniques. In parallel, a growing stream of research uses forecasting, diffusion, and simulation approaches to anticipate EV uptake and translate adoption trajectories into infrastructure needs. While these methods offer increased analytical sophistication, conventional AHP remains highly relevant for regional-scale planning due to its interpretability and ease of implementation.

2.3 GIS-Based Spatial Analysis and Weighted Overlay Techniques

Geographic Information Systems (GIS) provide powerful tools for spatial data processing, visualization, and analysis, making them indispensable for location-based decision-making. When combined with MCDM methods, GIS enables the transformation of abstract criteria weights into concrete spatial suitability maps, supporting transparent prioritization at provincial and corridor scales. One of the most commonly used GIS techniques for such integration is the Weighted Overlay method, which aggregates multiple standardized raster layers into a single composite index.

Weighted Overlay analysis has been widely applied in EVCS planning studies due to its flexibility and transparency. Research in Indonesian and metropolitan contexts shows that GIS-based multi-criteria approaches can effectively identify high-potential zones by integrating accessibility, activity centers, land-use proxies, and energy infrastructure constraints [11]. In addition to suitability mapping, complementary spatial analyses can help reveal service coverage gaps and equity implications, which is critical for avoiding concentrated deployment that leaves peripheral users underserved.

Despite its advantages, Weighted Overlay analysis requires careful selection and weighting of criteria to avoid bias. Therefore, integrating AHP-based weight derivation with GIS-based overlay is widely viewed as a practical best practice for policy-facing EVCS planning because it combines interpretability with spatial explicitness. This study adopts such an integrated approach to ensure methodological rigor and policy relevance.

2.4 Additional Evidence from Indonesian Charging Infrastructure Studies

Recent Indonesian and Southeast Asian studies increasingly provide actionable evidence for charging infrastructure planning, especially for rapidly growing urban–industrial regions. Public charging density and user awareness have been shown to influence purchase consideration, suggesting that station visibility and accessibility matter alongside technical adequacy. Range-related concerns remain prominent across contexts; evidence shows that perceived range and charging delays can strongly affect adoption intent, highlighting the role of well-distributed stations. Policy studies also indicate that ecosystem coordination and consistent incentives are important for sustaining adoption and infrastructure utilization. Broader international evidence also confirms that well-designed incentives and consistent policy signals can accelerate EV sales, making infrastructure roll-out more effective when synchronized with demand-side policy.

Beyond adoption-focused research, Indonesian technical studies support corridor-based and location-based planning. Demand projection work helps anticipate charging needs and informs phased expansion strategies. Spatial and optimization approaches have also been used to shortlist candidate locations and improve placement efficiency, including GIS-based modelling and metaheuristic optimization. In parallel, renewable-integrated charging station research highlights opportunities to align EVCS expansion with decarbonization goals through photovoltaic and storage integration. This is particularly relevant in Southeast Asia, where decarbonization pathways increasingly rely on integrating clean energy options with electric mobility systems [2].

These findings reinforce the need for a transparent, criteria-based provincial planning framework. By combining expert-based weighting and spatial suitability mapping, regional planners can better align EVCS investments with adoption drivers, projected demand, and infrastructure readiness.

3 Method

3.1 Study Area and Data Sources

The study area encompasses the entire administrative region of West Java Province, Indonesia, which includes both highly urbanized cities and extensive industrial and suburban areas. West Java is characterized by diverse land-use patterns, ranging from dense metropolitan zones to agricultural and mountainous regions. This heterogeneity makes it an ideal case for evaluating spatial planning methods for EVCS deployment.

Secondary data were collected from multiple official sources, including regional statistical agencies, transportation authorities, and the national electricity provider (PLN). Spatial datasets included administrative boundaries, road networks, industrial zones, existing fuel stations, and electricity infrastructure. All spatial data were processed and standardized using ArcGIS software.

3.2 Criteria Selection and Justification

Based on a synthesis of Indonesian charging infrastructure literature and EV adoption evidence, five criteria were selected to evaluate EVCS location suitability: proximity to city centers, main roads, industrial zones, existing fuel stations, and PLN electricity networks. These criteria reflect demand intensity, accessibility, economic activity, infrastructure co-location potential, and energy supply readiness.

City centers represent areas of high activity density and travel demand, making them strategic locations for public charging infrastructure. Main roads capture accessibility and traffic flow, which are critical for ensuring convenient charging access. Industrial zones are associated with commercial vehicle usage and logistics activities, while fuel stations offer opportunities for infrastructure co-location. Finally, proximity to electricity networks ensures technical feasibility and cost efficiency.

3.3 AHP Weighting Procedure

The AHP method was applied to derive relative weights for the selected criteria through pairwise comparisons based on expert judgment. Experts from academia, industry, and regional planning institutions were consulted to assess the relative importance of each criterion. The resulting pairwise comparison matrix was normalized, and eigenvectors were calculated to obtain criterion weights.

Consistency of expert judgments was evaluated using the Consistency Ratio (CR). The calculated CR value of 0.036 is well below the acceptable threshold of 0.10, indicating a high level of consistency and reliability in the weighting process.

3.4 GIS-Based Weighted Overlay Analysis

Each criterion was converted into a raster layer and reclassified into suitability classes using a standardized scale. The AHP-derived weights were then applied using the Weighted Overlay function in ArcGIS to generate a composite suitability map. This process resulted in a spatial representation of EVCS priority zones across West Java.

4 Results and Discussion

4.1 Results of AHP Weighting

Before presenting the spatial analysis results, the relative importance of each EVCS location criterion must be established to ensure transparency and consistency in the decision-making process. The AHP results summarized in Table 1 provide the quantitative foundation for subsequent GIS-based analysis.

Table 1. Final AHP Calculation Results

Criteria	Weight Calculation	Final Weight (%)
PLN Electricity Network Proximity	0.52 / 5.977 = 0.06 × 100%	8.70%
Industrial Zones Proximity	1.101 / 5.977 = 0.19 × 100%	18.42%

City Centers Proximity	1.822 / 5.977 = 0.31 × 100%	30.48%
Fuel Stations (SPBU) Proximity	0.712 / 5.977 = 0.13 × 100%	11.91%
Main Roads Proximity	1.822 / 5.977 = 0.31 × 100%	30.48%

Table 1 summarizes the AHP-based weighting results used in this study. The dominance of city centers and main roads indicates that activity intensity and accessibility are expected to be the strongest drivers of EVCS utilization. This aligns with Indonesian adoption evidence showing that charging availability, awareness, and convenience significantly influence users' consideration and willingness to adopt EVs. Industrial zones and fuel stations play a supporting role, especially for fleet operations and intercity mobility, where charging opportunities along economic corridors can reduce perceived risk.

Although proximity to the PLN network receives the lowest weight, it remains essential for feasibility and cost efficiency in deployment. In the Indonesian context, readiness and grid integration considerations have been highlighted as key constraints and enablers for scaling public charging infrastructure. For provincial-scale planning, this implies that highly suitable demand zones may still require staged investment if electricity capacity or connection costs are limiting.

The AHP analysis reveals that proximity to city centers and main roads are the most influential criteria, each receiving a weight of 0.31. This indicates that accessibility and activity density are primary drivers of EVCS suitability. Industrial zones and existing fuel stations received moderate weights, reflecting their supporting roles, while proximity to electricity networks had a lower but still essential weight.

These findings are consistent with system-level planning studies indicating that infrastructure expansion should be synchronized with projected demand growth and adoption dynamics [12], [13].

4.2 Spatial Priority Zones for EV Charging Station (EVCS) Development

Based on the AHP-derived weights, a composite spatial suitability analysis was conducted to identify priority zones for EVCS development across West Java. The resulting suitability map is presented in **Fig. 1**.

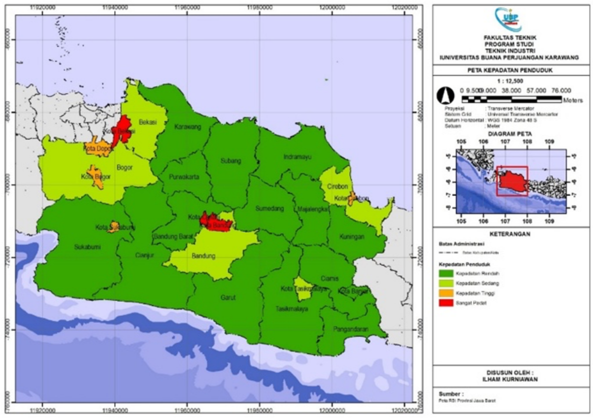

Fig. 1. EVCS suitability map generated using AHP–GIS weighted overlay analysis

Fig. 1 presents the composite EVCS suitability map produced by integrating AHP-derived weights with GIS-based weighted overlay analysis. High- and very-high-suitability zones cluster in Bogor, Bandung, Bekasi, and Karawang—areas characterized by dense activity centers, major transport corridors, and strong industrial demand.

To better understand the drivers behind the composite suitability results, it is necessary to examine the spatial distribution of each individual planning criterion. **Fig. 2** illustrates the distribution of key EVCS-related spatial variables used in this study.

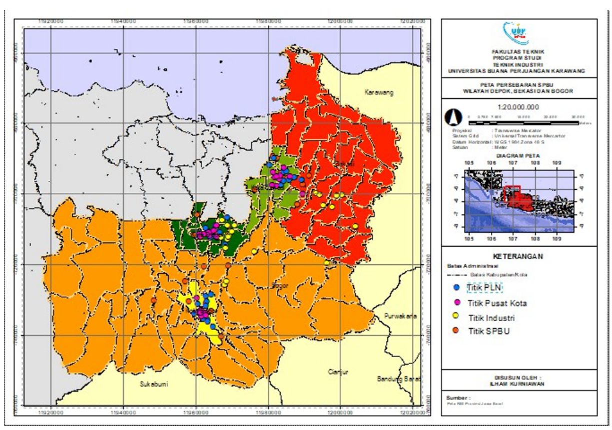

Fig. 2. Spatial distribution of EVCS location criteria in West Java

Fig. 2 illustrates the spatial pattern of key criteria layers (city centers, roads, industrial zones, fuel stations, and PLN infrastructure). Bekasi City shows the highest concentration of overlapping criteria due to dense population, extensive industrial activity, and electricity network coverage. Bekasi Regency also scores highly along logistics corridors, while Bogor and Depok show strong suitability near commuter routes and city nodes. These patterns are consistent with Indonesian GIS-based multi-criteria EVCS studies that recommend corridor-based and activity-center-based placement to increase visibility and expected utilization.

The Weighted Overlay analysis identifies high-priority zones for EVCS development concentrated in Bogor, Bandung, Bekasi, and Karawang. These regions combine high population density, strong industrial activity, and relatively robust electricity infrastructure. Medium-priority zones are observed in surrounding suburban areas, while rural and mountainous regions exhibit lower suitability scores.

Building on the composite suitability assessment, regions were further classified according to their readiness and priority for additional EVCS deployment. This classification is visualized in **Fig. 3**.

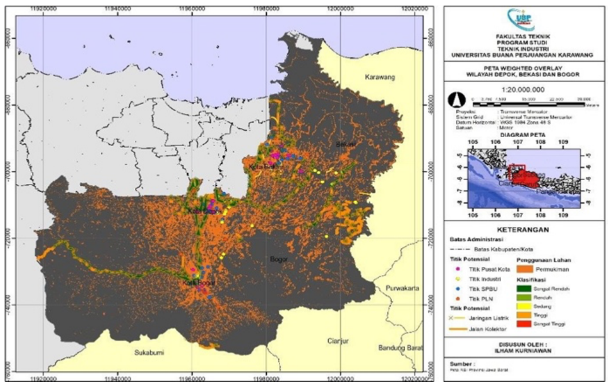

Fig. 3. EVCS readiness and priority zoning for additional deployment

Fig. 3 classifies regions by readiness for additional EVCS deployment. Bekasi City and Bekasi Regency emerge as the most prepared zones due to the convergence of demand intensity, industrial ecosystem maturity, and infrastructure readiness. Bogor and Depok appear as supporting zones where EVCS expansion can strengthen network continuity and reduce service gaps. A phased approach of this kind is consistent with system-level charging infrastructure planning that balances demand growth, investment feasibility, and adoption dynamics.

To translate the zoning analysis into practical planning recommendations, existing charging infrastructure was compared with proposed EVCS locations. The resulting spatial configuration is shown in **Fig. 4**.

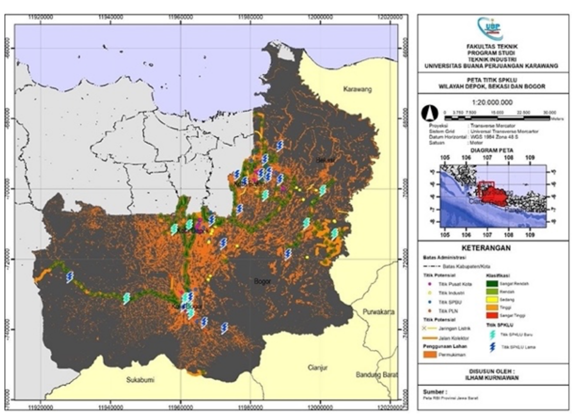

Fig. 4. Existing and proposed EVCS locations in West Java

Fig. 4 compares existing and proposed EVCS points across Bekasi, Bogor, and Depok. Existing charging stations remain concentrated in urban cores, leaving gaps in industrial and peripheral areas. Proposed points are allocated to eastern Bekasi, southern Depok, and central-to-eastern Bogor to improve spatial coverage and reduce accessibility gaps. This targeting supports evidence that charging density and user awareness shape adoption consideration, while range anxiety is influenced by both distance and waiting time—factors that can be mitigated by better network coverage.

5 Conclusion

This study demonstrates that an integrated AHP–GIS framework provides a robust and transparent approach for strategic EVCS planning at the provincial scale. By combining expert judgment with spatial analysis, the proposed methodology effectively identifies priority zones for EVCS development in West Java Province. The results indicate that city centers and main roads are the most critical factors influencing EVCS suitability, while high-priority development zones are concentrated in Bogor, Bandung, Bekasi, and Karawang. These findings offer practical guidance for policymakers and planners seeking to optimize infrastructure investment and support the transition toward sustainable mobility. Future research should incorporate additional variables such as travel demand modeling, EV adoption forecasts, and electricity grid capacity analysis. Integrating advanced methods such as fuzzy AHP, machine learning, or multi-objective optimization may further enhance planning accuracy and adaptability.

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