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RESEARCH ARTICLE

A Need Analysis of the Criteria Involved in Determining Suitable Locations for Photovoltaic Electric Vehicle Charging Stations in Malaysia

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Abstract The main concern is a lack of scientific planning for photovoltaic electric vehicle charging stations (PEVCS) that considers numerous main criteria and sub-criteria. PEVCS should be strategically positioned in an appropriate and ideal location to ensure that electric vehicle (EV) users may reach the stations within their driving range. While the adoption of solar is still minimal in Malaysia, Malaysia needs to move faster to allocate the PEVCS at the strategic locations. Regarding this matter, this study aims to determine the suitable criteria for allocating the location of PEVCS in Malaysia. 52 out of 177 sub-criteria and six main criteria items were selected for the Need Analysis in this study as part of the data collecting procedure, which involved 12 respondents. The result revealed that the Need Analysis was used to choose 41 of the sub-criteria, including society (8), economics (10), environment (7), technology (6), accessibility (6), and proximity (4). For future studies, it is recommended to use Likert scales for analysing the data from the Need Analysis, along with calculating the mean and standard deviation values, while utilizing GIS-based MCDM methods to allocate ideal PEVCS locations in Malaysia through the development of a new prediction location model.

Keywords: Need Analysis, criteria, photovoltaic electric vehicle charging stations, Malaysia.

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Introduction

International Energy Agency [1] figures that in 2022, the overall emissions from energy combustion and industrial processes climbed by 0.9%, or 321 Mt, to reach a new high of 36.8 Gt, while the total emissions from transportation increased by 2.1% (or 137 Mt) globally. According to Ritchie and Roser [2], the major three (3) sources of emissions in Malaysia are coal, gas, and oil. Thus, the number of electric vehicles (EVs) is rising quickly around the world as a sustainable energy-based transportation solution. Khan *et al*. [3] claim that EVs and solar photovoltaic (PV) systems are two parts that are projected to be the future generation of transportation and can reduce emissions and consumption of fossil fuels significantly.

The dearth of charging stations (CSs) along the route is a significant issue for EV users in Malaysia because the country has aggressively embraced EVs in recent years [4, 5]. However, by 2030, Malaysia intends to have 125,000 electric vehicle charging stations (EVCSs), including solar EVCS, and 100,000 EVs on the roads [6]. To achieve those goals, Malaysia should allocate photovoltaic electric vehicle charging stations (PEVCS) along the route. There are a lot of parameters or criteria that should be considered in the site selection of PEVCS. This Needs Analysis aims to determine the suitable criteria for allocating the ideal location of PEVCS in Malaysia. Section 2 discusses the methodology and the definition for each criterion involved in Need Analysis. Results and Discussions are elaborated critically in Section 3 and Section 4 to conclude this study.

Methodology

In the first place, conducting a Needs Analysis is necessary for determining the suitable criteria for distributing the PEVCS in Malaysia, which can be applied in this study. Prior study on the positioning of EVCS and PEVCS yielded a total of 177 sub-criteria spanning from 2015 to 2023. Hence, the experts had to evaluate the relevance of each criterion found in the literature review during the first stage [7]. This study employs a survey research design which includes a questionnaire with a set of criteria. The questionnaire consists of the main criteria and sub-criteria to determine the placement of the PEVCS in Malaysia. The data collection process involves 12 respondents which are lecturers, EV sales advisor, and EV users. The survey is distributed via both hands-on and Google Forms. To analyse the data, this study creates a questionnaire that consists of a dichotomous scale that includes the respondents' agreement or disagreement with each criterion. Thus, it is analysed using descriptive statistics by looking at frequency and percentage.

Criteria

52 out of 177 sub-criteria and six main criteria elements are chosen for the need analysis in this study. Initially, 52 criteria are chosen based on the specific conditions and geographical features found in Malaysia. More criteria may be considered for better outcomes [8]. Six dimensions, including society, economy, environment, technology, accessibility, and proximity, comprise the evaluation criteria, which are selected from literature reviews.

Table 1. The definition of each criterion

No	Main criteria	Sub-criteria	Definition	Studies
1.	Society	Traffic convenience	Refers to the main road condition, number of vehicle lanes, and number of intersections near the PEVCS location where the EV users can enter the station, charge, and exit without any problems.	[9]–[17]
		Service radius	PEVCS must consider the distance between two PEVCS locations. The closeness to nearby charging stations is unsuitable since it leads to resource waste.	[16], [18]–[20]
		Service capability	Refers to the total number of EVs that have access to PEVCS's charging service, as well as the daily and maximum charging volumes.	[11], [13], [20]
		Research and education	Research and educational buildings should be considered in allocating the PEVCS.	[21]
		Promotion of EVs potential	The demand for EVs may be boosted by the advancement of CSs, which is helpful for the fast growth of the EV market.	[22]
		Harmonization of PEVCS with urban development and state grid planning	Refers to coordination with the major road, entrance and exit, residential areas, urban main functional locations, and the uninterrupted supply of electricity.	[11], [13], [18], [19]
		Residents' acceptance	When choosing a location for PEVCS must consider the impact on people's lives. The daily routines of the concerned residents are negatively affected by the noise and electromagnetic field produced during the construction and operation of PEVCS.	[11], [13], [18], [20], [22]
		Habit compatibility	EV users do not need to re-adjust while traveling to a new location because they are accustomed to doing so.	[16], [23]
		Safety for driver and passengers	Feel protected from danger while the EV is charging (even at a late hour).	[23]
2.	Economy	Construction cost	The construction cost of PEVCS is including land costs, infrastructure costs, investment costs, demolition costs, and power distribution facility costs. Moreover, the construction cost will decrease if the location is connected by numerous transportation facilities.	[9], [11], [25]–[29], [13], [15]–[19], [22], [24]

No	Main criteria	Sub-criteria	Definition	Studies
		Annual operation and maintenance cost	This sub-criterion includes electricity fees, staff wages, taxes, equipment depreciation, business costs, battery amortization, and other financial expenses. Hence, repair and replacement expenses for the components of CSs can be broadly classified as preventative and corrective expenses.	[9], [11], [13], [15], [17]–[19], [22], [24], [30]
		Land value	PEVCS site selection's evaluation phase includes the price of purchasing land. To lower total construction expenses, the land value of the PEVCS should be marked down.	[24], [31]–[34]
		Investment payoff period	The investment payoff period represents the rate at which benefits on the whole construction investment are achieved and relevant to the cost and operating income. Moreover, the construction cost, operation and maintenance costs, PV subsidy policy, charging standards, and the anticipated power demand for electric vehicles are all included in the calculation of the investment payback period of a PEVCS project.	[9], [17], [20], [29]
		EV ownership in the service area	Service areas with a high degree of EV ownership are seen to be more suited since they can enhance EV usage and visibility.	[25], [26], [31], [34], [35]
		Distance to the power cut	PEVCS should be placed in a location that is not in areas where power cut occurs regularly.	[31], [34]
		Parking fee	Parking fees, whether free or paid, must be considered.	[12]
		Number of supplied EVs	Refers to the number of EVs in the region.	[12]
		Monthly average charging frequency by region	Refers to monthly average charging frequencies at installed CSs.	[12]
		Station equipment	The cost of the station's equipment varies according to the number of output ports mostly on the secondary side or the connectors attached to each of them, as well as their individual rated power.	[30]
3.	Environment	Electromagnetic interference	The distance between a specific location and massive radio transmitters and even an industrial electromagnetic environment. So, the electromagnetic interference at the PEVCS diminishes with increasing distance.	[15]
		The degree of damage to the surrounding environment	This is a measure of environmental deterioration, such as vegetation degradation, soil erosion, ecological balance disruption, and groundwater contamination.	[9], [17]–[19], [22], [26]
		Greenhouse gas (GHG) and fine particles emission reduction	Consider the lowering of environmental pollutants and particulate matter emissions by employing an EV rather than a vehicle powered by an internal combustion engine.	[11], [15], [17]–[20], [22]
		Air quality	One of the most significant reasons for increasing EV use is to reduce air pollution. This sub-criterion primarily assesses emissions of environmental pollutants (CO, SO_2, $PM2.5$, $PM10$) and particulate matter.	[9], [12], [13], [21], [24], [26], [33]
		Distance of water resources	PEVCS installation may have a bad impact on water resources. Thus, PEVCS should be located away from water sources.	[21], [26], [31], [33], [34]
		Distance of landslide risk	Considering landslide areas are risky, PEVCSs should not be built in landslide-risk areas.	[26], [31], [33], [34]
		Slope of land	PEVCS should be located on a flat area and areas with a low slope percentage should be selected for PEVCS placement when operating and construction costs are considered.	[9], [21], [26], [33], [34], [36]
		Land type	It is classified as a park, forest, farm, commercial land, industrial land, military zone, residential area, cemetery, orchard, shrub, and other types. Alternative stations should be placed in areas with human, building, and traffic flows, therefore barren and poorly populated places are excluded from this type of data.	[21], [29]

No	Main criteria	Sub-criteria	Definition	Studies
		Possibility of expansion	Since the increase in CSs is an essential trend for both environmental and economic development, future charging demand, adjacent land resources, local government regulations, and distribution network improvements need to be accounted for while expanding the number of CSs.	[18]–[20], [29], [31], [34]
		Waste discharge	This is a measurement of the waste and wastewater discharge and battery treatment during the construction and operation of the PEVCS, that might negatively impact the environment.	[9], [11], [13], [18], [19], [24]
		Protected area	The infrastructure availability layer created does not include protected areas like historical sites and environmental zones.	[27], [37]
		Flooding risk	Regularly flooded locations must be categorized as safe or risky.	[12]
4.	Technology	Power quality influence	Providing information on the local substation's capacity and the relative stability of the low-voltage electrical network should be taken into consideration while evaluating locations. Then, to guarantee the safe operation of the distribution network, the charging station should be placed far from the busy load lines.	[15]–[17], [20], [35]
		System reliability	Evaluates the PEVCS locations' potential to sustain future possible external conditions.	[9], [17]–[19]
		System security	Refers to the PEVCS's future protection, including grid safety, fire protection equipment, and the capacity to endure natural disasters, as well as its capability to deal with emergencies.	[9], [17]–[19]
		Number of installed rapid CSs	It refers to fast charging stations such as Direct Current (DC) connectors.	[12]
		Number of charging connectors	There are more charging connectors installed at the charging station including Alternative Current (AC) and DC connectors since the road traffic is often greater as it is closer to bigger cities.	[38]
		Solar energy potential	For renewable EVCS, solar energy can be important.	[33]
5.	Accessibility	Population density	Roads in highly populated regions and locations where EVs are used regularly are highly suitable since each CS can accommodate many users.	[24], [25], [27], [32], [35], [39]
		Shopping malls	Shopping malls are a common destination for many people.	[21], [32]
		Healthcare center	Refers to any healthcare center including hospitals and clinics.	[39]
		Roads/Road access	The CSs must be located near main roads and be easily accessible to all EV users and PEVCSs adjacent to road networks will have excellent operational performance.	[12], [21], [25], [27], [32], [35], [36], [40]
		Current EVCS	The new PEVCS should locate at the current EVCS so that EV users can decide whether to use solar or not when charging the EV and be able to acquire all the energy required from current EVCSs.	[25]
		Existing petrol station	The existing petrol stations are already located according to the current traffic network and the PEVCS should be placed near petrol stations as the hybrid car will use the gasoline products.	[21], [25], [26], [32], [35]
		Park areas	The high vehicle density in parking garages makes them a top stop for EV users.	[10], [21], [26], [27], [32], [33], [35], [36]
6.	Proximity	Proximity to junction	To increase the number of vehicles that may access the service, the PEVCS must be placed near intersections and adjacent to areas with high energy demand.	[31], [33], [34]
		Proximity to the main road	To keep the vehicles working, the PEVCS should be close to major roads and adjacent to areas with high energy demand.	[26], [31], [33], [34]
		Proximity to public transport	Being adjacent to high passenger flow and having good access to the public transportation network by taking the walking distance from the nearest transport hub/station into consideration.	[23], [26], [27], [39]

No	Main criteria	Sub-criteria	Definition	Studies
		Proximity to educational	Conveniently close to the nearest school or university.	[27], [39]
		Proximity to medical facilities	Conveniently close to the closest hospital or healthcare facility.	[27], [39]
		Proximity to petrol stations	Since hybrid vehicles require petroleum products, the best spot for the charging station should be close to petrol stations.	[27], [31], [34], [40]
		Proximity to point of interest	Conveniently close to the closest location for entertainment and enjoyment such as recreation sites, restaurants, malls, and other tourist attractions.	[21], [27], [39], [40]
		Proximity to current EVCS	Alternative PEVCS locations should not be too close to the current EVCSs.	[33]

Results and Discussion

Previous studies on the allocation of EVCS and PEVCS showed 177 criteria from 2015 to 2023. In addition, 52 out of 177 criteria and six dimensions of the main criteria are selected for the need analysis. The results of the data analysis technique reveal suitable criteria that should be addressed in determining the ideal location for PEVCS in Malaysia. Only percentage agreements of 80% or above are accepted in this study for each Need Analysis criterion, while the remaining criteria are neglected in this study due to respondents' disagreement. Table 2 shows the finding of Society's main criteria.

Table 2. Analysis of Society's main criteria

No	Sub-criteria	Frequency (*N*)		Percentage (%)	
		Yes	No	Yes	No
1.	Traffic convenience	11	1	91.67	8.33
2.	Service radius	10	2	83.33	16.67
3.	Service capability	12	0	100.00	0.00
4.	Research and education	12	0	100.00	0.00
5.	Promotion of EVs potential	11	1	91.67	8.33
6.	Harmonization of PEVCS with urban development and state grid planning	10	2	83.33	16.67
7.	Residents' acceptance	9	3	75.00	25.00
8.	Habit compatibility	10	2	83.33	16.67
9.	Safety for driver and passengers	11	1	91.67	8.33

From Table 2, eight (8) of the criteria are selected and the criteria of residents' acceptance are neglected due to disagreement among the respondents. In Wu *et al*. [20] study, those criteria are less important to be considered for allocating the suitable location of PEVCS. Next, Table 3 shows the finding of the Economy's main criteria.

Table 3. Analysis of Economy's main criteria

No	Sub-criteria	Frequency (*N*)		Percentage (%)	
		Yes	No	Yes	No
1.	Construction cost	12	0	100.00	0.00
2.	Annual operation and maintenance cost	11	1	91.67	8.33
3.	Land value	11	1	91.67	8.33
4.	Investment payoff period	10	2	83.33	16.67
5.	EV ownership in the service area	11	1	91.67	8.33
6.	Distance to the power cut	10	2	83.33	16.67
7.	Parking fee	11	1	91.67	8.33
8.	Number of supplied EVs	10	2	83.33	16.67
9.	Monthly average charging frequency by region	10	2	83.33	16.67
10.	Station equipment	10	2	83.33	16.67

Based on Table 3, all the criteria under the Economy dimension are considered in this study. None of them are rejected due to the agreement of the respondents being 80% or above. Besides, Table 4 analysed the Environment's main criteria.

Table 4. Analysis of Environment's main criteria

No	Sub-criteria	Frequency (*N*)		Percentage (%)	
		Yes	No	Yes	No
1.	Electromagnetic interference	8	4	66.67	33.33
2.	The degree of damage to the surrounding environment	8	4	66.67	33.33
3.	Greenhouse gas (GHG) and fine particles emission reduction	10	2	83.33	16.67
4.	Air quality	10	2	83.33	16.67
5.	Distance of water resources	7	5	58.33	41.67
6.	Distance of landslide risk	11	1	91.67	8.33
7.	Slope of land	10	2	83.33	16.67
8.	Land type	9	3	75.00	25.00
9.	Possibility of expansion	10	2	83.33	16.67
10.	Waste discharge	9	3	75.00	75.00
11.	Protected area	10	2	83.33	16.67
12.	Flooding risk	11	1	91.67	8.33

Only seven (7) criteria are accepted to be in this study and the rest are eliminated as shown in Table 4. Based on the result from respondents, they thought the distance of water resources does not affect PEVCS allocation because Kaya *et al.* [36] and Sisman *et al.* [34] also portrayed it as a less important criterion to be considered. However, the respondents agreed to choose the criteria of flooding risk compared to the distance of water resources. Consequently, the sub-criteria of electromagnetic interference are not influenced in determining the suitable location for PEVCS in Malaysia. Electromagnetic interference rarely happens in Malaysia because Fikry *et al.* [41] claimed that Malaysia's electricity transmission cables fall below the permitted exposure limits. The respondents believed that land type is not significantly important because, from the literature reviews, there are limited studies taken into consideration for that criterion. Hence, the respondents assumed that waste discharge is less important since Abdullah and Mohamad [42] stated the research and industrial phases of the disposal of batteries are currently developing and in the early stages. Then, Table 5 showed the analysed of the Technology's main criteria.

Table 5. Analysis of Technology's main criteria

No	Sub-criteria	Frequency (*N*)		Percentage (%)	
		Yes	No	Yes	No
1.	Power quality influence	12	0	100.00	0.00
2.	System reliability	11	1	91.67	8.33
3.	System security	12	0	100.00	0.00
4.	Number of installed rapid charging stations	12	0	100.00	0.00
5.	Number of charging connectors	12	0	100.00	0.00
6.	Solar energy potential	11	1	91.67	8.33

All the criteria for the Technology aspect are considered in this study as shown in Table 5. Since 80% or more of the respondents agreed with each criterion, none of them are disregarded. In addition, Table 6 indicates the finding of Accessibility's main criteria.

Table 6. Analysis of Accessibility's main criteria

No	Sub-criteria	Frequency (*N*)		Percentage (%)	
		Yes	No	Yes	No
1.	Population density	11	1	91.67	8.33
2.	Shopping malls	10	2	83.33	16.67
3.	Healthcare center	9	3	75.00	25.00
4.	Roads/ Road access	11	1	91.67	8.33
5.	Current EVCS	11	1	91.67	8.33
6.	Existing petrol station	11	1	91.67	8.33
7.	Park areas	12	0	100.00	0.00

In the Accessibility aspect, the respondents agreed six (6) out of seven (7) criteria need to be considered in determining the ideal location for PEVCS in Malaysia excluding healthcare centers. The healthcare center is not suitable criteria to allocate the PEVCS due to safety reasons. One of the respondents stated that the PEVCS should be located far from the healthcare center where the location is always crowded because many people with diverse medical illnesses, especially high-risk patients, are receiving treatment. Moreover, Table 7 displays the findings of Proximity's main criteria.

Table 7. Analysis of Proximity's main criteria

No	Sub-criteria	Frequency (*N*)		Percentage (%)	
		Yes	No	Yes	No
1.	Proximity to junction	6	6	50.00	50.00
2.	Proximity to the main road	11	1	91.67	8.33
3.	Proximity to public transport	10	2	83.33	16.67
4.	Proximity to educational	7	5	58.33	41.67
5.	Proximity to medical facilities	7	5	58.33	41.67
6.	Proximity to petrol stations	12	0	100.00	0.00
7.	Proximity to point of interest	10	2	83.33	16.67
8.	Proximity to current EVCS	9	3	75.00	25.00

According to Table 7, four (4) criteria indicate the agreement and disagreement of the respondents. Proximity to junction, educational, and medical facilities are rejected due to safety reasons. Thus, proximity to the current EVCS is a moderately important criterion as supported by Hisoglu *et al*. [7] and Kaya, Tortum, *et al*. [33]. Finally, this study chose 41 of the sub-criteria, including society (8), economy (10), environment (7), technology (6), accessibility (6) and proximity (4). In this study, only percentage agreements of 80% and more for each need analysis criterion are considered, with 9 of them being completely agreed upon, 15, scoring 91.67%, and 17, scoring 83.33%. Due to the respondents' disagreement, the other criteria are discarded in this study. Consequently, the most significant outcomes from the Needs Analysis focused on incorporating the criteria into ArcGIS software to enable the development of a prediction location model that would help determine the best locations for PEVCS installation in Malaysia. In this study, Multi-Criteria Decision-Making (MCDM) methods are used throughout the entire model development procedure.

Furthermore, to calculate the weight of the criteria and rank the alternatives for the allocation-location problem, MCDM methods are used [43]. In fact, there are numerous methods that address real-world MCDM problems, each with its own advantages and disadvantages [18]. Therefore, to pinpoint suitable locations for PEVCS in Malaysia, an advanced PEVCS location prediction model is developed in anticipation of future study. For the purposes of developing this model, Geographic Information System (GIS) approaches are integrated with MCDM methodologies. Thus, the forthcoming studies proposed the employment of Analytic Hierarchy Process (AHP) and Fuzzy Analytic Hierarchy Process (FAHP) methods with GIS to build the new location model. Consequently, the alternative locations are ranked using the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method.

Conclusions

From the Need Analysis conducted in this study, there are 41 of the sub-criteria from six (6) main criteria are selected in determining the suitable location for PEVCS in Malaysia. 11 of the sub-criteria are discarded from this study due to disagreement of the respondents. From this survey, some of the respondents mentioned in the comment section the suggestion for this study. They realize that the adoption of solar is still minimal in Malaysia. Besides, the respondents also suggested allocating the CSs every 50-100km within the driving range. In addition, they also recommended having a specific mechanism to monitor ICE vehicle users using the facilities at PEVCS and causing problems for EV users, especially in locations with high population density, high crime or vandalism rates, and famous spots during the weekend or holiday season.

Consequently, this survey helps the researchers to select the most suitable criteria from the previous studies. This study develops a questionnaire with a dichotomous scale inquiring respondents to either agree or disagree with each criterion to analyse the data. Therefore, this study suggests for future research to use Likert scales in analysing the Need Analysis' data and calculating the mean and standard deviation values for better results. As has been noted, GIS-based MCDM methods are recommended for future studies to allocate the ideal locations for PEVCS in Malaysia by developing a novel prediction location model.

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

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