# Location Selection of Battery Swap Station using Fuzzy MCDM Method: A Case Study in Indonesia

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## ABSTRACT

The rise of Electric Vehicles (EVs), supported by battery swap systems, brings various advantages, including reduced waiting times, lower upfront costs, and alleviating range anxiety. Battery Swap Stations (BSS) enhance green transportation by providing convenient options for EV users, especially in regions with limited fast-charging infrastructure. Many EVs, especially two-wheelers, need battery recharging after reaching their driving range. BSS availability can eliminate charging inconveniences for busy EV drivers. However, selecting BSS locations is often challenging due to budget constraints. This study aims to understand the criteria for selecting BSS locations in Indonesia. Potential location alternatives were identified using a fuzzy multi-criteria decision-making approach and input from government officials and industry experts. Factors like driving range, EV capacity, and budget availability were considered in determining the order of BSS establishment. The study found that technological and social aspects were the top criteria, suggesting that BSS development should prioritize established locations like mini markets and petrol stations.



## 1. Introduction

The International Energy Agency has predicted that Electric Vehicles (EVs) will play a critical role in future sustainable transportation options. EVs offer numerous advantages compared to internal combustion vehicles, including high energy efficiency [1, 2], low environmental impact, and high driving performance [3]. In Indonesia, the Ministry of Energy and Mineral Resources (MEMR) is responsible for the necessary infrastructure preparation for EVs. Under MEMR Regulation Number 13 of 2020, which addresses the provision of electric charging infrastructure for Battery Electric Vehicles (BEVs), the ministry has the authority to oversee the construction of charging facilities and EV battery exchange stations in selected cities. Additionally, MEMR is empowered to issue Business Permits for Electricity Provision, specifying eligible business areas such as gas stations, offices, shopping centers, or parking lots. As of July 2021, EVs have 166 charging stations (SPKLU) across 135 sites, predominantly on Java Island, and 74



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SPBKLU units in 73 sites [4]. Despite the presence of charging infrastructure, the inconvenience of waiting for the battery to charge sufficiently has impacted preferences toward EVs. The development of additional infrastructure for DC Fast Chargers, which enables faster charging times, proves expensive. Consequently, the Government has granted business permits for battery swap stations alongside the existing General Electric Vehicle Battery Exchange Station outlined in MEMR regulations. The General Electric Vehicle Battery Exchange Station, commonly known as Battery Swap Station (BSS), integrates green transportation concepts and energy sources, providing EV users with additional options for a more comfortable journey, given the limited availability of government-operated fast-charging infrastructure. At a BSS, a stockpile of fully charged batteries is readily accessible, allowing consumers to replace their depleted batteries with charged ones swiftly. This approach offers two key advantages: 1) it reduces waiting time for consumers, and 2) it eliminates the influence of irregular charging on grid functioning [5]. As a result, the proper development and investment in BSS are crucial for promoting EVs in alignment to encourage green transportation alternatives.

However, the EV industries face several limitations, including inadequate charging facilities, lengthy battery recharge times, and limited driving range [6], particularly in developing countries with less geographically distributed EV infrastructure [7, 8]. The Government and other stakeholders must establish a robust EV support infrastructure to overcome these obstacles. While battery charging stations can be helpful, the waiting time for a battery to be fully charged still impacts the overall performance of drivers. The most viable solution lies in battery swapping, which involves replacing depleted batteries with fully charged ones [9]. The battery-swapping system addresses the supply-demand imbalance in the power generation industries [10]. Also, it represents a significant breakthrough for electric motorcycle users in Indonesia, where two-wheeled EVs such as electric bicycles and motorcycles dominate the roads. By swiftly swapping and replacing batteries at BSS, drivers can minimize downtime and promptly resume work after battery replacement. Given the limitations of EV driving range and the characteristics of battery swapping, this development becomes a critical component in establishing green logistics.. According to Yang, et al. [11] third-party battery swap service providers can meet the future demand for fast and reliable EVs. In Indonesia, such services have flourished due to the limited availability of similar services. The development of EV charging infrastructure on par with conventional petrol stations is expected to increase electric scooter sales by 21%.

Many studies have addressed the location problem of BSS by employing mathematical modeling, as described in [12-17]. In terms of BSS operational aspects, Amiri, et al. [18] proposed a battery scheduling strategy for BSS, considering location and vehicle priority. Wu, et al. [19] investigated charging schemes for BSS to minimize operational costs and also considered the impact of battery charging damage on BSS performance. Mahoor, et al. [20] similarly proposed a swapping strategy to minimize costs, considering the uncertain demand for battery swapping. Once BSS locations have been determined, these strategies can be integrated. However, it is equally important to consider qualitative factors such as location preferences, sustainability, and other influences in order to make informed decisions. When selecting the optimal BSS location, investors are primarily concerned with two issues. The first is the identification of quantitative and qualitative criteria with conflicting properties [21]. The second issue is the selection of decision-making methods. The selection of BSS location is a complex Multi-Criteria Decision Making (MCDM) problem that cannot be reduced to a single factor, necessitating the consideration of multiple factors, including economic, environmental, social, and technological factors. Moreover, due to the subjective nature of qualitative

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judgments, the opinions of experts may include various responses, such as yes, abstain, no, and refusal, which cannot be accurately expressed using crisp values or even described by the fuzzy set (FS) theory [22].

The initial step in location selection involves identifying quantitative and qualitative criteria, which may have conflicting characteristics. Various MCDM methodologies, such as the Analytical Hierarchy Process (AHP), Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS), and Multi-Objective Optimization based on Ratio Analysis (MOORA), have been employed to make decisions considering multiple criteria. These methodologies have been incorporated into different decision-making processes, including supplier selection [23-25], material handling equipment selection [26], and location selection [27, 28]. The selection of locations for EVCS has been the subject of numerous studies, employing multi-criteria group decision-making approaches and focusing on various linguistic criteria [29, 30]. In recent years, studies have been conducted on EVCS. For example, Wang, et al. [31] developed a multi-objective strategy for designing EV charging stations, considering thirteen sub-criteria related to natural, managerial, public facility, and economic factors. Guo and Zhao [32] established an assessment model for EVCS that considered environmental, economic, and social concerns from a sustainability perspective and then evaluated the alternatives using fuzzy TOPSIS. Zhao and Li [33] also conducted a similar study, incorporating the sustainability aspect. Wu, et al. [34] incorporated five aspects, namely economic, social, environmental, technical, and service effectiveness, to address the EVCS location problem using the PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations) approach. A similar study was also conducted to solve the EVCS problem in Turkey using Fuzzy AHP and TOPSIS [35]. The location selection for EVCS using hexagonal fuzzy and incorporating it with different MCDM methods is conducted in India by considering new factors, namely transportation factors including traffic condition attribute, number of roads, and availability of parking area [36].

Unfortunately, there has been limited literature discussing the specific criteria set for BSS. The decision regarding the location of BSS is believed to be closely connected to the selection of sites for electric vehicle charging stations (EVCS). Wang, et al. [37] conducted a comprehensive study on BSS location decisions, considering economic, environmental, social, and technical aspects. They utilized a combination of Decision-Making Trial and Evaluation Laboratory (DEMATEL), Fuzzy Ordered Weighted Averaging (FOWA), and Multi-objective optimization based on ratio analysis plus full multiplicative form (MULTIMOORA) to determine the weights of sub-criteria and rank alternative regions for BSS adoption. Another study conducted in India incorporated both MCDM and location determination by considering economic, technical, and social criteria with a total of nine attributes [5]. However, these studies focused solely on the decision-making process of individual decision-makers.

Many studies have employed different methodologies to determine optimal locations for EVCS and BSS based on their respective criteria. However, there is a gap in the literature regarding case studies conducted in Indonesia. The studies have focused on regions or geographical sites as alternative locations, overlooking the potential suitability of existing public facilities for BSS placement. The objective of this study is to comprehensively understand the important criteria used in selecting BSS locations in Indonesia. In order to accomplish this objective, multi-decision-making attributes are employed to establish the order of BSS establishment, considering factors such as driving range, EV capacity limitations, and the budget availability of relevant parties. Data has been gathered through input from experts in private and government-owned companies directly involved in decision-making processes for BSS locations. Fuzzy multi-decision-

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making determines the weights assigned to each characteristic linked to the BSS placement. Furthermore, this study considers the financial constraints of the stakeholders. It provides viable options for BSS sites and the suggested construction order. This methodology offers valuable insights to decision-makers facing budget limitations and the need for efficient utilization. The findings show the importance of considering the perspectives of numerous decision-makers in order to facilitate coordination among the growing number of BSS stakeholders.

## 2. Methods

In order to consider the various factors that affect the decision-making process regarding the location of BSS, this study undertook assessments that involved engaging with key stakeholders. The primary objective of these assessments was to identify the factors that hold significant influence over this decision. Moreover, it was necessary to assign a weight to each attribute that precisely represented its importance in the process of decision-making. In this study, the utilization of the fuzzy factor rating method was proposed as part of the group decision-making process. This method addressed the inherent imprecision and uncertainty associated with location decision-making by incorporating fuzzy logic. The "fuzzy factor rating system under group decision-making conditions" developed by Maharjan and Hanaoka [27] was adapted to facilitate the calculation of subjective attribute importance weights. The proposed methodology is represented in Fig. 1.

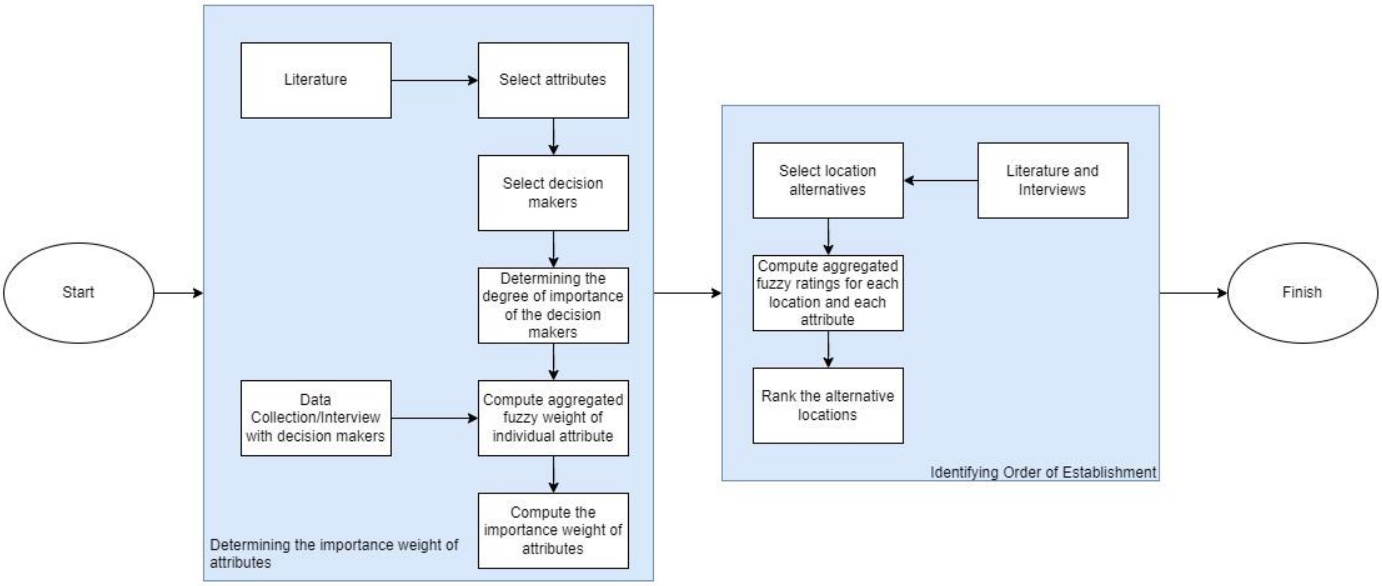


Fig. 1. Methodology/Framework for Location Selection of Battery Swap Station

### 2.1. Determining Attributes and Decision Makers

Several attributes played a role in determining the order of BSS establishment. In this study, " attribute " refers to subjective attributes. Criteria such as proximity to the city center, high traffic location, accessibility, and low risk of disasters, particularly floods, were selected based on interviews with four stakeholders involved in BSS establishment, including two EV and BSS development companies and two representatives from Indonesian government ministries and state-owned enterprises. These attributes were selected by considering both the literature and interview results. A committee of decision-makers could be formed based on their overall involvement in EV development activities, often leading to different scenarios and opinions.

## 2.2. Determining Degree of Importance of Decision Makers

The next step was to determine whether decision-makers were homogenous or heterogeneous. If all decision-makers had an equal degree of significance, the group was considered homogenous. Conversely, if there were variations, the group could be regarded as heterogeneous. In a group consisting of $K$ decision makers ($D_k$, $k$= 1, 2, …, $K$) who were responsible for evaluating $M$ alternatives ($A_m$, $m$= 1, 2, …, $M$) across $N$ attributes ($AT_n$, $n$ = 1, 2, …, $N$), as well as assessing the importance of these attributes, the significance of each decision maker was denoted as $I_k$, ($k$ = 1, 2, …, K), where $I_k \in [0, 1]$ and $\sum_k^K I_k = 1$. If $I_1 = I_2 = I_3 = \cdots I_K = \frac{1}{K}$, then the group of decision-makers was referred to as homogeneous. Otherwise, it was considered heterogeneous. The significance of each decision-maker could be determined through interviews with the ultimate decision-maker or by analyzing their involvement in BSS investment.

Each decision maker was provided with a questionnaire that utilized linguistic factors defined to evaluate the significance of the attributes. The rating scale used was consistent with the one employed by Liang [38], Yong [39], and Chou, et al. [40], as shown in Table 1.

Table 1.. Linguistic Variable for Importance of Attribute

| Linguistic Variable | Fuzzy Number |
|---|---|
| Very Low (VL) | (0, 0, 0, 3) |
| Low (L) | (0, 3, 3, 5) |
| Medium (M) | (2, 5, 5, 8) |
| High (H) | (5, 7, 7, 10) |
| Very high (VH) | (7, 10, 10, 10) |

To calculate the overall fuzzy rating of individual attributes, let $\widetilde{W_{nk}} == (a_{nk}, b_{nk}, c_{nk}, d_{nk})$, with $n$=1,2,…,$N$ and $k$=1,2,…,$K$, be the linguistic rating given to attributes $AT_1, AT_2, \dots, AT_N$ by decision maker $D_k$.

The aggregated fuzzy rating, $W_n = (a_n, b_n, c_n, d_n)$, of attribute $AT_n$ assessed by the committee of $k$ decision makers, as defined by Equation (1).

$$\widetilde{W}_n = (I_1 \otimes \widetilde{W}_{n1}) \oplus (I_2 \otimes \widetilde{W}_{n2}) \oplus .. \oplus (I_k \otimes \widetilde{W}_{nK}) \quad (1)$$

where, $a_n = \sum_k^K I_k a_{nk}$, $b_n = \sum_k^K I_k b_{nk}$, $c_n = \sum_k^K I_k c_{nk}$, $d_n = \sum_k^K I_k d_{nk}$.

## 2.3. Importance Weight of Attributes Calculation

This stage involved computing the importance weight of attributes, defuzzifying the fuzzy rating for each attribute, calculating the normalized weights, and constructing the weight vector. The signed distance method was used to defuzzify the evaluation of fuzzy properties. The defuzzification of $\widetilde{W}_n$, denoted as $d(\widetilde{W}_n)$ was provided by Equation (2).

$$d(\widetilde{W}_n) = \frac{1}{K}\,(a_n, b_n, c_n, d_n) \quad (2)$$

The crisp value of the normalized weight for attributes $AT_n$, denoted as $W_n$, was determined by Equation (3).

$$W_n = \frac{d(\widetilde{W}_n)}{\sum_{n=1}^{N} d(\widetilde{W}_n)} \tag{3}$$

Where $\sum_{n=1}^{N} W_n = 1$, the weight vector $W = [W_1, W_2, \dots, W_n]$ was therefore formed. The crisp value of the normalized weight of the attributes $AT_n$ could be used as the importance weight.

### 2.4. Order of Establishment Priority for BSSs

After ranking the attributes, an alternative location was provided to the decision-makers for tracing the BSS. The alternatives included gas stations, convenience stores, government buildings, public facilities (bus and train stations), and highway rest areas. The objective of this stage was to determine the order in which BSS should be established. In order to accomplish this, a fuzzy multi-attribute group decision-making strategy was employed, utilizing the qualitative qualities chosen in the second stage to assess each BSS site option generated in the first stage.

The step was to assess the fuzzy ratings of the location alternatives based on individual attributes and obtain the decision opinions of decision makers using the linguistic variables outlined by Liang [38], Yong [39], and Chou, et al. [40], as shown in Table 2.

Table 2. Linguistic Variable for Location Alternative

| Linguistic Variable | Fuzzy Number |
|---|---|
| Very poor | (0, 0, 0, 20) |
| Between very poor and poor | (0, 0, 20, 40) |
| Poor | (0, 20, 20, 40) |
| Between poor and fair | (0, 20, 50, 70) |
| Fair | (30, 50, 50, 70) |
| Between fair and good | (30, 50, 80, 100) |
| Good | (60, 80, 80, 100) |
| Between good and very good | (60, 80, 100, 100) |
| Very good | (80, 100, 100, 100) |

Let $\tilde{x}_{mnk} = (o_{mnk}, p_{mnk}, q_{mnk}, r_{mnk}), m = 1, 2, \dots, M;\ n = 1, 2, \dots, N;\ k = 1, 2, \dots, K,$ be the linguistic suitability rating assigned to alternatives $A_m$ for attributes $AT_n$ by decision maker $D_k$. The aggregated fuzzy rating $\tilde{x}_{mn}$ of alternative $A_m$for attribute $AT_n$ assessed by the committee of $k$ decision makers, was defined by Equation (4).

$$\tilde{x}_{mn} = (I_1 \otimes \tilde{x}_{mn1}) \oplus (I_2 \otimes \tilde{x}_{mn2}) \oplus \ldots \oplus (I_k \otimes \tilde{x}_{mnK}) \tag{4}$$

This was further represented and computed as $\tilde{x}_{mn} = (o_{mn}, p_{mn}, q_{mn}, r_{mn}), m = 1, 2, \dots, M;\ n = 1, 2, \dots, N$, where $o_{mn} = \sum_k^K I_k o_{mnk}$, $p_{mn} = \sum_k^K I_k p_{mnk}$, , $q_{mn} = \sum_k^K I_k q_{mnk}$, $r_{mn} = \sum_k^K I_k r_{mnk}$.
Based on these procedures, the fuzzy rating matrix $\tilde{F}$ was generated using the fuzzy ratings and written succinctly in matrix format as shown in Equation (5).

$$\tilde{F} = \begin{bmatrix} \tilde{x}_{11} & \cdots & \tilde{x}_{1N} \\ \vdots & \ddots & \vdots \\ \tilde{x}_{M1} & \cdots & \tilde{x}_{MN} \end{bmatrix} \quad (5)$$

where $\tilde{x}_{mn}\ \forall\ m, n$ is the aggregated fuzzy rating of alternative $A_m$ for attributes $AT_n$.

The total fuzzy score for individual alternatives was obtained by multiplying the fuzzy rating matrix by the corresponding weight vector $W$, as expressed in Equation (6).

$$\tilde{Z} = \tilde{F} \otimes W^T = \begin{bmatrix} \tilde{x}_{11} & \cdots & \tilde{x}_{1N} \\ \vdots & \ddots & \vdots \\ \tilde{x}_{M1} & \cdots & \tilde{x}_{MN} \end{bmatrix} \otimes \begin{bmatrix} W_1 \\ \vdots \\ W_N \end{bmatrix} = \begin{bmatrix} \tilde{f}_1 \\ \vdots \\ \tilde{f}_M \end{bmatrix} = [\tilde{f}_m]_{m \times 1} \quad (6)$$

where $\tilde{f}_m = (s_m, t_m, u_m, v_m)$

The crisp value was calculated by defuzzifying the fuzzy scores $\tilde{f}_1, \tilde{f}_2, \ldots, \tilde{f}_m$ using the signed distance method [41] as shown in Equation (7). The value $d(\tilde{f}_m)$ provided the defuzzified (crisp) value of the total fuzzy score of location alternative $A_m$.

$$d(\tilde{f}_m) = \frac{1}{4}(s_m + t_m + u_m + v_m) \quad (7)$$

This last stage was to determine the sequence of BSS installation and rank the geographical possibilities based on the crisp values. The location possibilities with the highest crisp values were prioritized, followed by those with the lowest values. A higher crisp number indicated better performance of the alternatives compared to the specified qualities.

### 2.5 Case Study

This study was conducted in the Jakarta Metropolitan Area, Indonesia. According to the Ministry of Energy and Mineral Resources, in November 2022, more than 7,600 electric cars and 25,700 electric motorcycles discreetly traversed the streets of Indonesia, which was more than five times the number in 2021. However, the majority of these vehicles were concentrated in the study location. It was noted that drivers still experienced anxiety regarding the driving range of EVs, even though the number of fast battery charging stations was the highest in this area.

## 3. Results and Discussion

### 3.1 Selection Location Result

According to the expert respondents, who were stakeholders in this study, sixteen attributes were suitable for analysis. These attributes were sub-criteria derived from four main criteria, namely environmental, economic, social, and technological factors. The selected attributes are shown in Table 3.

The interview was conducted with two objectives, namely determining the importance of attributes and the order of establishment for locations, incorporating the linguistic scale shown in Table 1 and Table 2. The results of the data collection could be seen in

Table 4.

Based on the unanimous agreement among all stakeholders, the decision-makers involved in assessing the qualitative factors were assumed to be homogenous, indicating

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that the degree of significance was the same for everyone. The aggregated fuzzy rating of individual qualities was produced using Equation (1) and fuzzy numbers corresponding to each linguistic variable. The relative importance of the characteristics was determined by defuzzifying the fuzzy numbers using the signed distance technique described in Equation (2), and the normalized weight was obtained through Equation (3). Fig. 2 show the aggregated fuzzy weight, crisp values after defuzzification, and the normalized weight.

Table 3. Criteria and Sub-criteria Selected as Attributes of BSS Location

| Criteria | Sub-criteria |
|---|---|
| Environmental (C1) | Use of already establish facility (consideration of destruction degree on urban vegetation and landscape) (C11) |
| | Greenhouse gas and fine particulate matter emission reduction (C12) |
| | Easiness of extension and reconstruction in the future (C13) |
| | Low-risk disaster (flood, etc.) (C14) |
| Economical (C2) | Construction cost (C21) |
| | Daily operation and maintenance cost (C22) |
| | Annual profits (C23) |
| Social (C3) | The convenience of accessing public facilities (C31) |
| | The scale of construction and peripheral population density (C32) |
| | Public awareness (C33) |
| | Traffic Convenience (C34) |
| | Service radius (C35) |
| | Harmonization of BSS with urban development and state grid planning (C36) |
| Technological (C4) | Reliability in the future (C41) |
| | Possibility of offering suitable services to the drivers at the BSS in the future (C42) |
| | Security and ability to deal with emergencies in the future (C43) |

Table 4. The results of the interviews for the importance weight of attributes

| Attributes | D1 | D2 | D3 | D4 |
|---|---|---|---|---|
| C11 | M | H | M | VH |
| C12 | H | M | H | VH |
| C13 | M | M | VH | H |
| C14 | M | V | V | M |
| C21 | H | VH | M | H |
| C22 | VH | VH | H | M |
| C23 | VH | VH | M | VH |
| C31 | VH | H | H | VH |
| C32 | VH | H | H | VH |
| C33 | H | VH | VH | H |
| C34 | H | M | VH | H |
| C35 | VH | H | H | VH |
| C36 | H | M | M | H |
| C41 | VH | H | VH | VH |
| C42 | H | M | VH | VH |
| C43 | M | M | H | VH |

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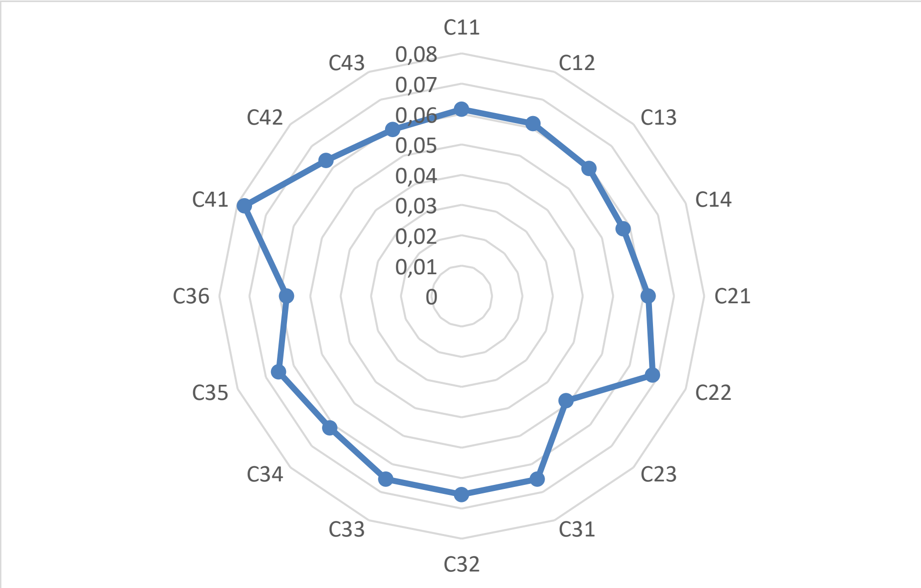

Fig. 2. Normalized Weight for Each Criterion

According to the calculation results, the attributes significant to decision-makers included reliability in the future (C41), daily operation and maintenance cost (C22), convenience in accessing public facilities (C31), the scale of construction and peripheral population density (C32), public awareness (C33), and service radius (C35). During the interview, it was discovered that one of the attributes, namely public awareness (C33), had not been previously addressed in the literature. This was attributed to the novelty of EVs in Indonesia, where decision-makers perceived the importance of BSS locations in improving consumer awareness. Meanwhile, the importance of other attributes was expected based on prior investigations, the current study showed that decision-makers were concerned about the reliability of BSS facilities, mainly due to the low awareness of their functions. Since each attribute was categorized based on four criteria, additional calculations were performed to determine the ranking of criteria importance. The results could be seen in Table 5.

Table 5. Ranking of Importance for Criteria

| Criteria | Average Defuzzified value of AFW | Normalized | Rank |
|---|---|---|---|
| Environmental | 6.765 | 0.240 | 3 |
| Financial | 6.708 | 0.238 | 4 |
| Social | 7.156 | 0.254 | 2 |
| Technological | 7.520 | 0.267 | 1 |

In order to ascertain the sequence of establishment, the study employed a fuzzy multi-attribute group decision-making approach as outlined in the third stage. The evaluation process involved assessing the five potential locations identified during the interview phase, namely gas stations, convenience stores, government buildings, public facilities (such as bus and train stations), and highway rest areas. The scores for each candidate location were calculated using the sixteen attributes selected and their respective importance.

The fuzzy evaluations of the candidate locations based on the language characteristics identified by Liang [38], Yong [39], and Chou, et al. [40], were provided by the decision-makers. The aggregated fuzzy ratings generated for each candidate location, corresponding to each attribute, were computed using Equation (4). By combining the normalized weight and the fuzzy ratings using Equation (5), the overall fuzzy scores for each candidate location were obtained. The crisp values of the total fuzzy scores were then generated through the defuzzification process using Equation (6).

The options were subsequently arranged in order based on the defuzzified total scores, determining the sequence of BSS establishment as shown in Table 6. According to the opinions of the decision-makers and considering budget constraints, locations that satisfied at least six prioritized attributes selected beforehand should be selected for BSS establishment. As a result, convenience stores and gas stations were identified as the preferred location for establishing BSS. This outcome is consistent with expectations since the six most important attributes were associated with the selected location in this study.

Table 6. Order of Establishment

| Candidate Location | Aggregate fuzzy number | Defuzzified total score | Rank |
|---|---|---|---|
| Gas station | (44.35, 64.31, 71.34, 89.87) | 67.46 | 2 |
| Convenience store | (47.21, 66.48, 72.38, 88.76) | 68.71 | 1 |
| Public facilities | (19.23, 37.85, 50.46, 69.17) | 44.18 | 4 |
| Highway | (10.42, 29.40, 43.04, 63.04) | 36.48 | 5 |
| Government building | (30.16, 49.51, 60.14, 77.29) | 54.27 | 3 |

### 3.2. Research Implications

Indonesia is pursuing its green agenda, supported by Presidential Regulation 55 of 2019, emphasizing "The Acceleration Program for Battery Electric Vehicles for Road Transportation". Against the framework of the widespread adoption of electric vehicles (EVs), several challenges have emerged, including the uneven distribution of charging and battery-swap infrastructure and the growing concern over battery longevity. Simultaneously, the inequitable allocation of charging and battery-swap pressure is also taken into account, resulting from the inadequate strategic placement of charging and battery-swapping stations. Consequently, there exists an imbalance in the distribution of these facilities and other associated concerns. This study contributed to the existing body of literature by implementing a methodology that considered different attributes and incorporated multiple decision-makers in determining the location and order of BSS establishment. It also highlighted the importance of integrating factors aside from number and spatial location in decision-making. This methodology provided valuable managerial insights for making informed decisions regarding BSS establishment when resources were limited and their utilization was crucial.

Understanding the criteria based on the different opinions of stakeholders related to EVs could help all stakeholders improve their decision-making processes. Having a homogeneous opinion can potentially contribute to creating a more conducive climate for collaboration, given the existence of varying perspectives on the significance of different criteria. As the Government aims to foster the growth of a well-established battery-swapping business by augmenting the population of electric motorbike riders via establishing an adequate network of battery-swapping stations, they possess the authority to interfere in matters pertaining to the advancement of the battery-swapping sector. The Government is anticipated to implement a viable intervention to support the battery-swapping provider to ensure the industry's sustainability. The battery-swapping providers constitute the second actor in this context, assuming a crucial role in delivering cost-effective services to the battery-swapping users. The battery-swapping provider is anticipated to establish a financially viable enterprise to foster the long-term viability of battery-switching services. Using the proposed methodology above, the provider could focus on developing the BSS infrastructure from the most prominent locations and then could develop BSS in a wider range area. Lastly, EVs use discretion in opting for or against availing themselves of the battery swap service. In order to sustain the utilization of battery switching, it is imperative to provide users with sufficient battery-swapping stations and cost-effective services.

## 4. Conclusion

In conclusion, this study aims to comprehend the significant attributes utilized in determining the establishment of BSS in Indonesia. By incorporating a multi-decision maker, the installation sequence of the BSS can be determined considering the driving range, EV capacity restrictions, and budgetary constraints of the involved parties. The results showed that among the decision-makers, the top six attributes were reliability in the future (C41), daily operation and maintenance cost (C22), convenience in accessing public facilities (C31), the scale of construction and peripheral population density (C32), public awareness (C33), and service radius (C35). Consistently, two locations were prioritized as BSS locations when considering the top six attributes.

This study has limitations in terms of confidentiality protection. Therefore, in-depth discussions regarding the specific locations of each stakeholder were not conducted. Several aspects, including decision-maker heterogeneity, can be the focus of future studies to better approximate real-world scenarios and incorporate parameters such as demand variability and traffic conditions. Further study using real location data is still necessary to understand the optimal location considering the six attributes selected. Several methodologies, such as optimization, can be utilized to determine the ideal location, considering the variability in demand, provided that the data can be gathered.

## Declarations

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