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Evaluating future scenarios for the power generation sector using a Multi-Criteria Decision Analysis (MCDA) tool: The Portuguese case

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ABSTRACT

A Multi-Criteria Decision Analysis (MCDA) tool was designed and used to support the evaluation of different electricity production scenarios. The MCDA tool is implemented in a user-friendly Excel worksheet and uses information obtained from a mixed integer optimization model, to produce a set of optimal schemes under different assumptions. Given the input, the MCDA allowed ranking different scenarios relying on their performance on 13 criteria covering economic, job market, quality of life of local populations, technical and environmental issues. The MCDA tool was used by a group of experts and academics with background in economics, engineering and environment. Regarding the totality of results, both the most and least expensive scenarios ranked first the same amount of times. These scenarios were, respectively, "Coal", relying mainly in new coal power plants and "Maximum Renewable", relying mainly in new wind and hydro power facilities. The opinions were divided towards these two solutions with different fundamental characteristics: "Maximum Renewable" with costs higher than "Coal" but leading to substantial reduction of the external energy dependency. Sensitivity analysis suggests that, although the costs are regarded as the most important criterion, those who had different rankings in their preferences have different attitudes towards other criteria.

1. Introduction

1.1. Background and motivation

Over the last two decades, international treaties, such as Kyoto Protocol, have been signed, and strategies to mitigate CO_2 emissions have arisen in all the developed world nations. At the same time, Sustainable Development is becoming part of political discourse in the European Union. According to the European Union Sustainable Development Strategy (EUSDS), Sustainable Development envisages the "continuous improvement of the quality of life of citizens through sustainable communities that manage and use resources efficiently and tap the ecological and social innovation potential of the economy, so as to ensure prosperity, environmental protection and social cohesion" [1].

As a result, the electricity production planning gets more constrained than before, resulting in a multi-objective problem [2]. What was regarded in the past as a cost minimization problem should now be evaluated also under a Sustainable Development perspective. In previous works, we identified papers concerning sustainability criteria in power systems planning [3,4], and concluded that the methodologies explicitly expressing economic, social and environmental criteria fall mostly under the umbrella of Multi-Criteria Decision Analysis (MCDA).

When using multi-criteria decision methodologies, one has to have in mind that there are no universal best solutions, as results are made upon personal judgement of different criteria. Therefore, for the present work, we invited a panel of experts on energy systems to map the diversity of opinions and preferences for the future of the Portuguese electricity system. We designed a new MCDA tool for the evaluation of different electricity generation scenarios and presented it to a group of experts in power systems. The use of the MCDA tool was then demonstrated for the evaluation of possible electricity scenarios drawn for Portugal in 2020, according to the experts input. Portugal depends strongly on a mix of natural gas, coal, wind and hydro power. Given that high potential for developing renewables still exists, there is higher uncertainty about what will become the power system within ten years. This uncertainty is higher than in other countries where lower potential exists for developing renewables, and choices are more limited.

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Therefore it was decided to test the MCDA using Portugal as an example, although our work can easily be adapted to other countries. Present work can give valuable inputs to energy decision makers for similar systems. The main objective of the paper is to assess the experts' opinion on the proposed scenarios and considered criteria, demonstrating then the importance of experts' participation in structured energy planning decisions.

The criteria used in the evaluation cover Sustainable Development (social, cost and environmental) issues, among others, visual impacts and technical issues of power systems, as addressed in Section 3. We retrieved the criteria from both interviews conducted in a previous phase of the work [5] and from the literature.

1.2. Energy decision-making and Multi-Criteria Decision Analysis (MCDA)

Literally hundreds of MCDA methodologies have been proposed [2]. These have been applied to a wide array of examples in the energy sector [6]. Recent examples range from assessment of applications in bioenergy systems [7] to space heating technologies ranking [8], or sustainability assessment of domestic hot water technologies [9], among many others. To what concerns the purpose of the present work, more specifically electricity and power systems, MCDA has also been applied. Following Hobbs and Meier [10] definition of electricity power planning, "the selection of power generation and energy efficiency resources to meet customer demands for electricity over a multi-decade time horizon", a number of papers found in the literature serve as a contribution to this topic, more specifically in evaluation of projects, technologies and scenarios. Some papers surveyed from the literature will serve as examples in the remainder of this section.

Discrete MCDA models, do not involve a description of the objectives or constraints in mathematical functions, but rather a characterization of a finite set of alternatives or projects aimed to be compared and evaluated. A large number of these studies perform comparisons between different electricity power production options, technologies or projects. Kahraman [11] used fuzzy Analytic Hierarchy Process (AHP) to compare renewable energy technologies. The fuzzy set theory was found useful for treating vague information and uncertainty. Their study concluded that wind power was the most attractive technology under the set of criteria they evaluated. Kaya [12] conducted an integrated MCDA approach, combining methodologies AHP and VIKOR (VIsekriterijumsko KOmpromisno Rangiranje), to aid the selection of the best technology in the first place, and evaluate the best location for wind power in the second place: this paper serves as an example where both technologies and projects were evaluated. Still in the application to specific projects, Choudhary [13] used a fuzzy AHP-TOPSIS (Technique for the Order of Prioritization by Similarity to Ideal Solution) approach for aiding the location for implementation of a thermal power plant.

Energy planning based on discrete models relies frequently on the comparative assessment of alternative scenarios explicitly known *a priori*. Each scenario describes a possible expansion plan and gives information about its technical, economic, environmental and social characteristics. The advantage of using scenarios is that they do not evaluate technologies per se as the cases we've presented so far in this section, but rather evaluate whole solutions that satisfy the electricity demand: more concretely, wind power can be the most "sustainable" technology on its own, but cannot satisfy the entire demand of a country on its own due to its variable production nature, so it will be used coupled with other technologies. The resulting feasible mix constitutes a scenario. MCDA applications are proven to be useful and have been extensively used to evaluate these scenarios.

Using MCDA allows the evaluation of the interaction between different technologies, by using this information in reliability indexes, such as the case of Prete [14]. Their scenarios are also evaluated under technical criteria, such as economic, environmental and social indexes. One example of an integrated approach to decision-making in energy systems considering sustainability criteria is McCollum [15], where an "optimal" scenario is created after criteria are weighted. Other works incorporate valuable technological aspects of power systems, such as Heinrich et al. [16], which provided a methodology to evaluate scenarios for generation capacity expansion under uncertainty in South Africa, allowing also

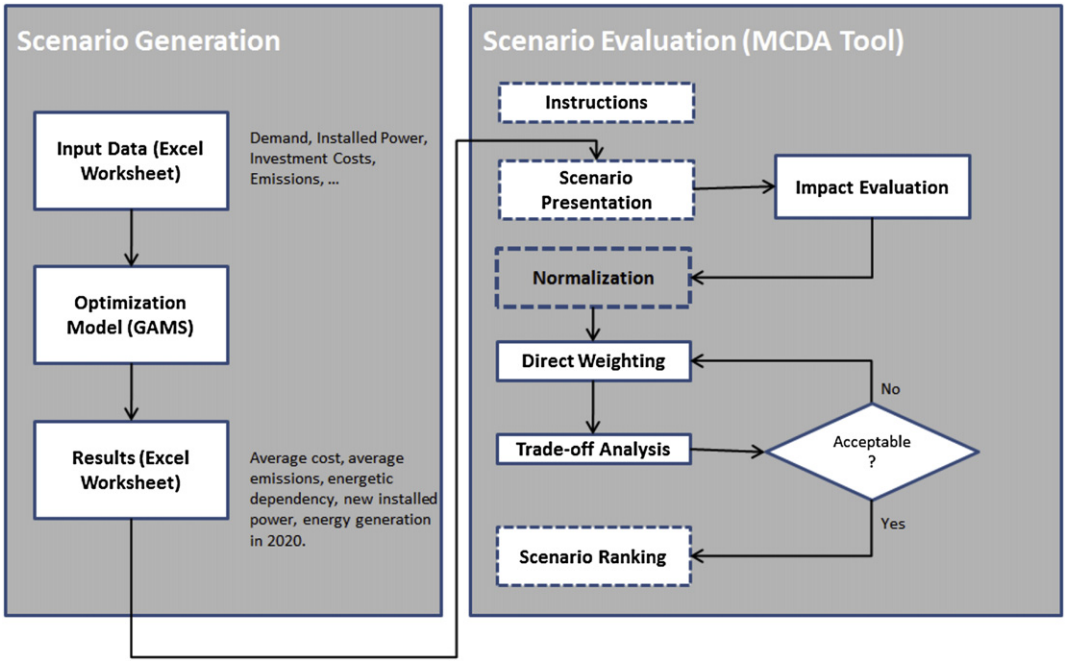

Fig. 1. Methodological approach of the research.