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RESEARCH ARTICLE

Ideal Spot for Photovoltaic Electric Vehicle Charging Stations (PEVCS) in Malaysia: An Analytic Hierarchy Process (AHP) Approach

N. A. Syahirah, R. N. Farah*

Department of Mathematics, Faculty of Science and Mathematics, Universiti Pendidikan Sultan Idris 35900 Tanjung Malim, Perak, Malaysia

Abstract The adoption of electric vehicles (EVs) in Malaysia is progressing rapidly, and the development of electric vehicle charging stations (EVCSs) is following suit. Despite this growth, the integration of solar power into these stations remains limited. To address this, it is essential to consider various criteria and parameters when selecting ideal locations for photovoltaic electric vehicle charging stations (PEVCSs) in Malaysia. This study aims to identify suitable locations for PEVCSs using the Analytic Hierarchy Process (AHP) method. The AHP method evaluates the weightage of criteria based on the judgments of seven experts from diverse fields, ensuring a multidisciplinary perspective. Six main criteria and twelve sub-criteria are assessed, drawing from comprehensive literature, needs analysis, and instrument validation. The results demonstrate that the consistency ratio (CR) for all pairwise comparisons is below 0.1, reflecting high reliability and consistency. 'Economy' emerged as the most influential and critical criterion, with a weight of 0.226210. Following closely is 'Proximity' with a weight of 0.208390 and 'Technology' with a weight of 0.205632. Finally, the findings are expected to offer valuable insights for policy makers and industry stakeholders, facilitating informed decision-making in the planning and development of sustainable charging infrastructure in Malaysia.

Keywords: Analytic Hierarchy Process (AHP), criteria, photovoltaic electric vehicle charging stations (PEVCS), Malaysia.

Introduction

Imagine a world where electric vehicles (EV) glide silently on the roads, yet a small voice of doubt creeps in: What if we cannot find a charging station (CS) when we need it? This feeling, known as range anxiety, is a real concern for EV users everywhere. According to Liu *et al*. [1], range anxiety and driver charging behaviour are crucial factors to consider when installing EVCSs along routes. Therefore, the availability of electric vehicle charging stations (EVCS) is essential to eliminate range anxiety and promote the widespread adoption of EVs. Owing to that, the distribution of EVCS in Malaysia reflects the growing demand for EVs [2]. The main reason most drivers prefer internal combustion engine (ICE) vehicles over EVs is the scarcity of CS along their routes [3]. Additionally, research conducted by various scholars indicates that the demand and trend for electric vehicles (EVs) in Malaysia have been increasing annually, especially since 2015 [4]. Indeed, an ideal CSs is essential to ensure the widespread acceptance and competitiveness of EVs [5].

Nowadays, global carbon emissions have reached a record high. According to the International Energy Agency [6], the transport sector is one of the top three contributors to carbon emissions, accounting for 22% of carbon dioxide emissions in Malaysia by 2021. The high energy demand and environmental destruction can be addressed by using renewable energy sources (RES) such as solar, wind, and biomass [7]. Bilal *et al*. [8] further mentioned that integrating RES with EVCS can alleviate environmental and economic issues. Thus, due to its availability and ease of installation, photovoltaic (PV) energy is the most suitable clean energy source among all RES [9]. Most importantly, the deployment of photovoltaic electric vehicle charging stations (PEVCS) is essential to boost the adoption of EVs among Malaysians. Markedly, installing PEVCS can address range anxiety among EV users and provide environmental benefits, thereby encouraging the broader adoption of EVs [10].

***For correspondence:**
raja_farah@fsmt.upsi.edu.my

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Furthermore, the installation of PEVCS required careful consideration of several criteria and parameters to ensure it is allocated in the most suitable locations. Nevertheless, the evaluation of criteria is crucial when addressing more significant topics [11]. By establishing a set of selection criteria and aiding in the process of choosing among multiple alternatives, multi-criteria decision-making (MCDM) methods such as Analytic Hierarchy Process (AHP), Analytic Network Process (ANP) and so on serve as tools for minimizing bias in decision-making [12]. According to Kencana [13], AHP has been widely used across various sectors because it offers a rigorous and statistical method to evaluate and prioritize groups, which is essential for the effective use of resources and the prompt resolution of complex issues. Correspondingly, pairwise comparison matrices are used in AHP to rank and determine the overall weight of each parameter or criterion [14].

Besides, Madzík and Falát [15] indicated that AHP has a significant research impact in the field of MCDM, particularly in the fields of engineering, computer science, business, and decision sciences. At the same time, the AHP methodology has proven to be widely applicable across various transportation-related disciplines, with its popularity in the industry growing steadily over the years [16]. Hence, the AHP method is used in this study to calculate the criteria weights to identify which criteria are most preferred by the decision-makers (DMs). Moreover, society, economy, environment, technology, accessibility, and proximity aspects are considered, with twelve sub-criteria underlying each main criterion, to allocate suitable PEVCS locations in Malaysia. Therefore, this study aims to identify suitable locations for PEVCS using the AHP method. Section 2 reviews the selection problem related to the AHP method. Section 3 describes the study's methodology, while Section 4 reports and discusses the results. Finally, Section 5 concludes by outlining the study's recommendations and future directions.

Literature Reviews

Analytic Hierarchy Process (AHP) in Various Fields

Many studies in the literature focus on selection using MCDM approaches, with particular emphasis on those employing the AHP method. The criteria weights for landslide site selection are calculated using the AHP method integrated with Geographic Information System (GIS) [17]. Alwedyan [18] selected the ideal location for a casual-dining restaurant and identifies the critical factors affecting the selection by employing the AHP method with Expert Choice software. The AHP method is also used to determine the most ideal location for an Urban Consolidation Center (UCC) from a sustainability perspective using a web-based AHP online system (AHP-OS) [19].

Besides, to assess hotel service quality, the AHP method is implemented to calculate criteria weights using Expert Choice software [20]. The AHP method is employed to evaluate transportation alternatives on the Karkh side of Baghdad [21]. Srebrenkoska *et al*. [22] stated that the selection of a flexible production system is solved using the AHP method. The four aspects including pre-qualification, project management, technical, and commercial are assessed in selecting contractors using the AHP method [23].

In addition, Borri et al. [24], the AHP method is implemented in Super Decision software to compare the ranking results of 30 areas for replacing network infrastructure with fiber optic networks. Srdjevic *et al*. [25] combined the AHP and Best-Worst Method (BWM) to evaluate the criteria weights of urban park quality, finding both methods to be efficient and effective decision support tools. Furthermore, Li and Gao [26] used the AHP method and Genetic Algorithm (GA) to determine influencing factors in English majors' achievements.

According to Wang [27], the AHP method assisted in choosing and employing personnel in military sports. A construction industry company is seeking a new business partner and using the AHP method with Expert Choice software to calculate the criteria weights [28]. Additionally, Abdul Rahman *et al*. [29] used the AHP method to determine the most preferred criteria for selecting the best supplier for a printing company, while the Decision-Making Trial and Evaluation Laboratory (DEMATEL) method identifies the influence and interrelationships among criteria. Finally, Tang [30] applied the AHP method for user requirement analysis, considering three main criteria: product, market, and company.

Criteria Involved in Allocating of EVCS and PEVCS

To determine the ideal location for EVCS or PEVCS, several criteria must be considered based on literature from past studies. First and foremost, the roadways, population density, accessibility, and environmental impact are evaluated in determining the best locations of EVCS by using TOPSIS method [31]. Six main criteria particularly environmental, societal, economic, political, technical, and traffic are assessed using the DEMATEL and Complex Proportional Assessment (COPRAS) methods to allocate

EVCS [32]. The Stepwise Weight Assessment Ratio Analysis (SWARA) and TOPSIS methods are integrated with GIS to determine the optimal location of EVCS by considering social and urban aspects [33]. Zhao *et al*. [34] used GIS-based Fuzzy DEMATEL and Fuzzy Multi-Objective Optimization by Ratio Analysis plus the Full Multiplicative Form (MULTIMOORA) to find ideal locations for PEVCS, considering economic, social, technical, and natural elements.

Additionally, Priefer and Steiger [35] found that proximity to users is the highest-weighted criterion for placing suitable EVCS locations using GIS-based AHP. Otherwise, Ghodusinejad *et al*. [36] indicated that the vicinity of two main squares is the most suitable place for PEVCS. While, three main factors are considered such as environmental/geographical, economic, and urbanity in allocating the EVCS locations [37]. Feng *et al*. [38] reported that operation and maintenance costs are the most preferred criteria under the economic aspect for installing EVCS. Karolemeas *et al*. [39] found that proximity to public services is the least preferred criterion for ideal EVCS placement, using semi-structured interviews and the AHP method. Lee *et al*. [40] identified three key indicators, including charging demand, user convenience, and ease of installation to determine the perfect EVCS locations in their country.

Methodology

Research Design

The process of planning and executing empirical studies, incorporating both quantitative and qualitative approaches to gather cross-sectional and time-series data across different geographic locations and periods, is known as research design [41]. This study employed a quantitative approach, specifically utilizing a survey method with an AHP questionnaire divided into three sections: Section A (Demographics of Respondents), Section B (Selection of Main Criteria), and Section C (Selection of Sub-Criteria). The questionnaire is distributed to a targeted sample of experts and includes the main criteria and sub-criteria relevant to selecting suitable locations for PEVCS in Malaysia.

Based on a literature review of EVCS and PEVCS allocation from 2015 to 2023, six main criteria and 177 sub-criteria are identified. Of these, 52 sub-criteria are selected for a needs analysis based on the geographical features in Malaysia, and 41 sub-criteria are chosen to develop the instrument [42]. Following a third round of instrument validation and incorporating feedback from experts, the number of sub-criteria is reduced to 12. After finalizing the criteria, the revised AHP questionnaire is distributed to experts for validation of their judgments. The AHP method is then applied to calculate and rank the criteria weights to determine the most preferred criteria. Thus, the flowchart of methodology is displayed in Figure 1.

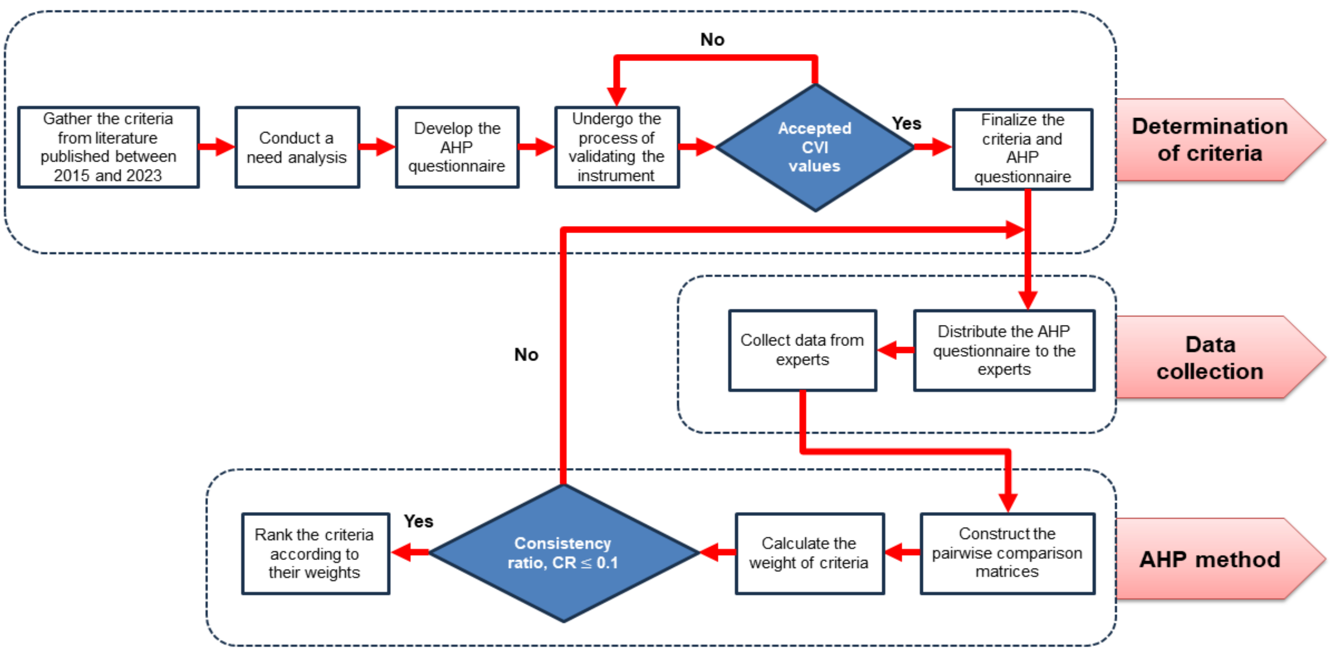


Figure 1. The flowchart of methodology

Respondent

The key informants in this study are a group of experts, referred to as decision makers (DMs). According to Islam *et al*. [43], data collection in AHP predominantly involves expert judgments, including obtained through interviews. Experts are selected based on specific criteria, such as their knowledge and informativeness in the field. Besides, AHP studies typically use small sample sizes [44]. For example, research on identifying ideal locations for EVCS and PEVCS using the AHP method has involved various groups of experts: three experts including EV users and academicians [45], [46], four experts comprising practitioners, policy makers, and academicians [47], [48], ten experts consisting of academicians and practitioners [49], and twelve experts, including project consultants, academicians, and prelectors [50]. For this study, seven experts are selected from various fields, including academician (specializing in mobility and Geographic Information Systems (GIS)), EV user, EVCS owner, policy makers, and practitioner. In addition, this aligns with the pattern set by past studies [45], where the number of experts ranged from three to twelve, ensuring that seven experts are adequate to represent a well-rounded and multidisciplinary perspective. Detailed profiles of the respondents are highlighted in Table 1.

Table 1. Detailed profiles of the respondents

Expert	1	2	3	4	5	6	7
Gender	Male	Male	Female	Male	Male	Male	Male
Race	Malay	Malay	Malay	Malay	Malay	Malay	Malay
Age group	45-54	45-54	25-34	45-54	45-54	35-44	45-54
Highest academic achievement	Doctorate	Bachelor's degree	Doctorate	Bachelor's degree	Bachelor's degree	Doctorate	Master's degree
Working experiences (years)	16-20 years	21 years and above	5 years and below	21 years and above	21 years and above	21 years and above	16-20 years
Types of stakeholders	Academician	EV user	Academician	Practitioner	EVCS owner	Policy makers	Policy makers
Do you own an EV?	No	Yes	No	No	Yes	No	No
*If not, do you plan to have one?	Yes	-	No	Yes	-	Yes	No

Source: Author's original study.

Instrument

During the instrument development process, a total of 41 out of 52 sub-criteria are initially selected. To ensure reliability, the instrument underwent validation by experts in Operational Research (OR) and Multi-Criteria Decision-Making (MCDM). However, as the Content Validity Index (CVI) did not meet the required standard, three rounds of validation are conducted. On the other hand, the number of sub-criteria is reduced to 12 to improve focus and applicability, based on experts' feedback. After all, aligning with expert feedback and ensuring a robust framework for analysis, this study finalized the selection of 6 main criteria and 12 sub-criteria. An instrument is crucial for data collection, and in this study, the AHP questionnaire serves this purpose. The AHP questionnaire, used as part of the survey instrument, is divided into three sections. Section A detailed the demographics of respondents as shown in Figure 2. Besides, Section B included the pairwise comparison for selecting main criteria as displayed in Figure 3, and Section C in Figure 4 covered the selection of sub-criteria, following Saaty's scale from 1 to 9. To ensure better understanding, the questionnaire is presented in both Malay and English. This study also included an appendix featuring instructions on completing the AHP questionnaire, which are illustrated in a figure and located in the appendix section dedicated to the questionnaire.

SECTION A: DEMOGRAPHICS OF RESPONDENTS

BAHAGIAN A: DEMOGRAFI RESPONDEN

Instruction: Please tick (/) to the relevant information.

***Arahan**: Sila tandakan (/) pada maklumat yang berkaitan*

1.	Gender / *Jantina*	Male / *Lelaki*	☐
		Female / *Perempuan*	☐
2.	Race / *Bangsa*	Malay / *Melayu*	☐
		Chinese / *Cina*	☐
		Indian / *India*	☐
		Others (please specify): ____________ *Lain-lain (sila nyatakan)*	
3.	Age group / *Kumpulan umur*	18 – 24	☐
		25 – 34	☐
		35 – 44	☐
		45 – 54	☐
		≥ 55	☐

Figure 2. The respondents' demographics. *Source:* Author's original study

SECTION B: SELECTION OF MAIN CRITERIA

BAHAGIAN B: PEMILIHAN KRITERIA UTAMA

Instruction: The following items pertain to the main criteria that could be utilized for the allocation of PEVCS in Malaysia. Please indicate, by circling a number on the scale, which main criteria you consider more important when comparing these criteria. Circle on the left if a criterion is more likely to fulfill main criteria 1, and on the right if it is more likely to meet main criteria 2. A single circle is needed in each row for comparison. Further details about the scale and criteria descriptions are provided in the Appendix.

***Arahan**: Item berikut berkaitan dengan kriteria utama yang boleh digunakan untuk menempatkan PEVCS di Malaysia. Sila nyatakan, dengan membulatkan nombor pada skala, kriteria utama yang anda anggap lebih penting apabila membandingkan kriteria ini. Bulatkan di sebelah kiri jika kriteria lebih berkemungkinan memenuhi kriteria utama 1, dan di sebelah kanan jika lebih berkemungkinan memenuhi kriteria utama 2. Hanya satu bulatan diperlukan dalam setiap baris perbandingan. Butiran lanjut tentang skala dan huraian kriteria disediakan dalam Lampiran.*

Scale / *Skala*					
1	**3**	**5**	**7**	**9**	**2, 4, 6, 8**
Equal Importance *Kepentingan sama*	Moderate importance *Kepentingan sederhana*	Strong importance *Kepentingan yang kuat*	Very strong importance *Kepentingan yang sangat kuat*	Extreme importance *Kepentingan yang amat kuat*	An intermediate value between two adjacent considerations *Nilai pertengahan antara dua pertimbangan bersebelahan*

Extreme *Amat kuat* ← **Equal** *Sama* → **Extreme** *Amat kuat*

Left / *Kiri* — **Right** / *Kanan*

Main criteria ***Kriteria utama***	**Scale** ***Skala***																	**Main criteria** ***Kriteria utama***
Society *Masyarakat*	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Economy *Ekonomi*
Society Masyarakat	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Environment *Persekitaran*
Society Masyarakat	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Technology *Teknologi*

Figure 3. The selection of main criteria. *Source***:** Author's original study

SECTION C: SELECTION OF SUB-CRITERIA

BAHAGIAN C: PEMILIHAN SUB-KRITERIA

Instruction: The following items pertain to the sub-criteria that could be utilized for the allocation of PEVCS in Malaysia. Please indicate, by circling a number on the scale, which sub-criteria you consider more important when comparing these criteria. Circle on the left if a criterion is more likely to fulfill sub-criteria 1, and on the right if it is more likely to meet sub-criteria 2. A single circle is needed in each row for comparison. Further details about the scale and criteria descriptions are provided in the Appendix.

Arahan*: Item berikut berkaitan dengan sub-kriteria yang boleh digunakan untuk menempatkan PEVCS di Malaysia. Sila nyatakan, dengan membulatkan nombor pada skala, kriteria utama yang anda anggap lebih penting apabila membandingkan kriteria ini. Bulatkan di sebelah kiri jika kriteria lebih berkemungkinan memenuhi sub-kriteria 1, dan di sebelah kanan jika lebih berkemungkinan memenuhi sub-kriteria 2. Hanya satu bulatan diperlukan dalam setiap baris perbandingan. Butiran lanjut tentang skala dan huraian kriteria disediakan dalam Lampiran.*

Scale / *Skala*					
1	**3**	**5**	**7**	**9**	**2, 4, 6, 8**
Equal Importance *Kepentingan sama*	Moderate importance *Kepentingan sederhana*	Strong importance *Kepentingan yang kuat*	Very strong importance *Kepentingan yang sangat kuat*	Extreme importance *Kepentingan yang amat kuat*	An intermediate value between two adjacent considerations *Nilai pertengahan antara dua pertimbangan bersebelahan*

Main criteria: Society / *Kriteria utama: Masyarakat*

Extreme *Amat kuat* ← **Equal** *Sama* → **Extreme** *Amat kuat*

Left / *Kiri* — **Right** / *Kanan*

Sub-criteria ***Sub-kriteria***	**Scale** ***Skala***																	**Sub-criteria** ***Sub-kriteria***
Service capability *Keupayaan perkhidmatan*	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Research and education *Penyelidikan dan pendidikan*

Figure 4. The selection of sub-criteria. *Source:* Author's original study

Analytic Hierarchy Process (AHP)

The AHP method, developed by Thomas L. Saaty, is a general theory of measurement designed to solve complex decisions in a hierarchical form, ranking options, or alternatives effectively [5], [52]. To address various complex objectives, AHP appears to be an ideal method for solving location-allocation decisions [19]. The consistency ratio (CR) is used to evaluate the consistency of judgements; a CR value of 0.1 or less is deemed acceptable [51]. The elements in the pairwise comparison are compared, and the primary eigenvector is obtained to get the priority weight [51]. Additionally, the most preferred criteria are determined using the AHP method, which is an established technique for calculating the weights of selected decision criteria [53]. This study employs the AHP method, which incorporates group judgments from experts to determine the weight of criteria. Additionally, the most effective method for combining different pairwise comparisons into a single representative result is the weighted geometric mean [54], [56]. On the other hand, the Aggregating Individual Judgements (AIJ) approach can be used by calculating the geometric mean of individual judgments for each element in the pairwise comparison matrices [48].

In this study, six main criteria are established using the AHP method: society, economy, environment, technology, accessibility, and proximity. Each main criterion has its own sub-criteria, totalling 12 sub-criteria. The study is structured hierarchically with three levels: goal, main criteria, and sub-criteria, as shown in Figure 5. Subsequently, after creating the pairwise comparison matrix, the consistency is evaluated. For the pairwise comparisons to be accepted, the consistency ratio (CR) must be less than or equal to 0.1.

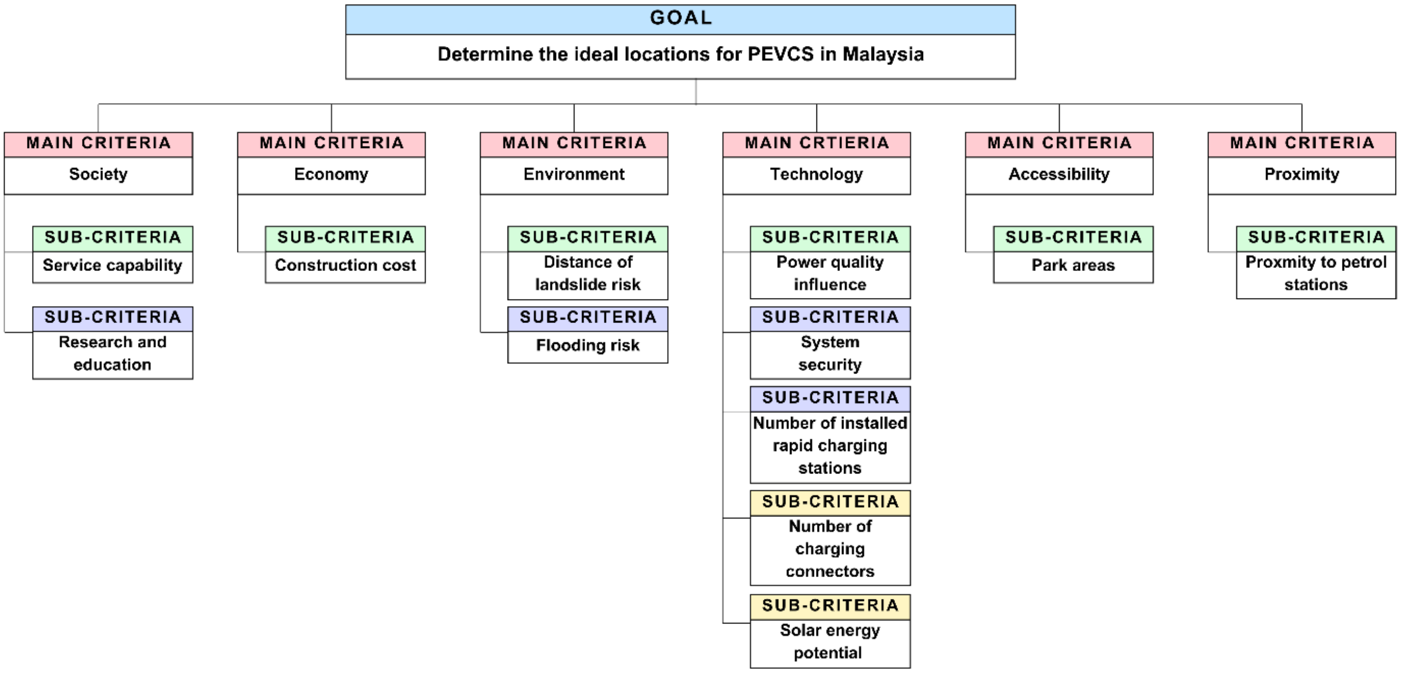


Figure 5. The hierarchy for determining the ideal locations for PEVCS in Malaysia. *Source:* Author's original study

In general, the AHP method involved four main steps [43], [47], [48], [52], [57]-[59]:

i. **Determine the problem:** Define the problem, which in this study is to identify the ideal locations for PEVCS in Malaysia.
ii. **Construct the hierarchy:** The hierarchy comprises a goal, criteria, and alternatives. In this study, the hierarchy consists of one goal at Level 1, supported by six main criteria at Level 2 and twelve sub-criteria at Level 3.
iii. **Construct a pairwise comparison matrix:** Develop a pairwise comparison matrix using a ratio scale from one to nine, known as Saaty's scale, as shown in Table 2. Besides, the criteria weights are identified. Utilize AIJ to calculate the geometric mean of individual judgments for each element in the pairwise comparison matrices. The geometric mean of individual judgments can be calculated manually in Microsoft Excel before entering the data into Super Decision software. Then, the CR is calculated to estimate the level of consistency between pairwise comparisons. If the CR is 0.1 or below, the evaluations are considered highly consistent.

Table 2. Scale of pairwise comparison by (T. L. Saaty, 2008)

Scale	Definition	Explanation
1	Equal Importance	Both criteria are equally important
3	Moderate importance	One criterion is slightly more important than the other
5	Strong importance	One criterion is strongly more important than the other
7	Very strong importance	One criterion is very strongly more important than the other
9	Extreme importance	One criterion is extremely more important than the other
2, 4, 6, 8	An intermediate value between two adjacent considerations	Represents a compromise between two scales

iv. **Establish the ranking:** Rank the criteria, including both main criteria and sub-criteria, based on their calculated weights. The greater the weight, the more preferred the criterion, but the value cannot exceed 1 and must be a non-negative number [60].

Results and Discussion

Demographic of Respondents

Based on Table 3, most experts are male, accounting for 85.71%, while females make up only 14.29%. All experts are Malay, with the majority (71.43%) falling within the 45-54 age group, and the remainder are aged 25-44. The demographic profile of the respondents revealed that a majority were of Malay ethnicity. While this reflects the national majority population, it does introduce a limitation in terms of representativeness. In addition, Malays comprised 58.1 percent of the population (up from 57.9 percent in Q3 2023), while the proportions of Chinese and Indian declined slightly to 22.4 percent and 6.5 percent (from 22.5 percent and 6.6 percent, respectively), and the share of Other Bumiputera remained steady at 12.3 percent in the third quarter of 2024 [61].The highest academic qualifications among the experts are Doctorate (42.86%), Master's Degree (14.29%), and Bachelor's Degree (14.29%), indicating a well-educated and knowledgeable group in this field. Besides, in terms of work experience, 51.74% of the experts have 21 years of experience, 28.57% have 16-20 years, and 14.29% have 5 years or less. This extensive experience contributes to the reliability of their responses. In addition, the experts come from various stakeholder groups: academicians (28.57%), policy makers (28.57%), EV users (14.29%), EVCS owners (14.29%), and practitioners (14.29%). Additionally, only 28.57% of the experts currently own an EV, while the majority do not. Among those who do not own an EV, 60% plan to acquire one in the future, suggesting that EV adoption among them is still relatively low.

Table 3. Summary of respondent profiles

		Frequency, N	Percentage (%)
Gender	Male	6	85.71
	Female	1	14.29
Race	Malay	7	100.00
	Chinese	-	-
	Indian	-	-
	Others	-	-
Age group	18 – 24	-	-
	25 – 34	1	14.29
	35 – 44	1	14.29
	45 – 54	5	71.43
	≥ 55	-	-
Highest academic achievement	Sijil Pelajaran Malaysia	-	-
	Diploma	-	-
	Bachelor's degree	3	42.86
	Master's degree	1	14.29
	Doctorate	3	42.86
Working experiences (years)	≤ 5 years	1	14.29
	6 – 10 years	-	-
	11 – 15 years	-	-
	16 – 20 years	2	28.57
	≥ 21 years	4	57.14
Types of stakeholders	Academician	2	28.57
	Policy makers	2	28.57
	Electric vehicle user	1	14.29
	Electric vehicle charging station owner	1	14.29
	Practitioner	1	14.29
	Others	-	-
Do you own an electric vehicle (EV)?	Yes	2	28.57
	No	5	71.43
*If not, do you plan to have one?	Yes	3 out of 5	60.00
	No	2 out of 5	40.00

Source: Author's original study

Criteria's Weight

In this study, the relative importance of the criteria is assessed, and the hierarchical structure for determining the ideal locations for PEVCS in Malaysia is developed using Super Decisions software, as illustrated in Figure 6. Super Decisions software is employed due to its development by Thomas Saaty's team and its user-friendly, free access, making it readily available and easy to use.

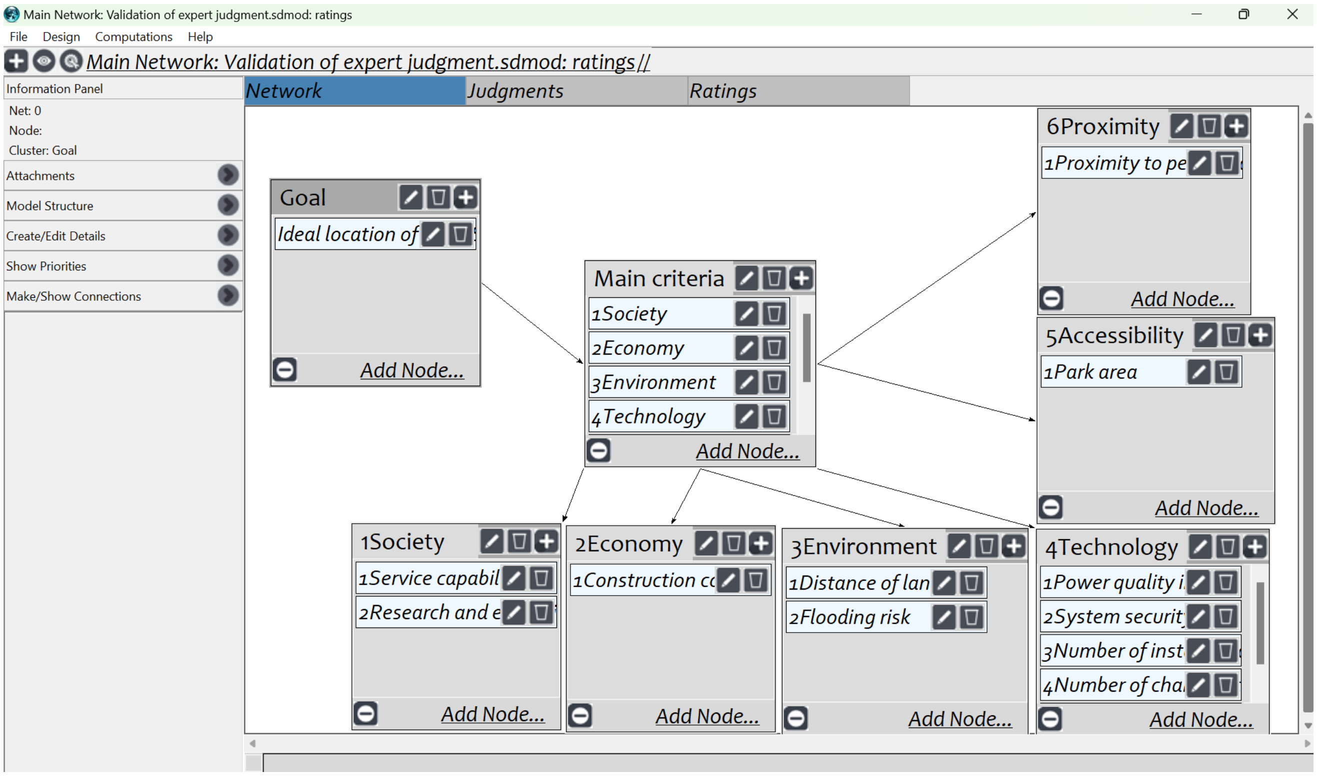


Figure 6. Hierarchical structure for determining the ideal locations of PEVCS in Malaysia. *Source:* Author's original study

Significantly, the pairwise comparisons provided by all seven experts are detailed in Tables 4-7. Using this data, the geometric mean is calculated in Microsoft Excel with the formula "**=GEOMEAN()**" as shown in Figure 7.

Table 4. Pairwise comparisons of the main criteria by all seven experts

	Society	Economy	Environment	Technology	Accessibility	Proximity
Society	1	$\frac{1}{9}$–$\frac{1}{9}$–3–$\frac{1}{6}$-$\frac{1}{5}$-1-1	$\frac{1}{7}$-1-$\frac{1}{5}$-$\frac{1}{7}$-1-$\frac{1}{3}$-1	$\frac{1}{9}$-$\frac{1}{9}$-$\frac{1}{5}$-$\frac{1}{8}$-3-$\frac{1}{3}$-1	$\frac{1}{9}$-$\frac{1}{9}$-$\frac{1}{3}$-$\frac{1}{7}$-$\frac{1}{5}$-$\frac{1}{3}$-1	$\frac{1}{9}$-$\frac{1}{9}$-$\frac{1}{3}$-$\frac{1}{7}$-5-4-$\frac{1}{5}$
Economy	9-9-$\frac{1}{3}$-6-5-1-1	1	9-9 -$\frac{1}{5}$-7-5-1 -$\frac{1}{6}$	9-3-$\frac{1}{5}$-$\frac{1}{7}$-5-3-$\frac{1}{6}$	9-4-$\frac{1}{3}$-$\frac{1}{7}$-5-$\frac{1}{3}$-1	9-5-$\frac{1}{3}$-$\frac{1}{8}$-5-4-1
Environment	7-1-5-7-1-3-1	$\frac{1}{9}$-$\frac{1}{9}$-5-$\frac{1}{7}$-$\frac{1}{5}$-1-6	1	$\frac{1}{9}$-$\frac{1}{9}$-3-$\frac{1}{7}$-1-2-2	$\frac{1}{9}$-$\frac{1}{5}$-3-$\frac{1}{8}$-1-4-3	$\frac{1}{9}$-$\frac{1}{9}$-3-$\frac{1}{8}$-1-4-1
Technology	9-9-5-8-$\frac{1}{3}$-3-1	$\frac{1}{9}$-$\frac{1}{3}$-5-7-$\frac{1}{5}$-$\frac{1}{3}$-6	9-9-$\frac{1}{3}$-7-1-$\frac{1}{2}$-$\frac{1}{2}$	1	$\frac{1}{9}$-5-$\frac{1}{3}$-8-5-$\frac{1}{3}$-1	$\frac{1}{9}$-1-$\frac{1}{3}$-7-5-3-1
Accessibility	9-9-3-7-5-3-1	$\frac{1}{9}$-$\frac{1}{4}$-3-7-$\frac{1}{5}$-3-1	9-5-$\frac{1}{3}$-8-1-$\frac{1}{4}$-$\frac{1}{3}$	9-$\frac{1}{5}$-3-$\frac{1}{8}$-$\frac{1}{5}$-3	1	$\frac{1}{9}$-$\frac{1}{6}$-1-$\frac{1}{8}$-1-1-1
Proximity	9-9-3-7-$\frac{1}{5}$-$\frac{1}{4}$-5	$\frac{1}{9}$-$\frac{1}{5}$-3-8-$\frac{1}{5}$-$\frac{1}{4}$-1	9-9-$\frac{1}{3}$-8-1-$\frac{1}{4}$-1	9-1-3-$\frac{1}{7}$-$\frac{1}{5}$-$\frac{1}{3}$-1	9-6-1-8-1-1-1	1

Source: Author's original study

Table 5. Pairwise comparisons of the sub-criteria for Society by all seven experts

	Service capability	Research and education
Service capability	1	7-9-5-8-5-4-2
Research and education	$\frac{1}{7}$-$\frac{1}{9}$-$\frac{1}{5}$-$\frac{1}{8}$-$\frac{1}{5}$-$\frac{1}{4}$-$\frac{1}{2}$	1

Source: Author's original study

Table 6. Pairwise comparisons of the sub-criteria for Environment by all seven experts

	Distance of landslide risk	Flooding risk
Distance of landslide risk	1	$\frac{1}{9}$-1-3-$\frac{1}{8}$-1-1-$\frac{1}{9}$
Flooding risk	9-1-$\frac{1}{3}$-8-1-1-9	1

Source: Author's original study

Table 7. Pairwise comparisons of the sub-criteria for Technology by all seven experts.

	Power quality influence	System security	Number of installed rapid charging stations	Number of charging connectors	Solar energy potential
Power quality influence	1	8-1-5-$\frac{1}{8}$-$\frac{1}{5}$-$\frac{1}{3}$-$\frac{1}{9}$	$\frac{1}{8}$-$\frac{1}{9}$-$\frac{1}{3}$-$\frac{1}{9}$-$\frac{1}{3}$-$\frac{1}{4}$-$\frac{1}{8}$	$\frac{1}{8}$-$\frac{1}{9}$-$\frac{1}{5}$-$\frac{1}{9}$-$\frac{1}{3}$-$\frac{1}{5}$-$\frac{1}{3}$	$\frac{1}{4}$-1-$\frac{1}{7}$-$\frac{1}{9}$-1-1-9
System security	$\frac{1}{8}$-1-$\frac{1}{5}$-8-5-3-9	1	$\frac{1}{9}$-$\frac{1}{9}$-$\frac{1}{5}$-$\frac{1}{8}$-5-$\frac{1}{2}$-$\frac{1}{9}$	$\frac{1}{9}$-$\frac{1}{9}$-$\frac{1}{5}$-$\frac{1}{8}$-5-$\frac{1}{3}$-$\frac{1}{9}$	$\frac{1}{4}$-1-$\frac{1}{9}$-$\frac{1}{9}$-5-3-9
Number of installed rapid charging stations	8-9-3-9-3-4-8	9-9-5-8-$\frac{1}{5}$-2-9	1	$\frac{1}{8}$-$\frac{1}{7}$-1-$\frac{1}{9}$-1-1-9	$\frac{1}{8}$-9-$\frac{1}{9}$-$\frac{1}{9}$-3-2-9
Number of charging connectors	8-9-5-9-3-5-3	9-9-5-8-$\frac{1}{5}$-3-9	8-7-1-9-1-1-$\frac{1}{9}$	1	8-9-$\frac{1}{9}$-$\frac{1}{9}$-3-2-9
Solar energy potential	4-1-7-9-1-1-$\frac{1}{9}$	4-1-9-9-$\frac{1}{5}$-$\frac{1}{3}$-$\frac{1}{9}$	8-$\frac{1}{9}$-9-9-$\frac{1}{3}$-$\frac{1}{2}$-$\frac{1}{9}$	$\frac{1}{8}$-$\frac{1}{9}$-9-9-$\frac{1}{3}$-$\frac{1}{2}$-$\frac{1}{9}$	1

Source: Author's original study

Moreover, Figure 7 shows that Microsoft Excel is used to calculate the geometric mean of the group decisions made by all the experts, referred to as AIJ. Subsequently, as shown in Figures 8-11, these geometric mean values are transferred to the Super Decisions software to evaluate consistency, indicated by the CR, and to determine the criteria weights.

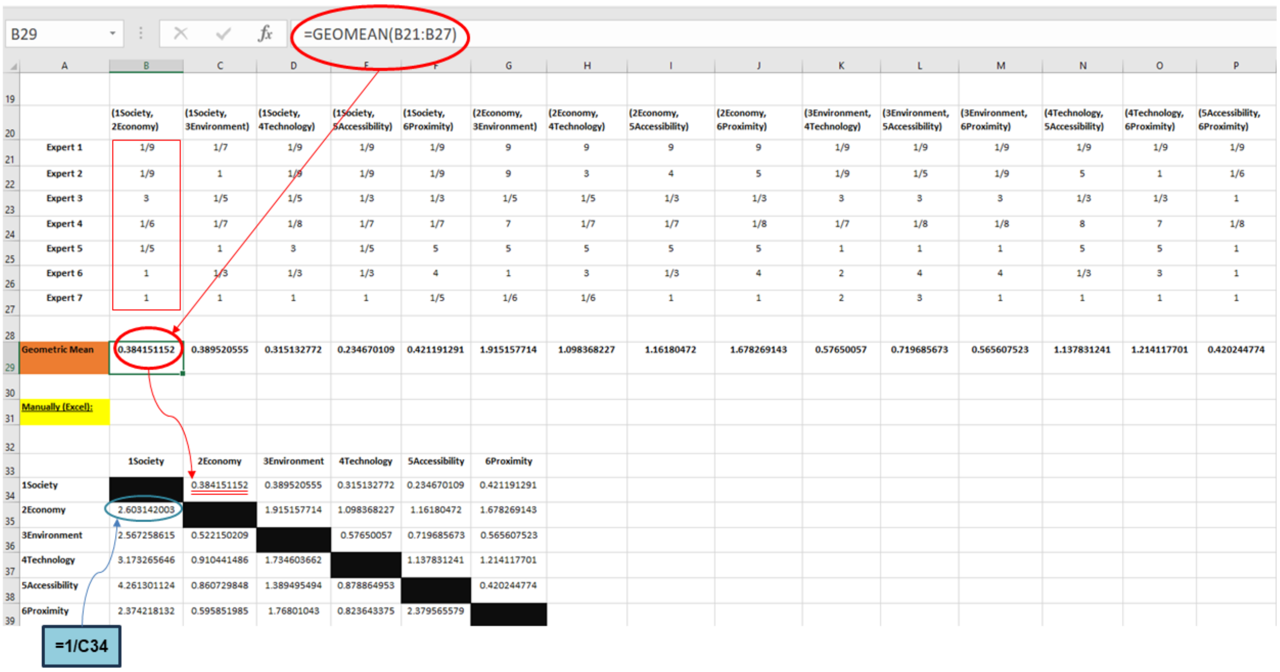


Figure 7. Geometric mean calculation in Microsoft Excel. *Source:* Author's original study

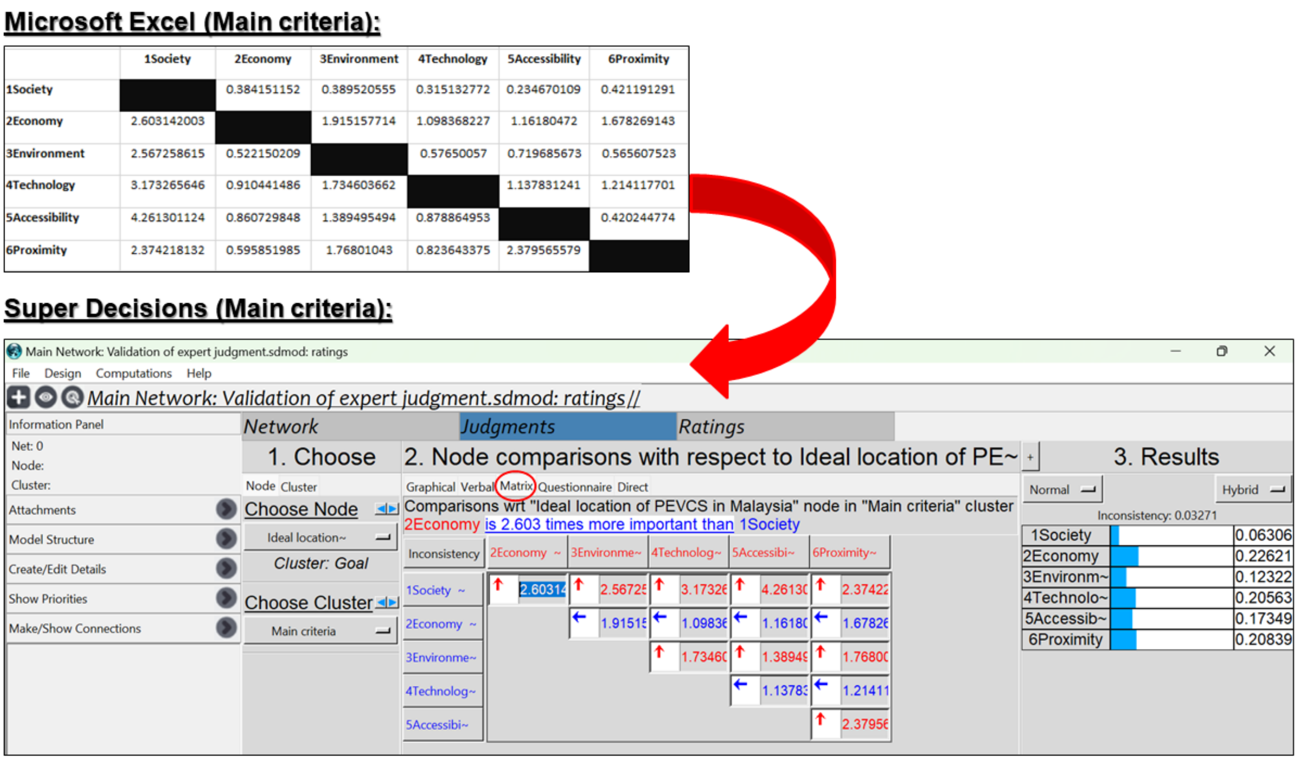


Figure 8. Transferring geometric mean values (Main criteria) from Microsoft Excel to Super Decisions software. *Source:* Author's original study

Microsoft Excel (Sub-criteria: Society):

	1Service capability	2Research and education
1Service capability		5.185373884
2Research and education	0.192850125	

Super Decisions (Sub-criteria: Society):

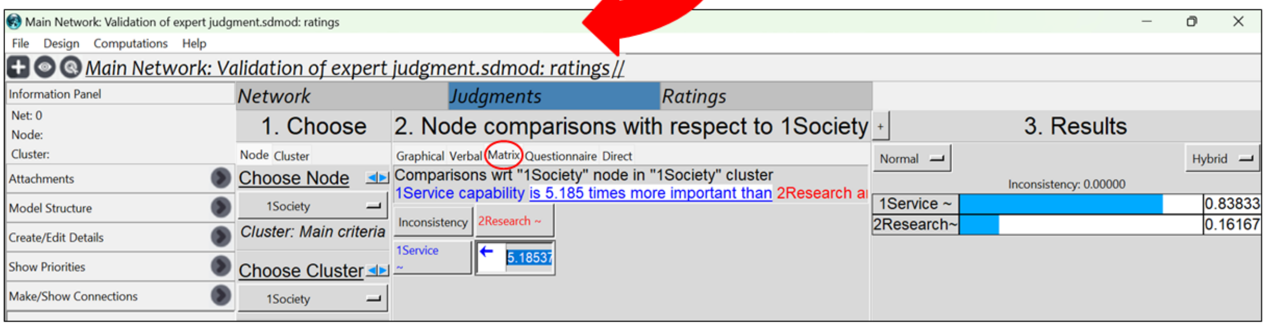


Figure 9. Transferring geometric mean values (Sub-criteria: Society) from Microsoft Excel to Super Decisions software. *Source:* Author's original study

Microsoft Excel (Sub-criteria: Environment):

	1Distance of landslide risk	2Flooding risk
1Distance of landslide risk		0.463987849
2Flooding risk	2.155228856	

Super Decisions (Sub-criteria: Environment):

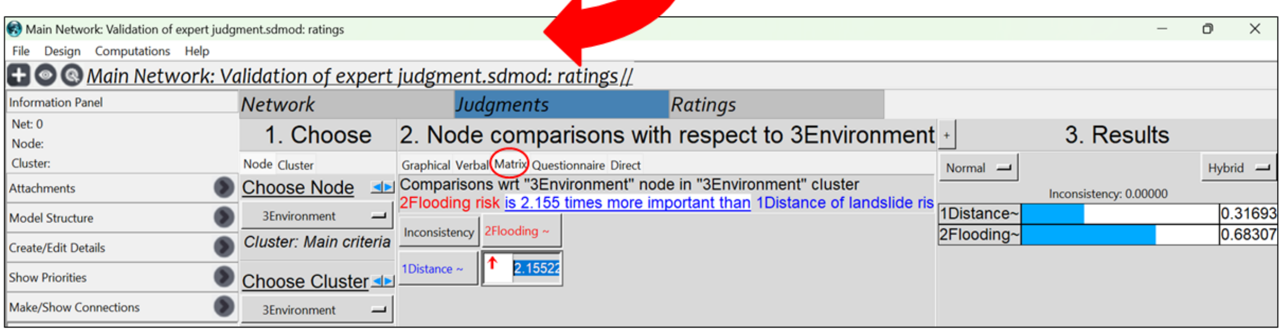
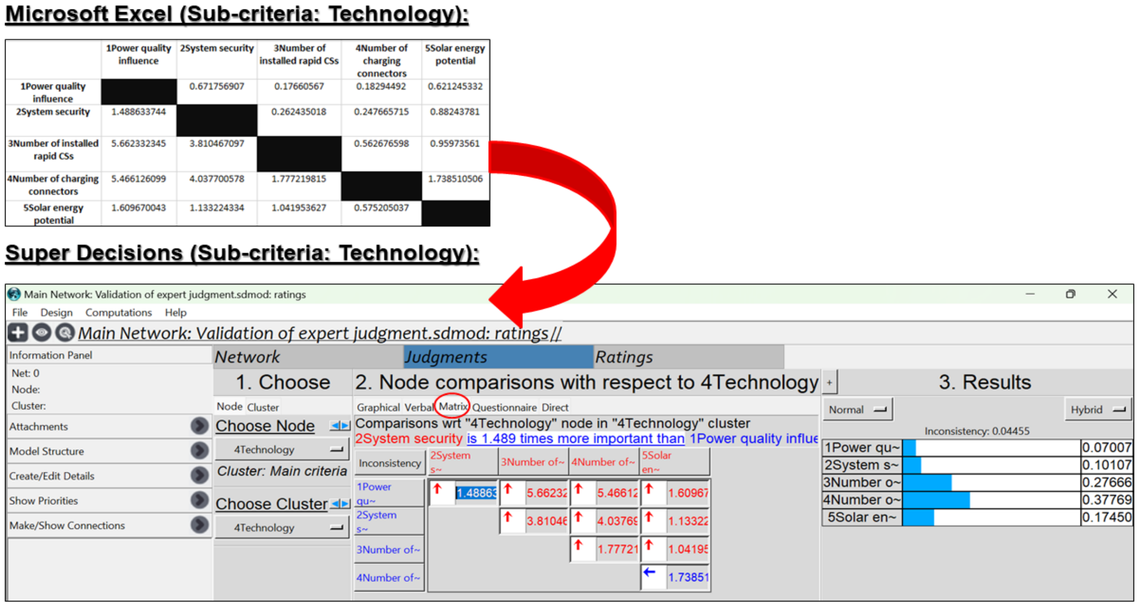


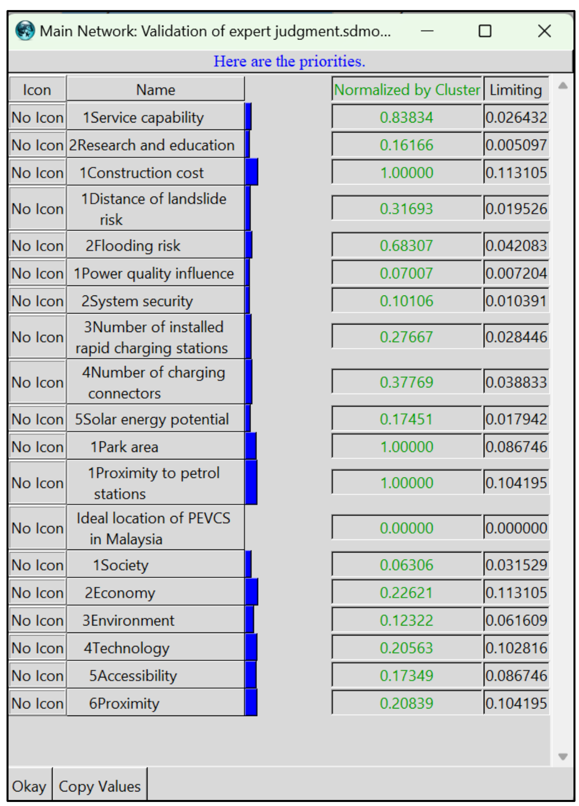
Figure 10. Transferring geometric mean values (Sub-criteria: Environment) from Microsoft Excel to Super Decisions software. *Source:* Author's original study



	1Power quality influence	2System security	3Number of installed rapid CSs	4Number of charging connectors	5Solar energy potential
1Power quality influence		0.671756907	0.17660567	0.18294492	0.621245332
2System security	1.488633744		0.262435018	0.247665715	0.88243781
3Number of installed rapid CSs	5.662332345	3.810467097		0.562676598	0.95973561
4Number of charging connectors	5.466126099	4.037700578	1.777219815		1.738510506
5Solar energy potential	1.609670043	1.133224334	1.041953627	0.575205037	

Figure 11. Transferring geometric mean values (Sub-criteria: Technology) from Microsoft Excel to Super Decisions software. *Source:* Author's original study

The CR value for the pairwise comparison of the main criteria is 0.03271. For the sub-criteria of society and environment, it is 0.0000, and for technology, it is 0.04455. According to Abdul Rahman *et al*. [29], a CR value of less than or equal to 0.1 signifies consistent expert judgment, while Nazri *et al*. [62] states that a CR value of 0 indicates perfect consistency. Therefore, the CR values, all below 0.1, demonstrate that the experts' judgments are reliable and acceptable. Subsequently, priorities are generated from the Super Decisions software based on the geometric mean, as shown in Figure 12.



Icon	Name	Normalized by Cluster	Limiting
No Icon	1Service capability	0.83834	0.026432
No Icon	2Research and education	0.16166	0.005097
No Icon	1Construction cost	1.00000	0.113105
No Icon	1Distance of landslide risk	0.31693	0.019526
No Icon	2Flooding risk	0.68307	0.042083
No Icon	1Power quality influence	0.07007	0.007204
No Icon	2System security	0.10106	0.010391
No Icon	3Number of installed rapid charging stations	0.27667	0.028446
No Icon	4Number of charging connectors	0.37769	0.038833
No Icon	5Solar energy potential	0.17451	0.017942
No Icon	1Park area	1.00000	0.086746
No Icon	1Proximity to petrol stations	1.00000	0.104195
No Icon	Ideal location of PEVCS in Malaysia	0.00000	0.000000
No Icon	1Society	0.06306	0.031529
No Icon	2Economy	0.22621	0.113105
No Icon	3Environment	0.12322	0.061609
No Icon	4Technology	0.20563	0.102816
No Icon	5Accessibility	0.17349	0.086746
No Icon	6Proximity	0.20839	0.104195

Figure 12. The priorities of the criteria. *Source:* Author's original study

Furthermore, the calculation results yield the overall priority for the six main criteria and twelve sub-criteria, as shown in Table 8. This priority highlights the most influential criteria for determining the ideal locations for PEVCS in Malaysia. The results revealed that 'Economy' is the most influential and critical main criterion, with a weight of 0.226210. The next most significant criteria are 'Proximity' with a weight of 0.208390 and 'Technology' with a weight of 0.205632. These three criteria are essential for identifying the strategic locations for PEVCS in Malaysia. Significantly, the high value assigned to the economic aspect underscores its central role in selecting the location for the CS, emphasizing that economic factors should be the focus and priority in decision-making for developing the ideal PEVCS locations.

Another key point, the proximity of PEVCS to one another addressed the practical concerns of EV users needing convenient charging locations. Similarly, the technological aspect is crucial for identifying ideal PEVCS sites, as EVs are inherently dependent on technology for their operation and management. To point out, the society factor is the less preferred by all the DMs with the weight of 0.063058. The findings of this study align with and complement prior research on the topic, highlighting the variation in priority criteria depending on regional and contextual factors. In this case, the dominance of Economic and Social aspects (60.8%) is emphasized in Janchomphu *et al*. [63] outcomes, which reflect this study's identification of the economy as the most crucial criterion. Similarly, Genevois and Kocaman [64] found that parking conditions were the most significant for EV users, while accessibility ranked second, which aligns with the importance of 'Proximity' in this study. Kaya *et al*. [49] highlighted transportation aspect as the key criterion, with sub-criteria like parking lots playing an important role. The similarities in emphasizing economic and accessibility aspects across studies demonstrate the reliability and relevance of this study's results, while the contextual differences underscore the need for localized criteria prioritization in developing optimal PEVCS locations. Owing to that, developing an EV ecosystem in the city is challenging due to public scepticism about EV performance, infrastructure, and costs, but focusing on social factors like charging station services and societal impact may help lessen these concerns [64].

Table 8. Weight of criteria

Main Criteria	Weight	Percentages	Rank	Sub-criteria	Local weight	Global weight	Percentages	Rank
Society	0.063058	6.3058%	6	Service capability	0.83834	0.052864	5.2864%	7
				Research and education	0.16166	0.010194	1.0194%	12
Economy	0.226210	22.6210%	1	Construction cost	1.00000	0.226210	22.6210%	1
Environment	0.123218	12.3218%	5	Distance of landslide risk	0.31693	0.039052	3.9052%	8
				Flooding risk	0.68307	0.084166	8.4166%	4
Technology	0.205632	20.5632%	3	Power quality influence	0.07007	0.014408	1.4408%	11
				System security	0.10106	0.020782	2.0782%	10
				Number of installed rapid charging stations	0.27667	0.056892	5.6892%	6
				Number of charging connectors	0.37769	0.077666	7.7666%	5
				Solar energy potential	0.17451	0.035884	3.5884%	9
Accessibility	0.173492	17.3492%	4	Park areas	1.00000	0.173492	17.3492%	3
Proximity	0.208390	20.8390%	2	Proximity to petrol stations	1.00000	0.208390	20.8390%	2

Source: Author's original study

Indeed, the sub-criterion 'Construction Cost' ranks first with a weight of 0.226210, highlighting the importance of cost considerations in installing PEVCS. This factor is crucial for ensuring a balance of benefits for both investors and EV users. As emphasized by Farah and Syahirah [66], the economic aspect serves as a key indicator when calculating the overall spending plan and assessing costs and potential revenues for investors and stakeholders involved in PEVCS deployment. Besides, 20.8390% of experts agreed that PEVCS should be located near petrol stations. Proximity to petrol stations facilitates easier access for EV users, as these locations are typically well-positioned and accessible, often situated along highways or at points of interest (POI). Furthermore, accessibility to parking areas ranks among the top three preferences for locating ideal PEVCS sites across Malaysia. Parking areas are strategically positioned to increase EVs public awareness and provide cost savings, as allowed users to both park and charge their vehicles conveniently.

Conversely, the sub-criterion 'Research and Education' received the lowest ranking, with only 1.0194% of experts selecting it for PEVCS location. This sub-criterion, was not favoured by experts which Farah *et al*. [42] pertains to placing PEVCS at research and educational buildings. Consequently, the criteria weights for determining the ideal PEVCS locations in Malaysia are integrated with GIS. Spatial data layers need to be gathered and pre-processed before overlaying the AHP criteria weights with these layers using ArcGIS software. The Weighted Overlay tool in ArcGIS will then be employed to combine the AHP criteria weights with the spatial data layers, producing a map that predicts the ideal locations for PEVCS in Malaysia.

Conclusions

This study addresses the critical issue of range anxiety among EV users by emphasizing the importance of strategically locating PEVCS in Malaysia. Given the growing need to support a greener and cleaner environment, integrating solar power with EVCS is necessary. To achieve this, careful consideration of various criteria is necessary to identify the ideal locations for PEVCS in Malaysia. The objective of the study is to identify suitable PEVCS locations using the AHP method. The AHP method is widely employed across diverse fields, including the selection of transportation alternatives, casual-dining restaurants, and new business partners. It is particularly effective for addressing complex decision-making problems by providing a structured approach to evaluating and prioritizing criteria. This employed the AHP method and analysed the data using Super Decisions software to determine the most suitable locations.

However, the results revealed that the economic aspect is the most crucial criterion for locating PEVCS, highlighting the importance of cost considerations in the decision-making process. Conversely, the societal aspect is ranked the lowest, suggesting that while social factors are relevant, they are less critical compared to economic factors in this context. Looking forward, the integration of AHP criteria weights with spatial data layers using GIS tools, such as the Weighted Overlay tool in ArcGIS, will enhance the predictive modelling of PEVCS locations. This approach will facilitate more informed and strategic decisions, ultimately contributing to the effective placement of PEVCS and supporting the broader adoption of EVs in Malaysia. In summary, the outcomes are expected to offer key insights for policy makers and industry stakeholders, helping to drive well-informed decisions in the creation and advancement of sustainable charging infrastructure across Malaysia.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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