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Designing a municipal sustainable energy strategy using multi-criteria decision analysis

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ABSTRACT

The development of more sustainable energy systems is at the top of political agendas around the world. Sustainability is inherently a multi-criteria concept, thus it is appropriate to use multi-criteria decision analysis (MCDA). This methodology facilitates the intricate decision process by which decision makers must go through to agree on robust long-term alternatives for the sustainable development of existing municipal energy systems taking economic/financial, technical, social and environmental criteria into account.

This work presents a methodology to help local authorities with the development of an Energy Action Plan (EAP) towards more sustainable municipal energy systems and, simultaneously, ease the related decision process, by using MCDA. The developed methodology was applied to the municipality of Odemira, Portugal. After several interactions with stakeholders, a set of 16 actions was chosen. Once applied the ELECTRE III method, public lighting, the conversion of the swimming pool water heaters for biomass fueled, the matching of bus and train schedules and the installation of solar photovoltaic systems on the municipal exposition park were the best-ranked actions to be adopted. Also, up to 3 kton of carbon dioxide emissions can be avoided per year if the EAP is implemented, being observed higher benefits at the residential and services sectors. The decision of implementing these actions now stands with the municipality, which should start by implementing the most preferred actions first, and then proceed with the implementation of the subsequent actions, according to financial and human resources availability.

1. Introduction

The global warming phenomenon coupled with the volatility of energy vectors prices and the depletion of fossil fuels, is increasingly placing the development of more sustainable energy systems at the top of political agendas around the world. These can be achieved through the increasing use of renewable energies, implementation of energy efficiency measures and by developing intelligent energy networks that integrate information and communication technologies (ICT). These actions aim at increasing environmental protection, security of energy supply and economic growth (Ferrão and Silva, 2012) and are ultimately driven by climate and energy efficiency goals set in international agreements. Subsequently, each economic region/country sets its own objectives (aligned with the international goals), creating plans and programs to be implemented by the municipalities, which operationalize them (Ferrão and Silva, 2012). The potential impact and responsibility of municipalities in the achievement of the energy efficiency and climate objectives is so relevant that it has motivated the launch of the European program 'Covenant of Mayors' (CoM), by which more than 6000 European municipalities have already voluntarily committed to reduce their CO_2 emissions in 40% by 2030 (Covenant of Mayors Office, 2015). Consequently, energy planning at the municipal level is critical, but the decision process by which decision makers (DMs) must go through to agree on

Abbreviations: CoM, Convenant of Mayors; DM, Decision makers; EAP, Energy action plan; FPV, Fundamental points of view; GHG, Greenhouse emissions; HRU, Heat recover units; ICT, Information and communication technologies; MCDA, Multi-criteria decision analysis; PV, Solar photovoltaics; RES, Renewable energy; ST, Solar thermal.

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robust long-term alternatives is not trivial, as it is necessary to take into account economic/financial, technical, social and environmental criteria, as well as different stakeholders' perspectives.

In order to understand how municipalities throughout the world have been developing energy action plans (EAP), a literature review was conducted among different methodologies and frameworks (Prasad et al., 2014; Salvia et al., 2015; Fenton et al., 2015; Campos et al., 2017; Engelken et al., 2016). On the one hand, Pablo-Romero et al. (2016) studied the implications of EAP in the decrease of electricity consumption within the CoM framework, concluding that they correlate positively for Andalusian municipalities. Beihmanis and Rosa (2016) address the concern of increasing renewable share and reducing CO_2 emissions by implementing an EAP at the municipal level in Eastern-Europe municipalities. In this case, the selection of actions was divided into training, information, monitoring and energy efficient supply, according to the required time and investment needed for implementation.

However, it has been seen that EAP often aims at different goals, besides increasing the share of renewables and therefore reducing the CO_2 emissions. Goals spread from addressing more social-energy related policies, as climate change and adaptation policies (Campos et al., 2017), or just energy related municipal policies (Engelken et al., 2016).

The main barriers to the implementation of an EAP are the lack of integration or accordance of the local stakeholders, and Gustafsson et al. (2015) studied, in Sweden, the influence of involving multiple actors for the success of specific measures implementation and follow up, however without providing definite conclusions.

In summary, methodologies for developing EAP focus on the application, and frequently they identify the same criteria or at least the same areas of intervention. For example, Salvia et al. (2015) developed a specific methodology (RE-SEEties) for developing EAP in municipalities, by pointing five main areas of intervention in real case studies: policy making, best practices/technologies, changing behaviors, technical data and tools, and criteria for EAP. Another study (Kostevšek et al., 2014) identified three main objectives on a ten-year horizon, related to the increase of renewable energy resources (RES) at regional level: ICT, energy systems monitoring, and improving end-users and supply connection. However, both studies do not explain how they get from the selection of a set of criteria to the selection/prioritization of actions.

Still, many studies argue the choice of poor energy indicators at the municipal level, and that is why Neves and Leal (2010) explore, in a literature review, the best indicators to look at when developing an energy plan at the municipal level. They summarize that indicators must address, in general, the energy supply chain, from primary energy resources (fossil fuel demand, etc.), to final energy indicators (e.g. electricity), to useful energy (as lighting, heating, etc.) and to energy services.

Furthermore, the most widely referred methodology at European level, which was developed to guide the signatories of the Covenant of Mayors program (European Commission, 2010) suggests using multi-criteria decision analysis (MCDA) for the above mentioned purpose of selecting and prioritizing actions. Yet, most of the municipalities fail to do so, although Neves (2012) and Dall'O' et al. (2013) have developed methodologies specifically suggesting the application of MCDA for energy planning at a local level.

MCDA methods have been applied over the years to decision problems in many different areas. According to Mirakyan and De Guio (2013), MCDA methodologies are not only appropriate to define the 'right' energy plan, but they also support the understanding of the multi-criteria complex situation, assisting interactive planning and learning, helping participants to systematically consider, articulate and apply their value judgments. By allowing the inclusion of the preferences and interests of multiple stakeholders in a transparent and fair way, it increases the solution's acceptance.

Regarding the potential alternatives to be considered, actions/measures associated with a single technology are preferred to scenarios (which regard several energy sources and/or energy technologies), even though the scenarios' approach can help policy-makers to scrutinize scenarios and stakeholder preferences in a robust, transparent and democratic way.

From the performed literature review, one can verify that there is no well-defined approach to energy planning problems: Both value and utility theory, and outranking methods have been implemented. In some cases, the MCDA methods have also been combined. However, for the energy related problems, the MCDA methods with the outranking approach, in particular the family of ELECTRE methods (*ELimination Et Choix Traduisant la REalité* - described in detail in Appendix A - Annex I), are very popular (Govindan and Jepsen, 2016). That is why, literature reports the application of MCDA using the ELECTRE III methods at the regional level (Beccali et al., 2003) and national level (Madlener et al., 2007) for sustainability and renewable energy deployment purposes. Further, it is also used in the energy planning of generation power plants and multi-source energy grids, as in the comparison of energy performance of different types of buildings (Govindan and Jepsen, 2016).

In this context, this paper presents a methodology to help local authorities plan the development towards more sustainable municipal energy systems and, simultaneously, ease the related decision process, by using a multi-criteria decision analysis, with ELECTRE III. The developed methodology is applied to the municipality of Odemira, in Portugal.

The remainder of this paper is organized as follows: Section 2 presents the methodology to support sustainable municipal energy planning, together with the case study; Section 3 describes the results from the application of the methodology and discusses those results; and in Section 4 the final conclusions are drawn.

2. Methods and data

The MCDA methodology has been widely suggested to develop municipal EAP (European Commission, 2010; Genchev et al., 2010) and the MCDA steps proposed by Bouyssou et al. (2006) served as the basis for the elaboration of this work. As previously stated, although several sources suggest the implementation of MCDA, none of them thoroughly describes how to apply them in detail. Consequently, the methods applied in this work evolve on a three-phase process presented in Fig. 1.

First, the ***Contextualization of the case study*** phase is where the case study is identified and characterized, based on the collection of data sets and identification of cooperating agents. In more detail, this stage consists of:

- Collecting data regarding energy demand and supply, which should be systematized in the different economic sectors and energy vectors, as well the CO_2 emissions and renewable energy production and potential;
- Identifying and assessing the main local stakeholders involved, as the mayor, population or major companies operating in the municipality. There must be a political commitment for the planning, monitoring and reporting phases, even if at different levels (see *How to develop a Sustainable Energy Action Plan - Guidebook*; European Commission, 2010).