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Technical, economic, and environmental analysis to define the conditions for the implementation of charge stations, a case study in the city of Azogues - Ecuador

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Abstract. Reducing environmental pollution caused by traditional mobility solutions, such as combustion vehicles, requires a deep dive into sustainable mobility. Consequently, promoting electric vehicles (EVs) constitutes a long-hanging fruit for establishing a route map for decarbonizing city mobility. Nevertheless, several tasks require urgent attention to allow EV technology to deploy in cities. For instance, optimal locations of charging stations for EVs by considering a multicriteria approach are urgently required. This work studies the most feasible alternatives for locating and implementing EV chargers (EVC) in Azogues, Ecuador. This study applies Promethee multicriteria method, considering three different location alternatives in the city and four criteria that will be divided into ten subcriteria for the analysis. First, the multi-objective function´s weighting factors were established using three weighting methods: equal weighting, point allocation, and critical weighting. Once the matrix of sub-criteria with their weights was established, Visual Promethee, which works with Promethee II, was applied to establish the optimal candidate site. The results of this optimization analysis indicate an optimal location for the EVC.

Keywords. Electric vehicles, Charge stations, Multicriteria methods, Promethee, Criteria.

1. Introduction

Electric vehicles (EVs) have been around since the end of the 19th century. They were popular and commercially available until about 1918. In 1900, there were about 4,200 automobiles on the road, of which 38% were electric, 22% gasoline, and 40% were impulse by carbon-steam propulsion.

With the development of oil-gasoline engines, the reduction in the cost of gasoline as a consequence of the huge amount of energy concentrated in this type of fuel made possible long-range and higher speed capability, integrated to the invention of the electric starter, the interest on electric vehicles decreased **[1]**.

But at the present, there is a strong trend towards replacing combustion motors to electric ones. The concerning's about climate change related affectations added to power costs reduction and the development of higher efficiencies of electric storage capabilities, made possible to resurge the EVs as a competitive technology **[2]**. Transportation generates almost 14% of global emissions, so decarbonization of the transportation could significantly reduce emissions to the atmosphere. The electrification of transportation is a promising alternative to clean urban air and health problems **[2]**. Introducing EVCs in cities is required due to the increase in the circulation of electric vehicles (EVs) within a country.

For instance, in concordance to Art. 14 of the Ecuadorian law ``Organic Law of Energy Efficiency" which mandates ``From the year 2025 all vehicles that are incorporated to the urban and inter-parish public transport service, in continental Ecuador, must be only of electric means of transport". This promotes the growth of EV alternatives considering it is more economical and environmentally sustainable. Consequently, a new problem arises, which is the lack of EVCS, which makes the use of EVs very limited in range. The main purpose of this paper is to provide a multicriteria analysis methodology for establishing a best location required for the implementation of EVCS in the city of Azogues - Ecuador.

2. Decision Multicriteria Methods Analysis (MCDA)

According to rec ent studies, S. D. Pohekar and M. Ramachandran **[3]**, had defined MCMs as those that give the "decision-maker" tools that allow defining the adequate alternative between others. In general, the multicriteria methods have built-in characteristics:

- A series of alternatives can be evaluated and ranked according to preferences.
- Criteria are based on the nature of the problem.

- A matrix with specific values for each criterion.
- Weights for each criterion.
- An evaluation of each alternative solution with respect to other alternatives.

In order to select a multi-criteria method within the electricity sector, it is important that it meets certain characteristics, such as being easy to apply, having wide acceptance, delivering results that are easy to interpret, from the knowledge from the participation of various stakeholders when making decisions **[4]**.

After a literature review in various fields of electric power planning, it is evident that several researchers have used the Promethee method, due to:

- It is well suited to problems for the selection of alternatives based on multiple criteria.
- It is well adapted to problems for the selection of alternatives based on multiple criteria.
- It is an easy-to-use, logical and rational model.
- It is well-known and widely used.
- It allows easy and direct comparison of alternatives with respect to a criterion.
- Effective and user-friendly computer programs are available for the decision-maker.

A. Promethee method.

Once the Promethee multi-criteria method has been established as the reference to work with, a flowchart could be drawn for setting the sequential steps to be followed for determining the most optimal situation of a decision. In this case the location for EVCS (Figure 1).

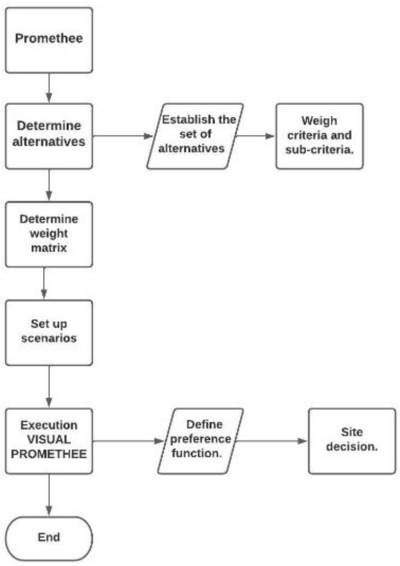

Fig. 1. PROMETHEE elaboration flowchart.

S. Guo and H. Zhao **[5]**, suggest that the PROMETHEE method constructs preference functions on the numerical difference between pairs of alternatives to describe the difference in priorities of decision maker's point of view.

Six functions (preferential) were introduced based on different criteria: true, quasi-criterion, criterion with linear preference, level criterion, criterion with linear preference and area of indifference, and Gaussian criterion.

In this analysis, we will use the criterion with linear preference and area of indifference, which is defined as follows in equation 1:

$$\boldsymbol{Pj(dj)} = \begin{cases} \mathbf{0} & \boldsymbol{d_j \leq s_j} \\ \dfrac{\boldsymbol{|d_j| - s_j}}{\boldsymbol{r_j - s_j}} & \boldsymbol{s_j < d_j < r_j} \\ \mathbf{1} & \boldsymbol{d_j > r_j} \end{cases} \quad (1)$$

Where $\boldsymbol{dj = yij - ykj}$, denotes the difference in preference between two alternatives in the criterion $\boldsymbol{gs.rj}$ and $\boldsymbol{sj}$ are preference and indifference threshold, respectively.

B. Aggregate preference index.

To calculate the aggregate preference, index the equation 2 is applied.

$$\forall \boldsymbol{a, b} \in \boldsymbol{A}, \ \boldsymbol{\pi(a,b)} \sum_{j=1}^{k} \boldsymbol{P_j(a,b) w_j} \quad \mathbf{(2)}$$

Where $\boldsymbol{w_j}$, will be the weight of each criterion and $\boldsymbol{\pi(a,b)}$ is associated with the degree of preference in which alternative *a* will outperform alternative b.
When $\boldsymbol{\pi(a,b) = 0}$, the overall preference *a* over *b* is weak.
When $\boldsymbol{\pi(a,b) = 1}$, the overall preference of *a* over *b* is strong.

3. Case of study

The Promethee method is used to determine the optimal place to implement electric vehicle charging stations in the urban area in Azogues city, Cañar province, Ecuador. For the selection of candidate sites, based on the vehicular flows, five candidate sites are established. Table I, details a summary of the vehicular flows data in concordance with the account of traffic conducted by staff of the Directorate of Mobility of the Municipality of the city of Azogues, in schedules from 8 am to 5 pm. The traffic accounting have been provided with the data tabulated in a summary in the Table.

Table I. Traffic flow of potential candidate sites.

Candidate sites	Total number of vehicle flux.
Terminal terrestre	2960
P. Infantil "Marco Romero"	2231
C.C Bartolomé Serrano	2736
Municipio de Azogues	2333
Bosque Azul	1928

When comparing traffic flow figures, it was decided to consider the three spots with the highest vehicle density as the main candidate sites. This spot corresponds to the city´s main bus station (Terminal terrestre), the main public park in the city known as "Parque infantile" and the "Bartolomé Serrano" shopping center.

4. Criteria and sub – criteria

An extensive literature review has been performed and some attributes of the economic factor and complementary factors of potential sites of implementation are a particular concern when selecting both candidate sites and load types. There are several aspects of engineering feasibility concerns that must be considered for safety and convenience. In the pursuit of service availability, an EVCS should be placed towards supplying high traffic and power requirements for achieving high service demands.

In D. Choudhary and R. Shankar **[6]**, it has been established as an important component of the infrastructure, aspects related to social development, which means that social factors also become an additional criterion for the infrastructure. Finally, it is necessary to consider the environmental factors that may be affected by the introduction of the new infrastructure.

A. Economic factors

This criterion is related to three sub-criteria as follows:

- Investment cost (USD)(C11) [**[7]**, **[8]**, **[9]**]: This includes the cost of installation and on-site infrastructure preparation resulting in different aptitude of suitability for site selection. The investment cost of the loaders is calculated by taking as reference the retail value of the "MODO-4 RAPTION-TRIO (CHAdeMO+CCS+Type charger II), which has a cost of 31,181.00 (USD) and its characteristics are: 1 CHAdeMO connector and 1 CCS Combo2 connector of 22kW each at 120A, and 1 Type2 connector of 22 kW at 32A. Power factor greater than 0.98, efficiency of 95% of rated power and frequency of 50 to 60 Hz.
- Cost of total operation and maintenance (USD/Year) (C12) **[7]**, **[8]**, **[9]**: Includes daily operation and maintenance costs and depreciation. This is an important criterion as it influences the project's profitability. In this study, we take into consideration the energy prices, so the supplier should keep the EVCS in operation the 24 hours a day. The percentage of resources to be allocated for maintenance is also calculated.
- Length of the conductor from the feeder to the EVCS (USD) (C13) **[7]**: This is relevant to obtain the economic investment in the $/km, which represents the conductor that transports the energy needed to distribute and market to the user. This sub-criterion allows to the establishment of the necessary quantity of conductors, for the construction of the subway aerial connection that will start from the electrical feeders.

B. Technical factors

Some conventional engineering feasibility criteria and others relevant to the EVCS load type selection problem are considered. The two sub-criteria are specified as follows:

- Grid connection distance (m)(C21) [**[10]**, **[11]**]: In the electricity market this is an important parameter as it is directly related to the reduction of losses due to the distance of connection to the grid and the cost of transmission.
- Feeder availability (%) (C22) [**[12]**]: Knowing the load requirements in the electrical feeders, is of great importance since it would help us to avoid a possible overload in the electrical power lines, and not generate instabilities in the power grid.

C. Social Factors

Two related sub-criteria are added as follows:

- Space availability (C31) [**[13]**, **[14]**]: Refers to the space area available for implementation of EVCS. This sub-criterion has been applied through measurements of the area of occupancy of the EVCEs, in detecting available space according to the geoportal of the municipality of Azogues [**[15]**]
- Level of social acceptance (C32) [**[15]**]: Analyses the degree of acceptance by the citizens of the area to the implementation of electric vehicle charging stations. It is important to consider the opinion regarding the degree of acceptance of the project proposed for each of the candidate sites. For this reason, work was carried out by consulting citizens about land use.

D. Environmental factors

Three sub-criteria are related as follows:

- Environmental Benefit (C41) **[11]**: Contemplates the reduction of oxides of nitrogen, which are generated by the temperature and height of the territory and are very pollutants.
- Visual impact (C42) **[16]**: Refers to the visual impact caused by the presence of EVCS in a location. The candidate sites are close to public spaces mostly of distraction for the user, so it is necessary to analyse the visual impact caused by that the construction of EVCS s in these areas.
- Noise impact (C43) **[13]**, **[11]**: It refers to the soundness level that will be produced by both vehicular flow as well as noise from the power equipment required. The amount of noise caused by vehicular traffic and population dynamics present at candidate sites is measured at certain dynamics present in the candidate sites, according to certain traffic schedules.

5. Sub – criteria matrix

The sub-criteria should be evaluated quantitatively and qualitatively. The quantitative indices should be calculated using math models, which, in this case for the economic criteria, considering each charger costs that it was estimated at $ 31,181.00 (USD) each, at the time that this research takes place. In addition to calculating the demand to obtain the cost of charging service, which will help to establish the costs of operation and maintenance of the EVCS along the time. Table II indicates the obtained costs per each sub-criterion.

Table II. Indexes for the sub criteria.

Criterion	Sub criterion	Terminal Terrestre	Parque Infantil	C.C. Bartolomé Serrano
Economic Factors	C11 *(USD)*	187.086	124.724	93.543
	C12 *(USD/AÑO)*	124.495,5	102.997	77.247,75
	C13 *(USD)*	620,88	595,92	171,6
Technical Factors	C21 *(m)*	59,7	57,3	16,5
	C22 *(%)*	42,56	12,49	9,98
Social Factors	C31	0,86	0,88	0,6
	C32	0,87	0,82	0,73
Environ ment Factors	C41 *(NOx/km)*	484,7	402,2	493,02
	C42	0,52	0,51	0,62
	C43 *(dB)*	69,74	63,82	65,71

6. Sub – criteria weights and study scenarios

Y. Wu and others **[17]** state that there are several methods for measuring and determining the weight of the respective criteria and sub-criteria. The incidence weight of the respective criteria and sub-criteria, among which there are subjective weighting methods, objective weighting methods, integrated or mixed weighting methods, and equal weighting methods.

A. First scenario

For this scenario, it has been decided to work with the equal weights method, according to this case a value weighting of 20% has been proposed. Table III below presents this case.

Table III. Weighting table (first scenario).

Criterion	Sub criterion	Scenario 1
Economic Factors	C11 *(USD)*	0.1
	C12 *(USD/AÑO)*	0.1
	C13 *(USD)*	0.1
Technical Factors	C21 *(m)*	0.1
	C22 *(%)*	0.1
Social Factors	C31	0.1
	C32	0.1
Environment Factors	C41 *(NOx/km)*	0.1
	C42	0.1
	C43 *(dB)*	0.1

B. Second scenario

The second scenario is in concordance with the allocation method, considered a subjective method. Under this case, it has been decided to work by applying surveys to 15 professional experts in this criteria, who have been asked to classify each sub-criterion according to levels of importance. Table IV presents the data.

Table IV. Weighting table (second scenario).

Criterion	Sub criterion	Scenario 2
Economic Factors	C11 *(USD)*	0.5
	C12 *(USD/AÑO)*	0.3
	C13 *(USD)*	0.2
Technical Factors	C21 *(m)*	0.4
	C22 *(%)*	0.6
Social Factors	C31	0.4
	C32	0.4
Environment Factors	C41 *(NOx/km)*	0.6
	C42	0.2
	C43 *(dB)*	0.2

C. Third scenario

It is applied to the critical weighting model which, according to K. Rajashekara [18], he does describe this method as the correlation between values of the sub-criteria that value the respective weighting levels. It is recommended that the weighting values be normalized as a first step. Then, the correlation matrix ljk should be found. Next, the amount of information Cj that the criterion j transmits. Finally, the results of the process explained above are presented in Table V.

Table V. Weighting table (third scenario).

Criterion	Sub criterion	Scenario 2
Economic Factors	C11 *(USD)*	0.07
	C12 *(USD/AÑO)*	0.10
	C13 *(USD)*	0.15
Technical Factors	C21 *(m)*	0.09
	C22 *(%)*	0.07
Social Factors	C31	0.09
	C32	0.07
Environment Factors	C41 *(Nox/km)*	0.06
	C42	0.13
	C43 *(dB)*	0.14

7. Visual Promethee

Fernandez, Escribano, García and Rodriguez [19], stated that Visual PROMETHEE is a software that assists in decision-making for applying the Promethee multi-criteria method according to (i) To evaluate a set of alternatives according to multiple conflicting criteria; ii) recognize the best trade-offs and rank them from best to worst. Iii) recognize the best compromise solutions and rank them from best to worst; iv) visualize decision problems to comprehend the difficulties of making good decisions; v) reach consensus decisions when different decision-makers have opposing views; and vi) validate decisions based on objective elements.

8. Results

Once the criteria and sub-criteria matrix were obtained, in addition to the 3 scenarios the data is applied as input into Visual Promethee. The results are analysed.

It should be noted that even though the 3 scenarios worked with different weights in their matrices, the hierarchical order at the time of the decision-making process was maintained. For the analysis of outflows, Visual Promethee performs a subtraction between the positive and negative flows, which yields a total exceedance flow comparison result. In the case of scenario 1, the mall Bartolomé Serrano has a total flow of 0.6934, the Parque Infantil has a total flow of -0.1449 and the T. Terrestre has a flow of -0.5485. This concludes that in descending order the best place is the Bartolomé Serrano shopping center, then the Parque Infantil, and finally the Bus station.

Based on the same analysis as before in Scenario 1, the hierarchy of exceedance flows remains in the same order for Scenario 2, but with minor variations in scale in concordance with the flow calculation. According to the analysis performed in the two previous scenarios, Scenario 3 maintains the hierarchical order, with a low variation in the values of exceedance flows. These results can be seen in Figure 2.

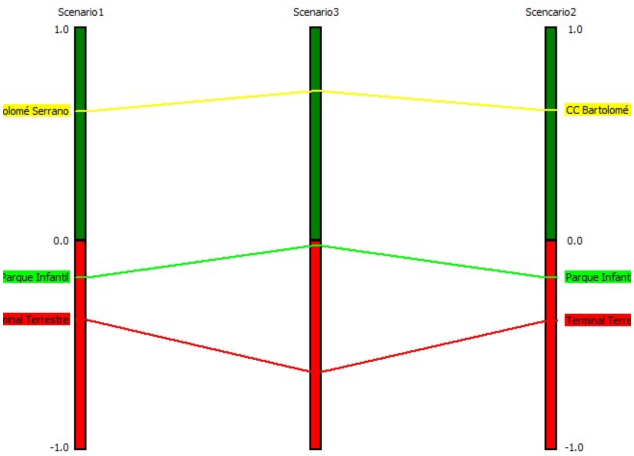

Fig. 2. Complete classification of Visual Promethee.

9. Discussion

In Azogues there were no previous EVCS studies until now; however, Cañar Yupanqui **[20]** studied possible EVCS location alternatives in Cuenca city located 33.1 km from Azogues. In this previous research, unlike this one, they use the PSO (Particle Swarm Optimization) location method. That corresponds to a metaheuristic, statistical and probabilistic optimization method, which aims to optimize a function under certain specific criteria. Cañar B has implemented this method, taking into account a criterion, considered as the distance between important destinations in Cuenca, considering gas station locations as possible EVCS. The objective of applying this method is to choose the minimum cost route and profitability as the main requirements to establish an optimal location for the EVCS. This article, in comparison to the previous one, goes beyond the economical issue and takes into account ten criteria to consider and a different method for the analysis of suitable locations to implement EVCS.

10. Conclusion

A multi-criteria method (Promethee) has been applied to find the optimal location for the EVCS in the city of Azogues based on certain decision criteria, such as economics, technical, social, and environmental.

Three scenarios have been proposed, each one with different weights of importance, concluding that under the mentioned criteria and the established weights according to preponderance, the optimal candidate site is the Bartolome Serrano shopping center, coinciding with this site in the three scenarios.

This is because the Bartolome Serrano shopping center has a greater weight of influence in the technical, economic, and environmental sub-criteria, which, unlike the other candidate sites, have a greater inclination towards the social sub-criteria. It should be noted that the technical and economic subcriteria, according to the Visual Promethee analysis, have greater weight or preponderance compared to the other sub-criteria.

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