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Sustainable Urban Planning: Criteria for Efficient Photovoltaic Electric Vehicle Charging Stations Deployment in Malaysia

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ABSTRACT

In Malaysia, the electric vehicle (EV) market is experiencing significant growth, necessitating the installation of charging stations (CSs) along routes to alleviate range anxiety among EV users. Integrating EVs with renewable energy sources (RESs), such as solar energy, is imperative to support the United Nations' Sustainable Development Goals (SDGs). Given the limited availability of photovoltaic electric vehicle charging stations (PEVCS) in Malaysia, their installation becomes imperative, requiring careful consideration of several key criteria for ideal allocation. This paper presents a comprehensive study focused on establishing criteria for strategically siting PEVCS in Malaysia. The objective of the study is to finalize the criteria for determining the ideal PEVCS placement, taking into consideration the unique geographical and infrastructural context of Malaysia. The methodology involved an extensive literature review, a rigorous needs analysis, and the validation of the selection criteria through expert feedback. In the initial phase, comprising 41 sub-criteria and six main criteria, the study meticulously narrowed down the selection to 12 sub-criteria and retained the six main criteria. This selection is made based on the valuable insights provided by experts, ensuring a refined and relevant set of criteria for the subsequent phases of validation and instrument development. The discussion section of the article details the rationale behind the chosen criteria and their alignment with the overarching goal of efficient PEVCS deployment. The findings of this study contribute to the ongoing efforts in sustainable urban planning and transportation infrastructure development, specifically in the domain of PEVCS in Malaysia. The paper concludes by recommending the application of the Fuzzy Delphi Method (FDM) to determine the final criteria for the ideal placement of PEVCS in Malaysia. This method is proposed as a robust method to handle the uncertainties and complexities associated with the dynamic nature of the decision-making process in this context.

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1. Introduction

Given its eco-friendly nature, capacity to mitigate transportation-related issues, and potential to improve air quality, photovoltaic electric vehicle charging stations (PEVCS) have been highlighted as a catalyst for sustainable mobility [1]. The issues of environmental pollution and charging can be resolved with the installation of PEVCS [2]. Therefore, the installation of PEVCS is deemed necessary as it can provide environmental benefits and address the concerns among electric vehicle (EV) users, thereby reducing their range anxiety. In addition, Alrubaie *et al.,* [3] highlighted the photovoltaic (PV) - powered charging station (CS) offers various advantages, such as continuous charging throughout the day, capitalizing on peak load demand and power prices, resulting in particularly significant savings. Hence, PV panels can be erected on rooftops, vehicle parking shades, electric vehicle charging stations (EVCS), electrochemical stationary storage, and public grid connections [4]. The off-grid EVCS system is powered by solar energy, collected through a PV array that supplies electricity to the CS, making the PV panel its primary energy source [5].

According to Bilal *et al.,* [6], the integration of EVs with renewable energy sources (RESs) is requisite for achieving the United Nations' Sustainable Development Goals (SDGs), particularly contributing to decarbonizing the transportation sector, fulfilling SDG Goal 7 (Affordable and Clean Energy), and addressing air pollution and its health-related impacts linked to SDG Goal 3 (Good Health and Well-being). To ensure energy security and diversify their energy sources, developing nations should transition towards the adoption of renewable energy resources [7]. Alghoul *et al.,* [8] agreed that implementing PEVCS has the potential to substantially enhance Malaysia's contribution to renewable energy (RE).

Several PEVCS are currently operational in Malaysia, with locations such as Rest and Relax (R&R) Gunung Semanggol, Tapah, and Ayer Keroh. As indicated by one of the respondents, the findings of the Need Analysis reveal that Malaysia has yet to witness significant adoption of solar energy [9]. Consequently, there is a critical need to strategically install additional PEVCS along routes to alleviate range anxiety among EV users. In other words, Farah *et al.,* [9] also suggested that Malaysia should strategically position PEVCS, considering various parameters and criteria during the site selection process. The novelty of this study lies in the necessary establishment of criteria for allocating ideal PEVCS locations, as the attributes derived from each criterion prove instrumental in the allocation process. Therefore, this study aims to finalize the criteria for pinpointing ideal locations for PEVCS in Malaysia, considering the unique geographical and infrastructural context of Malaysia. Section 2 delves into a comprehensive literature review, examining criteria identified in previous studies for determining ideal PEVCS locations in Malaysia. Section 3 outlines the methodology employed to establish these criteria. The results and discussions are presented in Section 4, while Section 5 concludes the study.

2. Literature Review

In prior research, various criteria were taken into consideration when determining the ideal locations for both EVCS and PEVCS. Abdel-Basset *et al.,* [10] reported that the results reveal the economic factor as the foremost consideration in choosing the ideal location of EVCS, followed by the technical, and the traffic factor. According to Sisman [11], sub-criteria of car parks emerged as the most crucial criterion, while major junctions were identified as the least significant. Besides, proximity to users holds the highest weight (49.9%) among the derived weights, followed by accessibility at 35.43%, with power grid impact weighted significantly lower at 9.60%, albeit still ahead of environmental impact at 5.07% [12]. Furthermore, "Tourism Attraction Areas" emerged as the most crucial criterion, holding the highest overall weighted value of 0.15332, while the lowest weighted value is attributed to "Gas Station," with a weight of 0.01008 [13].

Then, the economy criterion exerts the most significant influence on the ranking of alternatives, while the results show minimal variation in the technology and environmental criteria [14]. Moreover, EV ownership in the service area emerges as the most pivotal sub-criteria, while proximity to petrol stations ranks as the least significant [15]. In identifying the optimal location for EVCS, the operation and maintenance cost garnered a higher weight, particularly under the economic aspect [16]. Karolemeas *et al.,* [17] highlighted the findings indicate that primary factors influencing location selection include transportation hubs, designated or regulated parking areas, and points of interest, while public services play a relatively less significant role.

In addition, social factors carry a more significant weight, whereas natural factors hold a comparatively lower weight in the assessment of the appropriate location for PEVCS [2]. According to Hisoglu *et al.,* [18], the most crucial criterion to consider in the installation of PEVCS is solar potential energy. Emphasizing optimal site selection, Ghodusinejad *et al.,* [19] highlighted that 9.82% of the island area exhibited higher suitability for PEVCS placement, with the results pinpointing the vicinity of two main squares as the most suitable locations. As per the weight outcomes, the social aspect and future expandable potential hold greater significance in allocating the urban PEVCS [20]. Nonetheless, prior research has shown a scarcity of studies concentrating on the allocation of PEVCS in comparison to EVCS. Therefore, this study aims to establish the criteria for identifying the ideal locations for PEVCS in Malaysia.

3. Methodology

The selection of an ideal location for PEVCS in Malaysia is a multifaceted process, driven by a meticulous exploration of existing literature, a comprehensive Need Analysis, and the validation of instruments. To finalize the criteria, a thorough literature review is conducted, encompassing 52 out of 177 sub-criteria from studies conducted between 2015 and 2023. This selection is particularly influenced by the unique landform characteristics of Malaysia, emphasizing the need for criteria tailored to the country's specific context. Following this, the Need Analysis is carried out through surveys in Google Forms and face-to-face interactions, utilizing a dichotomous scale to measure agreement or disagreement among respondents, including lecturers, EV users, and EV sales advisors. A total of 41 sub-criteria and six main criteria are selected, considering an 80% agreement threshold from the respondents, with percentages below 80% being disregarded [9].

The outcomes from the Need Analysis are then utilized to develop an Analytic Hierarchy Process (AHP) questionnaire. In the process of developing the questionnaire, the validation of the instrument took place, involving three rounds of validation with feedback from experts. Face validity and content validity are conducted, using dichotomous scales and Content Validity Index (CVI) with Likert scales, respectively. In the first round of validation, feedback led to the reduction of sub-criteria from 41 to 12, focusing on those with 100% agreement in the Need Analysis. Notably, sub-criteria related to solar energy potential, while not reaching full agreement, achieved a significant agreement rate of 91.67%, considering the study's emphasis on solar energy. As shown in the chart in Figure 1 (a – f), this highlights the substantial consensus reached in this aspect [9].

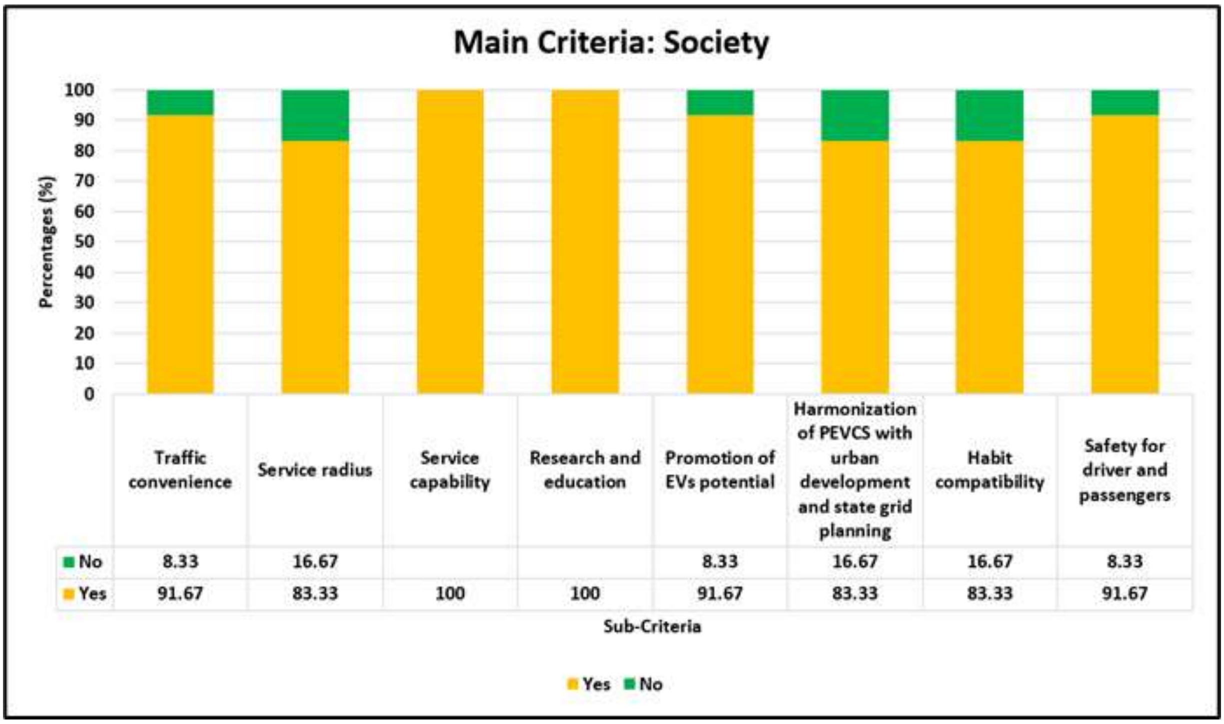

Fig. 1. (a) Analysis of main criteria within society

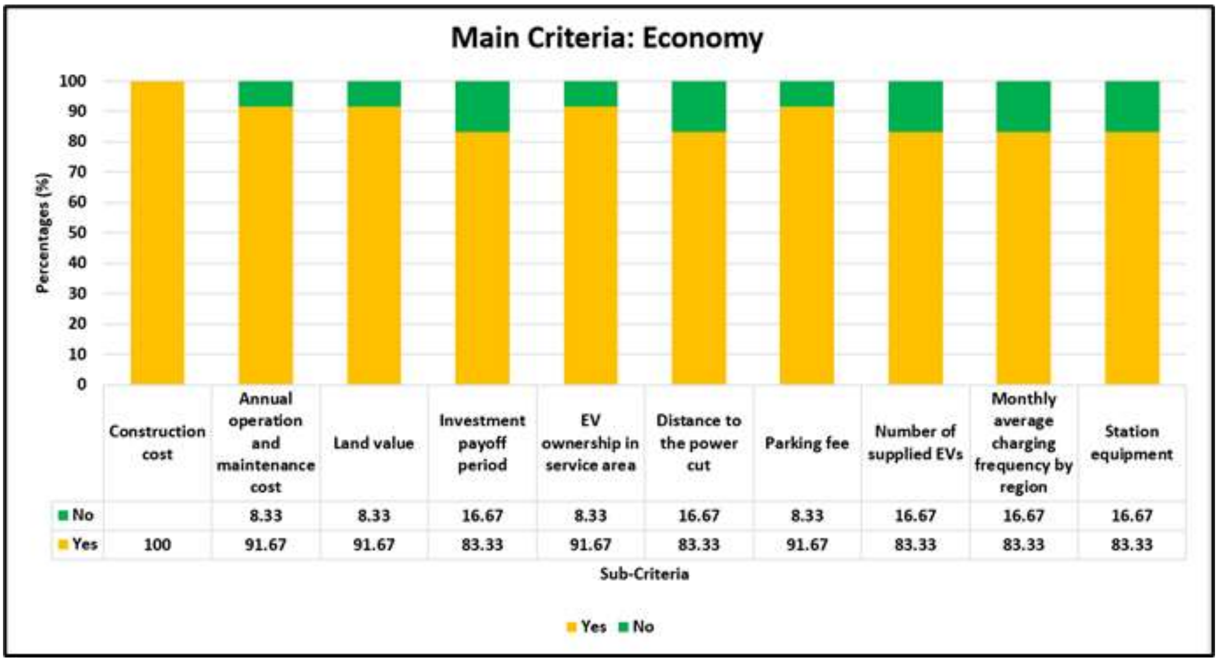

Fig. 1. (b) Analysis of main criteria within economy

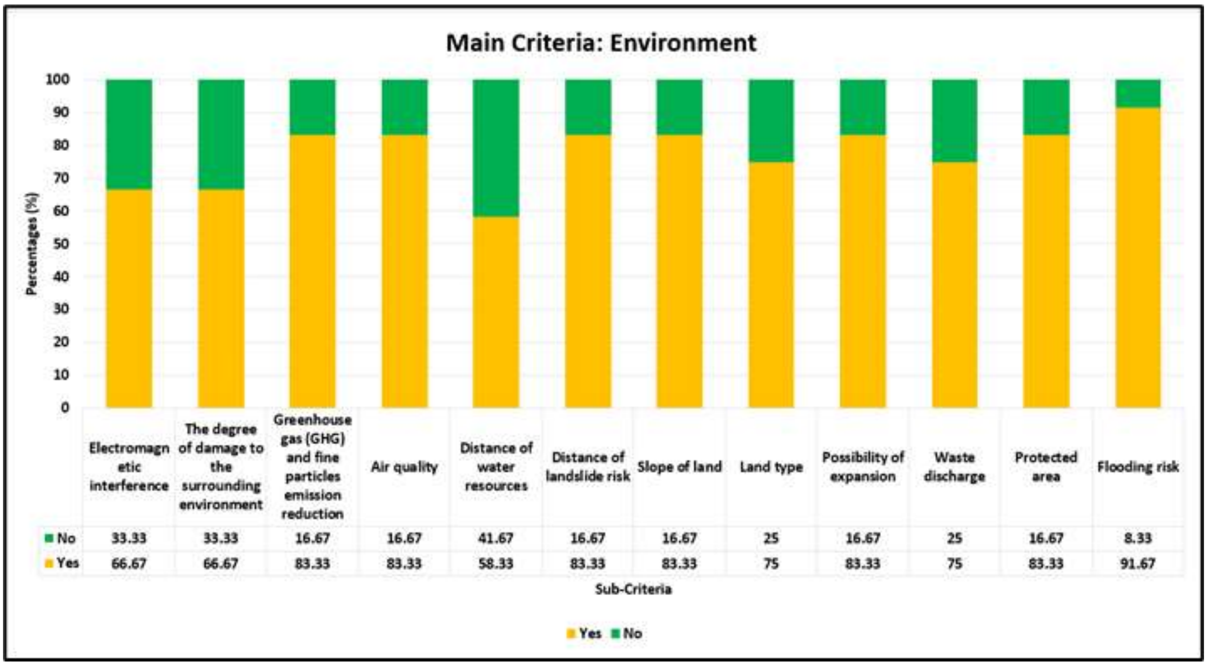

Fig. 1. (c) Analysis of main criteria within environment

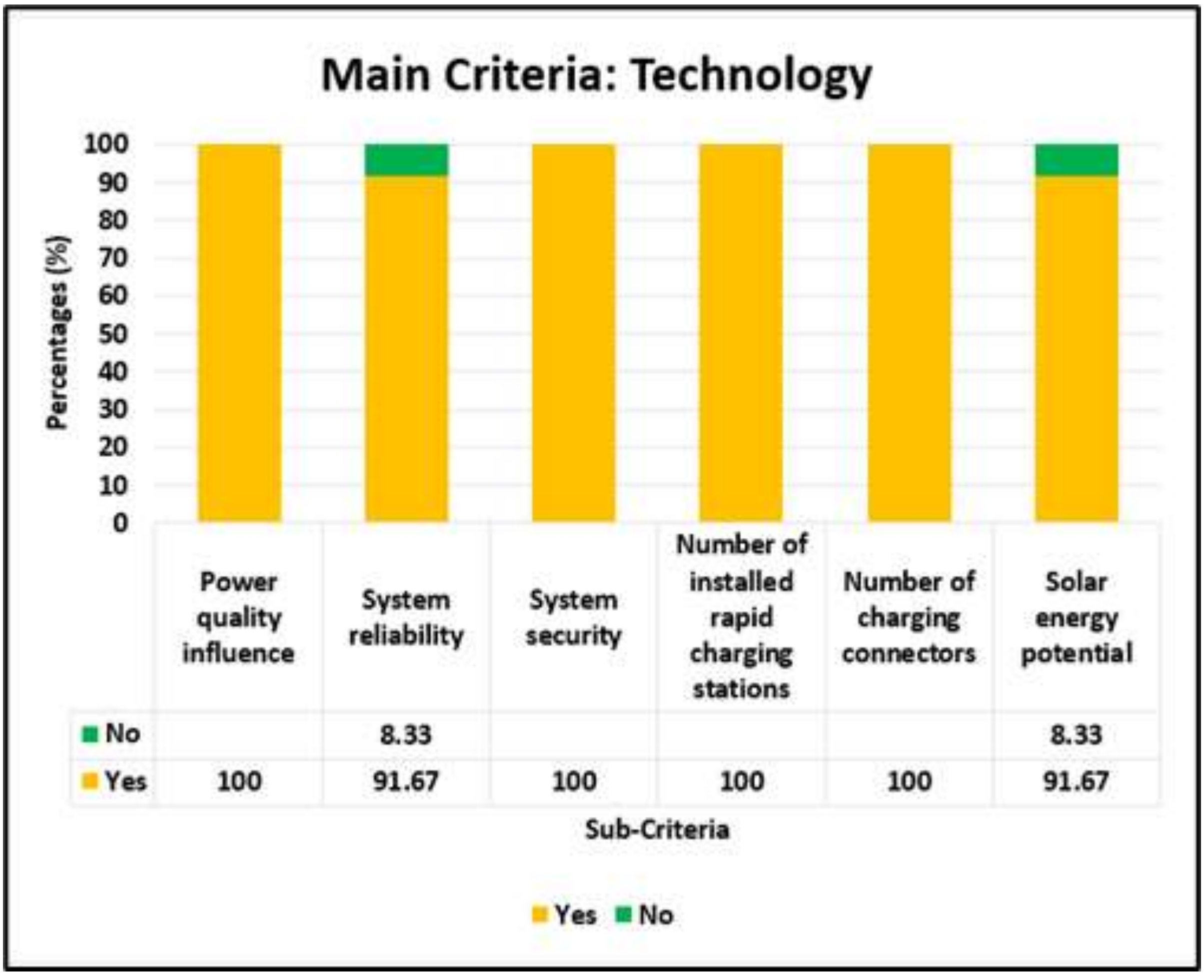

Fig. 1. (d) Analysis of main criteria within technology

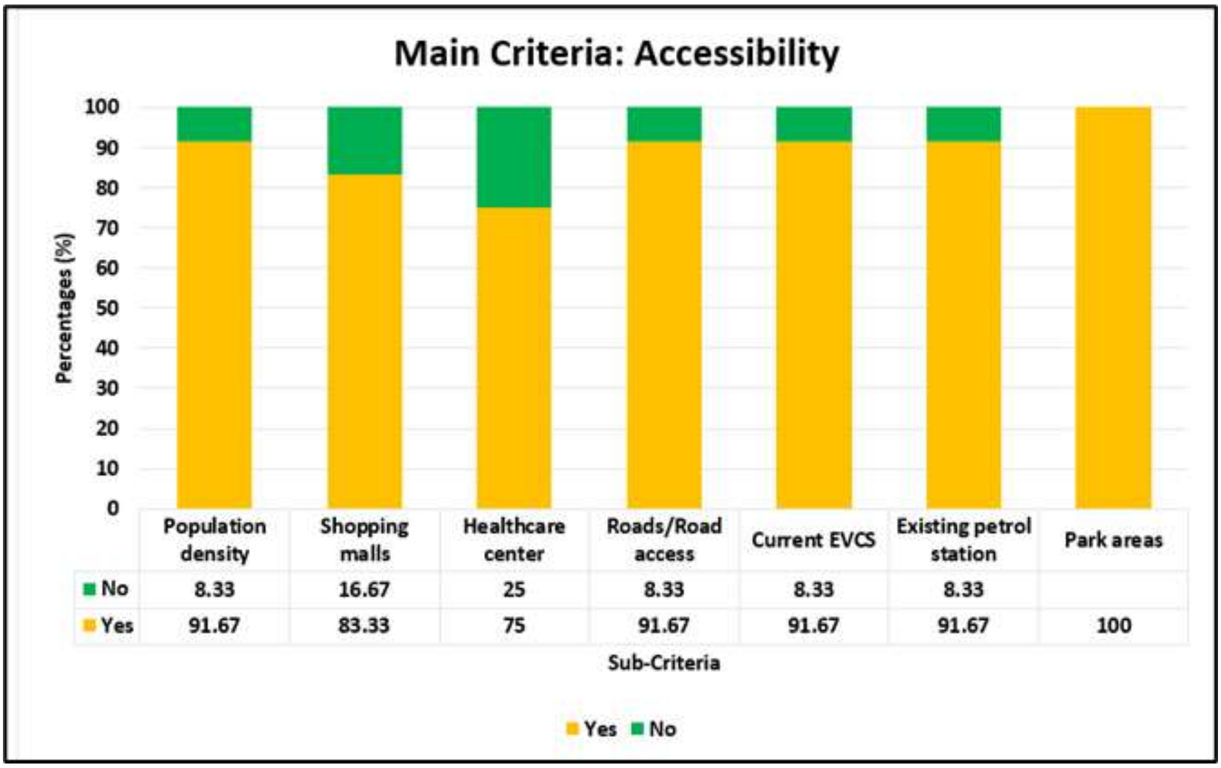

Fig. 1. (e) Analysis of main criteria within accessibility

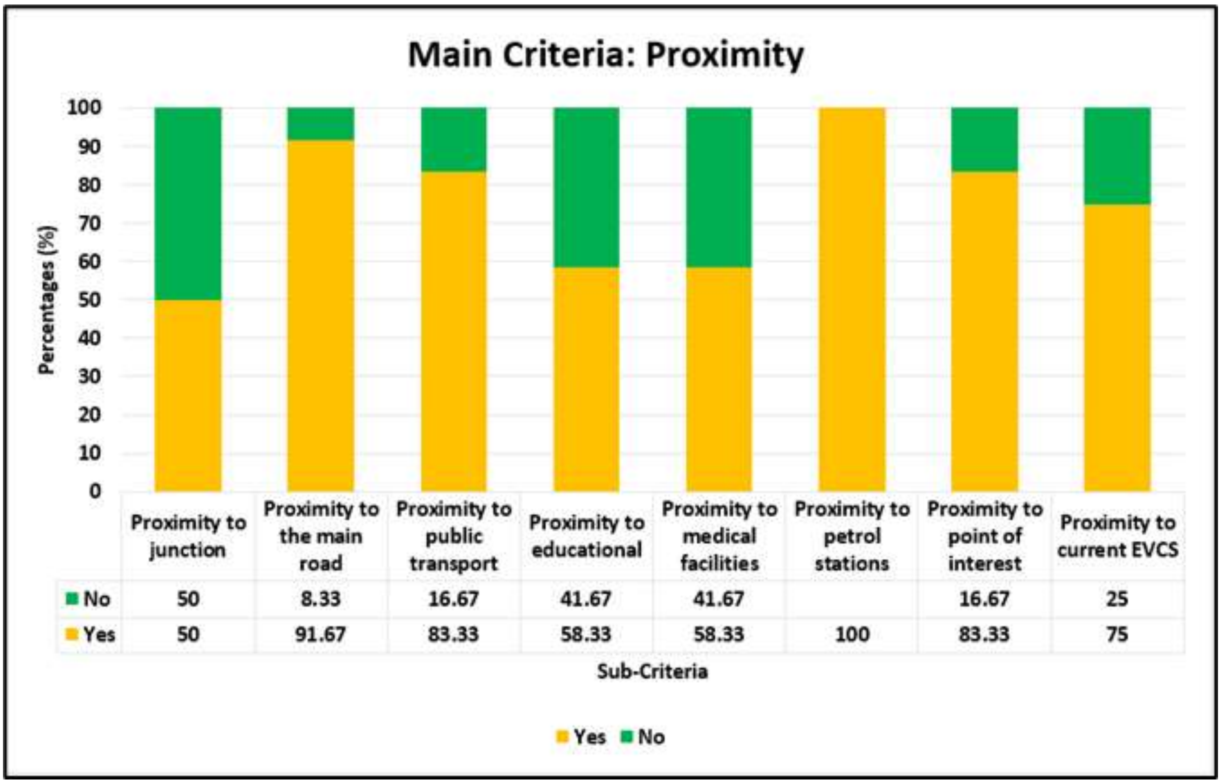

Fig. 1. (f) Analysis of main criteria within proximity

However, challenges surfaced due to the researcher's lack of expertise in proper pairwise comparison, leading to the erroneous combination of sub-criteria. A re-evaluation in the subsequent third round became imperative to rectify this issue. In the final round of validation, unanimous agreement among experts was reached on pairwise comparisons, finalizing the criteria. The AHP questionnaire was deemed validated and ready for distribution to a diverse group of experts, including scholars, policymakers, practitioners, and other relevant experts. This systematic approach ensures the robustness and relevance of the selected criteria for determining the ideal locations for PEVCS in Malaysia.

4. Results and Discussions

Having undergone three rounds of instrument validation, the criteria for determining the suitable location for PEVCS in Malaysia have been established. The item content validity index (I - CVI) for each pairwise comparison stands at 1.00, and the scale content validity index (S – CVI) also attains a perfect score of 1.00. A CVI value within the range of 0.95 to 1.00 suggests a scale with strong content validity [21]. Notably, face validity also achieves unanimous agreement, with 100% concurrence from the experts. Consequently, the hierarchical representation of these criteria is illustrated in Figure 2.

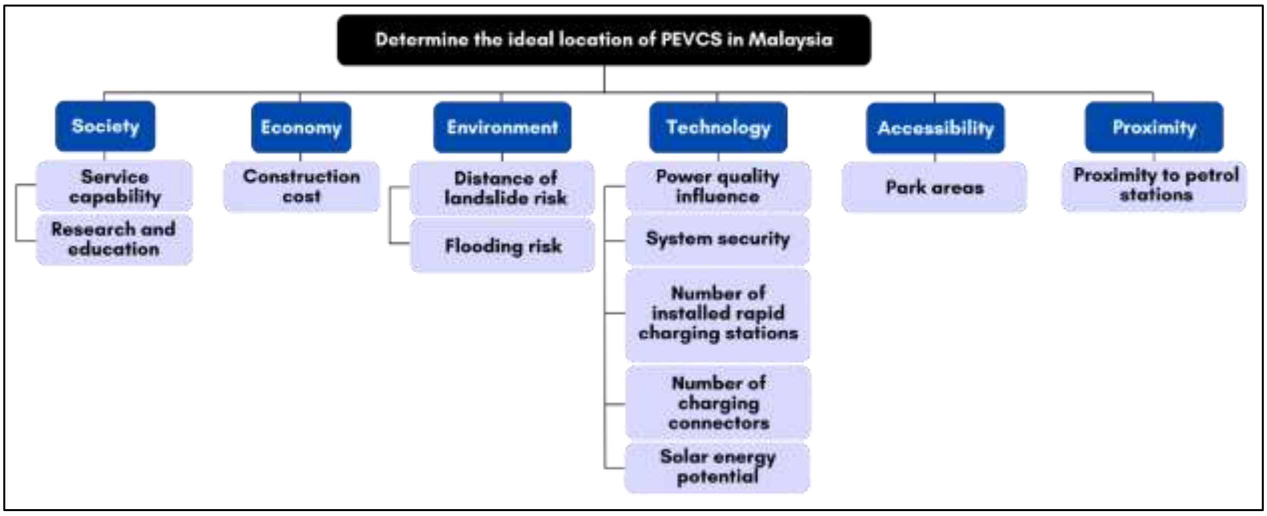

Fig. 2. The hierarchy of criteria in determining the ideal location for PEVCS in Malaysia

This study establishes six main criteria and twelve sub-criteria. Initially, the society dimension pertains to the significance or impact of an individual's decisions or actions on the collective well-being, values, and behavior of a community or society. The sub-criteria within the societal aspect encompasses service capability, and research and education. Service capability refers to factors such as the total number of EVs accessing PEVCS charging services, along with daily and maximum charging capacities [22]. On the other hand, research and education entail considerations related to institutions like universities, education centers, and schools in the allocation of PEVCS [25].

Besides, the economic aspect focuses on the financial and economic implications associated with the deployment of PEVCS in Malaysia. The sole sub-criteria considered within the economic aspect is construction cost, encompassing land costs, infrastructure expenses, investment outlays, demolition costs, and power distribution facility expenditures [12-14,16,20,22,23,26-33].

Furthermore, the environmental aspect entails a thorough assessment of the overall environmental benefits, carbon footprint, and sustainability inherent to the implementation of PEVCS in Malaysia. Within the environmental dimension, two sub-criteria are identified: the distance of landslide risk and flooding risk. The distance of landslide risk pertains to the proximity of the PEVCS location to areas susceptible to landslides which given the inherent dangers associated with landslide-prone zones, it is recommended to avoid constructing PEVCSs in such locations

[15,29,34,35]. Regarding flooding risk, it involves areas prone to frequent flooding [36]. Areas experiencing recurrent flooding should be categorized as either safe or risky and considering the associated hazards related to flooded areas, it is advisable to refrain from establishing PEVCSs in such areas.

In addition, within the technology criteria, the primary focus is on evaluating the technological feasibility, efficacy, and adaptability of the charging infrastructure. This involves a comprehensive examination of charging speeds, compatibility with various vehicle models, and integration capabilities with smart grid technologies. The sub-criteria under the technology aspect encompasses power quality influence, system security, the number of installed rapid CSs, the number of charging connectors, and solar energy potential. Power quality influence involves strategically placing the CS away from sources of electromagnetic interference, such as massive radio transmitters, industrial electromagnetic fields, and heavy load lines [14,24,32,33,37]. This positioning aims to minimize electromagnetic interference at the PEVCS and ensure the secure operation of the distribution network.

On the other hand, system security refers to the future protection of the PEVCS, encompassing grid safety, fire protection equipment, resilience to natural disasters, and the capability to handle emergencies effectively [14,16,31-33]. The number of installed rapid CSs pertains to the availability of connectors for fast-CSs, including Direct Current (DC) connectors at the PEVCS [36]. Meanwhile, the number of charging connectors refers to the total count of charging connectors installed at the station, encompassing both Alternative Current (AC) and Direct Current (DC) connectors [38]. Lastly, solar energy potential involves selecting a location with proximity to solar energy sources, emphasizing the importance of renewable energy integration in the PEVCS infrastructure [35].

Subsequently, the components of accessibility revolve around the public availability of the charging infrastructure, considering aspects like convenient positioning, user-friendly functionalities, and inclusivity for diverse user groups, including individuals with disabilities. Within the accessibility criteria, park areas stand out as a sub-criterion, indicating designated parking spaces in high-density vehicle areas, making them prime locations for EV users [12,25,29,35,37,39-41]. Therefore, the proximity aspect plays a pivotal role in evaluating the closeness of charging infrastructure to vital areas such as residential districts, commercial establishments, and transportation corridors. This guarantees convenient access and broad coverage for EV users. Specifically, one sub-criterion under proximity is the proximity to petrol stations, indicating the distance between the petrol station and the PEVCS [12,15,19,40].

As can be seen, the significance of this study lies in its capacity to identify ideal sites for PEVCS in Malaysia, considering six main criteria and 12 sub-criteria. The potential impact of this study is to enhance the convenience for EV users, allowing them to recharge within their driving range and alleviating concerns about range anxiety. The widespread presence of PEVCS along routes may contribute to increased acceptance of EVs among Malaysians. Additionally, choosing PEVCS over traditional EVCS could result in cost savings for EV users, as PEVCS utilizes solar energy for recharging. Ultimately, the installation of PEVCS emerges as the optimal choice for improving air quality and addressing transportation-related pollution issues, given that EVs recharge using Renewable Energy Sources (RES), such as photovoltaic (PV) systems. Thus, given the benefits of clean energy utilization and the establishment of sustainable CS, it is imperative to contemplate the installation of PEVCS along routes [42].

As shown above, these criteria serve as valuable tools for the government and policymakers to formulate strategies aimed at promoting the widespread adoption of EVs among Malaysians and fostering the expansion of PEVCS to safeguard the environment. Consequently, this study has the potential to make substantial contributions to the country's economic growth, as effective policies can indirectly boost the nation's economy as the correlation lies in the fact that well-executed investment planning typically yields positive returns for investors.

5. Conclusions

Malaysia is witnessing substantial growth in the EV market, leading to the need for strategically placing CSs along routes to reduce range anxiety among EV users. It is necessary to integrate EVs with RESs, particularly solar energy, to align with the SDGs. Due to the limited presence of PEVCS in Malaysia, their installation becomes crucial, necessitating careful consideration of various key criteria for ideal allocation. In conclusion, the study aimed to finalize criteria for identifying ideal locations for PEVCS in Malaysia, considering the country's unique geographical and infrastructural context. The literature review revealed various criteria used in prior research for determining suitable locations for both EVCS and PEVCS. The methodology involved a thorough exploration of existing literature, a comprehensive Need Analysis, and instrument validation, resulting in the establishment of criteria for determining suitable PEVCS locations in Malaysia. The rigorous validation process, with a perfect I - CVI and S - CVI of 1.00, signifies the reliability of the identified criteria. As a conclusive suggestion, the study recommends the application of the Fuzzy Delphi Method (FDM) for the final determination of criteria for the ideal placement of PEVCS in Malaysia, acknowledging its efficacy in handling uncertainties and diverse opinions in decision-making processes. This approach ensures a robust and well-informed selection of locations that align with the specific needs and circumstances of Malaysia.

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