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Technical versus socio-economic and environmental criteria in power transmission projects

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Abstract. In recent years, the efforts of countries to reach agreements on the development of cross-border electricity interconnection have intensified because they optimize energy resources and constitute the most significant instantaneous support for the security and continuity of electricity supply. In addition, interconnections play a key role in the integration of electricity markets. However, the planning of European electricity infrastructures constitutes complex analyses due to the large number of factors involved. This article applies a multicriteria methodology for the evaluation and prioritization of cross-border interconnection projects with the simulation of different scenarios, in total 12 scenarios, to study the effect of changes in the selected criteria on the results obtained. To test the defined methodology, the variation in the weight of different criteria in the assessment of a new cross-border electrical interconnection project between Spain and France is studied. It was verified that the tool is coherent and that the analysis developed improves the understanding of such large and complex projects and can facilitate the prioritization of project portfolios with a clear and explicit method.

Keywords. Cross-border electricity interconnections, multi-criteria technique, Analytic Hierarchy Process, power system security, scenarios.

1. Introduction

Cross-border electrical interconnection represents a key solution to address renewable energy variability and grid stability problems. On the one hand, from a technical perspective, electrical interconnections facilitate support functions between interconnected electrical systems and increase inertia in these systems. Therefore, interconnection lines improve power grid security and stability. On the other hand, from the economic perspective, cross-border interconnections allow a greater power exchange commercially to take advantage of the differences in energy prices in interconnected systems, greater competitive strength in electricity markets, more efficient management of losses and a lower operating reserve capacity, therefore lowering investment in generation plants [1].

The European Union promotes cross-border interconnections through its regulations to ensure uninterrupted electricity supply in the face of extended supply crises, favors the integration of renewable energies, promotes competition in the internal market and connects the most disadvantaged areas [2], [3], among others. In this context, the European Network of Transmission System Operators for Electricity, taking into account technological, market and political developments, proposes a portfolio of projects that provide socioeconomic well-being and help Europe meet its climate objectives [4]. Projects of Common Interest (PIC) are energy infrastructure projects necessary for the development of priority and strategic areas in the European Union. These projects have a short commissioning time and are funded by community grants [5].

Most of the reviewed works on electrical systems use multicriteria decision techniques, as they are efficient methods to handle decision-making problems under different and conflicting criteria. The works [6], [7] classify the main decision-making methods. There are numerous classifications based on the various characteristics of the methods (number of criteria, environment, alternatives or number of decision-makers). The main classification to consider is the one that refers to the number of alternatives. In this way, multicriteria methods are classified into continuous (multiobjective decision-making, MODM) and discrete (multiattribute decision-making, MADM) methods [8]. Continuous multicriteria methods are those in which the number of alternatives is not countable and therefore try to optimize the value of a technical parameter. On the other hand, discrete multicriteria methods are those in which the number of alternatives is countable and they are fundamentally explicitly defined.

Discrete multicriteria methods are divided into three categories: value measurement models, goal and preference levels models, and overclassification models. First, value measurement models are those that assign a numerical value to each alternative, thus establishing an order of preference. Each criterion or subcriterion is assigned a weight based on the importance of this criterion for decision-makers. This category includes the analytic hierarchy process (AHP) method [9], the analytic network process (ANP) method [9], and the multiattribute utility

theory (MAUT) or multiattribute value theory (MAVT) [10]. Second, the preference level models are those that seek to select the alternative that is closest to the ideal solution or to the level of preference. The methods that make up this category are VIKOR [11] and the Technique for Order-Preference by Similarity to Ideal Solution (TOPSIS) [12]. Finally, overclassification methods are those that compare the alternatives in the form of pairs in such a way that they determine which of them is preferred with respect to the previous criterion. Within this group, the preference ranking organization MeTHod for enrichment evaluations (PROMETHEE) [13] and ELECTRE [14] can be found.
Regarding the objective of the multicriteria analysis applied in the previous articles on the electricity sector, the works [15] - [18] mainly evaluate different energy sources to achieve an optimal energy system in different areas, such as Iran [15], India [16], Lithuania [17], and Bangladesh [18]. Other articles evaluate and prioritize different alternatives for the electrical planning of isolated areas [19], [20].
Based on the literature reviewed, the lack of sensitivity studies that validate the methodologies developed through a multicriteria decision process to reduce the subjectivity associated with any decision method is verified. Sensitivity analysis makes it possible to determine how the selection of alternatives changes when the relative weight of the criteria or requirements considered as determining factors in the selection process changes.
Therefore, sensitivity analysis is a necessary complementary tool in analyzing decisions. Based on the application of multicriteria techniques for the evaluation of electrical interconnection infrastructure projects, this article proposes to carry out a sensitivity analysis (changes in the weight assigned to the criteria and modification of the proposed criteria) to study the influence of the variation of the input data on the effect of the results obtained. The methodology is applied to a project of common interest for the cross-border interconnection of Spain-France that will be put into service in the coming years. It must be taken into account that if small variations in the inputs produce large changes in the results, the decision-makers should assess the validity of the judgments issued. Therefore, this research allows a complete and realistic analysis of the results, studies the importance of each of the selected criteria (social, economic, environmental and technical) and verifies which are the most important.
The rest of the article is structured as follows: Section 2 presents the multicriteria methodology. Section 3 defines the case study along with the proposed scenarios. Section 4 analyzes the results obtained. Finally, Section 5 summarizes the main conclusions of this research.

2. Methodology

Selecting the most beneficial project from a range of alternatives is one of the greatest difficulties faced by electrical infrastructure planners. The consideration of a large number of factors that intervene in the process and the variety of criteria, objectives and participants makes it necessary to plan a multidimensional decision process in which economic, technical, social and environmental aspects are involved.
Multicriteria techniques help in the analysis or decision- making thanks to dividing the problem into parts or subparts that are studied in isolation and that are easier to address that way. In addition to facilitating the selection of the best alternative through an in-depth study of the problem, multicriteria analysis can provide other advantages and benefits, even generating new alternatives that are better than those initially proposed [21].
In this article, the AHP method is used since it has many advantages over other defined techniques, such as the possibility of decomposing and analyzing the problem in parts and measuring quantitative and qualitative criteria using a common scale, including the involvement of different stakeholders, generate a synthesis and perform sensitivity analysis. In short, it is a simple and flexible method that can solve complex problems with multiple criteria.
Figure 1 represents the main steps that make up the methodology used to apply the AHP technique correctly and obtain the prioritization of cross-border interconnection projects.

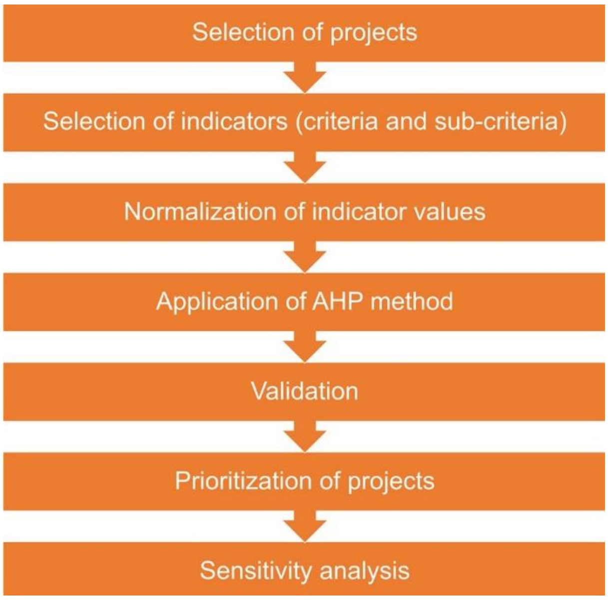

Fig. 1. Summary diagram of the multicriteria methodology.

Next, the stages of the proposed methodology are briefly defined:

- First, you must select the alternatives on which you want to apply the multicriteria tool.
- Subsequently, the indicators that directly affect the selection of one project or another are identified, and their values are normalized with respect to the target country.
- Then, once the alternatives to be evaluated and the different indicators have been selected, they are weighed through surveys of the different groups of experts. The total set of decision- makers must consist of professionals or specialists with different backgrounds in the planning of electrical infrastructures,

socioeconomic and environmental impact of energy systems, planning and land use planning, among others.

- The next step is to validate the results obtained through the consistency of judgments. The consistency ratio is calculated, which must be less than 0.1. If this does not happen, it is necessary to coordinate with the decision-maker to make the corrections where the inconsistency occurs until a consistency ratio of less than 0.1 is achieved.

  Equations (1)-(3) indicate the calculation of the consistency index of the comparison matrix (CI), the random consistency index (RI) and the consistency ratio (CR). Here, λmax is the maximum eigenvalue and n corresponds to number of criteria.

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

$$RI = \frac{1.98 \cdot (n-2)}{n} \quad (2)$$

$$RC = \frac{CI}{RI} \quad (3)$$

- Once the results are adequate, each of the projects selected for each of the subcriteria are compared.
- Finally, the evaluation and prioritization of the projects is obtained. The project with the highest AHP weighting value is the one selected.
- Finally, it is essential to carry out a sensitivity analysis through which the reliability of the results obtained is verified.

Figure 2 presents the criteria and subcriteria that are used to assess cross-border electrical interconnection projects. Consistent energy planning requires the implementation oftechnical, economic, environmental and social criteria. In addition, subcriteria must be established and linked to each of the criteria for decision-making. Therefore, in this case, four criteria and twelve subcriteria are chosen.
For a more detailed explanation of the indicators, see document [4].

3. Case study

To test the proposed methodology in various scenarios, it is applied to a new project of common interest for cross-border electrical interconnection between Spain and France [5]. The level of electrical interconnection in Spain is very low, and it is a priority to promote new interconnections to reduce Spain's isolation from the restof the European system.
Table I indicates the main characteristics of the capacity and costs of the project that is taken as a case study in this article. This project consists of a new HVDC (high-voltage direct current) interconnection by means of a direct current submarine cable in the Bay of Biscay. In addition, there is a converter station at each end of the electric transmission line to transform direct current into alternating current to connect to the electricity transmission network of each country.

Table I. Study project characteristics.

Substations	Capacity increase (MW)	Length (km)	CAPEX (€ M)	OPEX (€ M)
Gatika (Spain) - Cubnezais (France)	2200	370	1750	10.2

The scenarios that are proposed in this article to evaluate the importance of each criterion and obtain an adequate assessment of the judgments made are indicated in Table II.

Table II. Proposed scenarios.

Scenarios	Technical criterion (%)	Environmental criterion (%)	Social criterion (%)	Economic criterion (%)
1	100	0	0	0
2	0	100	0	0
3	0	0	100	0
4	0	0	0	100
5	50	50	0	0
6	50	0	50	0
7	50	0	0	50
8	33.33	33.33	33.33	0
9	33.33	33.33	0	33.33
10	33.33	0	33.33	33.33
11	25	25	25	25
12	35.50	33.46	16.22	14.82

Each of the criteria is modified separately, always ensuring a sum of 100% is met to observe the effects that the modifications have on decision-making. If only one criterion is considered, the analysis ceases to be multicriteria, but that is how the effects of conditioning decision-making on a single criterion can be analyzed.
Subsequently, criteria are added to evaluate the impact on their combination, generating different scenarios.
The technical criterion is considered the most influential in cross-border electrical interconnection projects since, with the increase in the flow of electricity transfer capacity, the study system achieves important benefits. The new interconnection allows greater stability and continuity of the electricity supply in the event of phenomena that endanger supply availability between the two countries, progress toward achieving the energy transition objectives and to creating a more efficient system with greater savings that benefit all consumers.

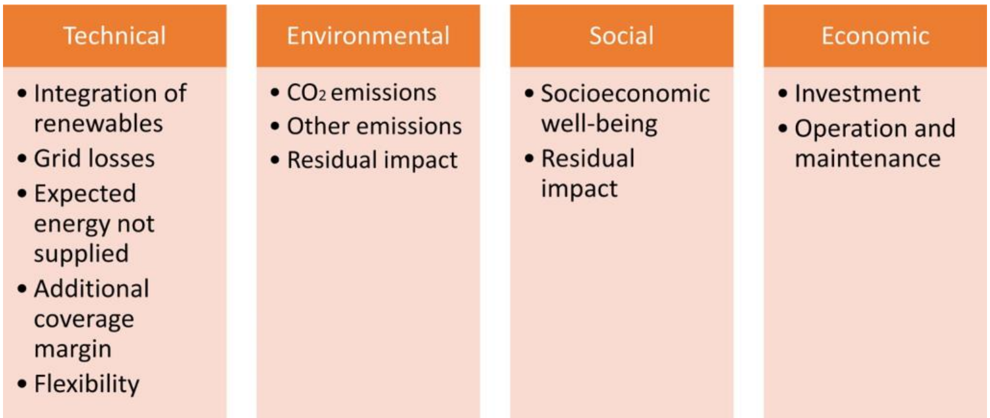

Fig. 2. Outline of the proposed criteria and subcriteria.

4. Results

Table III presents the results obtained from the AHP method when applying the weights of the criteria indicatedin Table II through the proposed methodology.

Table III. Results obtained in the different study scenarios.

Scenarios	Study project
1	0.9643
2	0.8795
3	1.0000
4	0.6299
5	0.7763
6	0.9821
7	0.7971
8	0.8507
9	0.8926
10	0.8646
11	0.9201
12	0.8937

It should be noted that the results shown are the result of the application of the criteria for the different scenarios, keeping the weights in the subcriteria. Scenario 12 represents the base case with the four criteria selected, and its weight is obtained through surveys carried out with groups of experts.

In the scenarios where the economic criterion was weighted more (scenarios 4 and 7), the score of the project decreases with respect to the base case since the investment and operation costs are high as a consequence of the use of submarine cables over the greater portion of the route in addition to the fact that the necessary transmission line is long (almost 400 km).

By increasing the weight of the social criterion, the AHP score of the study project increases. This project is at a very advanced stage for commissioning in the coming years, which is why it has been subjected to several public consultations throughout the planning process to ensure a rational use of natural resources, the prevention and reduction of pollution and strengthening social cohesion. For cross-border electrical interconnection projects, the citizen involvement during all stages through access to comprehensive and easy-to-understand information is critical for achieving greater social consensus and the best solution for the territory.

As a result, the final layout of this project avoids proximity to population centers and areas with potential urban development, as well as isolated homes, where noise emissions can become annoying for people. In addition, the increase in energy exchange capacity that this project allows translates into a reduction in the expected congestion at the border, as well as the use of cheaper energy at all times, due to the increase in flow in both directions, providing a greater socioeconomic benefit throughout Europe.

Similarly, by increasing the weight of the technical criterion, the score of the project increases, since, as obtained in the base scenario (scenario 12), it is the most important criterion. The increase in energy transfer capacity between countries (2200 MW) provides a better mesh with the rest of the European system with the consequent improvement of the quality and security of the electrical system and the possibility of mutual support in case of incidents and extreme situations. In addition, it avoids having to install backup generation in the Spanish and French systems with the possibility of sharing balancing mechanisms, achieving a more efficient European global system.

Regarding the increase in weight of the environmental criterion, a similar score is obtained in the project compared to the base case (scenario 12). In scenario 12, the groups of experts already scored high on the environmental criteria (33.46%) together with the technical criteria (35.50%). Cross-border electrical interconnection projects can affect vegetation, protected natural spaces, fauna and places with protected or endangered species. Therefore, it is essential to minimize this impact. The layout of this study project uses submarine cables that avoid affecting the mountainous system of the Pyrenees, which have vast areas outfitted for leisure highlighted by their beauty, species and climate. In addition, the project avoids fishing areas. Additionally, with this electrical interconnection, a greater integration of renewable energies is achieved with the consequent reduction of CO_2 emissions.

In summary, from this evaluation, the power of the tool for analyzing various case studies and the importance of conducting sensitivity studies to be able to visualize the influence of each of the criteria more clearly and validate the decisions taken emerge.

5. Conclusion

Cross-border electrical interconnections allow greater stability and security of the electricity supply as the number of interconnections increases with an increase in the energy exchange capacity and, consequently, a greater possibility of sharing resources and their more efficient use. This article aims to apply a multicriteria methodology for the evaluation of large and complex cross-border electrical interconnection infrastructure projects with the simulation of various scenarios to validate the prioritization of projects and study the influence of the different proposed criteria (technical, environmental, social and economic).

A new electrical interconnection project between Spain and France has been chosen as a case study. The impulse and political support for these interconnections is essential for Spain to reach the minimum value of 10% of the interconnection ratio established as a target in the European Union.

From the results obtained, the following conclusions have been drawn:

- The methodology allows simulating different scenarios and assessing the consequences of different decisions made.
- The study of scenarios allows a more consistent and exhaustive evaluation of electrical interconnection projects.
- An important criterion in the evaluation of this type of project is the technical one. This project presents good technical characteristics with the incorporation of the latest HVDC technology, greater integration of renewables and increased electrical security. Of similar importance is the environmental criterion, for which the new electrical interconnections must minimize the negative impact on the environment with the appropriate selection of its route.
- The methodology is valid since the evaluation of several scenarios shows that the proposed variations in the weights of the criteria do not leadto large changes in the project score.

In summary, the application of the multicriteria methodology to different study scenarios provides as complete a view as possible of the real impact of cross-border electricity infrastructure projects. In addition, it allows us to analyze in detail the variation of the different criteria and improve the selection process and, thus, beable to validate the prioritization of some alternatives over others.

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