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Original Article

Geospatial Analysis for Electric Vehicle Charging Infrastructure Development in Mindanao

Benjie Boy T. Santander , Ambrosio B. Cultura II, Christopher S. Dolino

Author Information:

University of Science and Technology of Southern Philippines, Cagayan de Oro City, Philippines

Correspondence:
benjieboy.santander@ustp.edu.ph

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Abstract. This study presents a geospatial methodology for the optimal siting of Electric Vehicle Charging Stations (EVCS) across the island of Mindanao, Philippines. With limited existing infrastructure and vast intercity distances, the research aims to support the country's transition to sustainable mobility by identifying technically viable and strategically located EVCS sites. Using a sequential site refinement approach, the analysis integrates shortest-path routing, elevation profiling, grid accessibility, and solar irradiance potential to evaluate candidate locations along long-haul transport corridors. Eleven strategic city pairs were selected based on criteria including corridor length, economic significance, terrain challenges, and infrastructure gaps. Initial EVCS placements were determined using midpoint and anchor-site strategies on validated road networks. These placements were then refined through a stepwise GIS-based filtering process. Of the nine initial candidate sites, four were identified as anchor sites and five as midpoint sites. Elevation constraints did not eliminate any candidate locations, indicating full topographic feasibility. Solar resource analysis confirmed suitability for the majority of the proposed network. In addition, thirteen assumed urban electric vehicle charging station (EVCS) locations were incorporated into the network assessment. Elevation data from SRTM DEMs informed terrain-sensitive adjustments, while the lack of substation-level grid proximity data necessitated prioritizing solar-hybrid solutions. GHI values from the Global Solar Atlas confirmed the suitability of off-grid solar deployment in most proposed sites. The final EVCS network consists of midpoint and anchor stations supported by solar or hybrid energy systems, complemented by assumed urban charging infrastructure in major city terminals. This research provides a replicable, data-driven framework for EVCS planning in emerging regions. It serves as a decision-support tool for policymakers, energy planners, and private-sector stakeholders seeking to accelerate electric vehicle adoption in the Philippines.

Keywords: *Electric Vehicle (EV); EV Charging Station; Geospatial analysis; Geographic Information System (GIS); Mindanao.*

Electric vehicles (EVs) are considered a significant way to lower transportation-related greenhouse gas emissions (Stringer et al., 2025; Bhat et al., 2025). In the Philippines, the transportation sector is one of the largest contributors to energy-related CO_2 emissions (Department of Energy, 2023). Thus, the national government has passed Republic Act No. 11697 of 2022, or the Electric Vehicle Industry Development Act (EVIDA), which promotes EV adoption and accelerates EV integration by developing an EV charging station (EVCS) network. This supports the Comprehensive Roadmap for the Electric Vehicle Industry (CREVI), which outlines sustainable vehicle deployment at national and regional levels. However, national integration of EVs is limited across large island regions such as Mindanao due to a lack of charging infrastructure (Observatory Philippines, 2025). While many stations are located in densely populated areas, significant gaps in intercity development remain, making long-distance travel difficult due to battery limitations. Moreover, current and planned charging infrastructure strategies focus primarily on urban modeling and often neglect intercity connectivity, particularly in larger regions like Mindanao. This research addresses these gaps through a network-based GIS analysis of Mindanao's road systems. A network-based approach is preferred over point-based methods because it considers travel patterns, accessibility, major junctions, and driving ranges, enabling more informed placement of charging stations (Kazempour et al., 2025). The methodology also integrates solar energy potential, which is critical because over 80% of the Philippines' energy is fossil-fuel-based (Department of Energy, 2022) and must be considered in sustainable EVCS development (Philippine Energy Plan, 2024; CREVI, 2024; Alrubaie et al., 2023). Beyond technical optimization, this study advances the concept of a geographically just EVCS network for Mindanao (Skaloumpakas et al., 2025). In this context, geographic justice is defined as the equitable distribution of charging infrastructure that extends beyond economically dominant urban centers such as Davao and Cagayan de Oro, to include intermediate and transit municipalities that support regional mobility and trade. Justice here emphasizes accessibility: anchor sites were prioritized near public transport terminals, logistics hubs, and economic zones that serve both private and shared mobility users. By explicitly linking site selection criteria to transport justice principles, the proposed network ensures that intercity and regional travelers—not only urban or private vehicle users—benefit from a low-emission, sustainable EVCS network aligned with EVIDA and CREVI objectives.

Methodology

This section outlines the geospatial and analytical processes used to determine optimal locations for Electric Vehicle Charging Stations (EVCS) in Mindanao. The methodology follows a two-phase structure: the first phase identifies EVCS locations through road network analysis, while the second phase refines those candidates using environmental and infrastructure constraints. The goal is to provide a clear understanding of how each dataset and spatial analysis tool contributes to addressing EV range anxiety, while ensuring compatibility with national electrification and sustainability goals.

In Phase 1, we perform a primary analysis of the road network, which includes cleaning the OpenStreetMap (OSM) road data, selecting strategic corridors based on range and socioeconomic criteria, and identifying anchor sites at key intersections. We also compute midpoints between city pairs using shortest-path algorithms to propose baseline EVCS candidate locations. In Phase 2, these candidate sites undergo a refinement process that considers terrain slope derived from elevation data, proximity to the national power grid, and solar irradiance levels, ensuring the final locations are technically feasible and suitable for solar-powered infrastructure. This two-phase structure, supported by QGIS and Multi-Criteria Decision Analysis (MCDA), draws on best practices from Zhang and Fujimori (2020) and the DOE EVCS planning frameworks.

Research Design

This study adopts a quantitative, GIS-based research design to identify optimal locations for Electric Vehicle Charging Stations (EVCS) across Mindanao. The methodology is structured into two interlinked phases: (1) primary EVCS network siting using road network and shortest-path routing analysis, and (2) spatial refinement through multi-criteria spatial overlays that incorporate environmental and infrastructural constraints. This design ensures that final EVCS locations are based on both technical feasibility and geographic relevance.

The core analytical framework centers on Geographic Information System (GIS) tools, using cleaned OpenStreetMap data and shortest-path routing to define realistic travel corridors. Anchor sites were identified at key intersections, while midpoint candidates were placed at ~150 km intervals, following electric vehicle range guidelines [1]. These initial placements form the backbone of a corridor-based EVCS network model. Spatial refinement was then carried out using Multi-Criteria Decision Analysis (MCDA), incorporating the Topographic variation (elevation data from Google Earth Engine SRTM DEM to assess slope and energy efficiency), Solar irradiance potential (from Global Solar Atlas datasets to support off-grid deployment), and Electrical grid proximity (using digitized transmission line data to identify feasible on-grid sites).

Candidate sites were either retained, adjusted, or classified as solar-hybrid based on these factors. This two-phase process allowed the study to refine EVCS placements using data-driven filters while accounting for Mindanao's terrain and infrastructure diversity. By aligning this geospatial approach with corridor connectivity, range buffering, and energy feasibility layers, the research design ensures that the resulting EVCS network is robust, adaptable, and supportive of broader transportation electrification efforts. The method is consistent with global practices in spatial EV infrastructure planning (Gota et al., 2019; Skaloumpakas et al., 2022; Zhang & Fujimori, 2020).

Data Gathering Procedure

This study uses geospatial data from official government sources and open-access platforms to enable comprehensive spatial analysis for electric vehicle charging station (EVCS) planning in Mindanao. All spatial layers are preprocessed, analyzed, and visualized in QGIS, an open-source Geographic Information System (GIS) platform that supports multi-criteria spatial decision-making. The selected datasets serve as the foundation for shortest-path routing, midpoint EVCS siting, service-area buffering, and renewable energy suitability assessment. The geographic scope of the study encompasses the island of Mindanao, Philippines, focusing on major inter-city corridors, urban centers, and rural regions identified as energy transition zones under the Comprehensive Roadmap for the Electric Vehicle Industry (CREVI).

The road network data is primarily used to compute the shortest travel paths between major city pairs, helping simulate real-world EV travel routes and identify areas with limited charging coverage. City coordinates act as the starting and ending points for these route analyses. A 150 km driving-range buffer—reflecting the average electric vehicle range—is applied around these paths and urban centers to evaluate which areas can realistically be served. To support the potential for renewable-powered charging stations, solar irradiance data is layered into the analysis. This helps pinpoint locations with high solar energy potential, which is especially valuable for remote areas with limited or no access to the electrical grid. Additionally, information on transmission lines and substations is integrated to assess the feasibility of connecting proposed EV charging sites to the existing power infrastructure.

All spatial data is processed using QGIS, a powerful open-source GIS platform. The data undergoes careful preparation, including cleaning the road network topology, aligning projections to WGS 84 / UTM Zone 51N, and performing raster and vector analyses of slope, solar potential, and grid proximity. Together, these datasets support a structured two-phase analysis—starting with network planning, followed by detailed site refinement—to guide smart, data-driven placement of EV charging stations across Mindanao. This integrated geospatial approach ensures that final EVCS locations directly address key challenges such as range anxiety, infrastructure gaps, and renewable energy potential, while promoting equitable and sustainable transport solutions for the region. The integration and processing of these datasets enable a data-driven approach to identify optimal EV charging station locations that address range anxiety, promote renewable energy use, and support equitable access across Mindanao's transport corridors.

Data Analysis Procedure

Road Network Analysis

The Road Network Analysis phase encompasses preparing and analyzing the road network, selecting corridors, performing shortest-path routing, identifying anchor sites, and placing midpoint EVCS. Each step contributes to mapping realistic, range-sensitive EVCS locations throughout Mindanao, ensuring alignment with infrastructure priorities and geographic constraints. Before any routing or corridor analysis can be performed, the road network data from OpenStreetMap (OSM) must be cleaned and validated to ensure that routing tools, such as the QGIS Road Graph plugin, can process the network without errors caused by topological inconsistencies, such as unconnected lines or overshoots.

The cleaning process involves two major stages. First, topology corrections are applied using the v.clean toolset in GRASS GIS. The road network was cleaned using GRASS GIS's v.clean tool with a snapping tolerance of 5 meters, which removes dangling segments, closes small gaps, and ensures that all roads form a continuous, navigable network. Second, a manual quality assurance (QA) step is performed in QGIS, where key junctions along priority routes—such as Cagayan de Oro–Davao and Butuan–General Santos—are visually inspected to verify network continuity and logical connectivity. The validated network is then exported and serves as the core input for all routing analyses in the subsequent sections.

Shortest-path routing is subsequently applied using the QGIS Road Graph plugin, which computes corridor paths based on segment lengths, speed limits, and turn penalties. Midpoint EVCS locations are initially placed at approximately 150-km intervals along each validated corridor to reflect EV range constraints. The 150-km interval represents a network distance constraint across road segments; travel time, derived from speed limits and turn penalties, is treated as a secondary factor to reflect realistic driving conditions, particularly on routes with varying terrain and road classifications.

Strategic corridors are selected to guide EVCS deployment based on three criteria: EV driving range, regional economic importance, and terrain constraints. Corridors between major cities are prioritized if they exceed 250 kilometers, align with national transport plans, and traverse challenging terrain. Economic corridors are cross-referenced with the Mindanao Spine Expressway Network and NEDA-identified growth clusters, ensuring that EVCS investment supports existing infrastructure agendas. Meanwhile, SRTM-derived elevation data helps flag mountainous areas such as Bukidnon, where steep gradients may increase energy demand. Shortest-path routing is applied to each selected city pair using the QGIS Road Graph plugin, which computes the most efficient travel route based on speed limits, segment lengths, and turn penalties. These computed paths define the primary EV corridors across Mindanao.

Following path computation, the analysis identifies anchor sites—towns or cities located at intersections of multiple routes. These are optimal for EVCS installation because they can serve multiple travel flows. For example, Maramag (Bukidnon) is located at the convergence of the CDO–Davao and Iligan–Davao routes, making it a high-impact site. To ensure consistent EV range coverage, midpoint EVCS sites were initially placed at approximately 150-kilometer intervals along each priority corridor. This spacing follows the IEA 2023 guideline for the average driving range of mid-range electric vehicles. Each corridor was segmented accordingly, and midpoint markers were generated as preliminary candidates for charging station deployment. While some corridors, such as those passing through central Bukidnon, traverse high-elevation terrain that can negatively impact EV battery efficiency, slope-related adjustments were not applied during the initial midpoint placement. Instead, these elevation effects were addressed during the second phase of analysis, where elevation profiling was used to evaluate and refine candidate sites. Specifically, high-elevation midpoints were shifted toward flatter, more energy-efficient segments during the spatial refinement stage to enhance both usability and infrastructure feasibility.

Elevation Overlay Analysis

Elevation is a key physical factor influencing electric vehicle (EV) performance, particularly in energy consumption and range. This section outlines how the researcher incorporated terrain elevation data into the spatial evaluation of EV charging station (EVCS) placement, ensuring that candidate sites consider not only road connectivity and range buffers but also elevation-induced energy demands. The primary elevation dataset used for this analysis was the Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) with a 30-meter resolution, sourced from open geospatial repositories and verified through QGIS elevation tools. The DEM was clipped to the extent of the Mindanao Road network and aligned with EV corridor and midpoint locations identified in previous sections.

To assess the impacts of elevation, the DEM layer was reclassified into five elevation zones using the Raster Reclassify tool in QGIS. The classification thresholds were based on studies indicating significant battery performance drop-offs above 300–500 meters above sea level (Banega & Mamkhezri, 2023; Zhang & Fujimori, 2020). These zones helped determine whether proposed EVCS sites lie within high-elevation segments that may warrant priority due to greater range depletion. The resulting reclassified elevation map was overlaid with the EVCS candidate locations identified by the shortest-path and midpoint analyses. Sites in high-elevation zones were marked as energy-sensitive and considered for higher EVCS priority or denser spacing to mitigate energy losses due to elevation and gradient. This terrain-sensitive planning ensures that EV users traversing mountainous routes in Mindanao, such as those passing through Bukidnon or parts of North Cotabato, are supported by appropriately spaced, strategically located charging stations. By integrating elevation into the geospatial analysis, the research enhances the resilience and practicality of the proposed EVCS network under real-world driving conditions.

Solar Irradiance Analysis

In addition to grid accessibility, solar potential is a key factor in identifying optimal locations for electric vehicle charging stations (EVCS) in areas with limited power infrastructure or where energy sustainability is a priority.

This section outlines the researcher's methodology for analyzing solar irradiance in Mindanao using GIS tools and publicly available solar datasets. Solar irradiance data for the Philippines were acquired from NASA's POWER Project and the Philippine Renewable Energy Resource Map [3]. These datasets were processed to extract Global Horizontal Irradiance (GHI) values, which are essential for estimating solar energy availability in various locations. Using QGIS, the raster-based irradiance data was clipped to the Mindanao boundary. A reclassification was performed to group irradiance values into low-, medium-, and high-potential zones. Following studies such as Banegas & Mamkhezri, 2023, and Zhang & Fujimori, 2020, areas with a daily average GHI above 4.5 kWh/m²/day were considered high-solar-potential zones, making them suitable for deploying solar-powered EVCS.

After identifying areas with high solar potential, the researcher overlaid these zones with the filtered EVCS candidate locations previously deemed grid-inaccessible. Sites in high-irradiance zones were identified as priority locations for solar-based EVCS development, with the potential to integrate PV panels and battery storage. This solar layer enhances the feasibility of EV infrastructure in underserved corridors, ensuring resilience and energy independence, particularly in remote or off-grid municipalities of Mindanao (CREVI, 2023; Gota et al., 2019).

This study employed a two-phase geospatial methodology to identify optimal locations for Electric Vehicle Charging Stations (EVCS) across Mindanao using Geographic Information Systems (GIS). The approach integrated road network analysis, elevation profiling, grid accessibility evaluation, and solar irradiance assessment to refine the spatial placement of EVCS infrastructure along key transport corridors. The first phase involved collecting and preprocessing spatial datasets, including administrative boundaries, OSM-based road networks, urban center coordinates, and digital elevation models. Shortest-path routing was used to trace intercity corridors and identify midpoint and anchor locations, guided by a 150-kilometer interval standard for EV travel coverage. Anchor sites were identified at major route intersections, and midpoints were placed equidistantly, with later refinement.

The second phase focused on spatial refinement of candidate sites using a multi-criteria decision approach. Elevation-constraint analysis was conducted using 30-meter-resolution SRTM data, with midpoints repositioned toward flatter segments to reduce energy demand and infrastructure complexity. Grid accessibility was evaluated using transmission line data from DOE and OSM; candidate sites were either adjusted to align with grid corridors or designated for solar-hybrid deployment in off-grid areas. Solar irradiance was then assessed using Global Horizontal Irradiance (GHI) data from the Global Solar Atlas to validate the feasibility of off-grid EVCS installations. A suitability threshold of 4.5 kWh/m²/day was adopted, following ADB (2021), to classify solar-ready locations. This method ensures that final EVCS locations are functionally connected, terrain-optimized, grid-aware, and energy-resilient. The spatial logic reflects both EV range constraints and infrastructure availability, offering a scalable deployment model for Mindanao. The integration of environmental and infrastructure criteria into a phased refinement strategy enables practical planning in both high-demand urban corridors and underserved rural regions.

Ethical Considerations

This study acknowledges several ethical considerations in the geospatial analysis of electric vehicle (EV) charging infrastructure. Foremost, we need to promote equity by avoiding spatial bias that could favor affluent or urban areas at the expense of underserved communities. Privacy concerns also arise from the use of location-based data; thus, all data used was anonymized, and no personally identifiable information was collected. Additionally, transparency in methodology and inclusion of community perspectives are essential to ensure that planning outcomes reflect public interest and social responsibility.

Results and Discussion

Road Network Analysis

This section presents the Phase 1 results of the geospatial analysis for identifying optimal locations for Electric Vehicle Charging Stations (EVCS) in Mindanao. Phase 1 focuses on siting EVCS based on road network analysis, range constraints, and key travel corridors. (Kazempour et al., 2025). It includes cleaning and validating OpenStreetMap (OSM) road data, identifying strategic intercity corridors, and placing candidate EVCS sites at route midpoints and corridor intersections. (Kłos & Sierpiński, 2023; Charly et al., 2023).

The refinement of these candidate sites using terrain, solar, and grid data will follow in Phase 2.

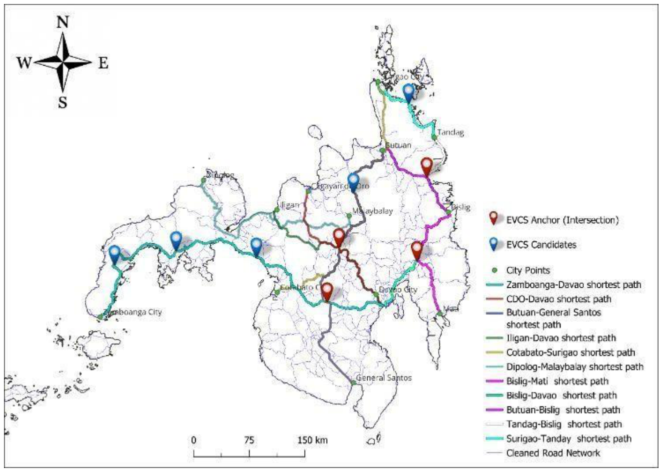

Figure 1. *Final EVCS Candidate Site Map for Mindanao*

The map shows cleaned road networks, shortest-path routes between major cities, anchor EVCS at corridor intersections, and midpoint EVCS candidates spaced at 150 km intervals along long-range routes. This spatial layout supports full- range EV travel and infrastructure optimization. Figure 1 presents the consolidated spatial output of the Phase 1 EVCS planning process, illustrating the cleaned and validated road network of Mindanao, along with the key strategic intercity routes selected through shortest-path analysis. These routes were chosen based on corridor length (>250 km), lack of existing EV infrastructure, economic importance, and terrain considerations, in line with international EV planning standards (IEA, 2023; ADB, 2021)

The figure highlights two types of EVCS candidate sites. First, *Anchor EVCS* sites (shown in red), placed at intersections of major corridors and nodes of overlapping travel demand. Second, the *Midpoint EVCS* candidates (shown in blue), spaced approximately every 150 km along long-haul routes to accommodate range limitations of mid-tier electric vehicles. It is important to note that other minor city roads and intra- provincial links are not included in this base network. This exclusion is intentional and based on the strategic corridor selection criteria outlined in Section 3.1.1. Only long-distance corridors with significant interregional mobility challenges were prioritized to optimize resources and address gaps in long-range EV coverage. Shorter routes between adjacent cities, or those with existing charging infrastructure (e.g., Davao–Tagum, GenSan–Koronadal), were excluded to maintain focus and relevance in the planning. Ultimately, the layout in Figure 1 forms the baseline EVCS distribution model prior to spatial refinement. It serves as a scalable foundation that will be enhanced in later stages through elevation, grid accessibility, and solar resource overlays, resulting in a technically feasible and geographically inclusive EVCS network across Mindanao.

Strategic Corridor Selection

Six intercity corridors were prioritized based on EV range limitations (>250 km), economic relevance, and terrain difficulty (Csiszár et al., 2020; Calvo et al., 2024). These corridors align with the Mindanao Spine Expressway and CREVI targets. Slope data from SRTM were used to identify segments with a gradient>10%, where EV energy consumption is higher.

Elevation Overlay Analysis

This terrain-aware refinement reduces elevation exposure while maintaining spacing coverage. The map reflects elevation-informed optimization in multi-node corridor planning. (Dávila et al., 2023). Figure 2 shows the adjusted EVCS placements along the Zamboanga–Kayaga corridor, with the final candidate moved from 450 km to 430 km. This modification was based on an elevation profile analysis, which revealed steeper, higher terrain beyond the 430 km mark. By shifting the third EVCS point backward by 20 km, the new location now falls within a lower and more stable elevation band, as confirmed by the DEM overlay. This refinement maintains adequate spacing between nodes while improving technical feasibility and reducing terrain-related challenges for construction and EV range efficiency. The updated map underscores the importance of integrating terrain data into the planning of multi-node EVCS networks.

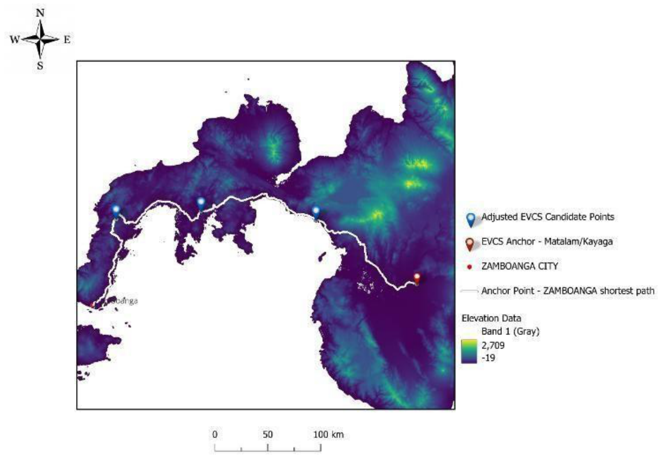

Figure 2. *Updated EVCS Placement Map with the Third Site Shifted from 450 km to 430 km*

Table 1. *Priority City Pairs for EVCS Planning in Mindanao*

City Pair	Approx. Distance (km)	Justification
Cagayan de Oro – Davao	300	Connects two major economic centers; exceeds the typical EV range (150–250 km), causing range anxiety.
Butuan – General Santos	470	Longest north-south axis; vital for cross-island logistics and mobility with no current EVCS chain.
Iligan – Davao	330	Links the western corridor with eastern Mindanao; crosses mountainous areas needing charging support.
Cotabato – Surigao	390	Crosses key inland and coastal zones; an underdeveloped corridor for EV infrastructure.
Zamboanga – Davao	600+	Critical for future long-range corridor; must be broken down by intermediate EVCS nodes.
Dipolog – Malaybalay	270	Represents secondary regional link with growing urban and tourism areas.
Surigao – Tandag	173	173 km corridor with limited EV infrastructure; important for connectivity and EV range coverage in east Mindanao.
Tandag – Bislig	120*	Coastal route connecting important towns; currently underserved by EV infrastructure.
Butuan – Bislig	190*	Connects northern and eastern Mindanao; supports regional economic and mobility integration.
Bislig- Mati	125*	Links two key eastern Mindanao cities; important for coastal connectivity and EVCS expansion.
Bislig - Davao	270*	Connects eastern to southern Mindanao; a corridor with growing transport and EV needs.

Table 2. *Criteria for Elevation Overlay Analysis*

Parameter	Criteria/Threshold	Reference(s)
DEM Source	SRTM 30-meter resolution elevation data.	(NASA SRTM, 2023)
Elevation Thresholds	>300 m = Medium Impact Zone, >500 m = High Impact Zone	(Banegas & Mamkhezri, 2023; Zhang & Fujimori, 2020)
Profile Segmentation	Elevation profile divided into halves or thirds.	(Zhang & Fujimori, 2020; Ajanovic & Haas, 2016)
Midpoint Adjustment	Shifted toward lower-elevation segments (by 10–20 km).	(Banegas & Mamkhezri, 2023; Bjerkan et al., 2020)
Elevation Sampling	Profile Tool in QGIS from the shortest-path line.	(Skaloumpakas et al., 2022)

Table 3. *Elevation Profile Summary – Butuan–Maramag Corridor*

Segment	Average Elevation (m)	Elevation Range (m)
0–50% (First Half)	548.94	1272
50–100% (Second Half)	482.08	995

Table 4 *Elevation Summary of EVCS Candidate Sites – Zamboanga–Kayaga Corridor*

EVCS Location	Distance (km)	Elevation (m)	Terrain Notes
Anchor Point (Kayaga)	0	26	Low-Elevation Urban Zone
Midpoint 1	150	56	Low Elevation, Suitable Site
Midpoint 2	300	210	Moderate Elevation, Acceptable
Midpoint 3 (Original)	450	262	Higher Elevation, Adjusted

Midpoint 3 (Adjusted)	430	210	Lower Zone, Refinement Applied

Table 5 *Elevation Profile Summary – Surigao–Tandag Corridor*

Segment	Average Elevation (m)	Elevation Range (m)
0–50% (First Half)	45.51	280
50–100% (Second Half)	33.06	158

Solar Irradiance Analysis

Figure 3 shows the spatial distribution of average daily Global Horizontal Irradiance (GHI) across Mindanao, based on data from the Global Solar Atlas. EVCS candidate and anchor sites were overlaid on this irradiance raster to extract GHI values for each location. These values were used to evaluate solar suitability and determine whether sites could be prioritized for solar-hybrid or off-grid deployment. The color gradient ranges from 2.9 to 5.4 kWh/m²/day, with higher irradiance concentrated in southern and central regions. (Hisoğlu et al., 2025; Minh et al., 2021).

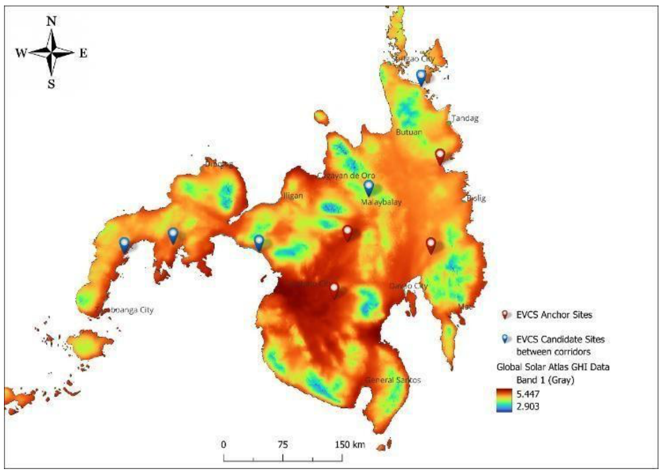

Figure 3. *Global Horizontal Irradiance (GHI) Map of Mindanao from the Global Solar Atlas, Overlaid with EVCS Anchor and Candidate Sites*

Table 6 *Solar Irradiance Assessment of Final EVCS Sites*

EVCS Corridor / Site	GHI (kWh/m²/day)	Solar Suitability	Recommended Type
Butuan–Maramag (Midpoint)	4.5	✅ Suitable	Solar-Hybrid EVCS
Surigao-Tandag (Midpoint)	4.758	✅ Suitable	Solar-Hybrid EVCS
Zamboanga (EVCS 1)	4.989	✅ Suitable	Solar-Hybrid EVCS
Zamboanga (EVCS 2)	4.839	✅ Suitable	Solar-Hybrid EVCS
Zamboanga (EVCS 3)	5.056	✅ Suitable	Solar-Hybrid EVCS
Matalam/Kayaga Anchor	5.248	✅ Suitable	Solar-Hybrid EVCS
Maramag Anchor	5.162	✅ Suitable	Solar-Hybrid EVCS
Payasan Anchor	4.913	✅ Suitable	Solar-Hybrid EVCS
Nabunturan Anchor	4.817	✅ Suitable	Solar-Hybrid EVCS

Final EVCS Map for Mindanao

The map includes validated anchor points, midpoint EVCS candidates, and assumed urban charging sites, excluding Cagayan de Oro and Davao, which already host operational EVCS infrastructure. The figure above presents the comprehensive spatial output of the EVCS planning process in Mindanao, integrating all geospatial analyses performed in this study. Each EVCS site shown on the map has undergone filtering based on elevation suitability, solar irradiance potential, and corridor alignment. Grid accessibility was considered where data were available, but it was ultimately deprioritized due to the lack of practical substation access across most corridor segments.

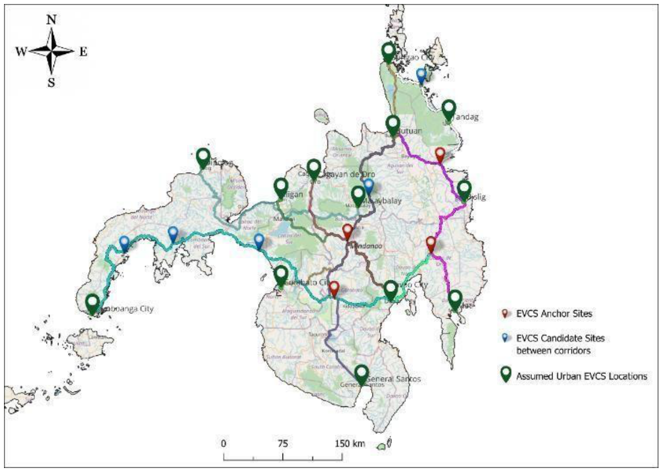

Figure 4. *Final EVCS Site Map for Mindanao Showing Elevation-, Solar-, and Corridor-Refined Candidate Sites Along Priority Intercity Routes*

The final configuration includes multiple anchor points, such as Payasan (serving both the Butuan–Bislig and Tandag–Bislig corridors) and Nabunturan (at the junction of the Bislig–Davao and Bislig–Mati routes), strategically placed at key road network intersections to support multi- directional EV flow. Midpoint EVCS candidates were confirmed for long-range segments, including Surigao–Tandag and Butuan–Maramag, where elevation profiles were stable and solar irradiance exceeded the deployment threshold (≥4.5 kWh/m²/day). No significant adjustments were required for these new sites, validating their original placement.

To ensure uninterrupted travel across Mindanao's EV network, urban EVCS installations were assumed in city endpoints of each corridor—including Butuan, Iligan, General Santos, Cotabato, Zamboanga, Surigao, Tandag, Bislig, Mati, and Marawi—except for Cagayan de Oro and Davao, which were excluded due to already existing commercial charging stations. This final map demonstrates a resilient, decentralized EVCS network that leverages hybrid energy strategies to overcome terrain and infrastructure gaps. It highlights the potential for sustainable and inclusive transport electrification across both urban centers and remote interprovincial corridors.

Conclusion

The primary objective of this study was to determine the optimal locations for electric vehicle charging stations (EVCS) in Mindanao using a GIS-based spatial analysis framework that considers geographic constraints, energy availability, and transport connectivity. In doing so, the study aimed to support a future-ready charging network that responds to both infrastructure realities and sustainability goals across the island. Through a stepwise methodological approach—including road network validation, shortest-path routing, midpoint and anchor site placement, and spatial refinement based on elevation, grid accessibility, and solar irradiance—the study successfully developed a hybrid EVCS siting model. Elevation analysis enabled terrain-aware adjustments to midpoints, improving EV efficiency and installation feasibility. Grid analysis was applied selectively due to the absence of substation-level access along many intercity corridors, prompting a shift toward solar hybridization. Solar irradiance analysis confirmed that all final EVCS sites fell within zones of moderate to high solar potential, validating the technical viability of solar-hybrid deployment across both remote and grid-inaccessible routes.

The final EVCS map synthesizes all spatial constraints and planning criteria into a comprehensive visual output. It features strategically distributed anchor and midpoint stations, optimized for corridor coverage and energy reliability. Assumed urban EVCS locations in terminal cities complete the network, excluding those cities (such as Davao and Cagayan de Oro) that already have operational stations. This refined layout ensures continuous long-distance travel support across Mindanao's major economic and logistical corridors.

Overall, this study presents a replicable geospatial planning framework for EVCS deployment in emerging regions. The final map and site database serve as actionable tools for policymakers, local governments, and private sector stakeholders to inform infrastructure investment, grant allocation, and system-level transport planning. While the present work focuses on spatial and technical feasibility, future research should extend beyond planning-stage optimization by integrating traffic demand analysis and electrical grid impact studies to assess usage potential, load implications, and long-term operational sustainability. Such extensions would bridge the gap between spatial planning and real-world deployment and system integration.

Contributions of Authors

Author 1: proposal writing, conceptualization, data gathering, data analysis
Author 2: conceptualization, checking
Author 3: conceptualization

Funding

None.

Conflict of Interests

No conflict of interest.

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