Jurnal TEKNO
(Civil Engineeering, Elektrical Engineeering and Industrial Engineeering)
Vol. 20, No : 1, April 2023 , p-ISSN:1907-5243, e-ISSN: 2655-8416

Selection of Charging Station Location based on Sustainability Perspective using AHP Method

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Abstract

The acceleration of electric vehicle (EV) development in Indonesia to support energy and environmental sustainability has taken over and attracted the attention of many parties. Various policies, programs, and research outputs have made the public aware of EVs. However, the availability of charging stations (CS) in the community and the optimal placement are matters of great concern as CS is an essential infrastructure that enhances EV development. Therefore, to support sustainable urban development, CS location selection must consider a sustainability perspective in decision-making. In this study, we employed Analytical Hierarchy Process (AHP) method to assess the best placement of CS in Surakarta based on a sustainability perspective. Ten sub-criteria were identified based on a literature review to establish a hierarchy structure of the problem. We distributed a questionnaire to five experts in different fields to assess the importance scale for each sub-criteria and five alternatives location. The priority value and rank of each sub-criteria and alternative were generated. We found that CS 1 obtains the highest-ranking of preferable sites. The level of water and vegetation damage, service capacity, and impact on society are the most critical parameters that must be considered carefully in choosing a CS location. This study supplements literature for location selection and the application of the AHP method.

Keywords: electric vehicle, charging station, location selection, sustainability, AHP

1. INTRODUCTION

Recently, EVs have attracted the attention of many groups, including the industry, society, and universities. The government has released various regulations and policies related to this EV program, for example, setting incentives, electricity tariffs, providing EV charging infrastructure, and so on [1]. Through this program, the government continues to gradually encourage the public to be able to use EVs, one of which starts with public transportation [2]. It is marked by the launching of the use of electric buses and startups engaged in online transportation that has used electric motorcycles in their operations [3], [4]. In addition, the industry and universities are also involved in this program since EV is one of the priority innovation products on the national research priority map. The output of research and development activities for EVs from top national universities in Indonesia [5],

[6], including energy storage systems and standards development [7]. Furthermore, the public is also becoming more aware of EVs, marked by an increase in the population of EVs circulating in the community, although not significantly [8].

As the energy supply provider of EVs, the availability of charging stations (CS) in the community is an essential infrastructure supporting EV development [9], [10]. The availability of efficient, convenient, and economical CS can increase consumer motivation to purchase EVs and encourage the development of the EV industry [11]. In addition, considering the government's priority to encourage the use of EVs for urban residents, developing CS infrastructure in locations that are easily accessible to users is of particular concern. Therefore, the selection of places in the development of CS infrastructure needs to be considered to significantly impact the operational efficiency and service quality of CS [12].

Gas stations, as the provider of fuel oil for conventional vehicles, already have a widespread network throughout the country. Due to its vast network and strategic location, gas stations can be used as a potential solution for CS development planning [13], [14]. CS at gas stations can provide better energy access for the community to encourage the reduction of carbon emissions and support the acceleration of the electric vehicle ecosystem. In addition, the presence of CS at gas stations can be seen as an innovation for future energy needs that are integrated with the new concept of environmentally friendly gas stations, namely green energy stations (GES) [15]. Furthermore, the provision of charging infrastructure at gas stations, which have high accessibility, is expected to encourage people to switch from oil-fueled to electric vehicles [16]. Thus, this innovation can be a driving force for changes in the lifestyle of the Indonesian people to become more empowered with clean and renewable energy.

CS development planning needs to consider several vital factors to support sustainable urban development [17]. Strezov et al. [18] proposed a sustainability index to measure the economic, environmental and social dimensions simultaneously in sustainable development. These dimensions can be introduced for EV charging infrastructure deployment in an EV growing market [19]. Furthermore, to encourage EVs adoption, Pradhan et al. [20] considered different criteria including technical, environmental, economic, and social factors affecting CS construction to select optimum location. Therefore, in determining the location of CS development, it is necessary to consider the sustainability perspective in decision making.

Given that multiple criteria are considered for selection of CS location, a Multiple Criteria Decision Making (MCDM) technique is required. This paper used Analytical Hierarchy Process (AHP) method to select the best CS site among all alternatives based on competing criteria. This study employed AHP method as a tool to analyze the required data, including the pairwise comparison of sub-criteria and CS candidate site alternatives. The calculation result generated a set of priorities and rank of CS alternatives.

The following describes the problem situation. The EVs development can be enhanced with adequacy of charging facility in the city. Since EVs charging process requires high voltage, the charging facility should be build separated from the residential area. Therefore, it is important to plan the optimal location for charging stations to anticipate the EVs growth in the city of Surakarta. This study proposes an AHP-based framework for prioritizing and ranking CS locations while taking into account environmental, economic, social, and planning factors. As an alternative to potential CS locations, we chose a gas station in each sub-district. Because of its pre-planned and strategic location, a gas station is a viable and more efficient solution.

2. METHODS

2.1. AHP

AHP is a decision-support model that defines complex multi-factor or multi-criteria problems into a hierarchical structure [21]. Hierarchy is defined as a multi-level representation of a complex issue, with the first level being the goal, followed by the factor level, criteria and sub-criteria, and finally alternatives. A hierarchy can be used to break down a complex problem into groups, which are then arranged in a hierarchical form to make the problem appear more systematic and structured.

AHP can help researchers and practitioners explore multicriteria decisions. The major advantage of AHP over other MCDM methods is that it does not require a large sample size to achieve statistically robust results [22], [23]. Darko et al. [24] suggest that AHP can help ensure a high level of consistency among the judgements obtained from multiple experts who might have different perceptions, experiences and understanding of the decision criteria.

The AHP problem structure is given as a level (hierarchy) from the top down, starting from the objectives, criteria, sub-criteria, and alternatives. The AHP method stages are described according to the flowchart in Figure 1.

The first step is defining the problem and determining the goals/knowledge to achieve. The hierarchical structure arranged in the top order is the expected goal (goal decision), followed by criteria (can be continued to sub-criteria), and the lowest level is alternative. Furthermore, we compiled a pairwise comparison matrix for each criterion/sub-criteria and alternatives that have been determined by assessing the relative importance of two elements (paired comparison) using priority scale references that show the intensity of importance from 1 to 9 [21].

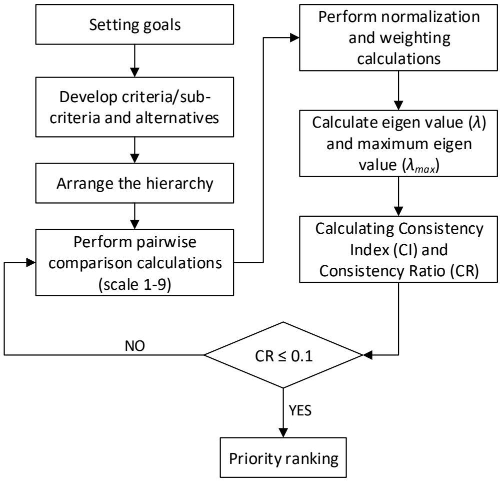

Figure 1. AHP Methodology

The pairwise comparison matrix was generated and the normalization process was carried out to obtain the criterion weight value by using the following formula:

$$w_i = \sum_{i=1}^{n} \frac{a_{ij}}{n} \quad (1)$$

where: a_{ij} states the geometric mean value, w_i is the weighted value, and $\frac{a_{ij}}{n}$ is the row normalization matrix.

Then, the eigenvector value is searched from each pairwise comparison matrix to obtain local priority. The following formula is used to calculate the eigenvalue (λ) and maximum eigenvalue (λ_{max}):

$$\lambda_i = \sum_{i=1}^{n} \frac{a_{ij}}{w_i} \quad (2)$$

$$\lambda_{max} = \sum_{i=1}^{n} \frac{a_{ij}/w_i}{n} \quad (3)$$

After calculating the element weights, the next step is to test the consistency of the matrix to ensure that the resulting priority order is obtained from a series of comparisons still within the limits of logical preferences. A Random Index (RI) table is needed whose values for each matrix order can be seen in Table 1:

Table 1. Random index

Matrix order	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

The consistency index (*CI*) is used to state the consistency of the matrix and is formulated as follows:

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (4)$$

where: λ_{max} is the maximum eigenvalue and n is the number of the matrix.

Furthermore, the Consistency Ratio (*CR*) was calculated to establish data consistency. Saaty [21] set a CR value of 10% for an acceptable standard of consistent data, and if CR > 10%, then the data is inconsistent, so data collection is repeated for pairwise comparisons. The formula used is:

$$CR = \frac{CI}{RI} \quad (5)$$

Finally, a ranking of priorities is drawn up. Priority ranking is based on the highest weighted score. Then a decision is made, where the best alternatives are selected based on the criteria.

2.2. Study Area

The area selected for this study is Surakarta city which is located between 110° 45' 15" and 110° 45' 35" East Longitude and 7° 36' and 7° 56' South Latitude. The area the city is a lowland area with an altitude of ± 92 m above sea level. The size of Surakarta City is 44.04 km² which is divided into five sub-districts: Laweyan, Serengan, Pasar Kliwon, Jebres, and Banjarsari sub-districts. Most of the land is used as a residential area by 65%, while for economic activities it also takes up quite a prominent place, around 16% of the existing land area.

With the opportunity of large population and economic activity, it encourages the government to accelerate the use of EVs in this city. It is marked by the cooperation of the local government with state-owned electricity companies to provide charging facilities for EVs. The choice of charging location needs to be studied through the application of the AHP method in this paper. Regarding the potential of gas stations as green energy station infrastructure, we randomly selected one gas station from each sub-district to be used as a charging station candidate site. In this case, the local government is the decision-maker in charging facility planning. Figure 2 shows a map of the Surakarta area and candidate points for charging station (CS) locations.

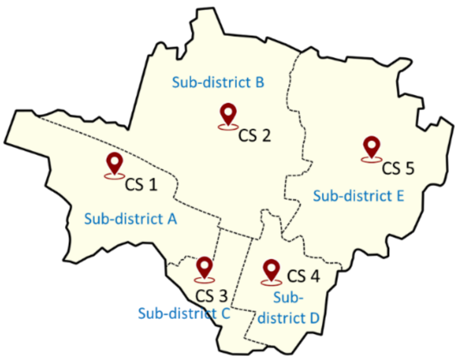

Figure 2. Study area

2.3. Selection criteria for EV charging infrastructure based on sustainability perspective

In the development of charging infrastructure, sustainability aspects have been considered in previous studies. Researches related to EV charging infrastructure consider one or more aspects of sustainability (for further details, see Table 3). Before selecting a charging station location, we conducted a literature review to identify the factors that influence the selection of a charging station based on a sustainability perspective. These factors include criteria and sub-criteria, which are used as parameters to choose a charging station location. The results literature review and identification are compiled in Table 2, which contains the details of the criteria, sub-criteria, and their description. We adopted these aspects in this study to serve as criteria in selecting the CS location in the city of Surakarta.

Table 2. Sustainability perspective of EV charging infrastructure

Criteria	Sub-criteria	Description	Ref.
Social (C_1)	Service capacity (C_{11})	Refers to the number of EVs using the CS charging service, the maximum charging volume, and the daily charging volume.	[25], [26]
	Traffic convenience (C_{12})	Situation at the primary road, the number of crossing points and vehicle paths near the CS location.	[27], [28]
	Impact on society (C_{13})	Related to the adverse effects of electromagnetic fields and noise on residents' daily lives caused by the construction and operation of CS.	[29], [30]
Environ-ment (C_2)	Waste discharge (C_{21})	Measures construction waste and sewage discharged during CS construction, as well as wastewater effluent from vehicle cleaning and battery disposal during CS operation.	[25], [31]
	Water and vegetation damage (C_{22})	Measures vegetation deterioration and water loss caused by land development to construct CS.	[32], [33]
Econo-my (C_3)	Annual operation and maintenance cost (C_{31})	Includes electricity costs, staff wages, financial expenses, tax, and battery depreciation.	[25], [34]
	Construction cost (C_{32})	Includes the cost of land, demolition, equipment acquisition, and project investment.	[35], [36]
	Investment payback period (C_{33})	The total cost of construction divided by the monthly returns	[36], [37]
Planning (C_4)	Accessibility (C_{41})	Ease of access to CS sites, including distance and CS operating hours	[38], [39]
	Parking situation (C_{42})	Enough space for a parking area and convenient access to the entrance and exit of the parking area	[40], [41]

A decision hierarchy can be created from the top to the bottom level by identifying the aspects that influence the charging location decision-making process. The top-level is the goal, namely selecting a charging station location. At the second level are the criteria for the sustainability of a system/management, and at the third level, there are alternatives, namely the site of the charging station candidate. Figure 3 shows the established hierarchy structure of the problem.

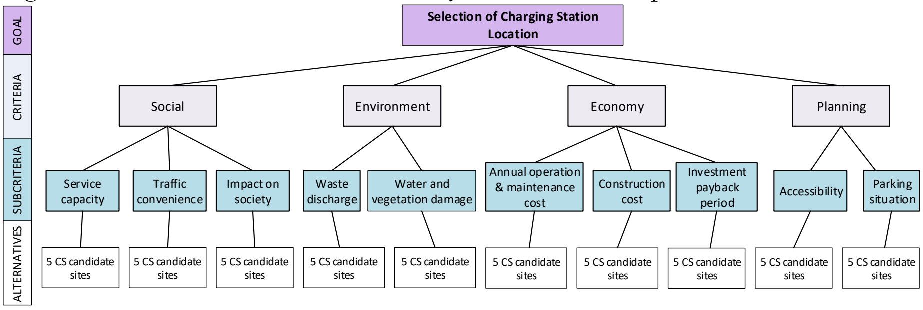

Figure 3. Hierarchy structure

2.4. Respondents

Respondents in this study were experts who gave a perception of the selection of CS locations within the scope of sustainability. Experts involved in the study were selected based on one or more of the assessment panel criteria [42], namely: the respondent has previous experience in at least one system component; current or previous leadership or management role in one or more specific areas of the EV infrastructure development scheme; at least five years of combined and professional experience in EV infrastructure development; publications, participation in professional meetings and symposia and current or previous membership in organizations involved in EV infrastructure development; and expertise given the time and resources available. The experts involved in the assessment process are from different fields, namely technology commercialization, energy, environment, supply chain design, and urban planning.

The assessment survey data from the experts were then recapitulated, and we input the comparison matrix into the Expert Choice software. With this software, we can generate the priority and rank of each alternative. From the data processing and analysis results, criteria and alternatives with the most significant weight are obtained as considerations for determining priorities for choosing a charging station.

3. RESULTS AND DISCUSSION

We have identified the parameters needed in deciding the location of the charging station construction. Ten sub-criteria of the four sustainability criteria were generated. We performed pairwise comparison calculations on the criteria and alternative elements using the AHP method and the Expert Choice software tool.

As a result, we generated a priority order of criteria elements that are compared by considering their relationship to goals. It should be noted that the social, environmental, economic, and planning criteria will not be evaluated directly but through their respective sub-criteria. Table 3 shows the results of a pairwise comparison of each sub-criteria.

Table 3. Pairwise comparison of sub-criteria

Sub-criteria	C_{11}	C_{12}	C_{13}	C_{21}	C_{22}	C_{31}	C_{32}	C_{33}	C_{41}	C_{42}
C_{11}	1	1	2	7	0.14	6	7	7	3	5
C_{12}	1	1	0.33	1	0.2	2	0.25	0.25	8	9
C_{13}	0.5	3	1	5	0.5	9	0.5	3	5	9
C_{21}	0.14	1	0.2	1	1	7	4	0.33	5	0.25
C_{22}	7	5	2	1	1	0.33	1	4	7	5
C_{31}	0.17	0.5	0.11	0.14	3	1	1	1	0.25	5
C_{32}	0.14	4	2	0.25	1	1	1	1	0.13	2
C_{33}	0.14	4	0.33	3	0.25	1	1	1	0.14	5
C_{41}	0.33	0.13	0.2	0.2	0.14	4	8	7	1	9
C_{42}	0.2	0.11	0.11	4	0.2	0.2	0.5	0.2	0.11	1

We used consistency analysis to validate the result and to prove that there is no bias with respondents [43]. We have presented the results of Consistency Ratio in Table 4. From the table, we know that the comparison matrix for the five CS with respect to each sub-criteria has a consistency of less than 0.1. Thus, it can be said that the AHP results is consistent, and the accuracy is guaranteed.

Table 4. Consistency ratio of each sub-criteria

Sub-criteria	Consistency Ratio (CR)
Water and vegetation damage	0.03
Waste discharge	0.07
Construction cost	0.06
Annual operation and maintenance cost	0.05
Investment payback period	0.04
Traffic convenience	0.07
Service capacity	0.1
Impact on society	0.09
Accessibility	0.05
Parking situation	0.03

Moreover, from the calculation results, the overall priority of the sub-criteria was also obtained and is shown in Figure 5. This priority indicates the most influential parameter in choosing the location of a charging station in the city. The results show that water and vegetation damage is the most influential and critical sub-criteria with a weight of 0.19. The high value of the water and vegetation damage sub-criteria indicates that in choosing the location of the charging station, the vegetation deterioration and water loss factors caused by land development to construct CS are things that need to be considered and prioritized in decision making.

Figure 4. Priority of each sub-criteria

Based on Figure 4, we can find out the sub-criteria that received greater attention from experts, namely: water and vegetation damage related to environmental criteria, service capacity & impact on society related to social criteria, followed by accessibility related to planning criteria. Meanwhile, sub-criteria related to economic criteria are not very important.

The results of the AHP where the water and vegetation damage sub-criteria rank first reflects the reality of the development of EV and charging infrastructure in the city of Surakarta. Currently the local government is concerned with the implementation of the green city policy in Surakarta, where the local government is intensively reforesting the corners of the city. In addition, the policies related to green cities include environmentally friendly city planning and design, efficient energy consumption, and the implementation of a sustainable transportation system. These policies are in line with the objectives of developing the EV ecosystem and charging infrastructure in the city. Thus, crop damage and water pollution due to waste are important concerns in urban spatial planning.

Meanwhile, the social criteria in the selection of CS locations also reflect the fact that there are challenges in developing an EV ecosystem in the city, where people are still hesitant to transition from conventional vehicles to EVs. The public is still skeptical about product capabilities, infrastructure availability and selling prices. Therefore, by paying more attention to social aspects such as service capability of CS and impact on society, it is hoped that the community's doubts will gradually dissipate. Furthermore, the process of educating the public about EV needs to be carried out continuously to open a positive view of the community towards EVs.

By applying AHP, we can generate the results of a comparison of alternative charging station locations when viewed from each sub-criterion. It is to determine the priority of the charging station location based on the weight value of each sub-criteria. The synthesis results for this section are shown in Figure 5.

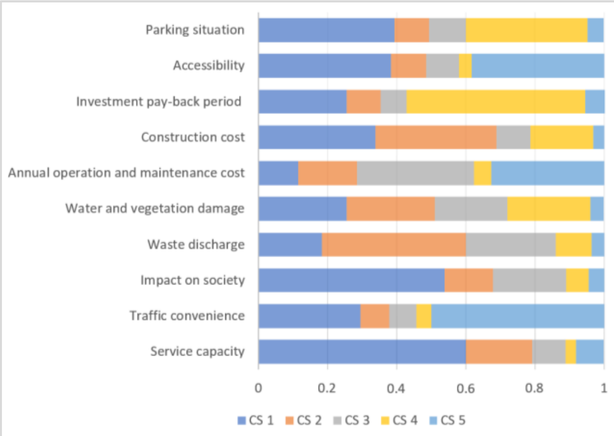

Figure 5. CS location priority based on each sub-criteria

For service capacity sub-criteria, the location of CS 1 is considered the best by the respondents, with a weight of 0.6. In addition to service capacity, CS 1 location also occupies the highest priority in the sub-criteria: impact on society, water, vegetation damage, accessibility, and parking situation, with weight values of 0.539, 0.255, 0.384, and 0.393, respectively. It makes the location of CS 1 rank first in the overall priority of CS site selection. That is, the location of CS 1 becomes the most prioritized and chosen location among the four other CS locations, as shown in Figure 6. Location CS 1 is the most preferred, with a priority value of 0.334.

Figure 6. Overall CS location priority

The high priority value of the CS 1 location is influenced by the situation at the actual site at the existing gas station. The place is quite far from residential areas, so if the CS is to be built there, the negative impacts of the CS construction and operation can be prevented. The noise of EVs passing by does not threaten the lives of residents, and their health is also protected from electromagnetic radiation from CS. Even so, CS 1 is still easy to reach because it is located on the edge of a busy highway with vehicles passing by. In addition, the gas station at the CS 1 location has a vast area, so there is enough space in case of a queue, and it usually opens for 24 hours, so it is convenient for EV users to charge there anytime. Therefore, the accessibility factor and parking situation are guaranteed. In addition, service capacity can be maximized with the broad area of CS 1 and supports the provision of many charging points at that location so that more EVs can use charging services. Thus, the charging volume at the CS 1 location can be maximized to meet the charging demands of EV users.

Furthermore, CS 2 ranks second in the priority of selecting the location of the charging station, which is indicated by a value of 0.21. It is because the CS 2 location has a higher weight value than the other alternatives on three sub-criteria: waste discharge, water, and vegetation damage, and construction cost. The site of CS 2 is the most prioritized in these three sub-criteria, marked by the weight values of 0.416, 0.255, and 0.351, respectively.

Meanwhile, CS 3 and CS 4 excel in economic parameters, namely the annual operation & maintenance cost and investment payback period with weights of 0.338 and 0.518, respectively. It shows that costs for operation and maintenance in CS 3 are expected to be lower, including electricity costs, labor wages, battery depreciation, taxes, and other expenses. It is because the area of the CS 3 location is smaller than the other CS locations, thus allowing fewer charging points to be installed due to the limited space. Therefore, fewer costs are incurred. For CS 4, it is estimated that it will produce a faster payback period than other locations. CS 4 is located in a shopping center close to tourist attractions, so it is estimated that more visitors will come there, which will affect the demand and income from the charging facility.

Moreover, the location of CS 5 excels in its traffic convenience with a weight of 0.5. It means that the primary road situation, the number of vehicle paths, and the number of crossing points near the CS 5 location draw the respondents to choose CS 5. However, this is not enough to make CS 5 the most preferred location, as the sub-criteria parking situation is the least prioritized parameter in determining CS location. Thus, CS 5 comes in last place in priority with a value of 0.134.

The high priority value of the water and vegetation damage sub-criteria generally indicates that environmental factors are crucial things to be considered and considered in the development of CS. It is critical to protect the environment's ability from damage in supporting life at a higher level to improve people's quality of life, which is the goal of sustainable development. To avoid the extinction of life, environmental protection is sought. In other words, damage can cause a significant decline in the ecosystem in which humans live, especially vegetation and water sources. This problem would cause many difficulties in the future of human life. Therefore, environmental sustainability affects the success of the sustainable development of CS.

In addition, the development of CS aims to improve the quality of life of the people and better meet people's basic needs. In other words, the impact of CS development on people's lives and how to fulfill their needs must be accommodated in sustainable development planning. It is in line with the high priority of the service capacity sub-criteria and the impact on society from data processing results. Thus, the target of CS development can be achieved by maintaining the benefits of action or managing natural and environmental resources that have long-term beneficial impacts. Therefore, the quality of human life between generations can be supported by considering sustainable public welfare, both now and in the future.

The government should prioritize places far from rice fields, gardens, and water sources so that the construction of charging stations does not damage the environment. In addition, adequate service capacity also affects the planning process, particularly the technical specifications of the charging station to be installed. Furthermore, the impact on society should also be a significant concern. The location of the charging station should be far from residential areas so that noise and electromagnetic fields due to construction activities and CS operations do not interfere with the population's daily activities.

4. CONCLUSION

In this paper, we addressed multi criteria decision-making problem of optimal charging station location in the city of Surakarta. We identified five alternative locations in the city's five sub-districts. From the literature review, we developed four main criteria and ten sub-criteria to compare the alternative locations with each other. The AHP methodology was employed to calculate the combined weight of each alternative location and rank them. The synthesis of the overall system shows CS 1 is the preferable location while CS 5 is the least preferable location. We found that the level of water and vegetation damage, service capacity, and impact on society are the most critical parameters that must be considered carefully in choosing a location to build a charging station.

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