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Towards Sustainable Mobility: Identifying Ideal Locations for Photovoltaic Electric Charging Stations (PEVCS) in Malaysia

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ABSTRACT

Photovoltaic electric vehicle charging stations (PEVCS) has been highlighted as an inspiration for sustainable mobility due to its environmental friendliness, ability to reduce transportation issues and potential to improve air quality. The establishment of PEVCS networks along major routes is projected to significant increase EV adoption in Malaysia, reducing EV customers' range anxiety. Given the current deployment of several electric vehicle charging stations (EVCS) and a limited number of PEVCS in Malaysia, there is a compelling reason for increasing the quantity of PEVCS along routes to magnify its positive environmental impact. Adding to the previously described problems, this study seeks to identify suitable locations for PEVCS in Malaysia. The findings of the Need Analysis completed as part of this study were used to develop these site-selection criteria, which include both main and secondary factors. Finally, 41 sub-criteria were chosen for this study, which are divided into the following categories: society, economy, environment, technology, accessibility and proximity. In conclusion, these criteria provide a comprehensive framework for decision-makers and stakeholders to determine suitable spots for PEVCS in Malaysia, supporting sustainable mobility and improving the entire experience for electric vehicle users.

1. Introduction

In recent years, electric vehicles (EVs) have gained popularity worldwide. This rising demand can be attributed to the recognition of EVs as environmentally friendly vehicles capable of reducing air pollution and addressing various transportation-related challenges. The main challenges to enhance EV adoption in Malaysia include the insufficient availability of electric vehicle charging stations (EVCS), the high cost of EVs and unclear regulations [1]. Veza *et al.,* [2] mentioned that there are very few EVCS, and their expansion has been progressing slowly since 2016 in Malaysia. Correspondingly, industry in Malaysia has sold approximately 2,270 EVs and installed around 519 EVCS in 2023 [3]. However, by 2030 Malaysia aims to have 100,000 EVs on the road, including 125,000 EVCS which may also incorporate solar EVCS [4]. In other words, after relying on coal and fossil fuels, Malaysia is currently exploring alternative sources of electricity generation [5]. Kumar *et al.,* [6] stated that

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photovoltaic (PV) solar stands out as one of the best clean energy sources among renewable energy sources (RES) due to its availability and ease of installation. Moreover one of the respondents, an EV user from the Need Analysis survey mentioned that the adoption of solar energy is still minimal in Malaysia.

Given Malaysia's current utilization of multiple EVCS and a limited number of PEVCS, there is merit in expanding the presence of PEVCS along routes to provide greater environmental benefits. This research has the potential to simplify the process of EV recharging for users, enabling them to recharge conveniently within their driving range and alleviate concerns about range anxiety. Additionally, the widespread availability of PEVCSs along routes could potentially boost the acceptance of EVs among Malaysians. Furthermore, EV users can realize cost savings when charging at PEVCS compared to traditional EVCS, as PEVCS harness solar energy for recharging. Lastly, the installation of PEVCS emerges as an optimal strategy for improving air quality and mitigating other transportation-related pollution issues since EVs are powered by RES like photovoltaic (PV) systems.

Building upon the aforementioned issues, this paper endeavors to identify suitable locations for PEVCS in Malaysia by considering a range of criteria. These criteria, including both main and sub-criteria, have been determined based on the results of the Need Analysis conducted in this study.

2. Literature Review

As EV adoption grows in Malaysia and around the world, the strategic allocation of PEVCS has become a major focus of studies and policy development, which requires a comprehensive review of the various criteria influencing their placement and distribution in the Malaysian landscape. From the previous studies, Hisoglu *et al.,* [7] identified that the top three most appropriate criteria for allocating PEVCS are solar energy potential, distance to high population density centers and solar panel installation cost. Transportation-related factors take precedence over other primary considerations [8,[9]. However, when examining sub-criteria, parking lot [8] and taxi stands [9] emerge as suitable choices for the allocation of EVCS and electric taxis charging stations (ETCS). Furthermore, Kaya *et al.,* [10] emphasized the significance of environmental or urbanity the leading main criterion, with sub-criteria related to parking space being instrumental in determining suitable EVCS locations. Additionally, tourist attraction areas are identified as the most critical primary criteria, while gas stations rank lowest in importance in the allocation of electric car sharing stations (ECSS) [11].

Besides, the proximity to users has been assigned the highest priority, followed by accessibility, with environmental impact registering as the least significant factor in the allocation of EVCS locations [12]. Ghodusinejad *et al.,* [13] asserted that optimal locations for PEVCS are characterized by their accessibility of two main squares. Furthermore, four primary criteria and eight sub-criteria to determine appropriate EVCS locations, ultimately highlighting technology and society factors as the most relevant considerations for identifying optimal sites [14]. In addition, proximity to the fuel stations and population distribution emerge as the most fitting criteria for positioning EV charging points [15]. Meanwhile, Sisman *et al.,* [16] introduced three main criterion categories and 15 sub-criteria for the allocation of ideal EVCS locations, with economy factors, including sub-criteria such as EV ownership in service area and distance to power cut, taking precedence in their findings.

Moreover, the economic factors particularly the operation and maintenance costs, emerge as the most appropriate considerations for EVCS allocation [17]. Karolemeas *et al.,* [18] have demonstrated that proximity to transport hubs, density of marked and controlled parking spaces, and proximity to points of interest constitute the top three sub-criteria, while proximity to public services rank lower in significance among the sub-criteria. These findings underscore that an ideal charging station (CS) location should exhibit a high EV penetration rate, solid charging infrastructures secured in a given area, high road network density and high traffic volumes in city centers [19]. In determining a suitable site for EVCS, it is imperative to account for environmental considerations, with easiness of extension and re-establishment in the future emerging as the paramount criterion, followed by considerations such as greenhouse gas (GHG) reduction and fine particulate matter emission reduction, and destruction degree on urban vegetation and landscape [20].

Ghosh *et al.,* [21] discovered that societal aspect took priority, with population density ranking first among the sub-criteria. According to Dang *et al.,* [22], the major characteristics highlighted in the context of island PEVCS allocation are total sun radiation, policy support and transportation convenience. Sun [23] highlighted the strong importance of social issues as the most critical element in an analysis including three main criteria and 18 sub-criteria to find possible EVCS sites. Guler and Yomralioglu [24] emphasized the importance of accessibility and environmental considerations in finding acceptable EVCS locations, concentrating on three main criteria and 10 sub-criteria. Zhou *et al.,* [25] discovered that social factors, as well as sub-criteria relating to possibility of capacity expansion in the future, are more important in the allocation of urban PEVCS. Finally, Hosseini and Sarder [26] found technical and environmental criteria as having the greatest and least influence on the likelihood of selecting EVCS locations, respectively.

Next, Liu *et al.,* [27] proved that the "adverse impact on people's lives" is a highly affected factor that warrants further consideration when identifying the ideal site for EVCS. When choosing an acceptable EVCS locations, Ju *et al.,* [28] analyzed four core factors and 13 sub-criteria, with environmental criteria ranking as the most important in their analysis. In addition, the most important criterion for EV drivers is criteria 1 (accessibility) which has a weight of 62 %, followed by criteria 3 (waiting time) and criteria 2 (traffic convenience), which have weights of 28 % and 9 %, respectively [29].

According to Erbaş *et al.,* [30], economic criteria have the largest effect on the study's findings. However for Genevois and Kocaman [31], the car parking situation of the shopping malls is the most important parameter to consider when determining the appropriate EVCS site. During their EVCS site planning, Wu *et al.,* [32] considered five key criteria: economy, social, environmental, planning and a feature portrait of residential communities. Within the environmental criterion, decision makers (DMs) assigned the highest importance to fine particle emission reduction. On the other hand, Wu *et al.,* [33] identified transportation convenience, fine particle emission reduction and investment payoff period as the top three criteria to consider when locating ideal EVCS sites.

Examining the assessment of EVCS, Philipsen *et al.,* [34] found that critical factors include dual use, reliability and accessibility. Zhao and Li [35] introduced four distinct perspectives including economic, society, environment and technology and highlighted that environment criteria take precedence over the others. Guo and Zhao [36] divided 11 sub-criteria into three sustainability perspectives: environmental, economic and social. Consequently, DMs assign greater significance to the environmental and social criteria compared to economic criteria.

3. Methodology

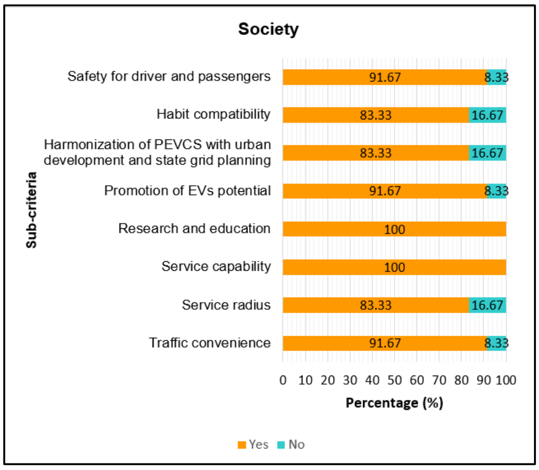
3.1 Need Analysis

This study used a survey-based approach as an essential part of Need Analysis to pinpoint and evaluate the criteria that are significant in the installation of PEVCS in Malaysia.

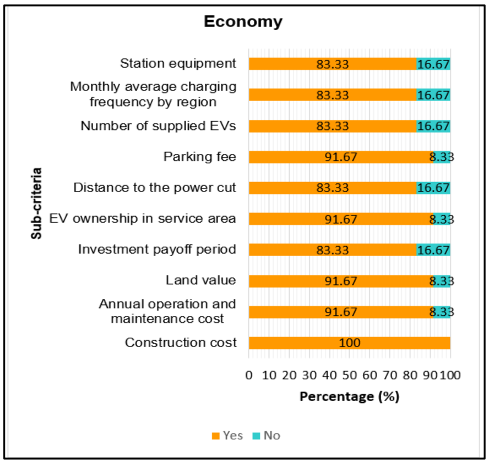
A survey research design is used in this study, with a questionnaire including a complete set of criteria. This questionnaire includes both main and sub-criteria in order to determine the ideal locations for PEVCS in Malaysia. A total of 12 respondents are involved in the data gathering process, including lecturers, EV sales advisor and EV users. The survey is distributed both physically and electronically using Google Forms. A questionnaire with a dichotomous scale is used to analyze the obtained data, allowing respondents to indicate their agreement or disagreement with each criterion. The data is then analyzed using descriptive statistics, which includes examining frequency and percentage distributions.

4. Results and Discussion

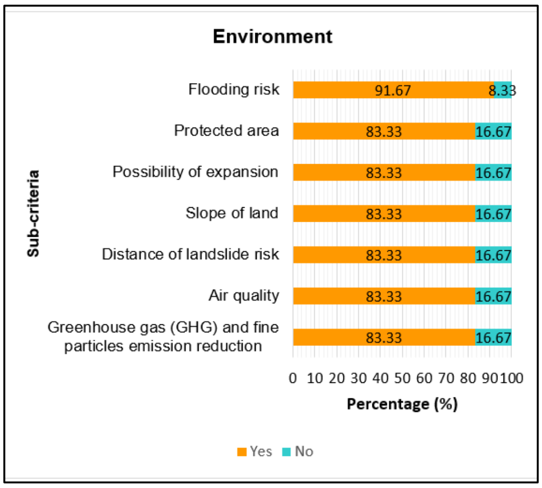
Ultimately, 41 sub-criteria are finalized for this study, which were divided into the following categories: society [8], economics [10], environment [7], technology [6], accessibility [6] and proximity [4]. Only criteria with a percentage agreement of 80 % or greater during the Need Analysis are kept in this inquiry. Among these, 9 criteria gained total approval, 15 earned 91.67 % agreement, and 17 received 83.33 % agreement. As a result of respondent disagreement, the remaining criteria are left out of this study. The findings from the Need Analysis are represented as follows in Figure 1.



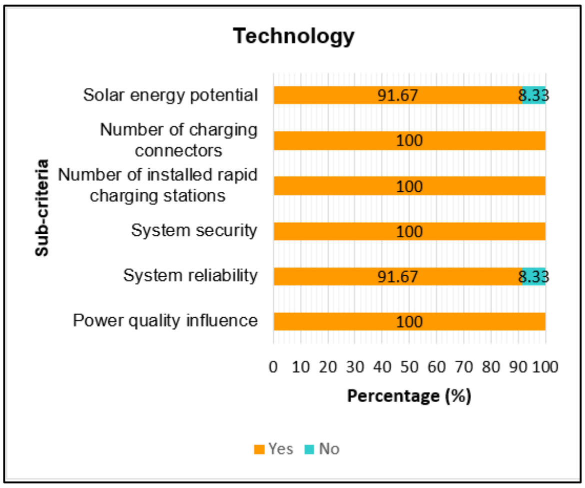
(a) Society criteria



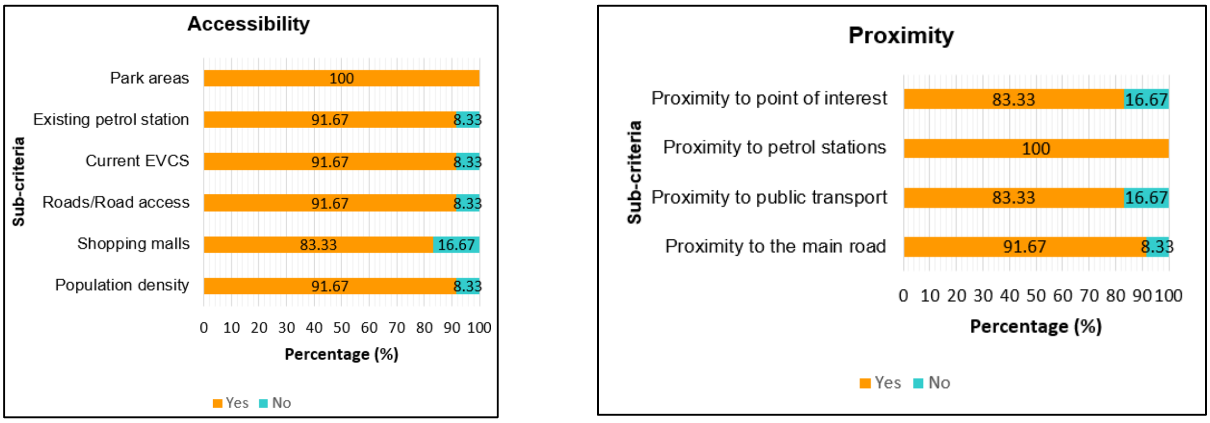
(b) Economy criteria



(c) Environment criteria



(d) Technology criteria



(e) Accessibility criteria (f) Proximity criteria

Fig. 1. Findings from the Need Analysis

Based on the data reported in Figure 1, six fundamental factors should be considered when choosing the best locations for PEVCS in Malaysia. These variables include society, economics, environment, technology and proximity. Within the societal context, the emphasis is mostly on individual behaviors and their impact on both EV users and non-EV users in their surroundings. Additionally, variables like as the location's closeness to main road traffic, the number of vehicles on the road and the proximity to intersections near PEVCS must be considered to offer convenient access for EV users without facing any difficulties. Besides, the safety of EV users and their passengers should not be taken for granted as safety always takes precedence. Thus, society aspect includes sub-criteria of traffic convenience, service radius, service capability, research and education, promotion of EVs potential, harmonization of PEVCS with urban development and state grid planning, habit compatibility and safety for driver and passengers.

Next, the economic factor serves as a parameter for setting the budget, as well as for assessing the costs and potential profits or income for stakeholders and investors involved in the installation of PEVCS. Indeed, to ensure the smooth operation of PEVCS, it is important to consider the station's equipment and its proximity to power sources. Hence, the construction cost, annual operation and maintenance cost, land value, investment payoff period, EV ownership in the service area, distance to the power cut, parking fee, number of supplied EVs, monthly average charging frequency by region and station equipment are the crucial sub-criteria that considered in allocating the suitable location of PEVCS in Malaysia.

In addition, the environmental aspect is evaluated based on the ecological impact and the environmental benefits derived from the installation of PEVCS. Given that the adoption of EVs can contribute to the reduction of air pollution and alleviate other transportation-related issues, the environmental factor emerges as one of the essential criteria in determining the ideal location for PEVCS. Moreover, GHG and fine particles emission reduction, air quality, distance of landslide risk, slope of land, land type, possibility of expansion, protected area and flooding risk are the important criteria in site selection of PEVCS in Malaysia.

On the other hand, the technology aspect encompasses the technical characteristics of the CSs, power grid and EVs. Stakeholders must analyze the potential for future expansion of PEVCS to identify ideal locations. However, prioritizing the security of PEVCS is crucial to ensure a systematic and technologically sound response to emergencies. Correspondingly, the sub-criteria of power quality influence, system reliability, system security, number of installed rapid CSs, number of charging connectors and solar energy potential are needed to consider in order to place the PEVCS in Malaysia at ideal locations.

Another important aspect to consider is accessibility, which ensures that EV users can conveniently access PEVCS and alleviate their range anxiety. PEVCS should ideally be situated in locations where EVs are frequently used and are common destinations for EV users. This includes areas such as shopping malls, well-connected road access points, current EVCS, existing petrol stations, park areas and considering population density to ensure seamless EV recharging without any problems.

Lastly, proximity is the sixth primary criterion considered when allocating PEVCS in Malaysia. Proximity refers to the closeness or nearness of one thing to another and describes physical closeness. It ensures that EV users can easily access CSs to recharge their EVs, especially in focal areas such as main roads, public transport, petrol stations and points of interest.

5. Conclusions

As previously said, the combination of PV systems with EVCS has the potential to have a greater influence on the global EV industry as well as the environment. In short, PEVCS provides significant benefits to every individual because of its ecologically friendly nature, potential to reduce transportation concerns and ability to enhance air quality. Furthermore, with the development of PEVCS along routes, EV adoption in Malaysia is projected to expand dramatically and reducing range anxiety among EV users. Overall, six significant criteria for the allocation of PEVCS in Malaysia are discovered and analysed in this study. Society, economy, environment, technology, accessibility and proximity are among the criteria. Each aspect is important in finding the suitable locations for PEVCS, ensuring that they suit the demands of EV users while also contributing to the broader aims of sustainability and practicality.

As can be seen, society criteria assess how PEVCS influence individuals and their surroundings, whereas economic aspects consider the cost implications of their installation and operation. Correspondingly, environment criteria highlighted the environmental benefits of PEVCS in reducing air pollution and resolving transportation-related issues. Additionally, technology criteria address the technological complexities of CSs, the power infrastructure and EVs. Similarly, the accessibility requirements focus on ensuring an accessible spot for PEVCS to reduce range anxiety among EV users. Finally, proximity criteria emphasise the importance of physical proximity, making it easier for EV users to reach PEVCS, particularly in locations such as main roads, transport hubs, petrol stations and points of interest.

Above all, these criteria offer an extensive basis for DMs and stakeholders to identify eligible PEVCS locations in Malaysia that encourage sustainable mobility and provide a pleasant journey for EV users. In future endeavours aimed at expanding the PEVCS network in Malaysia, policymakers and stakeholders should undertake a comprehensive cost-benefit analysis to assess the societal, economic, environmental, technological, accessibility and proximity impacts. Additionally, decision-makers can consider employing heuristic, metaheuristic or hybrid methods to identify optimal PEVCS locations in Malaysia.

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