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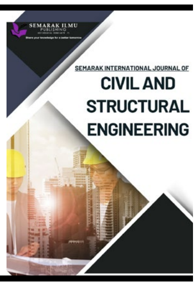

Assessing Criteria for Photovoltaic Electric Vehicle Charging Stations in Malaysia: Analytic Hierarchy Process and Content Validity Index Analysis

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ABSTRACT

Integrating electric vehicle charging stations (EVCSs) with renewable energy sources (RES) further enhances these advantages, addressing range anxiety among EV users. Allocating suitable locations for Photovoltaic Electric Vehicle Charging Stations (PEVCS) is crucial in Malaysia to optimize their utility and accessibility. This study employs a dual methodology combining the Content Validity Index (CVI) and the Analytic Hierarchy Process (AHP) to validate instruments and analyze expert judgment. Through a comprehensive literature review and need analysis, the study identifies and validates main criteria and sub-criteria influencing the placement of PEVCS in Malaysia. The CVI is used to develop an AHP questionnaire, ensuring the robustness of the instrument. The findings reveal six main criteria and twelve sub-criteria crucial for determining ideal PEVCS locations. Economic factors emerge as the most influential main criterion, with construction costs ranking highest among sub-criteria. Utilizing AHP calculations, these criteria weights are integrated into GIS modelling using ArcGIS software to identify optimal PEVCS locations. This study offers significant advantages to industry leaders, policymakers, and stakeholders in effectively allocating suitable locations for PEVCS in Malaysia. By enhancing environmental sustainability and addressing logistical challenges, this approach contributes to the advancement of EV infrastructure and adoption in Malaysia.

1. Introduction

In Malaysia, the electric vehicle (EV) industry is still developing at a slow pace and will take some more time to reach the level of aggressiveness seen in other countries. Many factors need to be considered for the widespread adoption of EVs in Malaysia. However, according to Khoo [1], the market share for battery electric vehicles (BEVs) has seen a significant increase, with EV sales rising from 3,079 units in 2022 to 11,624 units in 2023, boosting the market share from 0.43% to 1.45%. As

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we know, driving EVs is environmentally friendly and can cut downs on carbon emissions. Therefore, integrating them with renewable energy sources (RES) can further enhance their environmental benefits, making the overall impact even greener. Furthermore, that integration contributes to achieving SDG Goal 7 (Affordable and Clean Energy) while simultaneously addressing air pollution and its health-related impacts, linked to SDG Goal 3 (Good Health and Well-being) [2].

Despite these benefits, Farah *et al.,* [3] notes that solar adoption in Malaysia remains minimal. In addition, Malaysia aims to fully harness its solar energy potential to eliminate carbon emissions, mitigate climate change effects, and reduce dependence on conventional energy sources [4]. With the support of large-scale solar photovoltaic projects, Malaysia is aggressively tackling its carbon footprint, committing to a 45% reduction in greenhouse gas emissions by 2030 [5]. In fact, over time, a 1% increase in the use of renewable energy is associated with a 0.3% decrease in carbon dioxide emissions [6]. Accordingly, the Ministry of Investment, Trade, and Industry (MITI) also targeted to install 10,000 electric vehicle charging stations (EVCSs) along major routes by 2025 [7]. However, progress remains below target, particularly concerning the deployment of solar photovoltaic systems. This indicates a significant gap in Malaysia's development of EV infrastructure towards greater sustainability.

Moreover, the installation of photovoltaic electric vehicle charging stations (PEVCS) along routes can alleviate range anxiety among EV users [8]. To promote EV adoption among Malaysians and contribute to a greener future, PEVCSs should be strategically placed along routes [9]. For this reason, several criteria or parameters must be carefully considered when selecting optimal locations for PEVCS in Malaysia. The number of PEVCS locations in Malaysia is still minimal, and there is limited research on the criteria for determining suitable locations for PEVCS especially in Malaysia. To address this gap, this study employs a dual methodology, combining the Content Validity Index (CVI) and the Analytic Hierarchy Process (AHP), to validate instruments and analyze expert judgment. In Section 2, the literature review focused on the application of CVI in instrument validation and AHP for location-allocation problems. Section 3 detailed the utilization of CVI in developing the AHP questionnaire and the application of AHP methods. Section 4 presented the CVI results and criteria weights, along with a discussion of findings. Finally, Section 5 concluded the study with recommendations for future research

2. Literature Review

Determining criteria is crucial in site selection studies. Thus, this study employs instrument validation to identify and prioritize criteria using AHP methods. Therefore, this section delves into previous studies that have used CVI for instrument validation and AHP method for solving location-allocation problems.

2.1 Content Validity Index (CVI) in Instrument Validation

The evaluation of an instrument’s components or items for their representativeness or relevance, conducted through a two-stage process involving development and evaluation is known as content validity [10]. Besides, content validity is often verified by scale developers using the CVI, which is derived from content experts' judgments of item relevance [11]. The CVI is divided into two categories: the content validity of individual items (I - CVI) and the content validity of the overall scale (S - CVI) [12]. The CVI is widely and commonly used across many fields to validate instruments. First and foremost, Khalid *et al.,* [13] highlighted the current multidomain intervention module, iAGELESS, demonstrates strong content validity, reflected in its comprehensive CVI score of 0.83. According to

Indarta *et al.,* [14], CVI is employed to test the validity of interactive learning media from three experts and achieved 0.93 of average item-level content validity index (S – CVI/ Ave). In addition, Dalawi *et al.,* [15] utilized CVI to evaluate the Malay-language Understanding, Attitude, Practice, and Health Literacy Questionnaire on COVID-19 (MUAPHQ C-19), achieving a satisfactory S-CVI/Ave value of 0.90.

Furthermore, the Malay - translated version of the Consideration of Future Consequences (CFCs) 14 is suitable for Malaysian studies, as indicated by a high item-level index (I-CVI/Ave) value of 0.93 across all scale item [16]. Moreover, the study indicated reliable which assessed the Conjoint Community Resiliency Assessment Measure (CCRAM) with 21 items, utilizing nine psychology experts, by employing content validity measurement methods including interrater reliability (IRR), Aiken’s validity, content validity ratio (CVR), and CVI [17]. Another key point, only indicators with a CVI of 0.867 or higher were retained for this study which the questionnaire validation is for measuring the impact of COVID-19 on SME performance [18]. Notably, achieving a total CVI value of 0.992, with I - CVI ranging from 0.95 to 1.00 after three rounds of expert consultation, the questionnaire was structured into five dimensions and 44 elements [19].

However, several studies have utilized CVI to validate their AHP instruments. According to Zhao and He [20] the content validity of the constructed public management index system is deemed good and acceptable. Likewise, the instrument is deemed valid and acceptable, supported by CVI values of 0.89 obtained from two experts in the research aimed at developing a sustainable solid waste management system using the AHP method [21]. In the study evaluating the conceptual model of sustainable outsourcing with a balanced scorecard using the AHP method, 114 items out of a total of 152 items were confirmed after calculating CVI values, as assessed by 13 experts [22]. In conclusion, CVI remains widely used and relevant across multidisciplinary fields for instrument validation.

2.2 Analytic Hierarchy Process (AHP) for Location-Allocation Problems

AHP is a widely used multi-criteria decision-making (MCDM) method among decision makers (DMs). Based on Saaty [23], AHP is structures decisions hierarchically into goals, criteria, and alternatives. In the recent studies, AHP method commonly used in solving location-allocation problems. Firstly, the site selection criteria of “government policies” for private disabled care centers in Türkiye are obtained by calculating the criteria's weights using the AHP method [24]. Secondly, using the AHP method, the highest weights for selecting the location of a photocopy business branch are found to be the price of renting, market opportunities, and cleanliness of the location [25]. To select the right location for sports facilities, "financial issues" is identified as the most important main criterion by employing AHP method [26]. According to Türk and Yavuz [27], research using the gray AHP (G-AHP) method highlighted "transportation diversity of the region" as the most important criterion for selecting the cargo hub location for air cargo companies.

Besides, the AHP method is used to determine defensive zones based on accessibility criteria, revealing that easier access contributed to an increase in reported cases of Coronavirus Disease 2019 (COVID-19) [28]. Furthermore, using the AHP method, it is determined that in flood-susceptible regions of Bihar, India, the most prominent flood-causing criterion is hydrologic, while the least prominent is anthropogenic interference [29]. Teng *et al.,* [30] acquired the AHP method and Delphi analysis, “special trip planning” is given the highest weight compared to other factors to enhance the development of the cruise tourism industry in Taiwan. To identify off-site construction systems, Zaheraldeen *et al.,* [31] used the AHP method and found that volumetric systems are the most preferred criteria. Moreover, integrating the AHP method and verifying using Delphi into their studies showed that the slum population criteria hold the highest weight for the development and management of sustainable cities in Cambodia [32].

However, while the AHP method has been widely used by DMs to solve EVCS allocation problems, there remains minimal focus on PEVCS placement in existing studies. Yagmahan and Yılmaz [33] obtained aggregated weights with AHP, revealing that the technology criterion had the highest significance in identifying ideal spot for EVCS locations. The AHP method assigns the highest weight to the criterion of proximity to users when allocating EVCS locations [34]. Using thematic analysis and the AHP, the main key location selection factors are identified as transport hubs, marked or controlled parking spaces, and points of interest in determining the suitable place for EVCS [35]. To determine the optimal locations for EVCS, Kaya *et al.,* [36] found that the most preferred criterion is environmental/urbanity, followed by transportation, financially, properties of station, physiographic and energy/power, in that order. Otherwise, the optimal PEVCS location is determined using the AHP method, considering 10 criteria, with acquired solar energy potential being the most significant [37]. Additionally, Ghodusinejad *et al.,* [38]applied the AHP method, considering 12 sub-criteria, and found that only 9.82% of the island area is most suitable for PEVCS construction. Hence, the above studies highlight a significant gap in identifying suitable PEVCS locations, particularly in Malaysia. This is supported by Syahirah and Farah [39], who suggest that the identified criteria will be evaluated using approaches to determine appropriate sites for PEVCS in Malaysia.

3. Methodology

This section outlines the methodology, which involved four phases including the development of the instrument, finalization of criteria, validation of expert judgment, and criteria ranking, as illustrated in Figure 1.

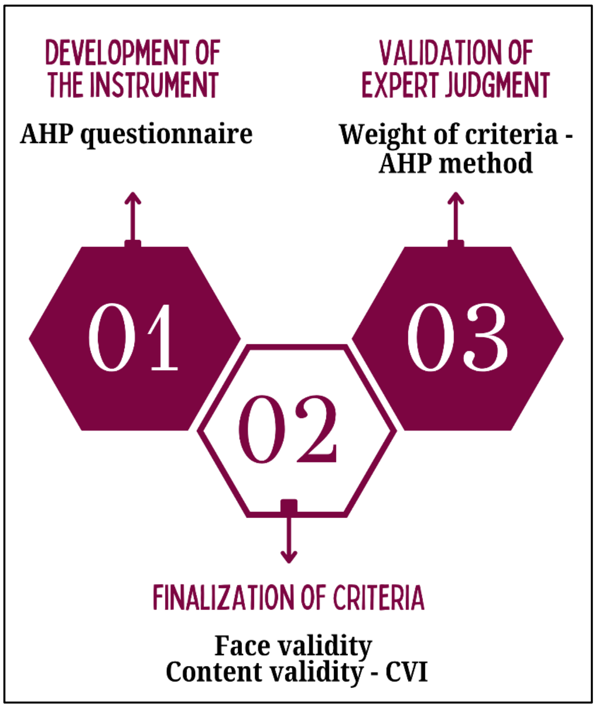

Fig. 1. The flowchart of the methodology

3.1 Phase 1: Development of the instrument

In Phase 1, the development of the instrument involves several stages. The AHP questionnaire, adapted from Ward [40], is tailored to the context of this study. Unlike other questionnaires, the AHP questionnaire used Saaty's scale and includes pairwise comparisons between criteria. The criteria are gathered from literature reviews on EVCS and PEVCS allocation from 2015 to 2023. Initially, six main criteria and 177 sub-criteria are collected. Researchers then identified criteria relevant to the landform of Malaysia, narrowing it down to 52 sub-criteria for a needs analysis [3]. Following this analysis, 41 out of the 52 sub-criteria were selected to develop the AHP instrument.

3.2 Phase 2: Finalization of criteria

Phase 2 describes the process of finalizing the criteria for this study. To ensure the instrument's validity and reliability, it undergoes validation by experienced lecturers with over five years of expertise in Operational Research (OR) and MCDM. Face validity and content validity are employed, with face validity assessed using a dichotomous scale and content validity using the CVI. Thus, the instrument validation involved three rounds, resulting in the reduction of sub-criteria from 41 to 12, based on expert feedback and comments. After finalizing the criteria, the study proceeded to validation of expert judgment using the AHP method.

3.3 Phase 3: Validation of expert judgment

Phase 3 emphasizes the validation of expert judgment. Based on their expertise and knowledge, the experts completed the AHP questionnaire to determine the most preferred criteria for locating PEVCS in Malaysia. After analyzing the experts' input, the study used the AHP method to calculate the criteria weights. The AHP method, developed by Thomas L. Saaty, involves four main steps [41]:

i. Identify the problem and the type of information needed to solve it: Determine the suitable locations for PEVCS in Malaysia.
ii. Construct the decision hierarchy, including the goal, criteria, and alternatives. In this study, the hierarchy consists of one goal supported by six main criteria and twelve sub-criteria.
iii. Compose the pairwise comparison matrices. This study includes four sets of pairwise comparison matrices: one for the main criteria and three for the sub-criteria categories of society, environment, and technology.
iv. Rank the criteria. All main criteria and sub-criteria are ranked according to their weights. The higher the value of the criteria weight, the more preferred the criteria [42].

To obtain a single representative value from the decision makers (DMs), aggregate individual pairwise comparisons are computed and divided into two methods: aggregating individual judgments (AIJ) and aggregating individual priorities (AIP) [43]. For each element in the pairwise comparison matrix, AIJ is performed by calculating the geometric mean of the individual judgments, while AIP is used when individuals work independently and hold distinct beliefs [44]. Hence, this study employed AIJ by calculating the geometric mean of the experts' judgments using Microsoft Excel, then transferring the data into Super Decision software.

4. Results and Discussion

In determining the ideal locations for PEVCS in Malaysia, six main criteria and twelve sub-criteria were finalized. These criteria were ranked based on their weights using the AHP method. Seven experts from diverse fields, including academia, EV users, policymakers, EVCS owners, and practitioners with at least five years of experience, are selected to complete the AHP questionnaire. The hierarchy for determining the ideal locations for PEVCS in Malaysia is displayed in Figure 2. It is divided into three levels: goal, main criteria, and sub-criteria.

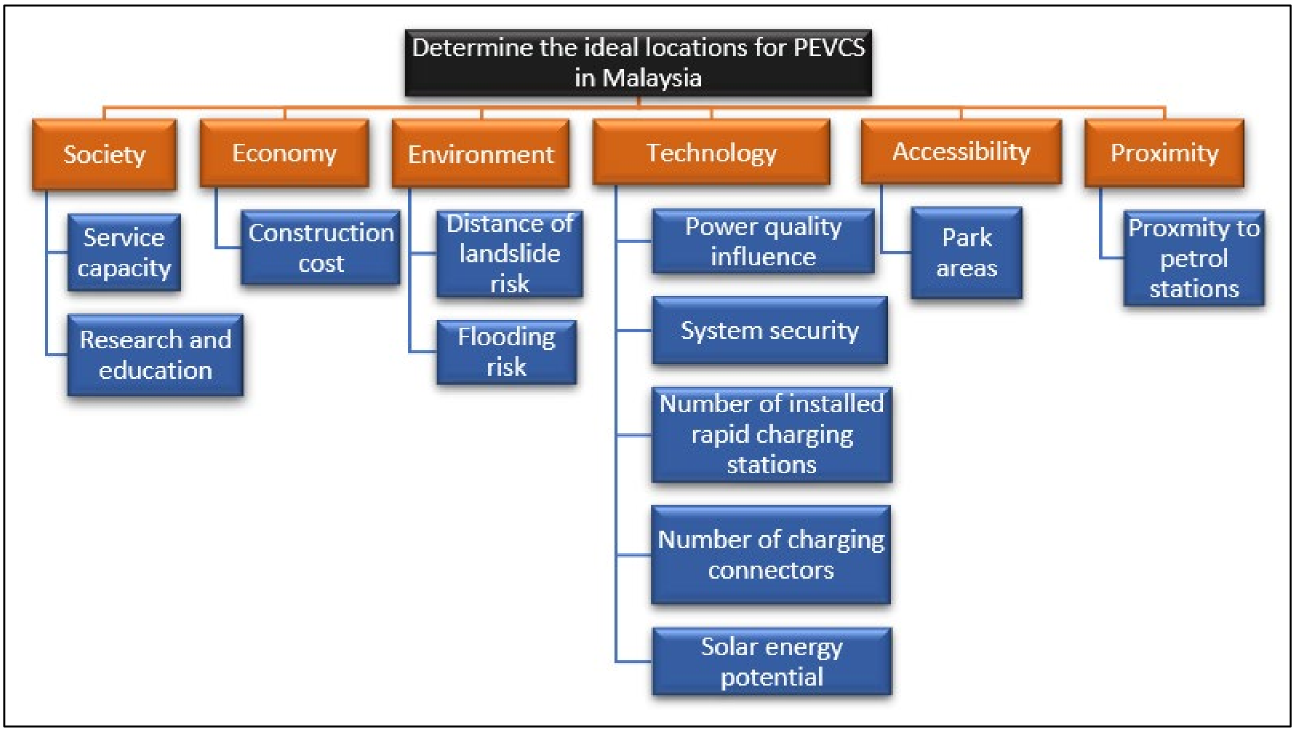

Fig. 2. The hierarchy of determining the ideal locations for PEVCS in Malaysia

All criteria weights are calculated using the AHP method. To ensure the acceptability of the pairwise comparison matrices, the consistency ratio (CR) must be less than 0.1 [23]. In this study, the CR value is below 0.1, indicating that the results are both acceptable and reliable. Table 1 shows the derived weights, with economy receiving the highest weight (22.62%), followed by proximity (20.84%), technology (20.56%), and accessibility (17.35%). The environment criterion is weighted significantly lower at 12.32%, but still ranks ahead of societal impact at 6.31%. Additionally, the sub-criteria of construction cost are the most important, indicating its vital role in determining PEVCS locations, while research and education sub-criteria are the least preferred.

Table 1
The criteria weight of main criteria

Main Criteria	Weight	Percentages	Rank	Sub-criteria	Weight	Percentages	Rank
Society	0.063058	6.31%	6	Service capability	0.052864	5.29%	7
				Research and education	0.010194	1.02%	12
Economy	0.226210	22.62%	1	Construction cost	0.226210	22.62%	1
Environment	0.123218	12.32%	5	Distance of landslide risk	0.039052	3.91%	8
				Flooding risk	0.084166	8.42%	4
Technology	0.205632	20.56%	3	Power quality influence	0.014408	1.44%	11
				System security	0.020782	2.08%	10
				Number of installed rapid charging stations	0.056892	5.69%	6
				Number of charging connectors	0.077666	7.77%	5
				Solar energy potential	0.035884	3.59%	9
Accessibility	0.173492	17.35%	4	Park areas	0.173492	17.35%	3
Proximity	0.208390	20.84%	2	Proximity to petrol stations	0.208390	20.84%	2

On the other hand, the construction and installation costs of EV charging infrastructure are crucial for maintaining performance [44]. Moreover, the deployment of PEVCS in Malaysia should prioritize considerations related to financial and economic implications [8]. According to Roslan *et al.,* [45], conventional EVCS systems that rely on fossil fuel-based energy are more expensive, less reliable, and have a greater environmental impact, despite being less complicated and simpler. Correspondingly, the goals of reducing greenhouse gas emissions and limiting the potential for extreme weather events and their effects on the climate can be achieved by integrating RES [46]. Therefore, these studies indicate that installing EVCS with RES including PEVCS is preferable and cost-effective compared to conventional EVCS.

Conversely, the sub-criteria 'research and education' under the societal aspect are among the least preferred for allocating PEVCS locations in Malaysia. With this intention, safety concerns, possibly related to high population density, might explain why experts did not prioritize this criterion. Nonetheless, PEVCS owners and developers need specific guidelines to ensure safety, especially in locations with high population density, high crime or vandalism rates, and popular spots during weekends or holidays [3].

Overall, the AHP criteria weights combined with geospatial data will be overlaid using ArcGIS software to predict suitable PEVCS locations in Malaysia. During the analysis, the spatial data for these 12 sub-criteria will be categorized into three levels of importance—high, moderate, and low—in ArcGIS software, as illustrated in Figure 3. To develop a predictive model, spatial data is sourced from various Malaysian agencies including *Jabatan Ukur dan Pemetaan Malaysia (JUPEM)*, *Jabatan Perancangan Bandar dan Wilayah (JPBD)*, *Jabatan Pengairan dan Saliran (JPS)*, and *Pusat Geospatial Negara (PGN)*, which is then analyzed using ArcGIS software. Thus, this study offers significant advantages in two key aspects. Firstly, from a geographical standpoint, the ArcGIS's Model Builder predicts optimal PEVCS locations. Secondly, mathematically, the model offers a generalized framework enabling mathematicians to pinpoint ideal PEVCS locations throughout Malaysia.

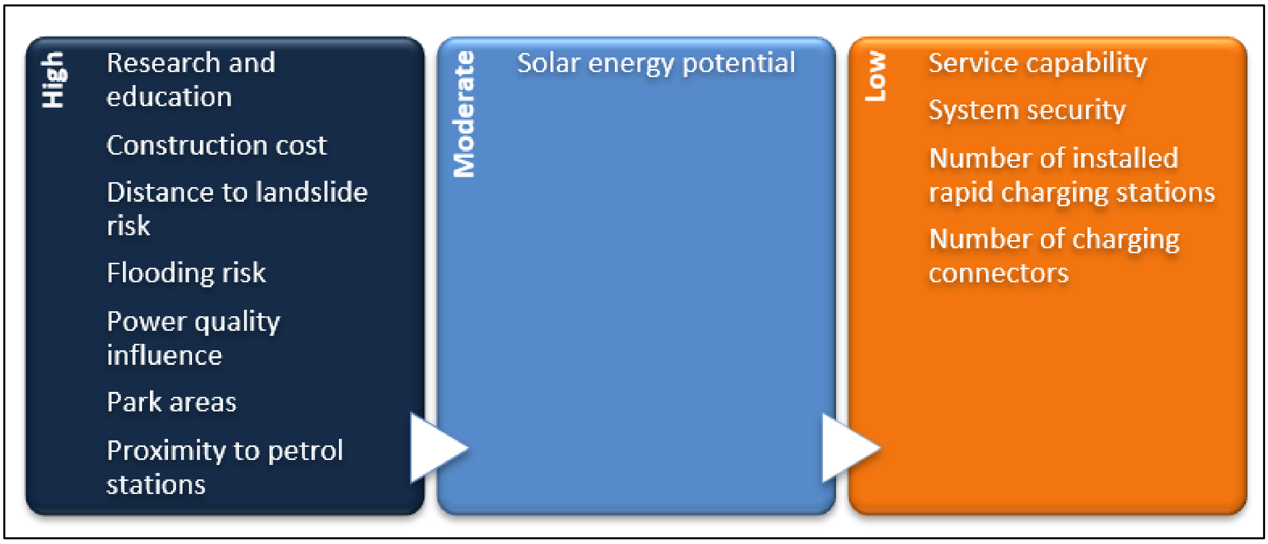

Fig. 3. The importance level of criteria

5. Conclusions

In conclusion, the growth of the EV industry in Malaysia is crucial for supporting SDGs, particularly SDG Goal 7 (Affordable and Clean Energy) and SDG Goal 3 (Good Health and Well-being). The successful integration of EVs with renewable energy sources (RES) can significantly address air pollution and health-related issues. To place ideal locations for PEVCS in Malaysia, this study employs a rigorous dual methodology combining the CVI and the AHP for instrument validation and expert judgment analysis. In addition, the study meticulously identified six main criteria and twelve sub-criteria through comprehensive literature review and needs analysis. These criteria are validated using CVI and weighted using the AHP method, involving seven experts from diverse fields.

On top of that, the findings revealed that economic factors hold the highest weight, followed by proximity, technology, and accessibility. Despite being weighted lower, environmental considerations (12.32%) still surpass societal impact (6.31%). Among the sub-criteria, construction cost emerged as the most significant, highlighting its critical role in determining PEVCS locations, while research and education are the least prioritized. However, the study presents significant advantages both geographically and mathematically. Geographically, ArcGIS's Model Builder effectively predicts optimal PEVCS locations. Mathematically, the model provides a generalized framework that can be utilized by mathematicians to identify ideal PEVCS locations across Malaysia. This research offers substantial benefits to industry leaders, policymakers, and stakeholders, aiding in the strategic allocation of PEVCS and promoting the widespread adoption of EVs in Malaysia. By enhancing environmental sustainability and addressing logistical challenges, this approach contributes to the advancement of EV infrastructure and supports Malaysia's commitment to sustainable development.

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