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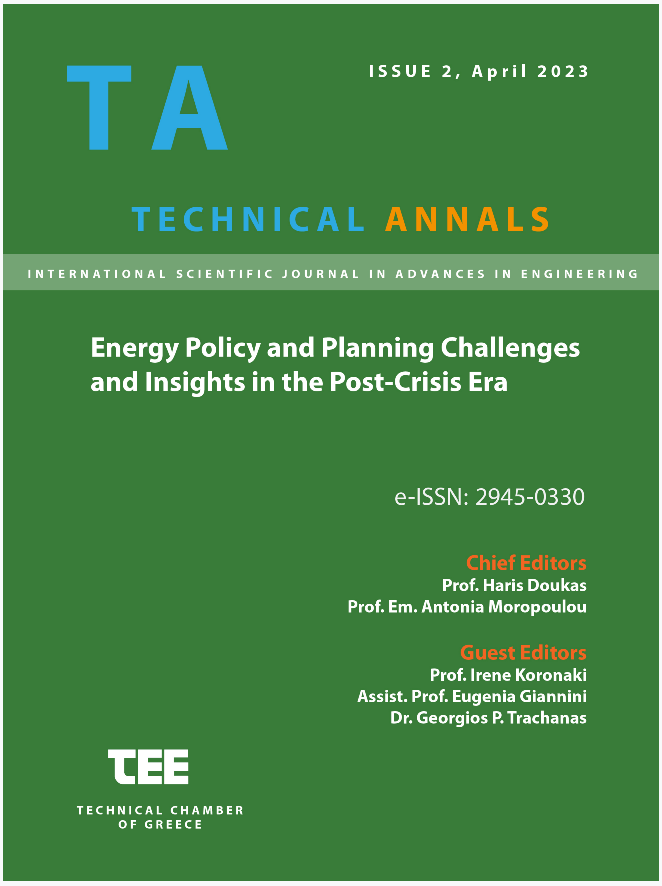

Optimal site selection of electric vehicle charging stations exploiting multi-criteria decision analysis: The case of Greek municipalities

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Optimal site selection of electric vehicle charging stations exploiting multi-criteria decision analysis: The case of Greek municipalities

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Abstract. The opportunities created in the Greek electric vehicle (EV) market have allowed potential investors to participate in developing the country's EV charging infrastructure. Yet, the decision process of relevant stakeholders for strategic investments is challenging, involving the identification of the most promising charging sites from a set of multiple alternative locations of various features that may significantly affect their business competitive advantage. This paper attempts to facilitate decision-making in such settings using a comprehensive, yet thorough multi-criteria decision analysis framework. The proposed approach is validated by considering ten Greek municipalities of different characteristics. The results showcase the overall strengths of the proposed approach and its utility in the strategic planning process of potential investors.

Keywords: Electric Vehicles, Charging Stations, Multi-criteria Decision Analysis, PROMETHEE.

1 Introduction

The entry of battery electric vehicles (BEVs) in the Greek market is quite recent, with the first models appearing only in the last few years [1]. Most car manufacturers have been promoting the use of BEVs, but the response from Greek drivers has been relatively slow. This is in contrast to plug-in hybrid electric vehicles (PHEVs) that have become particularly popular in Greece. Lack of information about the benefits of electric vehicle (EV) mobility, high purchase cost, limited driving autonomy, and lack of public charging infrastructures are just some of the factors contributing to this phenomenon [2].

From the aforementioned factors, the development of an adequate public charging network is imperative for the promotion of EV mobility [3, 4] and the improvement of air quality in residential areas [5]. This is particularly true in Greece where a large proportion of drivers do not have access to private parking, especially in large urban areas. The municipal authorities are expected to play an active role in the correct and orderly development of such infrastructures based on the local geographical specifications, the residential needs, and the required layout and capacity of EV charging stations (EVCSs). With government funding, Greek municipalities have been conducting extensive research to identify the most suitable locations for placing EVCSs. The model for developing the charging network has not been decided yet, but the most prevalent seems to be that of the auction, i.e. assigning the deployment of EVCSs to private entities in exchange for a price.

The opportunities created by this situation in the field of EV mobility enable investors to actively participate in the national map of EVCSs in Greece. Choosing between municipalities for the installation of EVCSs is important for investors because it allows them to prioritize their investment decisions based on the potential return on investment in each location. While it is true that EVs will likely appear in many cities in Greece and investors can diversify the location of their stations, it is still crucial to identify the most promising ones to ensure the highest possible utilization rates and profitability. However, the strategic investment decision process involves identifying, evaluating, and choosing among numerous alternative projects that, depending on their features (e.g. construction and maintenance cost, recovery period, and accessibility), may have a major impact on the realized business competitive advantage of the investors. Therefore, selecting the most promising municipality for the installation of EVCSs becomes an important, multi-dimensional problem that most potential investors will ultimately have to face.

In this paper we present a methodological framework for comprehensively selecting the optimal site to install future EVCSs, taking into consideration four categories of factors that influence the final investment decision: economic, environmental, social, and technological factors. Due to the multi-dimensional nature of the problem, the proposed approach builds on a multi-criteria decision analysis (MCDA) method that effectively filters the alternatives and identifies the optimal solution such that no other feasible option exists that is equally good to the selected solution [6]. Apart from considering trade-offs among the various criteria defined, the proposed approach can also incorporate the judgment of decision makers (DMs), experts, and stakeholders (estimation of criteria weights), while also accounting for uncertainty (evaluation of criteria using qualitative measures) [7].

The rest of the paper is structured as follows: Section 2 includes a presentation of past studies on the problem of optimal EVCS placement. Section 3 presents the proposed methodological approach, including the criteria and MCDA method used, while Section 4 illustrates and discusses the results of an experimental application conducted in Greece. Finally, Section 5 concludes the paper and suggests areas for future research.

2 Literature review

Over the last decade, many studies have been conducted to solve the problem of EVCS optimal siting. The problem is naturally influenced by various conflicting factors, rendering it a multiple-criteria evaluation problem. Consequently, the success of its solution mainly depends on the MCDA method used, the criteria defined, and the weights assumed, all directly affecting the evaluation of the examined EVCS locations (alternatives to the problem). Table 1 presents a collection of such recent studies.

In [8], an MCDA method is developed through Linguistic Entropy Weight (LEW) and Fuzzy Axiomatic Design (FAD) to select a suitable location for an EVCS. Based on the opinions of experts from different fields, a literature survey, and an on-site survey, an evaluation system is designed for EVCS site selection with a sustainable perspective. The system includes 5 criteria about technology, economy, society, environment, and resources and 13 sub-criteria. The weights of the criteria are determined by the LEW method and the most suitable position of the EVCS is determined using the FAD. Furthermore, a comprehensive LEW-FAD analysis framework is constructed and the procedure for determining the optimal EVCS location is given. To assess the stability and robustness of the proposed method, sensitivity and comparison analyses are conducted. The results of the sensitivity analysis show that the ranking of the alternatives is not affected by changes in the functional requirements of the criteria, but is significantly affected by changes in the weights of the criteria. The advantages of the proposed method are highlighted in terms of stability and reliability by comparing it with three MCDA methods (TOPSIS, VIKOR, and MULTIMOORA) applied in previous studies. The results show that the application of the LEW-FAD analysis framework in EVCS location selection is robust, making it suitable for other developing or emerging economies.

The location selection of EVCS is extremely important regarding harmonious and sustainable development. However, errors in the use of multi-criteria decision-making methods could lead to inaccurate and irrational results. In [9], the PROMETHEE method is proposed in combination with the Cloud model to solve the problem of optimal location selection of an EVCS. Using the PROMETHEE method enhances confidence and visibility for DMs and the Cloud model is recommended to fully and accurately describe the randomness of linguistic terms. Finally, an Analytical Network Process (ANP) method is adopted to measure the correlation of indicators with a highly simplified calculation of the parameters and the required steps. The authors conclude that the proposed framework can compensate for many imperfections and inadequacies of traditional MCDA methods proposed in the literature.

Anthopoulos & Kolovou [10] introduced an MCDA framework for the development and operation of EV charging infrastructures in Greece. The Analytical Hierarchy Process (AHP) was the proposed method and the alternative actions were evaluated based on economical, technical, social, environmental, and policy criteria using 13 sub-criteria. The relative importance of each criterion was weighted based on a structured questionnaire given to the participating companies active in the charging infrastructure market in Greece. The results showed that the installation and operation of publicly accessible charging stations located in private spaces, exploited by private entities that can ensure their protection from vandalism, was the preferred action. Based on the criteria weights, it was concluded that with the current condition in Greece, the main incentives for charging operators are not the economic prospects of their investments, but mainly developmental and environmental ones. The selection of a viable installation site plays an important role in the life cycle of an EVCS, which must consider some conflicting criteria.

Guo & Zhao [11] used the Fuzzy TOPSIS method to find the optimal placement area. Based on the literature, research reports, and expert opinions in various fields, the evaluation system for EVCS site selection was built from a sustainability perspective, which consists of environmental, economic, and social criteria, as well as 11 related sub-criteria. Afterwards, the weight of each criterion was selected by five expert groups in the fields of environment, economy, society, electricity, and transport systems. Finally, the alternative EVCS area solutions were ranked using the Fuzzy TOPSIS method, and a sensitivity analysis was performed. The results of the sensitivity analysis showed that the original ideal alternative always secures its top ranking, no matter how the sub-criteria weights change. Moreover, environmental and social criteria required more attention from DMs than economic criteria.

Skaloumpakas et al. [12] also iteratively used the TOPSIS method to dynamically evaluate the alternative locations for the EVCS placement, considering a set of practical criteria related to the traffic intensity and the relative location of the charging stations with interchanges, major cities, and existing stations. The optimal locations were determined by taking into consideration constraints about the EV driving range and installation preferences and were showcased in the Egnatia Motorway, the longest highway in Greece.

Considering the shortcomings of previous heuristic optimization models in dealing with subjective factors, the GRA-VIKOR method was used in [13] to address the issue of EVCS placement. Economical, societal, environmental, and technological criteria were used and further sub-criteria were specified using the fuzzy Delphi method (FDM). In addition, to incorporate subjective opinions as well as objective information, expert ratings, and the Shannon entropy method were used to determine the weights. Next, the applicability of the proposed framework was demonstrated by an empirical study of five alternative EVCS locations in Tianjin. Environment-related sub-criteria received much more attention than other sub-criteria and the sensitivity analysis showed that the selection results remained stable no matter how the sub-criteria weights changed, which verifies the robustness and effectiveness of the proposed model and evaluation results. This study provides a comprehensive and efficient method for optimal placement of EVCS and also innovates in the weight determination and the distance calculation of the conventional fuzzy VIKOR.

In [14], an integrated EVCS site selection decision framework was built for residential communities (EVCSRC) in Beijing with triangular intuitive fuzzy numbers (TIFNs). First, the distinctive index system of EVCSRC site selection factors was established, including economy, society, environment, planning, and a characteristic portrait of residential communities. TIFNs were then used in place of DMs to express unspecified information. In addition, the Fuzzy-VIKOR method was used to rank the alternative EVCSRC positions. Finally, the case of Beijing was studied to demonstrate the validity of the proposed site selection framework. The result showed that the EVCSRC site located in the Haidian District of the Sijiqing Community should be selected as the optimal site and presented a feasible and easy-to-use decision-making framework for investors.

Table 1. Studies on optimal placement of EVCSs.

Title	**Method**	**Reference**
A multi-criteria approach for optimizing the placement of electric vehicle charging stations on highways	Dynamic TOPSIS	Skaloumpakas et al. (2022) [12]
A novel multi-criteria decision-making method for selecting the site of an electric-vehicle charging station from a sustainable perspective.	LEW & FAD	Feng et al. (2021) [8]
A Multi-Criteria Decision Process for EV Charging Stations' Deployment: Findings from Greece.	AHP	Anthopoulos & Kolovou (2021) [10]
A decision framework for electric vehicle charging station site selection for residential communities under an intuitionistic fuzzy environment: A case of Beijing.	Fuzzy VIKOR	Wu et al. (2017) [14]
Optimal siting of charging stations for electric vehicles based on fuzzy Delphi and hybrid multi-criteria decision-making approaches from an extended sustainability perspective.	GRA-VIKOR	Zhao & Li (2016) [13]
Optimal site selection of electric vehicle charging stations based on a cloud model and the PROMETHEE method.	PROMETHEE	Wu et al. (2016) [9]
Optimal site selection of electric vehicle charging station by using fuzzy TOPSIS based on sustainability perspective.	Fuzzy TOPSIS	Guo & Zhao (2015) [11]

Following the best practices identified in the literature, the present paper utilizes the PROMETHEE method and incorporates the most common, yet representative criteria of past studies, being based on four pillars: environment, economy, society, and technology. The contribution of the paper is found in the examination of a multi-complex ecosystem that includes islands, urban, and rural municipalities. To the best of our knowledge, this is the first paper that compares different geographical areas for the optimal site selection of EVCSs.

3 Multi-criteria decision analysis approach

3.1 General discussion

To assist DMs select the most promising municipality for placing a new EVCS, the proposed approach utilizes an MCDA method, a set of environmental, economical, social, and technical criteria identified in the literature, and the preferences of DMs to properly weigh each criterion. Consequently, the alternatives are evaluated and ranked, determining the municipalities of the highest potential. An overview of this proposed approach is presented in Figure 1.

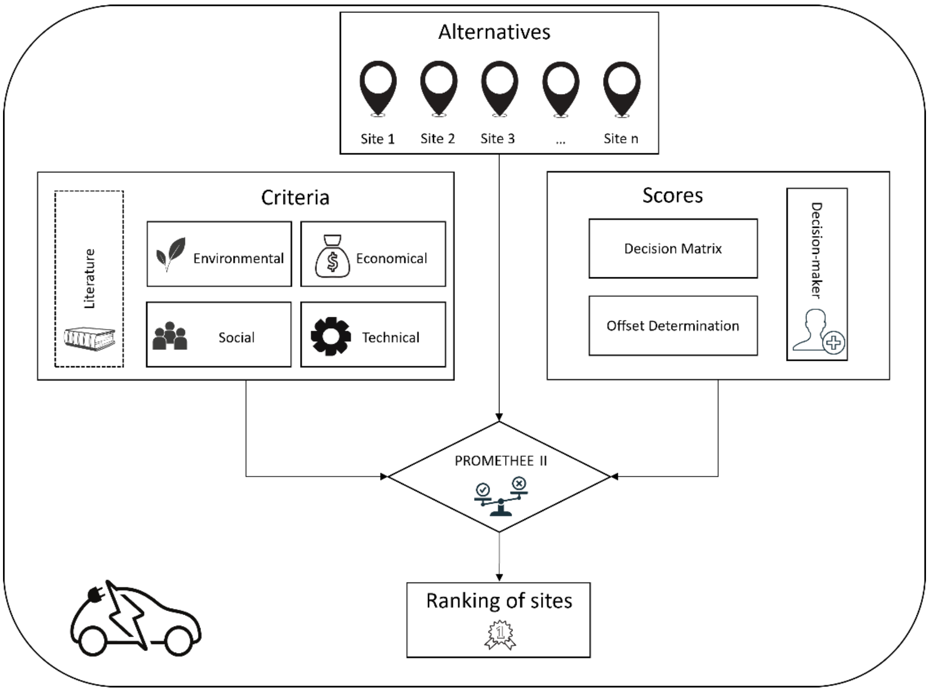

Fig. 1. Overview of the proposed MCDA approach

The MCDA considers seven sub-criteria {g1, g2, g3, g4, g5, g6, g7}, four of which have a positive impact {g1, g2, g6, g7}, while three a negative impact {g3, g4, g5}, as follows:

- **g1**: System safety, reflecting how the distance of the EVCS from the sea can impact the lifetime of the installation.
- **g2**: System reliability, indicating the frequency of power distribution network failures that impact the operation and lifetime of the EVCS.
- **g3**: Total construction cost, including different types of capital costs for constructing the EVCS.
- **g4**: Operation and maintenance cost, consisting of the costs for operating and maintaining the EVCS.

- **g5**: Investment recovery period, indicating the payback period of the investment.
- **g6**: Accessibility, suggesting how easy it is to access the EVCS in terms of traffic congestion.
- **g7**: Air quality index, demonstrating the expected atmospheric pollution reduction that an EVCS can result in.

The seven sub-criteria are organized into four main criteria, as displayed in Figure 2.

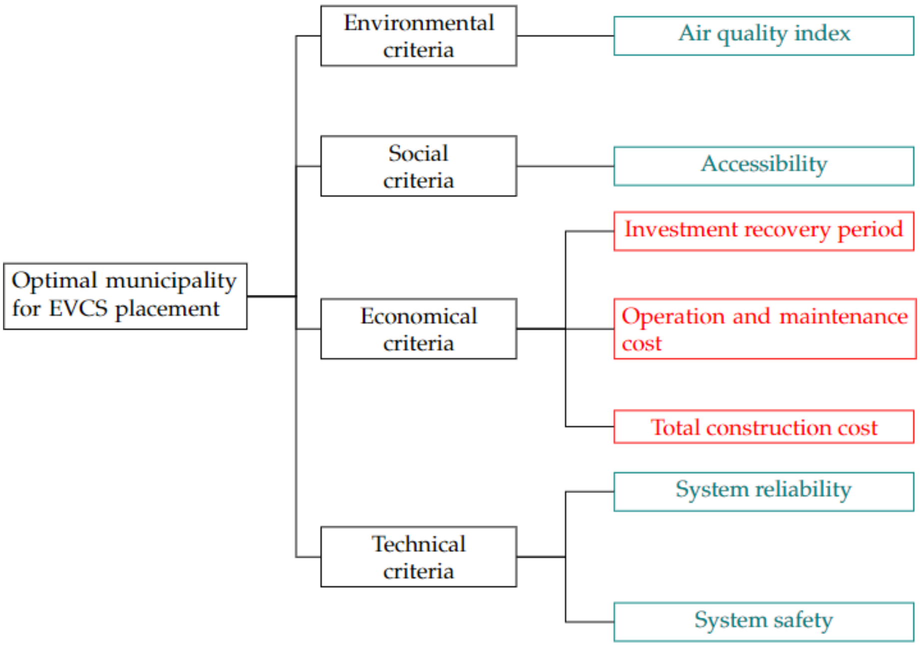

Fig. 2. Overview of the criteria and sub-criteria used in the proposed MCDA approach. Sub-criteria of a positive impact are denoted by green colour, while sub-criteria of a negative impact are denoted by red colour.

3.2 The PROMETHEE II method

The PROMETHEE I and PROMETHEE II (Preference Ranking Organization METHod for Enrichment of Evaluations) MCDA methods, introduced in [15], have been extensively applied to support decisions in businesses, healthcare, and education. PROMETHEE I provides a partial ranking of the actions, as it is based on the positive and negative flows of the criteria, including preferences, indifferences, and incomparabilities. On the contrary, PROMETHEE II provides a complete ranking of the actions, as it is based on the multi-criteria net flow. It includes a preference and indifference threshold, which will be explained in the following paragraphs. The steps followed by the PROMETHEE II method, as presented by Sarmas et al. [16]; Xidonas et al. [17], are the following:

- Firstly, pairwise comparisons are made between all the alternatives for each criterion:

$$d_k(a_i, a_j) = f_k(a_i) - f_k(a_j), \tag{1}$$

where $d_k(a_i, a_j)$ is the difference between the evaluations of alternatives a_i and a_j for criterion f_k, with i,j being the alternatives indices and k being the criterion index.

- These differences are translated to preference degrees, according to the selected criterion, as follows:

$$\pi_\kappa(\alpha_i, a_j) = P_k[d_k(a_i, a_j)], \tag{2}$$

where P_k: $R \rightarrow [0, 1]$ is a positive non-decreasing preference function, such that $P_j(0) = 0$.

- The pairwise comparison of the alternatives is completed by computing the multi-criteria preference degree of each pair, as follows:

$$\pi(a_i, a_j) = \sum_{i=1}^{q} \pi_\kappa(a_i, a_j) \times w_k, \tag{3}$$

where w_k represents the weight of criterion f_k, assuming that $w_k \geq 0$and $w_k = 1$.

- The positive (ϕ^+) and negative (ϕ^-) outranking flows are defined. The positive outranking flow expresses how an alternative is outranking the others. A higher positive outranking flow implies a better alternative.

$$\phi^+(\alpha) = \frac{1}{n-1} \sum_{x \in A} \pi(a, x), \tag{4}$$

The negative outranking flow expresses how an alternative is outranked by all theothers. A lower positive outranking flow implies a better alternative.

$$\phi^-(\alpha) = \frac{1}{n-1} \sum_{x \in A} \pi(a, x), \tag{5}$$

The positive and negative outranking flows are aggregated into the net preference flow:

$$\phi(\alpha) = \phi^+(\alpha) - \phi^-(\alpha), \tag{6}$$

The PROMETHEE II final ranking is obtained by ordering the alternatives accordingto the decreasing values of the net flows.

PROMETHEE II preference functions In PROMETHEE II, the preference functions are used to assess the relative preference of two alternatives $\{a_i, a_j\}$, based on their evaluation of different criteria. The difference between the evaluations of a_i and

a_j on a particular criterion is denoted by d_k. Two thresholds are defined to use the preference functions: the indifference threshold (q_k) and the preference threshold (p_k). These thresholds are used to determine whether the difference between the evaluations of a_i and a_j on a particular criterion is negligible, significant, or somewhere in between. If the difference (d_k) is smaller than the indifference threshold (q_k), it is considered negligible, and the preference degree between the two alternatives on that criterion is set to zero. In other words, there is no preference for one alternative over the other if the difference between their evaluations is negligible. On the other hand, if the difference (d_k) is larger than the preference threshold (p_k), it is considered significant, and the preference degree is set to one. This means that there is a clear preference for one alternative over the other if the difference between their evaluations is significant. Finally, if the difference (d_k) is between the indifference threshold (q_k) and the preference threshold (p_k), the preference degree is calculated using a linear interpolation between zero and one. This allows for a gradual increase or decrease in the preference degree between the two alternatives as the difference between their evaluations on a particular criterion changes from negligible to significant.

For the criteria of the examined MCDA problem, the usual preference function is used as it is the simplest to implement, and also not depending on thresholds that may be challenging to define. The usual preference function is summarized as follows:

- If the difference d_k between the alternatives is zero, then the preference degree becomes equal to zero.
- If the difference d_k between the alternatives is greater than zero, then the preference degreebecomes equal to one.

3.3 Weighting system

Simos [18, 19] proposed a technique that allows DMs to practically express how they wish to prioritize a set of criteria in a given MCDA problem. This procedure aims to communicate to the analyst the information needed to attribute a numerical value to each criterion when used in ranking-type MCDA methods. The Simos method was later revised by Figueira and Roy [20] to address certain robustness issues of the original method. Their method is summarized below.

The DM is given a set of n cards displaying the name of the examined criteria. The DM uses the cards to rank the criteria from the least to the most important by arranging them in ascending order. If some criteria have the same importance for the DM, he/she can place them together in the same position. The importance of two successive criteria (or two successive subsets of ex aequo criteria in case two or more cards have been placed together) in the ranking can be more or less close. To depict this smaller or larger difference in the importance of successive criteria, the DM introduces white cards between two successive cards. The more the number of white cards between two successive criteria, the greater the difference between their importance. If no white card is placed between two successive ranks, then the difference between the weights of the criteria in these two successive ranks is set equal to the unit u used for measuring the intervals between weights. Hence, if one white card is placed between two successive ranks, then there is a difference of 2u between the weights of the criteria in these two successive ranks. Finally, the DM should state how many times the last criterion is more important than the first one. This ratio is denoted by the parameter z.

4 Experimental application

4.1 Alternatives

The proposed approach will be used to evaluate 10 municipalities of Greece and, subsequently, identify the most promising for placing an EVCS. The alternatives are shown in Figure 3 and consist of 4 municipalities located in Attica (Argyroupoli, Cholaros, Galatsi, and Kaisariani), 2 island municipalities (Chios and Kythera), and 4 province municipalities (Karpenissi, Lamia, Loutraki, and Pilos). These alternatives were selected because they sufficiently represent the geographic, demographic, and economic variations of Greek municipalities and have already attracted the interest of some investors in the Greek EV market.

Fig. 3. Location of the examined municipalities, classified based on their geographical position.

4.2 Sub-criteria description and evaluation

This subsection provides details on the seven sub-criteria considered for ranking the alternatives of the examined MCDA problem.

- **g1**: This sub-criterion reflects the extent the distance of the EVCS from the sea is expected to affect the lifetime of the installation (damage due to salt and moisture). A scale from 1 to 3 is used to rank the safety of the alternatives, where higher values indicate greater distance from the sea and, therefore, longer life expectancy for the installation. Specifically, municipalities located up to 2km from the sea receive a rating of 1, municipalities located up to 4km from the sea receive a rating of 2, while municipalities located farther than 4km from the sea receive a rating of 3 (see Table 2).

Table 2. Evaluation values of the alternatives in terms of safety (sub-criterion g1).

Distance from the sea	Scale
≤ 2km	1
2 – 4km	2
> 4km	3

- **g2**: This sub-criterion indicates the general reliability of the electric power distribution network, i.e. how likely it is for charging to be conducted without unexpected interruptions or disturbances that may damage the installation. A scale of 1 to 2 is used to evaluate the alternatives, where higher values indicate a more reliable power supply. The installations on the islands receive a lower rating than the installations on the mainland due to the more frequent outages and disruptions observed in the distribution network of the former. Therefore, island municipalities receive a rating of 1, while the rest of the municipalities a rating of 2 (see Table 3).

Table 3. Evaluation values of the alternatives in terms of reliability (sub-criterion g2).

Location of municipality	Scale
Island	1
Other	2

- **g3**: This sub-criterion illustrates the total construction cost of an EVCS which includes the cost of leasing or acquiring land, the cost of research and design, the cost of building the infrastructure, the cost of purchasing the required equipment and tools, the cost of construction management and production, and other capital costs of the project. To evaluate and rank each municipality based on this sub-criterion, the expertise of a research associate from one of the largest charging point operation companies in Greece was utilized. The associate possesses knowledge regarding the total construction cost required for installing a charging station in each of the municipalities under examination. A scale of 1 to 3 is used for evaluating the total construction cost at each municipality, where higher values imply higher costs (see Table 4).

Table 4. Evaluation values of the alternatives in terms of total construction cost (sub-criterion g3)

Total construction cost	Scale
Low	1
Average	2
High	3

- **g4**: This sub-criterion reflects the cost of operation and maintenance. Similar to g3, a scale of 1 to 3 is used for evaluation. In particular, due to the lack of specialized technical staff in islands and the province of Greece, the maintenance costs for municipalities outside Attica are typically higher. To that end, municipalities located on islands receive a rating of 3, municipalities located in Attica receive a rating of 1, while province municipalities a rating of 2 (see Table 5).

Table 5. Evaluation values of the alternatives in terms of operation and maintenance cost (sub-criterion g4).

Location of municipality	Scale
Attica	1
Province	2
Island	3

- **g5**: This sub-criterion pertains to the recovery period of investment, which is primarily determined by the anticipated number of EVs that will utilize the EVCSs. A higher volume of EVs is expected to result in increased usage of the EVCS, thus reducing the payback period and subsequently lowering the investment risk. The expected number of EVs is calculated based on the number of internal combustion engine cars that have been recorded in each municipality. However, it does not consider the seasonality of EV usage on an island due to tourism, as there is no clear way to measure it. According to the Greek Statistical Authority, more cars have been recorded moving in the region of Attica, fewer in the province, and significantly fewer on the islands. For this reason, municipalities located on islands receive a rating of 3, municipalities located in Attica receive a rating of 1, while municipalities in other locations receive a rating of 2 or 3, as there are provinces that have recorded similar car usage to municipalities located in islands (see Table 6).

Table 6. Evaluation values of the alternatives in terms of the investment recovery period (sub-criterion g5).

Location of municipality	Scale
Attica	1
Province	2 or 3
Island	3

- **g6**: To attract more customers, EVCSs must be easily accessible and located in areas with as little traffic congestion as possible. In the province and islands, traffic congestion is limited, even in the summer months. In contrast, municipalities of Attica typically experience high traffic congestion. As a result, municipalities located on islands receive a rating of 3, municipalities located in the province receive a rating of 2, while municipalities located in Attica receive a rating of 1 or 2, depending on their traffic congestion (see Table 7).

Table 7. Evaluation values of the alternatives in terms of accessibility (sub-criterion g6).

Location of municipality	Scale
Attica	1 or 2
Province	2
Island	3

- **g7**: Reducing air pollution is one of the most important incentives to promote the use of EVs. A higher value on the scale of this sub-criterion implies a greater reduction in air pollution. In metropolitan areas, the concentration of internal combustion engine vehicles tends to be higher due to higher population density, more extensive infrastructure, and greater economic activity. As a result, emissions from these vehicles can accumulate and lead to increased air pollution levels. For this reason, the installation of EVCSs in municipalities of big cities can increase the adoption of EV usage and lead to a significant reduction in air pollution. Therefore, municipalities located on islands receive a rating of 1, municipalities located in cities receive a rating of 3, and municipalities located in the province receive a rating of 2 or 3, depending on their population (see Table 8).

Table 8. Evaluation values of the alternatives in terms of expected air pollution reduction (sub-criterion g7).

Location of municipality	Scale
Attica	3
Province	2 or 3
Island	1

4.3 Sub-criteria weights

To evaluate the importance of the examined sub-criteria, the opinion of a research associate who works at one of the largest charging point operation companies in Greece was considered. The specific expert possesses extensive expertise in the realm of EV charging infrastructure, as well as the Greek EV market, and has significant experience in the installation of EVCSs across various regions in Greece. Based on his opinion, we arrive at the schema presented in Figure 4, illustrating the revised SIMOS method. In the problem of optimal EVCS placement across different municipalities according to the expert, the investment recovery period (g5) is identified as the most critical factor of the decision-making process, while sub-criteria such as safety (g1) and accessibility (g6) have the least impact on the judgment of the DM. The computational steps of the SIMOS method and the final estimated weights are presented in Table 9. Overall, economic criteria account for about 46% of the alternatives' value, technical criteria for 27%, and environmental andsocial criteria for just 13% each.

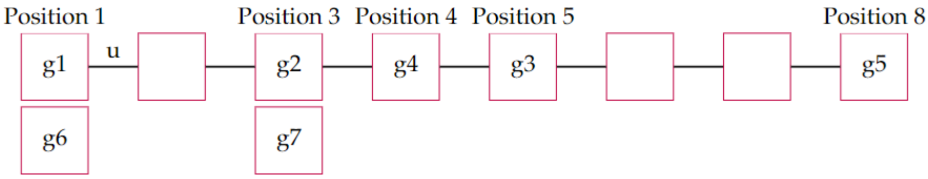

Fig. 4. Schema of cards during the application of the revised SIMOS method for the examined MCDA problem.

Table 9. Calculation of the normalised steps using the revised SIMOS method (z = 1.2).

Rank	Subsets of ex aequo	Number of white cards between rank n, rank $n+1$	Non-normalised weights $k(r)$	Normalised weights k_i %
1	g_1, g_6	1	1.00	12.95
2	g_2, g_7	0	1.08	13.99
3	g_4	0	1.12	14.51
4	g_3	2	1.16	15.03
5	g_5	...	1.28	16.58

4.4 Results and discussion

Based on the sub-criteria description and the expert's judgment, the evaluation of the alternatives across the sub-criteria is presented in Table 10. By utilizing the proposed EVCS placement approach, we identify the most promising municipality for the potential investors, as determined by the PROMETHEE II method, the defined sub-criteria, and the estimated sub-criteria weights. Table 11 shows the exact values of the calculated positive and negative outranking flows, as well as the net preference flow. Based on the latter, the final ranking of the municipalities is established.

As seen, the top-ranked alternatives (Argyroupoli, Galatsi, Kaisariani, and Cholargos) are the municipalities of Attica, while the bottom two alternatives (Kythera and Chios) are the municipalities of the examined islands. This finding can be attributed to the relatively higher evaluation values all city municipalities receive at key sub-criteria, such as g4 and g5. Therefore, we conclude that investing in EV charging infrastructures in islands is less promising than investing in cities. Yet, even within cities, different opportunities may be present depending on the particular characteristics of each municipality. For instance, Cholargos is significantly less promising than the rest of the Attica municipalities, mostly due to the higher total construction cost that was judged by the CPO and, simultaneously, its less accessible location.

To better showcase the differences between the PROMETHEE II rankings of the alternatives, two figures are rendered. In Figure 5, the vertical axis shows the overall ranking of the alternatives (the green colour indicates the positive outranking flow, while the red colour the negative outranking flow). The axes that create a 45°with the vertical axis, corresponding to the positive (left axis) and negative (right axis) flow values, are also provided to facilitate comparisons. In Figure 6, a node-based network is presented based on the ranking of the alternatives. The highest node is the top-ranked alternative (a. Argyroupoli) and the preferences are indicated by the arrows. The larger the difference between the net preference flows of each alternative (node), the bigger the distance between the nodes.

Table 10. Evaluation values of the alternatives based on the sub-criteria descriptions and the DM's knowledge. Values are presented for each criterion separately.

Alternative	g1	g2	g3	g4	g5	g6	g7
a.Argyroupoli	3	2	3	1	1	2	3
b.Galatsi	3	2	2	1	1	1	3
c.Kaisariani	3	2	2	1	1	1	3
d.Cholargos	3	2	3	1	1	1	3
e.Loutraki	2	2	2	2	2	2	3
f.Lamia	3	2	1	2	3	2	3
g.Karpenissi	3	2	1	2	3	2	2
h.Pilos	2	2	2	2	2	2	2
i.Kythera	1	1	1	3	3	3	1
j.Chios	1	1	1	3	3	3	1

Table 11. Ranking of the alternatives based on the PROMETHEE II net preference flow.

Alternative	ϕ^+	ϕ^-	ϕ	Ranking
a.Argyroupoli	0.4018	0.1638	0.2380	1
b.Galatsi	0.3921	0.1687	0.2234	2
c.Kaisariani	0.3921	0.1687	0.2234	2
d.Cholargos	0.3584	0.2361	0.1223	4
e.Loutraki	0.3263	0.2056	0.1208	5
f.Lamia	0.2961	0.2963	-0.0002	6
g.Karpenissi	0.3040	0.3229	-0.0189	7
h.Pilos	0.2737	0.4136	-0.1399	8
i.Kythera	0.2169	0.6013	-0.3844	9
j.Chios	0.2169	0.6013	-0.3844	9

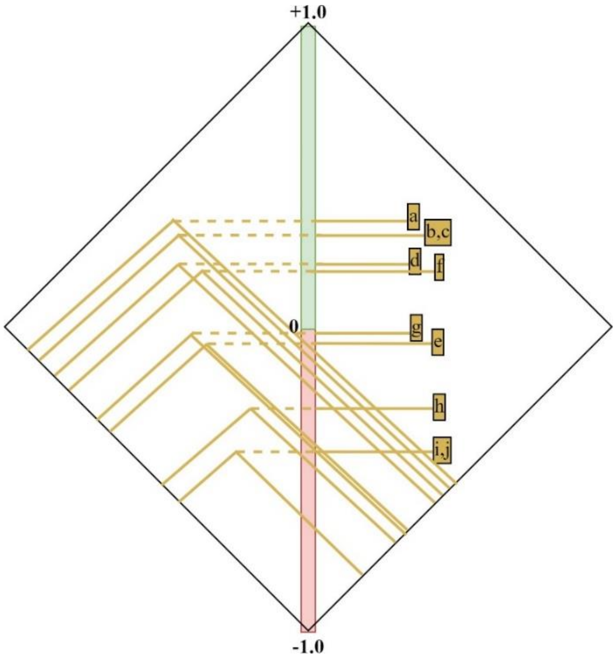

Fig. 5. The PROMETHEE II diamond illustrates the differences between the alternatives in terms of net preference, positive outranking flow, and negative outranking flow.

5 Conclusions

This study proposed a framework to support decisions related to the optimal placement of EVCSs in diverse municipalities to maximize profits and minimize the risks of potential investors. The proposed approach is based on the PROMETHEE II MCDA method and exploits a set of comprehensive criteria that cover critical aspects of said investments.

The utility of the proposed approach was validated using a set of ten municipalities in Greece. Our results indicate that municipalities located in large cities are preferable for investing and that island municipalities should be carefully assessed before deploying EVCSs. Yet, even within similar city municipalities, bigger opportunities can still be identified depending on the special characteristics of each alternative. Moreover, it is found that the most crucial criteria for assessing the examined investments are of an economic nature, consisting of the total construction cost, the operation and maintenance cost, and the investment recovery period. This conclusion is based on the expert's opinion, which in our case was the CPO. Technical, environmental and social criteria may have greater importance if other experts from their respective fields were to be included in the study.

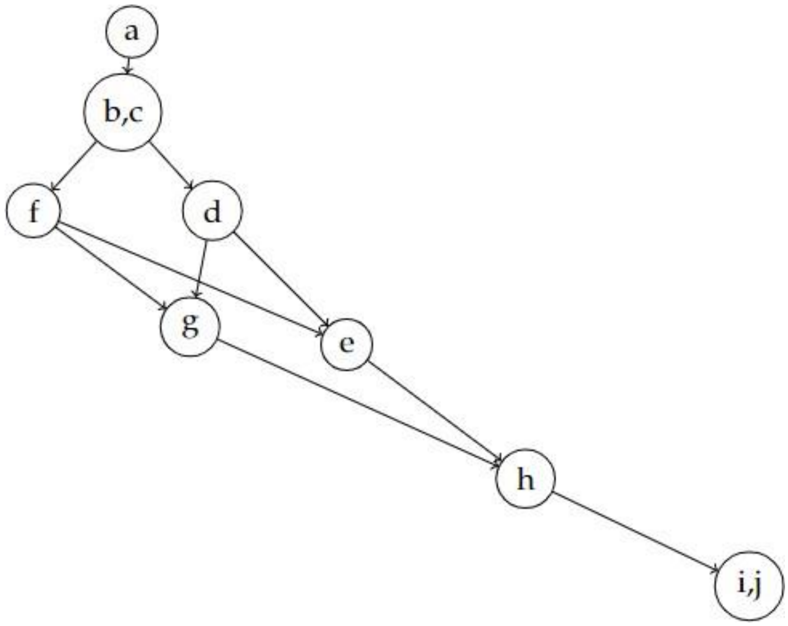

Fig. 6. Network based on the positive and negative outranking flows calculated by the PROMETHEE II method.

Future work in different directions could assist in improving some limitations of the present work. First, the criteria used could be expanded to reflect the competition (e.g. current number of EVCSs) in each municipality and the number of chargers that should be deployed per case based on the predicted demand to better estimate the costs and risks of the potential investors. In addition, when further data becomes available for each municipality, it would be recommended to take into account criteria related to the existing power network and the convenience of connecting the chargers to it. Second, the number of alternatives could be increased so that the analysis covers more locations and the results demonstrate the relative strengths and weaknesses of multiple municipalities. Third, the judgment of more experts that have significant experience in the EV market of Greece could be analysed, contributing towards the more accurate estimation of the criteria weights. Finally, the reported results, ranked from an investor perspective, could be compared to those computed from a social perspective to better understand how sustainable mobility could be reconciled with financial prosperity.

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