Participatory multi-criteria decision analysis for sustainable energy planning

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Abstract: Public participation is constantly gaining attention in the context of decision-making process at local level, given that citizens are the main beneficiaries of the implemented policy measures. In this respect, stakeholder engagement has found itself at the core of the dialogue process for integrating multiple perspectives in sustainable energy planning, with the minimum social disruption. This paper aims to present a multi-criteria decision analysis (MCDA) framework for enhancing stakeholder engagement in the policy-making process, enabling decision-makers together with experts, citizens and other beneficiaries to jointly prioritise sustainable energy and climate actions to be implemented. The proposed framework allows marginalised population groups to express their views on issues of the everyday life, which are eventually incorporated in an MCDA analysis along with the experts' assessments. The proposed methodology is applied in a Greek municipality to showcase its functionalities and highlight future challenges that will make it even more integrated.

Keywords: stakeholder engagement; public participation; sustainable energy planning; decision-making; multi-criteria analysis; TOPSIS.

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1 Introduction

The Paris Agreement in 2015 was a great opportunity to bring the public into decision-making (Doukas and Nikas, 2021). Although the term 'participation' has been attributed several definitions throughout the years (Bousset et al., 2005), primarily because of its vague link with the socio-economic context (Fritz et al., 2019), a coordinated shift of decision-making hubs towards transdisciplinary approaches has emerged in recent years (Bouzguenda et al., 2019) that include different stakeholder groups at the core of the sustainable energy planning process (Doukas et al., 2018). The roots for such proposals lie in the anticipation that integrating different perspectives and priorities within the policy-making area (Arsenopoulos et al., 2020), especially from underrepresented or marginalised population groups, will enhance the three-fold rationale for the positive effects of public participation: legitimacy of the administrative authorities; transcendence of individuality; and effectiveness of governance (Musch and von Streit, 2020).

Participation is not a panacea, although the ever-growing awareness and interest of citizens in environmental, public health and quality of life issues, combined with an in-depth lack of trust in politics (Jabareen, 2015), highlight public participation to be as of major significance within the social design context (Brandt and Svendsen, 2013). If we also reckon in the complexity and the uncertainty that come with the latter because of the rapid environmental, economic, cultural and technological developments, the participatory approach seems to be constantly gaining traction and the perspective of co-creation by all interested parties is deployed in a large pool of problems (Macintosh and Whyte, 2008) at various spatial scales, to address these challenges (Karl, 2002).

Local governments, being the closest authority to the citizens and other stakeholders at local level, are responsible for setting the groundwork to addressing a great deal of their daily life-related issues, taking into account that their fundamental role is not strictly established upon providing public services, but they must also lay equal emphasis on the political, social and developmental aspect of their role as well (Marinakis et al., 2017). As collective spokespersons of the local community, key mechanisms for improving the quality of life and main communication channel with the central government, they play a major part in policy formulation and implementation. However, up until recently, public participation in sustainable energy planning processes at local and regional level has been squeezed (Milan et al., 2015). Their engagement is mainly focused on the direct contact with the elected and high-ranking executives of the local government, following the small piece of attention that has been given by the local government representatives to encouraging the participatory innovation.

The policy-making process involves two stakeholder groups: on the one hand there are the numerous 'beneficiaries' comprising citizens, organisations, businesses, institutions, etc. and on the other hand a smaller group of 'experts' comprising representatives from public authorities, private bodies, etc. The heart of the problem lies in the fact that a few decision-makers bear the burden of the whole decision process, whilst at the same time the role of beneficiaries at first, and of the experts to a lesser extent, are pushed down to the point of providing only a limited input towards capturing the final policies to be implemented. On top of that, the potentially large number of policy combinations to be included in the final portfolio, pinpoints the perspective of co-creation of policy actions by all stakeholders at local level as a necessity. The fast breeding of information and communication technologies (ICT) (Marinakis and Doukas, 2018), the significant progress in the research areas of crowdsourcing and the ever-growing expertise in simulating complex dynamic systems along with the high availability of related open data on that matter, are perceived to be the main allies in dealing with the abovementioned issues.

In this context, this paper aims to foster participatory innovation in the sustainable energy planning process at local level, through employing a multi-phased analysis framework that incorporates different perspectives. The framework is established upon the expectation of citizen participation and decision support tools into the development of an optimal policy portfolio (Forouli et al., 2019; Gkonis et al., 2020), allowing decision-makers with the support of beneficiaries and experts to jointly design and prioritise the most effective combinations of actions. From a methodological point of view, the proposed framework is broken down into two distinct phases, both of which utilise a multi-criteria decision analysis (MCDA) method called technique for order of preference by similarity to ideal solution (TOPSIS). TOPSIS, being one of the most common MCDA methods, has been extensively used in literature, both standalone and in combination with other evaluation methods, for further elaborating on policies of environmental and technological nature as well as for the evaluation of parameters and potentials on that matter (Brand and Missaoui, 2014; Büyüközkan and Güleryüz, 2017; Mourhir et al., 2016; Onu et al., 2017).

This framework adds to the literature by providing useful insights through presenting how:

1 a bottom-up stakeholder-based MCDA framework

2 a qualitative prioritisation technique can be gathered under a common conceptual umbrella into a co-creative process with massive participation of beneficiaries and experts to support local authorities in designing sustainable policy mixes.

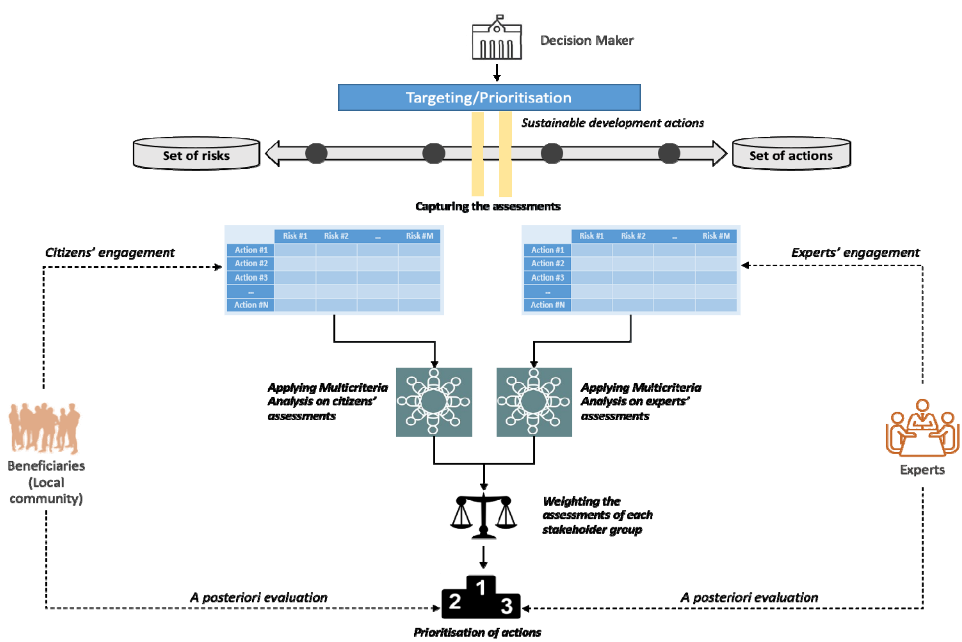
Eventually, the proposed framework will be stress-tested in a real-life case study in the municipality of Salamina, Greece, in order to showcase its functionalities towards its primary cause of enhancing stakeholder engagement in the local sustainable energy planning process. The focal area of the case study lies in the prioritisation of a set of waste management policy actions.

The remaining paper is structured as follows: Section 2 presents an in-depth description of the methodological approach. In Section 3, the results of the proposed framework's application are presented, followed by a respective discussion in Section 4. Finally, Section 5 summarises the key points of the analysis and concludes the paper.

2 Methodological approach

The proposed methodology introduces a framework for exporting prioritised portfolios of sustainable energy and climate actions, at local level, based on the application of an MCDA method multiple times, in order to calculate a final score for each policy action under consideration. These scores are eventually used to provide the prioritisation of policy actions. Each policy action is evaluated against a set of risks that have been identified in the literature and through interviews with experts, both by the experts themselves as well as by the citizens. An overview of the proposed methodology is graphically presented in Figure 1.

Figure 1 Proposed methodology (see online version for colours)



More specifically, the capture of the experts' and citizens' assessments is carried out through customised questionnaires. Given that the subject matter and the scientific background of the experts differ significantly from that of the citizens, it was deemed necessary to formulate two separate questionnaires to represent and incorporate the specifics of the two groups involved. In this respect, the experts are encouraged to assess the impact degree of the identified risks on the implementation of the policy actions, while the citizens are required to assess the extent to which they agree with the implementation of the proposed policy actions as well as the contribution of the latter to their working environment. In both cases a five-tier linguistic scale is used (0: very low, 1: low, 2: medium, 3: high, and 4: extreme).

In order to aggregate the assessments of all citizens and experts involved in this process, the linguistic evaluations of the two engaged groups (i.e., experts and citizens) are appropriately weighted, following their initial translation into their respective numerical values. The weights of the two engaged stakeholder groups are complementary and sum up to 1 (or 100% in terms of percentage).

Methodologically speaking, drawing from the work done in Nikas et al. (2018), there is an extensive set of available MCDA frameworks to serve the purposes of this paper, nevertheless only a few of them seem to fit right in. By further delving into their analysis, Nikas et al. (2018) presented an in-depth review of several traditional MCDA frameworks that have stimulated significant attention in academia up until recently, such as the pairwise comparison-based PROMETHEE and ELECTRE, as well as a number of distance-based approaches such as TOPSIS.

Throughout the years, several MCDA frameworks have been employed to evaluate policy actions at either national or regional and even local level. Consequently, applications in the field of sustainable energy planning are not something new to discover, thus leaving the whole armoury of MCDA techniques at the authors' disposal to select. However, the exclusively qualitative nature of the evaluation criteria to be included in the methodological framework, combined with the large number of stakeholders to evaluate the policy actions, led the authors to employ TOPSIS (Hwang and Yoon, 1981) method as the key implementation pillar of the methodological framework.

TOPSIS is diversified from the bilateral comparison-based ELECTRE family of MCDA methods, and constitutes a compensatory aggregation method that was developed upon the claim that a solution must meet two specific criteria:

a minimum geometric distance from the optimal solution

b maximum geometric distance from the worst solution.

Although the original TOPSIS method was established upon a numerical data-driven framework, its extensive architecture provoked several customisations throughout the years, in order to be able to handle different types of input data (Chen and Lee, 2010).

One of these extensions enabled the option of providing easy-to-digest linguistic evaluations (Herrera et al., 2005), which are perceived to stimulate greater interest from the stakeholder group, in terms of eagerness to provide their inputs based on a more comprehensible way (Agell et al., 2012; Estrella et al., 2017). The latter has eventually led to allowing each stakeholder to decide the nature of his/her evaluations (i.e., numerical or linguistic), thus highlighting the need to create a pair of scales. In this respect, two distinct scales have been formulated, a linguistic and a numerical one, where the linguistic terms are matched to the numbers of the numerical scale, to ensure consistency among the input data.

The TOPSIS approach can be deconstructed into six distinct mathematical components as follows:

1 Formulation of the decision table which includes the performance score of alternatives against evaluation criteria:

$$\begin{array}{c} \overbrace{C_1 \quad C_2 \quad \dots \quad C_n}^{C} \\ A\begin{cases} A_1 & x_{11} & x_{12} & \dots & x_{1n} \\ A_2 & x_{21} & x_{22} & \dots & x_{2n} \\ \vdots & & \vdots & & \\ A_m & x_{m1} & x_{m2} & \dots & x_{mn} \end{cases} \end{array} \tag{1}$$

where $A_1, A_2, \dots, A_m$, $i = 1, 2, \dots, m$ are the alternatives, $C_1, C_2, \dots, C_n$, $j = 1, 2, \dots, n$, are the evaluation criteria and x_{ij} is the performance score of alternative A_i against criterion C_j.

2 Normalisation of the decision table's performance scores (r_{ij}):

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \tag{2}$$

where r_{ij} represents the normalised score of alternative A_i against criterion C_j.

3 Calculation of the weighted decision table's performance scores (p_{ij}) of the decision table taking into consideration the criteria weights (w_{norm_i}):

$$p_{ij} = w_{n_j} \times r_{ij} \tag{3}$$

where $w_{n_j} = \frac{w_j}{\sum_{k=1}^{n} w_k}$, $j = 1, 2, \dots, n$ so that $\sum_{j=1}^{n} w_{j_n} = 1$ and $w_j = [w_1, w_2, \dots, w_n]$ is the initial weight vector for each criterion C_j.

4 Determination of the positive (P^+) and negative (P^-) ideal solutions, for benefit and cost impact criteria, respectively:

$$P^+ = \left(p_1^+, p_2^+, \dots, p_n^+\right) = \left[\left(\max p_{ij}, j \in J\right) \text{ or } \left(\min p_{ij}, j \in J'\right)\right] \tag{4}$$

$$P^- = \left(p_1^-, p_2^-, \dots, p_n^-\right) = \left[\left(\min p_{ij}, j \in J\right) \text{ or } \left(\max p_{ij}, j \in J'\right)\right] \tag{5}$$

where J represents positive impact criteria and J′ represents negative impact criteria.

5 Calculation of the geometric distance (S_i^+, S_i^-) of each alternative from the optimal solutions [equations (4) and (5)]:

$$S_i^+ = \sqrt{\sum_{j=1}^{n} \left(p_{ij} - p_j^+\right)^2} \tag{6}$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} \left(p_{ij} - p_j^-\right)^2} \tag{7}$$

6 Calculation of the relative closeness D_i to the ideal solution for each A_i:

$$D_j = \frac{S_i^-}{S_i^+ + S_i^-} \tag{8}$$

The proposed approach is designed to apply the TOPSIS methodological framework twice for each stakeholder group (i.e., experts and citizens): once for providing individual rankings for the stakeholders within each stakeholder group, and then again for aggregating the individual rankings into an upscaled global model based on which a final ranking of the alternative policy actions will be extracted (Krohling and Campanharo, 2011). Drawing from the above, the TOPSIS method is initially applied for each one of the l stakeholders of each stakeholder group (the number of stakeholders comprising the stakeholder groups does not necessarily have to be the same), thus formulating l preference vectors that will eventually be unified under a new global matrix (GM):

$$GM = \begin{bmatrix} C_1^{exp} & C_1^{cit} \\ C_m^{exp} & C_m^{cit} \end{bmatrix} \tag{9}$$

where C_i^{exp}, C_i^{cit}, $i = 1, 2, \ldots, m$ are the performance scores of the experts' and citizens' stakeholder group respectively, across m alternatives.

In case the engaged stakeholder groups are attributed weights through the weight vector WE = (we_{exp}, we_{cit}), where we_{exp} stands for the weight of the experts' stakeholder group and we_{cit} stands for the citizens' stakeholder group, then the weighted global matrix (WGM) will be eventually calculated. At this point, it should be noted that the stakeholders within each stakeholder group are equally weighted.

$$WGM = \begin{bmatrix} we_{exp} C_1^{exp} & we_1 C_1^{cit} \\ we_{exp} C_m^{exp} & we_1 C_m^{cit} \end{bmatrix} \tag{10}$$

3 Experimental results

Moving on, the proposed methodology is applied in a case study in Salamina, in order to be stress-tested and showcase its functionalities and/or even its niches to be further elaborated. Salamina Island is located in the Saronikos Gulf, extended to an area of 93.5 km^2, at the southwest of Athens and just 2 km far from the port of Piraeus (Karymbalis et al., 2014). Its total population is calculated to approximately 25,370 inhabitants, according to the 2011 census, and combined with its coastline length which covers about 131 km, make Salamina the largest island settlement of its home Gulf and one of the largest in Greece (Tziourrou et al., 2019).

Among the various sectors examined in the context of formulating a sustainable energy planning problem for the proposed methodology to deal with, it was acknowledged by all engaged stakeholders that the island's waste management and recycling sector features many opportunities and large potential for easy-to-implement improvements. Municipal waste is broadly understood as trash or garbage, and comprises of items of the everyday life, including among others household waste from garden and yard, waste from commercial and trade processes, offices and business institutions, with multiple adverse effects in the environment and health, if not dealt properly (Mesjasz-Lech, 2014).

Rational waste management, is based, among others, on the installation of optimised waste management systems, replacement of old, generic recycle bins with newer, tailor-made for each waste's nature (e.g., glass, paper, plastic, organic, etc.), investments in raising awareness campaigns, and diffusion of knowledge and best practices from other more technologically advanced municipalities, either at national or European and even global level. These constitute both available and efficient technological solutions, but can, however, be expensive and highly context-specific, thus requiring joint prioritisation by the experts and the citizens as well, before implementing. The waste management and recycling actions that have been identified for the purpose of this paper, are presented in Table 1, along with the evaluation criteria and their weights.

3.1 Stakeholder engagement

Given the diverse socioeconomic, legislative, behavioural and institutional factors that are emerged when the case is for a municipality's intention to effectively deal with waste management and recycling issues (Muneeb et al., 2019), two stakeholder groups were engaged in the decision process in order to elicit their knowledge on this matter, i.e., 32 experts on behalf the Salamina municipality were interviewed in order to assess the identified waste management alternatives as to their level of impact against specific risks-evaluation criteria, and 211 inhabitants of Salamina were asked to assess the extent to which they agree with the implementation of the aforementioned sustainable energy and climate actions as well as the contribution of the latter to their working environment.

3.2 Evaluation criteria and waste management actions

Following extensive rounds of discussion with the stakeholders, seven risks (evaluation criteria) were considered and classified according to the stakeholder group that they are addressed to, acting as the evaluation criteria in the MCDA problem (Table 1).

Table 1 Evaluation criteria and criteria weights

Evaluation criteria		*Weights*	*Stakeholder engagement*
C1	Cost of implementation	4	'Experts', incl. representatives from the public authority and private bodies
C2	Bureaucracy	3	
C3	Technical feasibility	2	
C4	Market conditions	2	
C5	Acceptance within municipality	1	
C6	Acceptance within society	4	'Beneficiaries', incl. citizens, organisations, businesses, institutions, etc.
C7	Contribution to the working environment	2	

The process that was followed in order to engage the stakeholders into eliciting their knowledge, comprises two distinct phases:

a a first phase of detailed discussion rounds for gathering the risks-criteria on the examined topic

b a second phase where semi-structured questionnaires bore the burden of the engagement process, in order to capture the necessary information required for carrying on with the MCDA analysis.

The set of identified evaluation criteria is more of representative rather than exhaustive, taking into consideration the diverse nature of the risks that are attributed to the problem of waste management. The stakeholder groups evaluated the following alternative policy actions against the seven evaluation criteria, based on a five-tier linguistic scale (0: very low, 1: low, 2: medium, 3: high, 4: extreme):

A1 Creation of a central green point in conjunction with smaller peripheral points (per community).

A2 Installation of six-stream bins on the main streets.

A3 Installation of household compost bins.

A4 Installation of brown bins in restaurants for disposing organic materials.

A5 Organisation of webinars for raising awareness of the citizens about the waste management actions.

A6 Creation of an informative video regarding the actions carried out for better waste management.

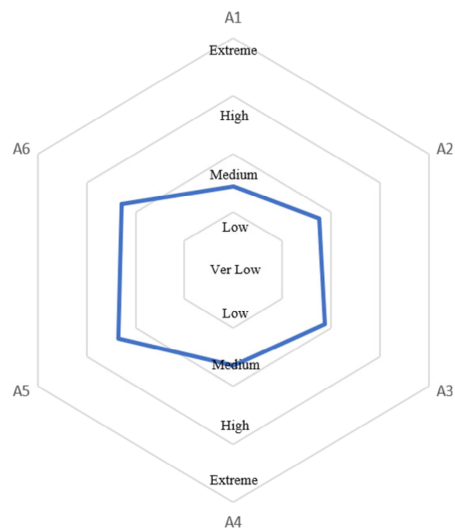
The respective weight vector of the evaluation criteria was agreed after several discussion rounds between the stakeholders of the municipality, once a pre-defined level of consensus was reached within the discussion rounds (Table 1).

3.3 Multi-criteria analysis results

In the final MCDA analysis, following the unification of the two separate MDCA analyses for the experts and the beneficiaries in the municipality of Salamina respectively [equation (10)], on the perceived performance of the six waste management policy actions against their cost of implementation, bureaucracy, technical feasibility, market conditions, acceptance within municipality, acceptance within society and contribution to the working environment, stakeholders appeared to fancy most the low-cost and minimum-effort behavioural-driven actions, which lie in the organisation of webinars for raising awareness of the citizens about the waste management actions considered for implementation, closely followed by the creation of informative-based audiovisual material regarding the actions carried out for better waste management (Figure 2).

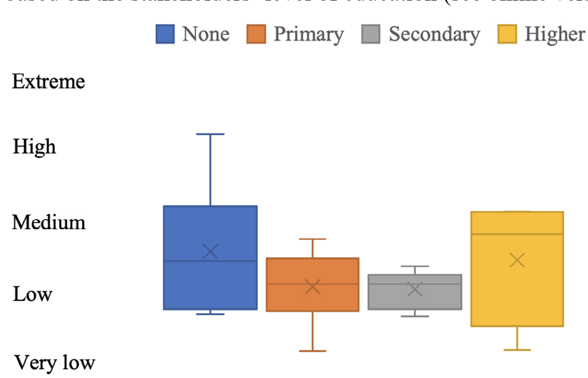
On the other hand, stakeholders appeared to feel that vertical, high-cost policy actions that require in-depth action on behalf of both the experts and the beneficiaries, i.e., the installation of bins in restaurants and main street arteries, as well as the installation of household compost bins, are of medium importance/relevance to the effective design of a sustainable and robust waste management pathway (Figure 2). Finally, the action that requires more coordinated effort from all engaged actors, public bodies, institutions and beneficiaries, namely the creation of a central green point in conjunction with smaller peripheral points per community, appears to draw the least attention among the stakeholders (Figure 2).

Figure 2 Final MCDA results of the significance of the six waste-management policy actions (see online version for colours)



Beyond the aggregated results depicted in Figure 2, the proposed methodology is also designed to provide additional results in order for the decision-makers to gain useful insights, broken down based on the demographic characteristics of the involved stakeholders, through applying TOPSIS yet again. To specify, TOPSIS is applied on the citizens' and experts' assessments, following a categorisation based on their level of education. In this respect, Figure 3 presents the final ranking of the examined waste management actions, taking into consideration the stakeholders' level of education. It is worth noted that the demographics based on which the following results are extracted, are provided voluntarily by the stakeholders upon filling in the evaluation questionnaires.

Figure 3 Aggregated MCDA results of the significance of the six waste-management policy actions based on the stakeholders' level of education (see online version for colours)

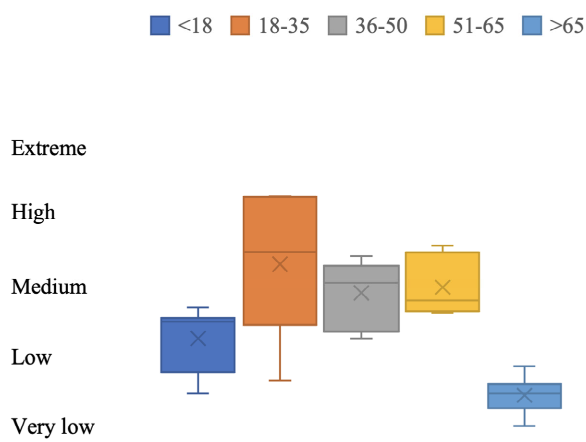


In this regard, Figure 3 presents the importance of the waste management policy actions under consideration, not broken down for each action but rather aggregated. The boxes of the graph are formed based on the stakeholders' preferences across all policy actions. The solid line running through the boxes stands for the median value, while the 'X' mark indicates the average value of the estimations. The lines protruding on either side of the boxes are called outliers and stand for the extreme preference values.

It is observed that the stakeholders of secondary education show the least dispersion in their preferences, which fluctuate from low to medium importance. In the same context, those who have only completed primary education are at about the same range of assessments, while greater dispersion is observed at the preferences of those of the lower and the higher education levels. More specifically, in the latter case, both the higher median and the higher mean value are noticed, which lead to the claim that the more extended the scientific background of the stakeholder, the easier it is to understand the value of taking action on such a serious issue as the waste-management.

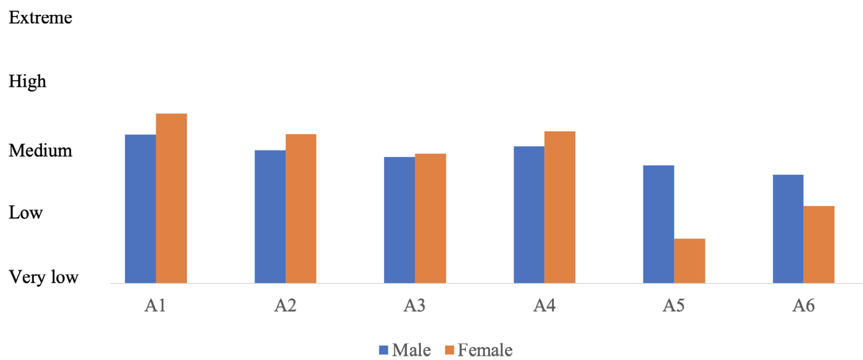
Drawing from the above, Figure 4 presents the importance of the examined waste-management policy actions broken down for each age cluster of the engaged stakeholders. It is noticed that the stakeholders of greater than 65 years old, feature the least dispersion among their preferences, which, nevertheless lay within the lowest layers of the importance scale. On the contrary, mid-aged stakeholders, especially those of the age cluster 18–35, despite having a greater dispersion on their preferences, seem to perceive that the policy actions to be implemented are of medium to high importance towards formulating a more integrated waste-management framework, which underlies their greater intention to take action on that matter. Finally, the younger stakeholders (<18 years old) can be found somewhere in the middle, with their preferences ranging from low to medium criticality.

Figure 4 Aggregated MCDA results of the significance of the six waste-management policy actions based on the stakeholders' age (see online version for colours)



Last but not least, the proposed methodology is capable of providing MCDA results based on the stakeholders' sex. In this respect, Figure 5 presents such results, where it is obvious that both sexes seem to have adopted the same attitude regarding the significance of the examined policy actions. The largest deviation can be found in the action that is focused on the organisation of webinars for raising awareness of the citizens about the waste-management actions, which the engaged male inhabitants of Salamina deem of medium importance whilst on the other hand females seem to disregard it, as of almost very low importance.

Figure 5 MCDA results of the significance of the six waste-management policy actions based on the stakeholders' sex (see online version for colours)



4 Discussion

The proposed methodology constitutes a first step to develop an effective and easy-to-use approach for prioritising actions through joint evaluations, towards setting the groundwork for a sustainable energy planning pathway at local level. In this respect, there is a set of different results that can be drawn at various sectors, based on the input information and data. From a methodological point of view, the approach presented here incorporates several perspectives, so that decision-makers can select the one that best fit their purpose.

Nevertheless, there are also some major issues that have emerged and need to be further elaborated, drawing from the results presented here. To specify, the assessments of the policy actions against each criterion are heavily stakeholder-dependent, in that they are subjective evaluations based on the knowledge of the municipality's stakeholders. To avoid such situations, the proposed methodology should constitute the reference point for engaging a more diverse set of stakeholders in the procedure, in order to widen the pool of perspectives and increase objectivity.

In the same context, the weight vector of the evaluation criteria presented in Table 1 was extracted from several multilateral discussion rounds of the municipality's stakeholder group, to the point that a pre-defined consensus level is reached. On the one hand, this has significantly reduced the complexity of the whole decision-process and made it more user-friendly, however it has also prevented stakeholders from expressing their personal views by providing individual weighting vectors for the criteria, that eventually could have been unified into a final vector to be used. The author team recognises the value of the multiple weight vectors, but the main intention was to set in the spotlight the proposed MCDA-based framework and the multi-perspective results stemming from it, rather than lay emphasis on the MCDA process itself.

Furthermore, the need to further elaborate on the examined evaluation criteria in order to create a consistent set of criteria is highlighted, following up on the discussion rounds with the stakeholders, based on extensive literature review and best practices. Last but not least, a portfolio analysis could be used as a significant extension of high added-value to the existing MCDA framework, to provide decision-makers with the optimal combinations of policy actions to be implemented, moving the analysis one step beyond prioritisation.

5 Conclusions

The developed methodological approach has been established upon the enhancement of public participation in the context of collective decision-making process, enabling all interested stakeholders, beneficiaries, experts and decision-makers to jointly prioritise and eventually select the combination of policy actions that maximises social benefit and reduces social disruption. In other words, it helps administrative authorities to trigger a massive participatory innovation far from conventional techniques, such as the in-hand completion of questionnaires or even vague discussion rounds in terms of consultation, and sets the groundwork for better social choices.

In this respect, the presented methodology employs a TOPSIS-based MCDA framework that is applied multiple times across all engaged stakeholders, in order to incorporate citizen participation into the decision-making process towards formulating a sustainable energy planning pathway at local level. The utility of the framework is demonstrated using in a case study in Salamina, Greece, with the participation of a large number of stakeholders both on behalf of the municipality and the citizens.

Nevertheless, there are also some challenges that need to be taken into consideration in the future, such as the underlying subjectivity in the stakeholders' assessments, the current inability of the proposed approach to enable stakeholders to provide individual criteria weighting vectors, rather than a global, consensus-driven one, and most importantly the integration of a portfolio analysis as an extension to the existing framework. Although these challenges could be difficult to be addressed in full, it is argued that the proposed framework does display great potential.

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