A methodology to support sustainable municipal energy planning by using multi-criteria decision analysis

Application to the Portuguese municipality of Odemira

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Abstract – Global warming, climate change, and both the prices and the depletion of fossil fuel, increasingly place the development of more sustainable energy systems at the top of political agendas around the world. Municipal energy planning is very important since it plays a key role in the achievement of the national and transnational energy and climate objectives. As sustainability is inherently a multi-criteria concept, it is appropriate to use multi-criteria decision analysis (MCDA) to facilitate the intricate decision process by which decision makers must go through in order to agree on robust long-term alternatives for the sustainable development of existing municipal energy systems, taking economic/financial, technical, social and environmental criteria, and different perspectives, into account.

This paper proposes a methodology to help local authorities through municipal energy planning, by using MCDA. According to the literature review conducted, MCDA is also suggested by most widely implemented methodologies. However, none of them thoroughly describes how to implement MCDA contrarily to the methodology here proposed.

The methodology has been applied (although only partially) to the Portuguese municipality of Odemira in order to prove that it can be operationalized. Odemira has 25,770 inhabitants and a total final energy consumption of 319 GWh (2013). Even though Odemira already comprises renewable energy production, which adds up to about 16% of the final energy annual consumption (2013), most part is assigned to firewood. However, Odemira is endowed with a much larger energy production potential which could be exploited. It is also endowed with a great potential for improvement in energy efficiency.

Keywords – sustainable development of energy systems; multi-criteria decision analysis; municipal energy planning; ELECTRE III

1 INTRODUCTION

Global warming, climate change, and both the prices and the depletion of fossil fuel, increasingly place the development of more sustainable energy systems at the top of political agendas around the world.

Developing existing energy systems towards more sustainable ones is accomplished by (i) introducing or increasing the use of renewable energies, (ii) implementing energy efficiency measures, and/or by (iii) implementing intelligent energy networks that integrate information and communication technologies. This energy systems’ development increases environmental protection, security of energy supply and economic growth (Ferrão & Silva, 2012).

The energy systems’ development is ultimately driven by the climate and energy goals which are set in international agreements. Each economic region and/or country sets its own objectives (aligned with the international goals) and creates plans and programs to be implemented by the municipalities, which operationalize them (Ferrão & Silva, 2012).

The potential impact and responsibility of municipalities in the achievement of the energy and climate objectives is so relevant that it has motivated the launch of the European program ‘Covenant of Mayors’, by which more than 6,000 European municipalities have already voluntarily committed to reducing their CO₂ emissions beyond the 20% European target (Covenant of Mayors Office, 2015). Energy planning at the municipal level is therefore critical. Yet, the decision process by which decision makers (DMs) must go through in order to agree on robust long-term alternatives for the sustainable development of existing municipal energy systems, taking economic/financial, technical, social and environmental criteria, and different perspectives, into account, is a really intricate one.

As sustainability is inherently a multi-criteria concept, it is appropriate to use multi-criteria decision analysis (MCDA) to support the planning of the development of more sustainable energy systems. Furthermore, by taking into consideration the several sources of uncertainty at stake, it
allows drawing up more robust recommendations (Antunes & Henriques, 2014).

Despite this fact, the methodologies which are more widely implemented to help developing municipal energy plans do not suggest using MCDA in a systematic way. Plus, there is still a very limited number of case studies where this methodology has been applied to address energy planning problems at municipal level specifically.

This paper presents a methodology to help local authorities plan the development towards more sustainable municipal energy systems, and simultaneously, facilitate the related decision process, by using multi-criteria decision analysis.

The remainder of this paper is organized as follows: Section 2 presents a literature review on MCDA application to municipal energy planning; Section 3 describes the methodology to support sustainable municipal energy planning; Section 4 provides results from the application of the methodology to a case-study and the discussion of those results; and Section 5 presents the conclusions.

2 LITERATURE REVIEW

In order to understand how municipalities throughout the world have been developing energy plans, a literature review was conducted. It was possible to identify a gap between what the existing methodologies suggest and what local authorities have been implementing, regarding the selection and prioritization of actions. For instance, the most widely followed methodology at European level (developed to guide the signatories of the Covenant of Mayors program; European Commission, 2010) suggests using MCDA for the above mentioned purpose of selecting and prioritizing actions, and yet, most of the municipalities fail to do so. Moreover, the few municipalities that mention the MCDA in their action plans, do not explain how they get from the selection of a set of criteria to the selection/prioritization of actions. Lately, methodologies specifically suggesting the application of MCDA for energy planning at a local level have been developed (Dall’O’ et al., 2013; Neves, 2012). Nonetheless, they have only been implemented by one municipality each.

A sample of sixteen case studies where MCDA was applied (outside the framework of the Covenant of Mayors program) has been reviewed, showing how this methodology is adequate to support energy planning at municipal level. According to Mirakyan and Guio (2013), MCDA methodologies are not just appropriate to define the ‘right’ energy plan – they also support the understanding of the multi-criteria complex situation, supporting interactive planning and learning, helping participants to systematically consider, articulate and apply value judgments. By allowing the inclusion of the preferences and interests of multiple stakeholders in a transparent and fair way, it increases the solution 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, also enabling to explicitly address complexity and uncertainty and to foster social learning, the utilization of actions/measures as alternatives can significantly reduce the great effort required for scenario building.

From the sample of articles, 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.

The outranking approaches seem appropriate for the problem being considered. This type of methods are based on weaker assumptions than utility-based multi-criteria algorithms (e.g., no additive utility function necessary) and require less information from DMs. These methods allow working with quantitative and qualitative scales and dealing with imperfect knowledge regarding the data considered. Moreover, these methods do not allow for compensation between criteria.

3 METHODOLOGY

The methodologies most widely implemented (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 methodology. As previously stated, although these methodologies suggest the implementation of MCDA, none of them thoroughly describes how to do it. The methodologies will be modified, inasmuch as the ‘development of an energy action plan’
phase further explains the ‘selection/prioritization of actions’ topic.

The two-phase methodology is presented in Figure 1.

![Diagram of the methodology](image)

Figure 1 – Outline of the methodology

Please mind that the preparation phase is very similar in the existing methodologies and comprehensively described by them. For this reason, the upcoming description of this phase consists of a summary of the information presented in the guidebooks of these methodologies.

3.1 Preparation

3.1.1 Steps 1 & 2 – Political commitment & Adaptation of administrative structures

The Mayor shall commit to the elaboration of a plan to develop the municipal energy system into a more sustainable one. The political commitment throughout all phases – planning, monitoring and reporting – is essential.

After committing to the development and implementation of a plan, the local authority shall create the necessary organizational structure to carry out the task. A clear organizational structure and assignment of responsibilities are prerequisites for the successful planning and subsequent implementation of the action plan (see How to develop a Sustainable Energy Action Plan - Guidebook; European Commission, 2010).

3.1.2 Step 3 – Development of the municipality’s current framework

This step consists on defining the municipality’s current situation in terms of energy and climate change.

The aspects about the municipality that should be covered comprise, e.g., the annual final energy consumption and CO₂ emissions by sector of economic activity and energy carrier, the renewable energy current and potential production, and the identification of potentialities for improvement in energy efficiency (EE) in the municipality’s buildings and transport and mobility areas (see European Commission, 2010).

The assessment of the current situation allows elaborating a plan that is suited to the emerging issues and specific needs of the municipality. The baseline review not only allows prioritizing actions but also to monitor their effect after their implementation.

3.1.3 Step 4 – Identification of the local stakeholders

This step consists of identifying the main local stakeholders involved.

Regarding energy planning problems at the municipal level, examples of main stakeholders are the mayor, the inhabitants, the local energy agencies, consultants, the transportation companies, and the business and industries (European Commission, 2010).

The roles and level of influence as well as the concerns and values of each stakeholder must be assessed.

3.2 Development of an energy plan

3.2.1 Step 5 – Definition of the objectives of the plan

This step consists on determining the goals of the action plan.

The implementation of this step starts with the definition of the set of fundamental points of view (FPV; Bouyssou et al., 2006). These FPV represent the different perspectives from which the potential alternatives are evaluated, and consist of the preoccupations of the DMs.

Sustainable development involves many preoccupations, namely the economic/financial, the social, and technono-environmental aspects.

The second part of this step consists of determining the criteria which operationalize the FPV and are used for
characterizing and comparing the potential actions (Bouyssou et al., 2006). The different criteria represent the objectives of the DMs regarding the implementation of the energy plan.

The three FPV presented may be operationalized by the 10 criteria presented on Figure 2, which must be either maximized or minimized.

The actions may concern both public and/or private investment. Furthermore, they may regard either private sites or public sites (being either municipal or state property).

Great attention shall be paid to the public sector, since the local authority is expected to play an exemplary role and therefore to take outstanding measures related to the local authority's own buildings and facilities, vehicle fleet, etc. (European Commission, 2010).

3.2.3 Step 7 – Selection/prioritization of the actions

This step consists of prioritizing the previously generated actions because undertaking the entire list of possible actions will often surpass the capabilities of the local authority, in terms of costs, project management capacities, etc.

In order to prioritize the action, the set of actions shall be ranked from best to worse. For this reason, the MCDA method chosen is ELECTRE III. Some of the following steps of the methodology are constrained by the selection of this specific method and might be carried out differently if another method is chosen. The variety of activities in this step requires special qualification which may not be available in every municipal administration. That is why the involvement of external technical support could be decisive for the successful development of the plan.

3.2.3.1 Step 7.1 – Construction of the selection criteria

Each of the criteria defined by the DMs in step 5 is built from at least one dimension, which is a ‘sub-objective’. Each dimension is defined by an elementary consequence and a primary scale or metric.

The criteria built from more than one dimension must be associated with a descriptor each (an ordered set of plausible impact levels associated with that specific criterion; Bana e Costa & Beinat, 2005).

3.2.3.2 Step 7.2 – Weighting of the criteria

This step consists of determining the weights of the criteria selected on step 5.

The weights shall express the subjective importance the DMs assign to each criterion, when compared to the remaining. In a decision aiding context, this process is very hard (Figueira & Roy, 2002).

The weighting method selected is the revised Simos’ procedure, also called ‘the playing cards’ approach,
developed by Figueira & Roy (2002) specifically for the ELECTRE methods. This option is particularly useful because it allows DMs which are not familiar with MCDA to easily express their opinion and to state in what way they want to rank the criteria.

The SRF software (coded with Borland Delphi 3) shall be used to help determine the weights of criteria. It is able to cope with multiple DMs evaluating the same set of criteria.

3.2.3.3 Step 7.3 – Evaluation of the performance of each action

In this step the impact matrix is built, i.e., the performance of each action in each and every criteria is assessed. It requires performing a forecast about the impact of every action considered, regarding the criteria chosen in step 5.

The performance of each action shall be measured as if the action was to be implemented alone, on the existent energy system described in step 3.

3.2.3.4 Step 7.4 – Definition of the thresholds

This step consists of the definition of the discriminating (indifference and preference) thresholds for every criteria. The veto thresholds are also defined for the desired subset of criteria.

The thresholds are used by ELECTRE methods to take into account the imperfect character of data from the computation of the actions’ performances (in step 7.3) as well as the arbitrariness that affects the definition of the criteria.

The thresholds shall be defined by experts.

3.2.3.5 Step 7.5 – Results and sensitivity analysis

This step consists of implementing the ELECTRE III method in a software, in order to obtain the ranking of the actions and draw conclusions.

As ascertained in the literature review carried out, in order to test the robustness of the conclusions when using outranking methods, sensitivity analysis can be performed by (i) simply varying the weights of the criteria or by (ii) forecasting different possible futures which will be translated on different weightings of the criteria.

3.2.4 Step 8 – Elaboration of the energy action plan

Based on the ranking of the actions and on the subsequent sensitivity analysis, an action plan for the municipality must be created.

The municipality shall choose to start implementing the most preferred action first, and proceed with the implementation of the subsequent actions according to the financial and human resources availability. In case two or more actions are mutually-exclusive, when the one ranked first is implemented, the remaining shall be discarded (not further considered for implementation).

For each action, the following aspects must be defined (European Commission, 2010): the timing (both begin and end dates); the person/department responsible for implementation; the modality of financing; the modality of monitoring (the kind of data that need to be collected in order to monitor the progress and results of the action; how and by whom the data will be collected, and who will compile it).

4 CASE STUDY

The methodology developed has been implemented in the Portuguese municipality of Odemira. Odemira has launched the ‘Efficient Odemira’ program (‘Odemira Eficiente’ in Portuguese) which promotes the mitigation of climate change. The program includes a project for the development of a sustainable energy system, named ‘S-Odemira’, which will be implemented by the Instituto Superior Técnico (IST) which has signed a protocol with the city council on January 26th, 2015.

Within this framework, two workshops have been held in Odemira with the deputy mayor and ten representatives of different departments of Odemira’s city council.

4.1 Preparation

4.1.1 Step 1 – Political commitment

The first occurrence concerning this step was the signature of the protocol for the implementation of the project ‘S-Odemira’. The participation of the aforementioned representatives of the city council, namely the deputy mayor, on the two workshops has further reinforced this political commitment.

4.1.2 Step 2 – Adaptation of administrative structures

The adaptation of the administrative structures performed by the city council is not known (no information on this topic has been shared with the IST team so far).
4.1.3 Step 3 – Development of the municipality’s current framework

Description

The Portuguese municipality of Odemira is part of the district of Beja and is located in the region of Alentejo, more specifically, in the sub-region of Alentejo Litoral. It is the largest Portuguese municipality regarding the area; it spreads over a total area of 1,720.6 km² (FFMS - PORDATA, 2015) and covers 55 km of the Portuguese Atlantic coastline. It is subdivided in 13 civil parishes. 18% of its territory is part of the Sudoeste Alentejano e Costa Vicentina Natural Park and 43% belongs to Rede Natura 2000.

The municipality has 25,568 inhabitants (2014, FFMS - PORDATA, 2015). The corresponding population density of 14.9 inhabitants/km² is significantly lower than the national average population density of 112.8 inhabitants/km². The sub-region of Alentejo Litoral has 18.2 inhabitants per km², and there is only one municipality of this region with an inferior population density than Odemira which is Alcácer do Sal (8.3 inhabitants per km²). Also, Odemira has a similar population density to Baixo Alentejo (inland) region which has 14.4 inhabitants per km² (FFMS - PORDATA, 2015).

In Odemira, 75% of the people live in villages with less than 2000 inhabitants. The population is especially dispersed on the interior. Odemira has an ageing population. In 2011, 26.2% of the people were over 65 years old (19% in Portugal) in comparison to 24.9% in 2001 (16.4% in Portugal). Also, 13.5% of the families were composed by a single elderly person (10.1% in Portugal) in comparison to 12.5% in 2001 (8.8% in Portugal).

Between 2001 and 2014 the population had a negative population growth rate of 2%. However, this indicator does not translate the fact that the coastal regions have, mostly, high positive population growth rates and the inland ones have, mostly, high negative population growth rates.

The foreign population occupation in Odemira has been increasing over the last years. It is currently 12%, the largest of the district of Beja (José Guerra, personal communication, April 29, 2015). Most immigrants work in agriculture, mainly for the intensive agriculture companies operating in the parish of São Teotónio.

It is also important to state that during the summer, the population on the coast triplicates.

Odemira’s economy is based on the primary sector, namely on agriculture, forestry, and cattle breeding. Intensive agriculture is practiced on the coastal side, especially on the parish of São Teotónio, thanks to the mild climate and to the irrigation from the dam of Santa Clara. On the inland areas, people practice extensive agriculture.

The manufacturing industry is basically inexistent and practically confined to the agri-food industry.

Regarding tertiary sector, retail trading and services stand out. The tourism sector has been growing significantly and has become fundamental for Odemira’s development.

Odemira’s buildings are much degraded and in need of reparation, especially on the interior of the municipality. On the coast, the buildings which have been renovated between the 70s and the 90s (in order to cope with the tourism demand), have high heating, ventilation, and air conditioning invoices since no importance was given to EE at the time. The municipal buildings are also still not optimized in terms of EE and have high energy bills, as the energy consumed is not endogenous.

The dwellings are mostly single family houses; in São Teotónio and Vila Nova de Milfontes, collective dwellings are more usual.

The mobility in the municipality constitutes a great problem. Most part of the inhabitants’ journeys are made individually and the routes more often taken by the inhabitants cover great distances. The access to services (health, social security, etc.) is hampered by the lack of transportation structure and because of the restricted mobility of the senior population, forcing the inhabitants living on the interior to generally travel by taxi (José Guerra, personal communication, April 29, 2015).

The parish councils secure part of the school transport, making use, besides of their own fleet, of the services of ‘Rodoviária Nacional’ which operates the public transportation network (Manuel Rafael, personal communication, 2015).
Energy consumption

The final energy consumption by sector of economic activity and by energy carrier is presented for the year of 2013 in the energy matrix developed (Table 1).

Table 1 – Odemira’s energy matrix in 2013 (GWh)

<table>
<thead>
<tr>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>AFCBF</td>
<td>28.5</td>
<td>1.6</td>
<td>1.6</td>
<td>17.4</td>
<td>32.1</td>
<td>0</td>
<td>0.0</td>
<td>79.6</td>
</tr>
<tr>
<td>Industrial</td>
<td>1.7</td>
<td>0.7</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0</td>
<td>0.0</td>
<td>2.4</td>
</tr>
<tr>
<td>Transp.</td>
<td>0.3</td>
<td>27.2</td>
<td>83.0</td>
<td>2.0</td>
<td>0.0</td>
<td>0</td>
<td>0.0</td>
<td>110.5</td>
</tr>
<tr>
<td>Services</td>
<td>32.1</td>
<td>3.3</td>
<td>2.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0</td>
<td>0.0</td>
<td>37.3</td>
</tr>
<tr>
<td>Resident.</td>
<td>29.4</td>
<td>5.0</td>
<td>5.5</td>
<td>0.0</td>
<td>0.0</td>
<td>0</td>
<td>0.0</td>
<td>48.74</td>
</tr>
<tr>
<td>Total</td>
<td>92.6</td>
<td>5.0</td>
<td>11.1</td>
<td>27.2</td>
<td>102.4</td>
<td>0</td>
<td>32.2</td>
<td>319.2</td>
</tr>
</tbody>
</table>

*Elec.* - Electricity; *But.* - Butane; *Prop.* - Propane; *Gas.* - Gasoline; *Dies.* - Diesel; *NG* - Natural Gas; *Fire.* - Firewood; *AFCBF* - Agriculture, forestry, cattle breeding and fishery; *Transp.* - Transportation; *Resident.* - Residential

From the data presented on the matrix, it is possible to conclude that the transportation sector accounted for 35% of the total consumption, the residential for 28% and the agriculture one for 25%. The services sector accounted for 12% and the industrial one for less than 1%. This analysis matches what was previously stated regarding Odemira’s economy: it relies on agriculture and on the tertiary sector, and not on energy-sucking industries like manufacturing.

The city council was responsible for around 2.5% of the municipality’s total final energy consumption in 2013 (the city council’s buildings’ final energy consumption totals about 2 GWh per year; the energy consumption relative to public street lighting is approximately 4 GWh per year; and the municipal fleet consumes about 1.8 GWh per year).

GHG emissions\(^1\) in 2013

In 2013, the GHG emissions totaled 57,493 ton of CO\(_2\) equivalent. The transportation sector was responsible for more than 50% of the total emissions and the agriculture one for about 27%. The residential and services sectors accounted for about 10% of the emissions each.

Odemira’s energy production

In 2013, the renewable energy production represented 16% of the total final energy consumption of Odemira. More than 15% is assigned to firewood and the remaining 1% to hydro power and solar energy.

4.1.4 Step 4 – Identification of the local stakeholders

The local stakeholders identified by the DMs were the city council and the parish councils, IST, the inhabitants, the Private Social Solidarity Institutions, the local/rural tourism entrepreneurs, and the transportation companies.

4.2 Development of an energy plan

4.2.1 Step 5 – Definition of the objectives of the plan

When directly asked about their preoccupations, the DMs explained that the city council is committed to developing a green municipality, and simultaneously, concerned about contributing to social welfare. It intends to invest on both areas mentioned above, in the most cost-effective way and to implement solutions which are as technologically mature as possible. The FPVs proposed in chapter 4 to rank actions in a sustainable development context – economic/financial, the social, and techno-environmental – have therefore been validated by the DMs.

The set of criteria presented on Figure 2 was validated by the DMs. Actually, it has been built with the help of the DMs during the second workshop – as the initial structure was being presented, the participants expressed their suggestions. For instance, the criterion ‘Land use’ was substituted by ‘Impact on the land used’ and the ‘Energy independence’ one by ‘Energy savings’.

4.2.2 Step 6 – Generation of actions

During the first workshop, the DMs identified 22 actions to be analyzed and evaluated. The actions concern the residential, the services and the transportation sectors and regard private, municipal and public sites.

Due to the lack of data available up to the date of elaboration of this document, only five actions have been analyzed and compared:

- Installation of photovoltaic (PV) modules for self-consumption in the single-family houses inhabited as main residence (A1);
- Installation of solar domestic water heating systems (solar panels) in the single-family houses inhabited as main residence (A2);

\(^1\) The CO\(_2\) emissions have been assessed using the standard emission factors suggested by IPCC (2006)
- Installation of heat recovery units (HRU) in open fireplaces of the single-family houses inhabited as main residence (A3);
- Substitution of the gas fired boilers of the municipal swimming pool by biomass boilers (A4);
- Substitution of the gas fired boilers of the municipal swimming pool by heat pumps (AS).

4.2.3 Step 7 – Selection/prioritization of the actions

The method ELECTRE III was selected by the IST team to rank the actions from best to worse. The method was implemented on the MCDA-ULaval software (http://cersvr1.fsa.ulaval.ca/mcda/?q=en) by entering the data relative to steps 7.2 to 7.4.

4.2.3.1 Step 7.1 – Construction of the selection criteria

Each of the 10 criteria selected by the DMs in step 5, g
i
, is built from at least one dimension, which is a ‘sub-objective’. Each dimension is defined by an elementary consequence, c
j
 (as presented in Table 2) and a primary scale or metric. Some criteria are further described below:

The fourth criterion is the contribution to local welfare which shall be maximized. It is built from three dimensions and has been associated with a continuous performance value function, which ranges from 0 to 100. The fifth criterion is the impact on the utilized land which shall be minimized. It is associated with a three-level qualitative scale. The eighth criterion is the technical maturity which shall be maximized. It is associated with a two-level qualitative scale. The tenth criterion is the local environment effects which shall be minimized. This criterion is built from two dimensions and has been associated with a two-level qualitative scale.

The construction of the criteria is thoroughly detailed by Simões (2015).

4.2.3.2 Step 7.2 – Weighting of the criteria

As proposed in section 3.2.3.2., the revised Simos’ procedure was implemented in SRF software (coded with Borland Delphi 3) to determine the weights of criteria.

The participants of the second workshop were divided into 3 groups according to their departments, in such a way that people with similar major preoccupations were grouped together. The first group (Group I) was constituted by 3 people which are more concerned about the financial aspects concerning the implementation of the energy plan. The second group (Group II) was constituted by 4 people which are more concerned about the social impact of the plan. And lastly, the third group (Group III) was constituted by 4 people which are particularly concerned about the environment and energy related aspects.

The normalized weights of the criteria, defined by Groups I, II and III are presented in Table 3.

4.2.3.3 Steps 7.3 and 7.4 – Evaluation of the performance of each action and definition of the thresholds

The impact matrix is presented on Table 4. The indifference (q) and preference (p) thresholds for each specific criterion have been defined based on the range between the best and worst possible performances of the actions regarding that criterion. The veto thresholds (v) for some of the criteria are also presented on Table 5.
Table 3 – Weights of the criteria

<table>
<thead>
<tr>
<th>g1</th>
<th>g2</th>
<th>g3</th>
<th>g4</th>
<th>g5</th>
<th>g6</th>
<th>g7</th>
<th>g8</th>
<th>g9</th>
<th>g10</th>
</tr>
</thead>
<tbody>
<tr>
<td>w_i</td>
<td>17</td>
<td>17</td>
<td>15</td>
<td>5.5</td>
<td>1.7</td>
<td>5.5</td>
<td>12.2</td>
<td>12.2</td>
<td>12.2</td>
</tr>
<tr>
<td>w_{ij}</td>
<td>13.4</td>
<td>13.4</td>
<td>16.3</td>
<td>18.3</td>
<td>7.4</td>
<td>1.5</td>
<td>9.4</td>
<td>9.4</td>
<td>9.4</td>
</tr>
<tr>
<td>w_{iii}</td>
<td>12.2</td>
<td>2.1</td>
<td>10.6</td>
<td>16.8</td>
<td>12.2</td>
<td>3.7</td>
<td>13.7</td>
<td>5.2</td>
<td>15.2</td>
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</tbody>
</table>

Table 4 - Impact matrix

<table>
<thead>
<tr>
<th>g1</th>
<th>g2</th>
<th>g3</th>
<th>g4</th>
<th>g5</th>
<th>g6</th>
<th>g7</th>
<th>g8</th>
<th>g9</th>
<th>g10</th>
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</thead>
<tbody>
<tr>
<td>A1</td>
<td>258,545</td>
<td>8.35</td>
<td>1.57</td>
<td>41.63</td>
<td>L2</td>
<td>342.35</td>
<td>1.80</td>
<td>L2</td>
<td>0.50</td>
</tr>
<tr>
<td>A2</td>
<td>187,385</td>
<td>14.40</td>
<td>0.89</td>
<td>37.86</td>
<td>L2</td>
<td>1053.40</td>
<td>3.86</td>
<td>L2</td>
<td>4.75</td>
</tr>
<tr>
<td>A3</td>
<td>226,620</td>
<td>8.39</td>
<td>4.05</td>
<td>39.63</td>
<td>L3</td>
<td>0.00</td>
<td>-10.66</td>
<td>L2</td>
<td>0.00</td>
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<tr>
<td>A4</td>
<td>38,838</td>
<td>4.71</td>
<td>0.21</td>
<td>25</td>
<td>L1</td>
<td>222.18</td>
<td>0.98</td>
<td>L2</td>
<td>0.98</td>
</tr>
<tr>
<td>A5</td>
<td>39,927</td>
<td>4.73</td>
<td>0.29</td>
<td>25</td>
<td>L2</td>
<td>183.24</td>
<td>0</td>
<td>L2</td>
<td>0.92</td>
</tr>
</tbody>
</table>

Table 5 - Thresholds of the criteria

<table>
<thead>
<tr>
<th>g1</th>
<th>g2</th>
<th>g3</th>
<th>g4</th>
<th>g5</th>
<th>g6</th>
<th>g7</th>
<th>g8</th>
<th>g9</th>
<th>g10</th>
</tr>
</thead>
<tbody>
<tr>
<td>q_I</td>
<td>15,000</td>
<td>2</td>
<td>0.5</td>
<td>5</td>
<td>0</td>
<td>10</td>
<td>2</td>
<td>0</td>
<td>0.5</td>
</tr>
<tr>
<td>p_j</td>
<td>25,000</td>
<td>4</td>
<td>1</td>
<td>8</td>
<td>0</td>
<td>20</td>
<td>5</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>v_j</td>
<td>150,000</td>
<td>10</td>
<td>n.a.</td>
<td>20</td>
<td>n.a.</td>
<td>500</td>
<td>10</td>
<td>n.a.</td>
<td>6</td>
</tr>
</tbody>
</table>

4.2.3.4 **Step 7.5 – Results and sensitivity analysis**

The MCDA-ULaval software ran three times, using three different sub-configurations, each concerning one of the groups of DMs and, consequently, different sets of weights for the criteria. The rankings obtained for the actions, regarding the weights assigned by Groups I, II, III are presented in Figure 3. For instance, concerning the ranking from Group I, actions 1 and 2 are placed first but are incomparable between each other. Action 4 is ranked second and Actions 3 and 5 are indifferent and ranked last.

Based on the final rankings and on this sensitivity analysis regarding criteria weights, the recommendation for the sequence of implementation of the actions is:

- 1\textsuperscript{st} and 2\textsuperscript{nd}: Actions 1 (PV panels – RES) and 2 (Solar Panels – RES)
- 3\textsuperscript{rd}: Action 4 (Biomass boilers – MUN)
- 4\textsuperscript{th}: Action 3 (Heat Recovery Units – RES)

The prioritization between Actions 1 and 2 shall be carried out by the DMs, which need to carefully analyze the actions, since they are incomparable (i.e. disparate).

The reason why Action 5 does not figure in the recommendation is that Actions 4 and 5 are mutually exclusive, and Action 5 is always ranked worse than Action 4, independently of the set of weights of the criteria considered.

**Figure 3 - Rankings from Groups I, II, III, from left to right, respectively**
5 CONCLUSIONS AND FUTURE WORK

The methodology developed to support sustainable municipal energy planning thoroughly details, in a simple and practical manner, the steps for the development of energy action plans which include the implementation of the MCDA methodology, and specifically, the implementation of the ELECTRE III outranking method.

Up to the date of elaboration of this document, the methodology proposed had been partially implemented to the municipality of Odemira (namely, the steps 1 to 6 and 7.2). Two workshops were held with the deputy mayor and ten representatives of several departments of Odemira’s city council. The workshops have been very successful and the attendees participated actively. The DMs have participated on the definition of ‘Odemira’s current framework’, they have identified the main local stakeholders, defined the major objectives to be met by the energy action plan (which are translated by a set of criteria), and assigned weights to the criteria.

The construction of the criteria (step 7.1) has been carried out by the team from IST. This step is one of the most intricate; the construction of criteria from multiple dimensions is particularly complex. The evaluation of the performance of each action on each criteria (step 7.3) was also performed by the IST team. The data available so far has allowed the evaluation of five actions.

From the evaluation of actions performed, it is already possible to understand that using MCDA can be very useful for city councils.

Regarding Odemira’s case study, it is necessary that the DMs validate the construction of the criteria performed by the team of IST and that they agree on a consensual set of weights for the criteria defined. A collection of more data from the city council needs to be done in order to evaluate the impact of more actions. After running the software for the final sets of actions and weights of the criteria, a workshop shall be held to show the results (and how the results were obtained, in order to enhance the transparency of the process). After the presentation of a recommendation by the IST team regarding the sequence of actions’ implementation, the DMs shall elaborate an action plan.

It would be important that other municipalities implement this methodology to further validate it.

6 REFERENCES