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Report (1) on policy instruments' assessment methods and comparative analysis

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Contents

1. INTRODUCTION

The last 30 years have seen radical changes in the world's energy scene that made energy decisions and policy making a highly complex issue. The sharp increase of energy prices disclosed all the hidden constraints behind the simple-minded perception of plentiful, affordable and cheap energy. At almost the same time, environmental concerns for either the depletion of conventional energy resources or the ongoing environmental degradation imposed a reconsideration of values and a shift towards new technological solutions. Cost, although still being the market's driving force, was no longer enough to reflect the society's multiple, incommensurate and often conflicting concerns. Typical questions illustrating the task of energy planners in this new context were:

- Which type of energy resource or conversion technology to use?
- How to combine different energy sources and technologies in order to meet present and future energy needs?
- Where to locate new energy conversion or transmission facilities?
- How to produce more sustainable electricity?
- How to reduce the emissions of the power sector?

Multiple criteria decision analysis (MCDA), developed during the same period, has offered valuable methodological approaches and tools providing reliable solutions to complex decision situations in the energy sector focusing on several alternative options evaluated along multiple conflicting criteria. Moreover, MCDA allowed for a better understanding of the intrinsic features of each separate decision problem, facilitated the involvement of all concerned stakeholders and supported negotiations for the achievement of widely accepted collective decisions. Thus, the energy sector turned out to be one of the most privileged fields of MCDA applications.

During the last 30 years an enormous amount of papers and reports dealing with problems encountered during the energy planning procedure are found in the MCDA-related literature. A variety of MCDA methods, using simpler or more sophisticated model formulations, have been implemented in order to tackle the diversity of operational and planning problems arising in the energy sector.

This report presents the methodological approach adopted in the framework of the CASES project for the comparative evaluation of alternative policy instruments aiming at internalising the external costs of electricity generation, either through the minimization of CO_2 emissions, or through the promotion of renewable energies. Next section includes a short review of this literature in order to illustrate the scope and relevance of the developed MCDA approach. The selected MCDA method and the weighting methods used for deriving the stakeholders' preferences are presented in the third section, followed by the description of the developed decision support tool in the fourth section. Finally, the obtained results from implementing the tool for the assessment of policy instruments are shortly discussed, as to show the capacity of the tool to elicit the stakeholders' preferences, the degree of consistency of the derived weights and the consensus between the participants of the stakeholders' workshop. The analytical results concerning the relative importance of criteria and the ranking of the examined instruments are included in deliverables D.8 and D.9.

2. LITERATURE REVIEW

The present review aims at collecting and classifying articles using MCDA methods in energy planning applications. It is based on a thorough review regarding MCDA and Energy Planning (Diakoulaki et al., 2005) which is completed and consolidated with additional information. The performed analysis is principally confined to the most recent literature and in particular to publications in the most known Energy and Operational Research journals. Although efforts have been made to include a large number of relevant articles, the review is by no means exhaustive since our main goal was only to identify the variety of energy-related problems dealt with a multicriteria methodology. Moreover, the review is restricted to problems dealing with discrete alternative options, as is the case of discrete policy instruments evaluated in this project. Therefore, a vast body of literature devoted to multi-objective programming models, in which alternatives are not a priori determined but are implicitly defined by a set of constraints, have not been considered in this review.

The majority of MCDA applications with discrete alternatives in the energy sector concern complex one-off decisions of strategic importance. The performed review led to the classification of publications on the basis of the type of problem concerned

The principal aim in most applications is to take into consideration all the different aspects that should guide future actions and policy choices. The electricity sector appears as a vast source of inspiration mainly because it represents in most countries the larger primary energy consumer and the larger pollutants emitter, while an increasing variety of technologies are competing within a gradually deregulated market. Besides the electricity sector, there is also a great variety of decision contexts arising at either the supply or the demand side of the whole energy sector.

The analysis identified the following broad categories of applications:

2.1. Comparative evaluation of power generation technologies

The aim in most papers classified in this category is to prioritize the available technological options, while the -often not explicitly stated- intention is to establish development plans and accordingly to identify the most suitable policy instruments. However, it is hardly visible how the obtained rankings will be translated into operational action plans or policy priorities. The considered alternatives are in all cases defined at the outset and reflect the technological progress and the prevailing concerns of utility planners in the period and area of the application.

Thus, in earlier publications the predominant dilemma was mostly to compare nuclear energy with its conventional competitors and sometimes also with emerging renewable technologies (Siskos and Hubert, 1983). The work developed by Hämäläinen and his co-authors is characteristic of this research line, in which MCDA methods are used to clarify opposing views in the debate about the social benefits of the nuclear option if compared with coal fired power plants and a decentralised alternative based on conservation and small electricity units (Hämäläinen and Seppäläinen, 1986; Hämäläinen, 1990; Hämäläinen and Karjaläinen, 1992). A common feature in these papers is that the authors' main preoccupation is to provide a rigid framework to handle this type of problems rather than to find a global answer. Problem structuring results from the investigation of the most critical issues with the implicit or explicit involvement of stakeholders, while particular attention is paid to the treatment of uncertainties. The dilemma between nuclear energy and fossil fuels is found also in a more recent publication (Güngör and Arikan, 2000) which assumes a complete lack of quantitative data justifying the use of fuzzy decision analysis.

In the late nineties, the risks associated with nuclear energy and the serious concerns about climate change have shifted the interest of utilities and other stakeholders towards renewable energy sources. A ranking procedure based on the consideration of an apparently exhaustive set of evaluation criteria is followed in (Beccali et al., 1998) in order to select the most promising set among alternative renewable technologies for establishing an action plan for the Sardinia region. The increasing emphasis on renewable power generation technologies is also reported in (Kablan, 1997; Akash et al., 1997; Mamlook et al., 2001), where a small set of predefined alternatives are compared to each other in order to derive priorities complying with broad policy objectives.

Finally, in (Burton and Hubacek, 2007) small- or large-scale approaches to renewable energy provision are examined in order to achieve energy targets in the most socially, economically and environmentally effective way. In addition, detailed frameworks have been developed for the comparative assessment of bioenergy systems (Elghali et al., 2007), natural gas technologies (Afgan et al., 2007), various options of the power system of Bosnia and Herzegovina (Begic and Afgan, 2007) and sustainable technologies for electricity generation in Greece (Doukas et al., 2006).

2.2. Selection among alternative energy plans and policies

The typical problem in this category is the choice among alternative strategies for the electricity sector at a country or regional level by taking into account a number of scenarios for the likely evolution of external conditions (Lootsma et al., 1990; Voropai and Ivanova, 2002; Pan and Rahman, 1998). Similarly, scenarios that have been formulated according to the specific characteristics of the autonomous electricity system of the island of Crete are evaluated with respect to a large set of sustainability criteria in (Georgopoulou et al., 1997). In (Liposcak et al., 2006) the aim is to assess 3 scenarios regarding the future development of the Croatian co-generation sector with respect to sustainability goals.

Finally, in (Karni et al., 1992) policy options are perceived as composed of a set of consistent actions and the intention was to develop a framework to help utility managers find out the policy option securing the most satisfactory achievement of their strategic goals. The proposed structuring and analytical procedure has been illustrated with a case study referring to the selection of the most appropriate electricity pricing policy. In (Ulutas, 2005) the aim is to identify the most effective policies in Turkey within the context of the long range and strategic process through the evaluation of alternative energy sources. Similarly, four mutually exclusive scenarios for the expansion of the Greek electricity system developed by official authorities and representing alternative views on meeting electricity demand are evaluated in (Diakoulaki and Karangelis, 2007). Recently, Neves et al. (2007) propose a multi-criteria decision approach for sorting energy-efficiency initiatives, promoted by electric utilities, with or without public funds authorized by a regulator, or promoted by an independent energy agency. Finally, the subject about how to overcome potential barriers for the promotion of cleaner and energy efficient technologies and strategies in small power systems in Sri Lanka is studied in (Wijayatunga et al., 2006).

Besides the electricity sector, there are publications dealing with the selection among discrete policies and action plans for the whole energy system. Keeney et al. (1990) and Jones at al. (1990) address the broader topic of energy policy at the national level by structuring and formalising the whole decision procedure with the active involvement of several interest groups. In (Georgopoulou et al., 1998) alternative plans for the development of renewable energies in Greece are constructed and evaluated by a group of stakeholders in order to identify a compromise solution giving place to the widest possible consensus. In (Bell at al., 2003) climate change experts participating in a workshop tested several MCDA methods in order to rank policies for abating greenhouse gas emissions. Respectively, Shackley and McLachlan (2006) examine the responses of stakeholders from the public and private sectors to future energy scenarios for the year 2050 for the North West of England regarding the mitigation option of capturing CO_2 from power stations and storing it in suitable off-shore geological reservoirs.

At a much smaller scale, choice problems are faced in the selection of the best option among a number of mutually exclusive alternative plans exploiting to a different extent and in a different way a certain energy resource, especially a locally confined renewable energy resource. Three papers found in the literature, authored by different researchers in different time periods, are all concerned with identifying the best exploitation plan of different geothermal fields in Greece (Capros et al., 1988; Goumas and Lygerou, 2000; Haralambopoulos and Polatidis, 2003). Another relevant application is described in (Hanegraaf et al., 1998). Here, the choice is among alternative biomass crops for use in electricity generation and/or in the transport sector, while the evaluation process is taking into account the economic and ecological impacts generated through each alternative's entire lifecycle.

2.3. Sorting out a subset of candidate energy projects

A quite different problem typology is developed in cases where the number of projects is large and the desired outcome is the identification of the most attractive subset of alternatives. In the absence of any further constraint or complementary relation between alternatives, the problem can be treated with a MCDA ranking procedure designed as to single out the best projects according to the decision maker(s)' preferences. In (Mills et al., 1996) and (Hobbs and Horn, 1997) the aim is to find out the best exploitation of the possibilities offered by the multiplicity of demand side management (DSM) options within the broader context of Integrated Resource Planning of electricity systems. In (Goletsis et al., 2003) the aim is to sort out a limited number of both supply and demand side energy projects among a large number of proposals submitted by various bodies and organizations for the restructuring of the Armenian energy sector. Matos, (1999) has developed a fuzzy filtering method based on the degree of acceptance for reducing the initial large set of efficient solutions in the power distribution problem, in particular a set of alternative plans for expanding or reinforcing the network. Finally, in another interesting application, the Greek programme for the mitigation of greenhouse gases has resulted through the classification of a large number of DSM and supply options into groups of different attractiveness and then by elaborating the obtained results for scheduling their implementation (Georgopoulou et al., 2003).

Other examples of project evaluation are the evaluation of 41 agricultural biogas plants located in Austria (Madlener et al., 2008), of Combined Heat and Power (CHP) systems (Alanne et al., 2007 and Pilavachi et al., 2006), of hybrid energy systems (Afgan and Carvalho, 2008), of new medium and large hydropower plants in Portugal centre region (Almeida et al., 2005), of wind energy turbines in a site on the island of Salina (Cavallaro and Ciraolo, 2005) and of hydrogen energy systems in comparison with renewable energy systems (Afgan and Carvalho, 2004).

A further subdivision in this group refers to decision contexts in which budget constraints are imposed and/or complementary or competitive relations between the candidate proposals should be taken into account. Thus, a portfolio approach has to be followed in order to single out the subset of projects that complies with the decision maker(s)'preferences and satisfies the imposed limitations. In (Mavrotas and Diakoulaki, 2003), the problem faced by a regulatory authority is to license a number of independent electricity producers (wind farms) that are competing for a limited land area and a restricted grid's capacity, securing, at the same time, the competition rules of the free electricity market. A similar decision situation is faced by a regulatory authority trying to select among a large number of applications concerning gas transmission facilities (Stewart and Horowitz, 1991), while in (Lootsma et al., 1986; Stewart, 1991), the task was the allocation of a certain budget to various technological areas for Energy R&D projects. The combinatorial nature of these problems and the need to consider a large number of evaluation criteria imposed the combination of integer programming models with MCDA approaches intended to assign an overall score to each alternative.

2.4. Siting and dispatching decisions in the electricity sector

A further decision situation is the classical location problem. In the electricity sector major concern for the siting of facilities is concentrated on thermal or nuclear power plants and on transmission lines. In (Barda et al., 1990) the aim was to identify the most suitable among a large number of potential sites to locate thermal power plants in three coastal regions in Algeria, while Rietveld and Ouwersloot (1992) developed a stochastic MCDA approach for siting two new nuclear power plants in the Netherlands. In (Gamboa and Munda, 2007) is proposed a general framework for dealing with the problem of wind park location taking into account oppositions regarding the extensive land use of windfarms, their possible impacts on tourism or their visual impact and some social actors which are normally in favor of wind parks because they perceive them as a possibility of development or simply a source of income. Finally, an MCDA approach was applied in an environmental impact assessment problem related with the pathway of an electric transmission line was solved through (Rousseau and Martel, 1994).

Besides the medium-to long-term planning problems, MCDA is also exploited for assisting dispatchers in the routine operation of electricity systems. Gandibleux (1999) developed a multicriteria DSS with the intention to support dispatching decisions in electricity generation in front of abnormal situations, i.e. various disturbances threatening the system's stability and security.

3. METHODOLOGY AND DEVELOPMENT OF TOOL

A major objective of the CASES project is to proceed to the comparative assessment of policy instruments aiming at the internalisation of external costs in electricity generation. For this type of decision problem a methodological framework has been established and a dynamic and interactive MCDA tool was developed to help respondents identify the relative importance of criteria and accordingly rank the policy instruments in a descending order of preference.

3.1 Selection of MCDA method

MCDA methods used to rank discrete alternative options are classified into the two following categories:

I). Multi-Attribute Value Theory methods (MAVT) trying to associate a unique number ('value') representing the overall strength of each alternative if all criteria are taken into account.

II). Outranking methods trying to associate a preference index to each pair of alternatives that is further exploited to rank alternatives in a descending order of preference.

Between these two categories, MAVT methods present the advantage of greater simplicity and transparency and can be more easily understood by stakeholders in the constrained time frame of a workshop. In addition, they are more compatible with CBA, because they use a similar utilitarian background where decisions result from explicit or implicit trade-offs between conflicting interests or points of view. Therefore, they can act in a complementary way to the external and internal cost values assessed in the CASES project, by including evaluation aspects that can not be expressed in monetary terms.

Multi-Attribute Value Theory (MAVT) methods associate with each alternative option a unique number (‘value’) providing an overall evaluation of this option if all criteria are taken into account according to the decision maker’s preferences.

The starting point in all MAVT models is the definition of partial value functions in each criterion for reducing performances in the [0-100] interval. This means that partial value functions are defined with a strict reference to the worst and best performance, which are usually assigned with 0 and 100, respectively. Worst and best performances refer to either the considered set of alternatives (local scale) or to potentially achievable scores (global scale).

Value functions differ according to the attitude of stakeholders against risk. However, taking into account the relatively short range of performances identified for the examined set of policy instruments and the fact that these performances are mostly expressed in ordinal value scales, it is assumed that all value functions are linear denoting a neutral attitude against risk.

The basic property of these partial value functions is that alternative a is strictly preferred to alternative b if $v_i(a)>v_i(b)$, while indifference between the two alternatives holds only if $v_i(a)=v_i(b)$.

The calculation of partial values differs according to the preferred direction of the performance scale in each criterion. When a criterion is to be maximised the partial value associated with alternative a is calculated by

$$v_i(a) = \frac{g_i(a) - g_i(\min)}{g_i(\max) - g_i(\min)} \qquad (1)$$

and when a criterion is to be minimised the partial value is calculated by

$$v_i(a) = \frac{g_i(\max) - g_i(a)}{g_i(\max) - g_i(\min)} \qquad (2)$$

It is important to mention that in the case of criteria with qualitative scales in which the performances do not cover all the available scale, the partial values are calculated as a percentage of the relatively best performance. Hence, formulas (1) and (2) are converted in the simpler form of formulas (3) and (4), for the maximisation and minimisation criterion, respectively

$$v_i(a) = \frac{g_i(a)}{g_i(\max)} \qquad (3)$$

$$v_i(a) = \frac{g_i(\min)}{g_i(a)} \quad (4)$$

Partial values are then aggregated for deriving total values and constructing a complete preorder of the examined alternatives. The transition from partial to global value functions (taking into account the whole set of criteria) implies the use of an aggregation formula together with the weights provided by the decision maker. The simplest and most commonly used aggregation model is the additive one:

$$V(a) = \sum_i w_i \bullet v_i(a) \quad (5)$$

where, V(a) is the total value associated with each alternative a, and w_i is the weight attached to criterion i by the stakeholder. Policy options are then ranked according to V(a) from the highest to the lowest value.

3.2 Selection of weighting methods

Several weighting methods have been developed in the framework of MCDA. The choice is restricted among methods facilitating stakeholders to realize their own preferences without being two complicated and leading to inconsistencies that would be difficult to resolve within the short duration of a 1-day workshop. For this reason more complicated methods like the Trade-off method which is the most appropriate method for use in combination with a MAVT method have been excluded.

It has been decided to use in parallel two weighting methods. As found in the literature review this gives stakeholders the opportunity to proceed in an iterative way in the articulation of her/his preferences and confirm or revise the initially defined weights. Among the available simple and meaningful weighting methods we have selected the RATIO method and the LEVEL method to be integrated in the MCDA procedure.

In the RATIO weighting method stakeholder is firstly asked to rank the criteria from the most the least important and then he is asked to rate them according to the assumed difference in their relative importance. More specifically, the most important criterion is assigned with a value of a=100 and the stakeholder defines a value b≤ 100 to denote the relative importance of the second ranked criterion. The closer is the value b to 100, the less is the difference between the relative importance of the two criteria. Then the stakeholder assigns a value c≤b to the third ranked criterion and so on, until the bottom ranked criterion. The defined values are translated into relative weights by normalizing them to sum to one.

In the LEVEL weighting method a hierarchical scale is utilised in which the stakeholder has the opportunity to place each criterion according to its relative importance. In this way, he is not obliged to specify her/his preferences in a numerical scale. The most important criterion is simply placed at the highest level and the least important at the lowest. One or more blank lines can be used in order to denote a greater difference in importance between two consecutive (in terms of importance) criteria. The numerical weights are derived by assigning a number to each level (line) starting with number 1 for the bottom line, 2 for the next line and so on, until the top of the scale which is assigned with the total number of lines used in placing the examined criteria (including all blank lines). The defined values are translated into relative weights by normalizing them to sum to one.

3.3. The MULTI-CASES TOOL

The Multi-Cases Tool has integrated the selected MCDA and weighting methods in the EXCEL computational framework and can be directly used by any user or stakeholder wishing to rank a number of alternatives by taking into consideration their performances in multiple criteria. The tool is developed in a dynamic and interactive way giving the user the flexibility to define the elements of the decision problem to express and eventually revise preferences, to add or reject alternatives or criteria and finally to perform sensitivity analyses. It is crucial for the functionality of the tool to enable the MACROS settings.

The Multi-Cases Tools consists of 11 pages (sheets), as follows:

1. *Home*: Introductory sheet to the tool.
2. *Steps*: Provides an overview of all methodological steps.
3. *Criteria*: Definition and ranking of the examined criteria.
4. *Alternatives*: Definition of the examined alternatives
5. *Performances*: Specification of the performances of each alternative in each criterion.
6. *RATIO Weights*: Calculates the RATIO weights.
7. *LEVEL Weights*: Calculates the LEVEL weights.
8. *RATIO Results*: Calculates the RATIO results.
9. *LEVEL Results*: Calculates the LEVEL results.
10. *Sensitivity Analysis*: Implements a sensitivity analysis with RATIO and/or LEVEL weights.
11. *Stakeholder Data*: Stores all necessary input and output data to be used in the elaboration of results.

3.3.1. Introduction to the tool

The Multi-Cases Tool always opens in the sheet “Home”. The “ENTER” arrow leads to the next sheet named “Steps”, which provides an overview of the methodological steps to be followed. It is important to complete all steps in order to obtain the full set of results. In each step a hyperlink can lead you directly to the corresponding sheet.

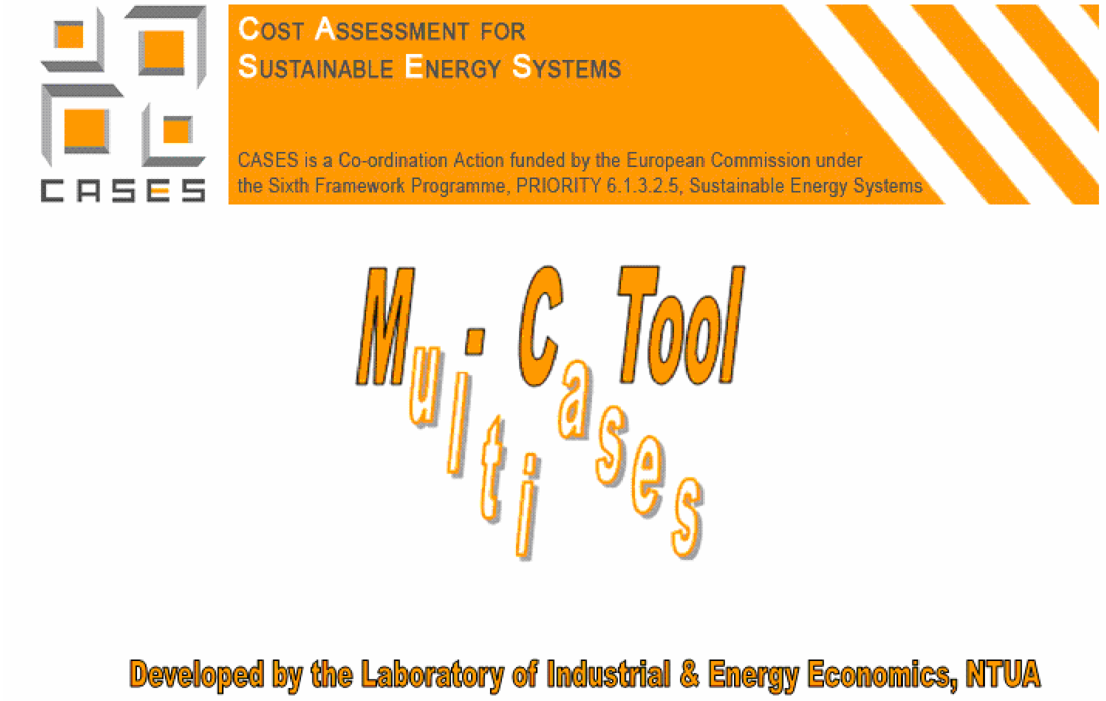

Figure 1: The Home page of the Multi-Cases tool.

There are 3 buttons for the navigation through the sheets: to the previous step, to the next step and to the sheet “Steps”.

3.3.2. Problem definition

The sheet “Criteria” provides the platform for the definition of the evaluation aspects that have to be taken into account in the comparative assessment of the examined alternative options. The criteria can be inserted in any order the user thinks appropriate and are specified with their name, their acronym and the units in which the performances are measured.

The platform allows the insertion of maximum 15 criteria. This limit is due to the perception that human mind can not easily perform the necessary comparisons and identify differences in relative importance if the number of criteria exceeds 15.

After defining the criteria, the user is asked to specify the rank order of the criteria. This procedure includes the assignment of number 1 to the most important criterion up to number N for the least important criterion. The procedure will finish when all chosen criteria are assigned with their rank order. Finally it is necessary to define the direction of preference in the evaluation scale of each criterion by choosing either Max or Min from the two options provided in the last column. He can select Max if greater values are preferred to smaller ones (e.g. profit values) or Min if smaller values are preferred to greater ones (e.g. cost values).

The list of criteria is rearranged according to the specified rank number by pressing the button “Sort Criteria”. This order is automatically transferred to the sheet “Performances”, and to the sheets “RATIO Weights” and “LEVEL Weights”.

The sheet “Alternatives” provides the platform for the definition of the alternative options that have to be comparatively assessed. The alternatives can be inserted in any order the user thinks appropriate and are specified with their name and their acronym. The alternatives will be automatically numbered when inserted. The specified order will be transferred to the sheet “Performances” and to the sheets “RATIO Results” and “LEVEL Results”.

The maximum number of alternatives that can be specified and assessed with the Multi-Cases Tool is 100.

The sheet “Performances” includes an empty evaluation matrix constructed on the basis of the already specified criteria and alternatives. The columns refer to criteria and the rows to alternatives. The matrix is filled by considering each column separately and defining the performances of the alternatives in the respective criterion. According to the direction of preference, the best and worst performances appear in green and red colour, respectively.

There is the opportunity to utilise different evaluation scales for the considered criteria either qualitative scales of various widths for ordinal criteria or quantitative scales of various units for cardinal criteria. All these scales will be automatically normalized through a linear transformation by assuming that a linear value function relates initial performances and relative scores.

3.3.3. Expression of preferences

The Multi-Cases Tool provides two alternative weighting methods to help users articulate their judgments regarding the relative importance of criteria.

a) The RATIO method

b) The LEVEL method

The user can implement both methods, in order to better realize and confirm her/his preferences or only one method, the one that seems most convenient to her/his way of thinking. Small differences in the resulting weights cannot be avoided. However, these differences are unlikely to influence the obtained results. Large differences offer an opportunity to rethink the preferential input provided in the respective sheets and decide on the final judgment.

The sheet “RATIO Weights” provides an easy and interactive framework to implement the corresponding method as described in 3.2. The user is asked to determine the difference in the relative importance of the specified criteria in quantitative terms. If a higher value is assigned to a criterion that has been identified as less important in the sheet “Criteria”, a red colour will indicate that this value has to be changed to a lower one. The tool automatically displays the normalised weights resulting from the specified values. In any case, if the user thinks that these weights do not adequately reflect her/his preferences she can either change the specified values in this sheet, or the initial rank order of criteria by returning to the sheet “Criteria”.

The sheet “LEVEL Weights” provides an easy and interactive framework to implement the corresponding method as described in 3.2. The user is asked to determine the difference in the relative importance of the specified criteria in visual qualitative terms. The tool indicates that all criteria are placed in different levels of an empty table and that there is no inconsistency with the initial rank order. The tool automatically displays the normalised weights derived by the values implicitly assigned to each level. Here also, the user is given the opportunity to revise either the placement in this sheet or the initial rank order of criteria by returning to the sheet “Criteria”.

3.3.4. Results and sensitivity analysis

The sheets “RATIO Results” and “LEVEL Results” display the global score of the examined alternatives calculated according to formula (5) by using the performances defined in the sheet “Performances” and the specified weights in the respective sheet. Alternatives appear in the random order defined when completing the sheet “Alternatives”. The user can rank them according to their global score in a descending order of global preference by pressing the button “Sort Alternatives”.

The results can be stored on the right of the sheet “RATIO Results” or “LEVEL Results” in order to be subsequently used for comparison and reporting by pressing the button Copy/Paste Results of Basic Scenario. The user can perform a sensitivity analysis in order to check the robustness of the obtained results. Besides the basic scenario, it is possible to construct up to 3 additional scenarios by revising any of the subjective/preferential inputs (number of criteria, weights of criteria, performance of alternative(s) on criteria). These results are stored next to the results of the Basic Scenario by pressing the button Copy/Paste Results of Scenario 1, 2 or 3, respectively. If the user wishes to examine additional scenarios, he can clear the results already stored for placing the new results.

The sheet “Sensitivity Analysis” displays the final ranking of the examined alternatives for a maximum of 4 scenarios as derived from the sheets “RATIO Results” and “LEVEL Results”.

The displayed results have been automatically saved when constructing the scenarios in the previous sheets. For better differentiating the most preferred alternatives, 3 different colours indicate 3 different priority groups:

- The orange colour indicates the alternatives ranked in the top 5 places.
- The blue colour indicates the alternatives ranked between the 5th and 10th place.
- The white colour indicates the alternatives ranked below the 10th place.

Finally in the sheet "Stakeholder Data" all the necessary input data (rank order of criteria, calculated RATIO and LEVEL weights and the performances of the alternatives) are stored for all scenarios automatically.

4. ASSESSMENT OF POLICY INSTRUMENTS

A major objective of the CASES project is to proceed to the comparative assessment of policy instruments aiming at the internalisation of external costs in electricity generation. Specifically, the following two sets of policy instruments have been identified:

A) Policy instruments to minimise CO_2 emissions from electricity generation (hereafter referred as Policy Problem A).

B) Policy instruments to promote the penetration of renewable energy sources in the electricity sector (hereafter referred as Policy Problem B).

The policy options in each set have been evaluated along a number of criteria reflecting different aspects of performance, such as environmental effectiveness, flexibility, dynamic efficiency, acceptability etc. The evaluation was performed in the framework of a workshop with the active participation of stakeholders (SHs) coming from different institutions.

4.1. The Workshop

The workshop was held on April 23rd 2008 in Bruges, Belgium. The aim was to communicate the overall framework and most important outcomes of the CASES project by giving emphasis on the analysis and evaluation of policy instruments. To this purpose, the following actions have been performed:

- Selection and invitation of the stakeholders to the workshop.
- Adaptation of the Multi-Cases Tool to the two policy problems.
- Preparation of the material to be delivered to the stakeholders.
- Workshop organisation and realisation.
- Collection and elaboration of stakeholders' responses during the workshop.
- Presentation and discussion of basic findings during the workshop.

Invitations were sent to about 20 individuals or organizations (including utilities, industry, governmental organisations, NGOs and the EC), together with a brief summary of the policy problems. Most of the invitees expressed their interest, even though many had already other commitments for the proposed date. Finally 30 individuals attended the workshop. The 67% of them was CASES Partners and the rest 33% Non-CASES Partners. The 47% was male and the 53% female. Finally, the 73% of the stakeholders represented Universities and Research Centres, the 17% Power Companies and the rest 10% governmental organizations.

During the workshop, the 2 policy problems have been described by analysing the selected criteria, the examined policy instruments and their performances in the criteria. Moreover the MCDA framework was explained and instructions were given to the SHs for the implementation of the 2 case studies by means of the Multi-Cases Tool.

The detailed presentation of criteria, policy instruments and scores is included in the deliverables D.8.1 and D.9.1 for each policy problem respectively.

The proposed assessment procedure that has been followed by the SHs included the following steps:

- Introduction to the policy problem and careful examination of the pre-defined instruments, criteria and performances.
- Ranking the list of criteria according to the relative importance of each criterion.
- Definition of the relative importance of criteria through the two different weighting methods (RATIO and LEVEL method).
- Examination of the obtained rankings of policy instruments.
- Construction of additional scenarios for sensitivity analysis.

The proposed assessment procedure is depicted in Figure 2.

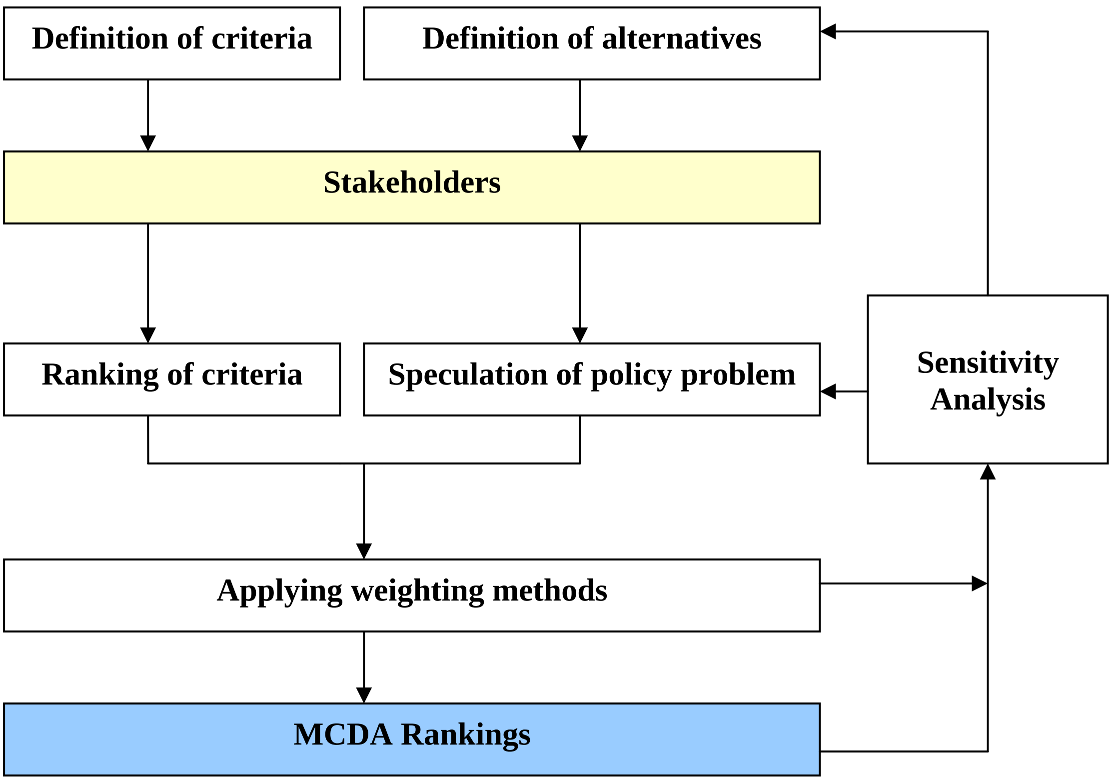

Figure 2: Workflow of the proposed assessment procedure.

The majority of SHs have used both weighting methods, while some of them constructed additional scenarios for sensitivity analysis. The obtained results are analytically described in deliverables D.8.1 and D.9.1. The analysis presented in the following paragraphs is restricted to statistical elements related to methodological issues, such as the proximity of weights and rankings resulting from the two weighting methods, the dispersion of preferences and the consensus to an average judgement. In particular, the analysis aims to identify:

- The impact of the weighting method on the elicited preferences and the corresponding stability of the produced rankings of instruments.
- The consensus between SHs as regards the relative importance of criteria and the produced rankings of instruments.

4.2. The impact of the weighting method

4.2.1. Convergence of weights

The use of two weighting methods gives SHs the opportunity to realize and confirm the priority attached to the evaluation criteria used in the two policy problems. Large deviations between the two sets of weights indicate a low consistency in the articulation of preferences, which is possibly due to either the different preference elicitation approach followed in the two weighting methods, or to the vagueness of the criteria used. The consistency of preferences is measured through the mean deviation of weights, D_W, for each separate SH and for the average weights of the whole group calculated with formula (6):

$$D_W(j) = \frac{\sum_i \left| W_{RATIO\_ij} - W_{LEVEL\_ij} \right|}{n} \qquad (6)$$

where, W_{RATIO_ij} is the weight of criterion i derived from RATIO method by SH j, W_{LEVEL_ij} is the weight of criterion i derived from LEVEL method by SH j, and n is the total number of criteria in each policy problem.

Table 1 shows the calculated values of mean deviation, D_{WA} and D_{WB} for the two policy problems A and B. It can be seen that consistency is generally higher in policy problem A compared to policy problem B, as proved by the deviation between average weights produced for the whole group of stakeholders. In addition, in policy problem A about 37% of SHs show a very low deviation between the two sets of weights (D_W < 1%) and 25% present a high D_W exceeding 3%. On the contrary, in policy problem B the percentage of highly consistent SHs is about 20%, while D_W > 3% is calculated for 40% of the SHs. The difference between the two policy problems indicates that SHs are not very stable in their judgement about the relative importance of criteria in policy problem B, although the number of criteria is the same in the two problems (10).

Table 1: Mean deviation of weights produced by the two weighting methods.

Stakeholder	Policy Problem A D_{WA}	Policy Problem B D_{WB}
SH1	2.9%	3.1%
SH2	0.7%	1.0%
SH3	1.4%	1.1%
SH4		
SH5	4.4%	6.1%
SH6		
SH7		
SH9	3.0%	1.9%
SH10	1.4%	0.8%
SH11		
SH13	0.7%	1.2%
SH14	0.8%	1.6%
SH15	2.4%	4.3%
SH16	0.7%	3.8%
SH18	3.9%	2.6%
SH19	1.7%	2.1%
SH20		2.0%
SH22	0.5%	1.2%
SH23	0.5%	0.7%
SH24	0.9%	0.3%
SH25	2.4%	3.9%
SH26	5.2%	7.0%
SH27	3.8%	3.9%
SH29	1.1%	2.2%
SH33	1.7%	5.1%
SH35	6.4%	
SH36	0.6%	2.2%
SH37	3.3%	6.0%
SH40	0.7%	0.5%
Average	0.8%	1.2%

Blank lines denote that the SH has used in one or both problems only one weighting method.

Figures 3 and 4, show that the average weights derived by the two methods were remarkably close in both policy problems, especially for the middle-ranked criteria. It can be seen that the weights derived from RATIO method present a greater dispersion in comparison with the weights derived from the LEVEL method, leading to bigger deviations in the top- and bottom-ranked criteria. This is due to the relatively constrained framework of placing criteria in the LEVEL method.

Moreover, a comparative view on Figures 3 and 4 reveals that the spread of average weights is slightly lower in policy problem A (from approximately 8% up to around 15%) compared to the corresponding dispersion of weights in policy problem B (from approximately 7% up to around 17%).

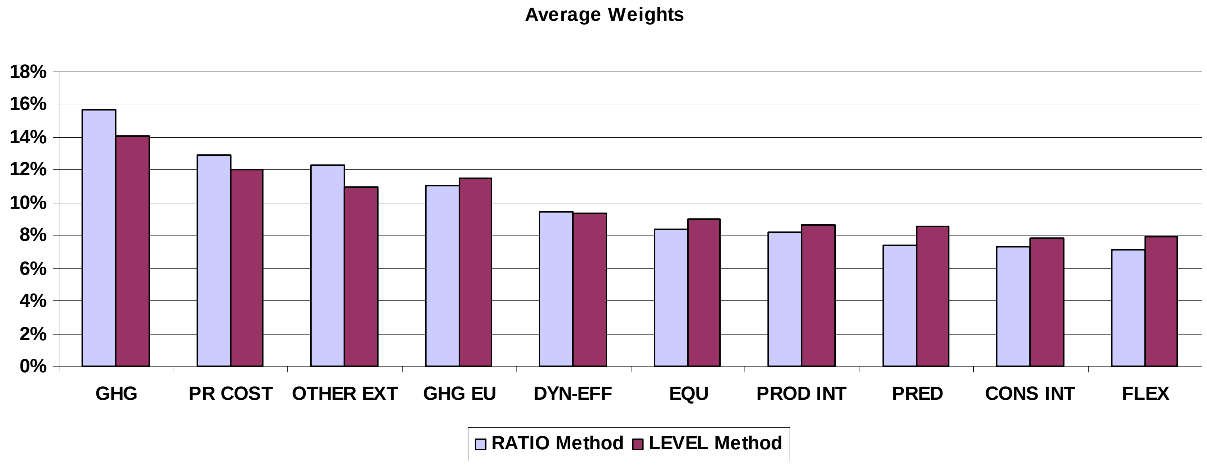

Figure 3: Convergence of average weights of criteria in policy problem A.

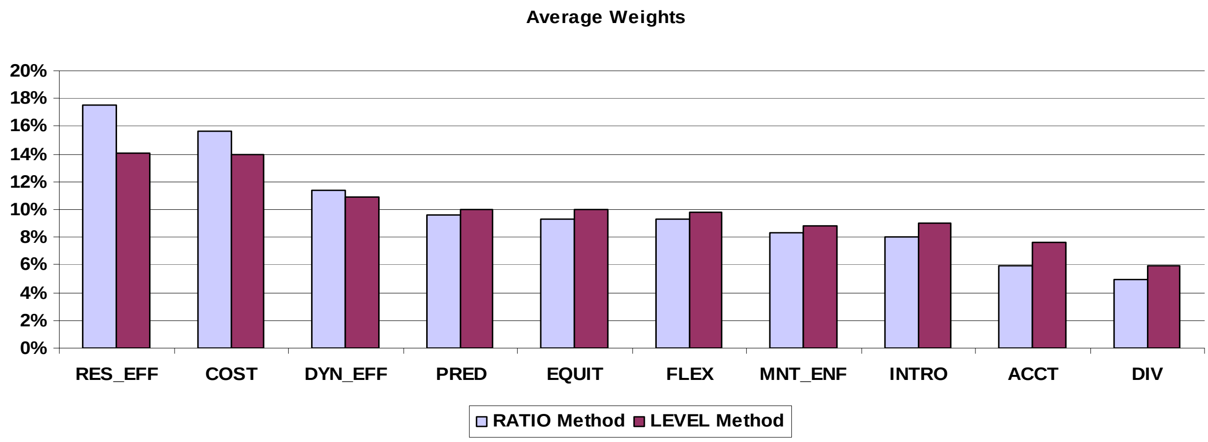

Figure 4: Convergence of average weights of criteria in policy problem B.

4.2.2. Stability of rankings

The average scores of the examined instruments in the two policy problems are presented in Figures 5 and 6. It can be seen that the impact of the weighting method on the global score and consequently on the final ranking of policy instruments is generally very low. This means that the observed deviations in the weights produced by the two weighting methods in the two policy problems, were not large enough for differentiating the rank order of the examined alternatives. In other words, the ranking of policy instruments is not sensible to mean deviations of weights of 1-2%, since the produced global scores were almost identical.

However, it can be seen that the dispersion of scores is much higher in policy problem A, compared to policy problem B. In the latter, the examined policy instruments are practically divided in two groups: one group including instruments with a global score above 0.8 (with 1 assigned to an ideal instrument presenting the best performance in all evaluation criteria) and a second group with the rest of instruments presenting a global score between 0.7 and 0.8. Only one instrument presents a global score of approximately 0.6. The observed convergence is due to the fact that criteria performances in problem B were spread into a small range of qualitative scales and therefore the normalisation was based on formulas (3) and (4) leading to smaller dispersions of global scores (no 0 score is assigned to the worst performance as is the case with formulas (1) and (2)). On the contrary, in policy problem A, one can distinguish at least three groups of instruments, one group of best performing instruments (0.75-0.85), one medium group (0.5-0.65) and the bottom ranked instruments with a global score lower than 0.5.

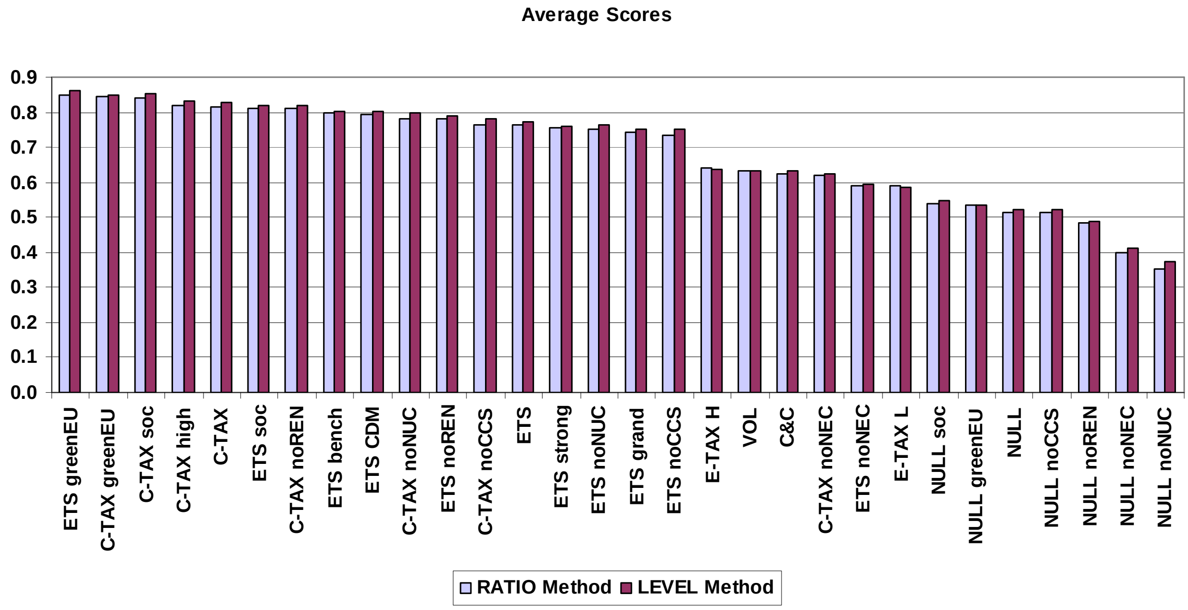

Figure 5: The average scores of the policy instruments in policy problem A.

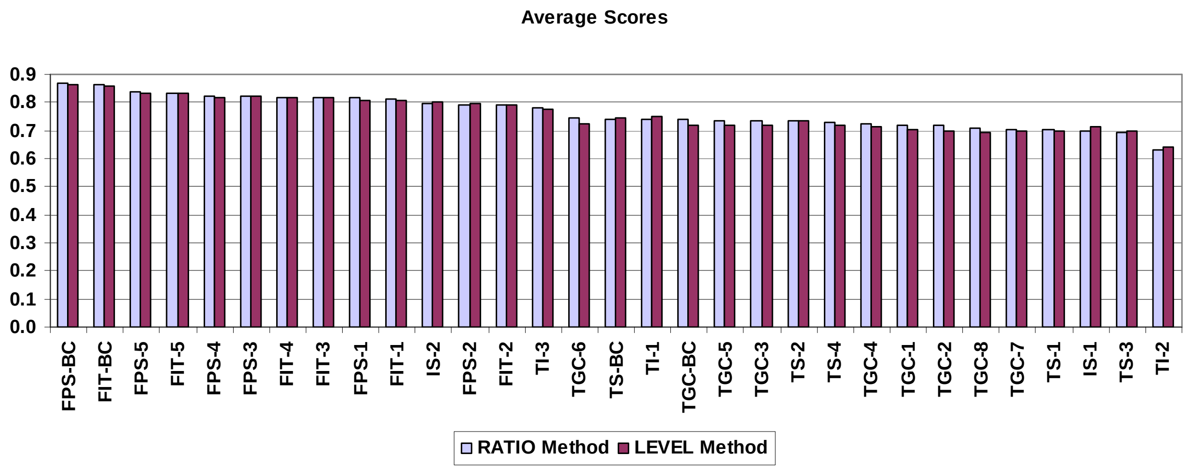

Figure 6: The average scores of the policy instruments in policy problem B.

The differences between average rankings of the policy instruments produced by the two weighting methods are more clearly presented in Figures 7 and 8 for policy problems A and B, respectively. It can be seen that in policy problem B, the changes in the produced rank orders are more pronounced. This result is in accordance with the lower convergence between the two sets of weights shown in Table 1.

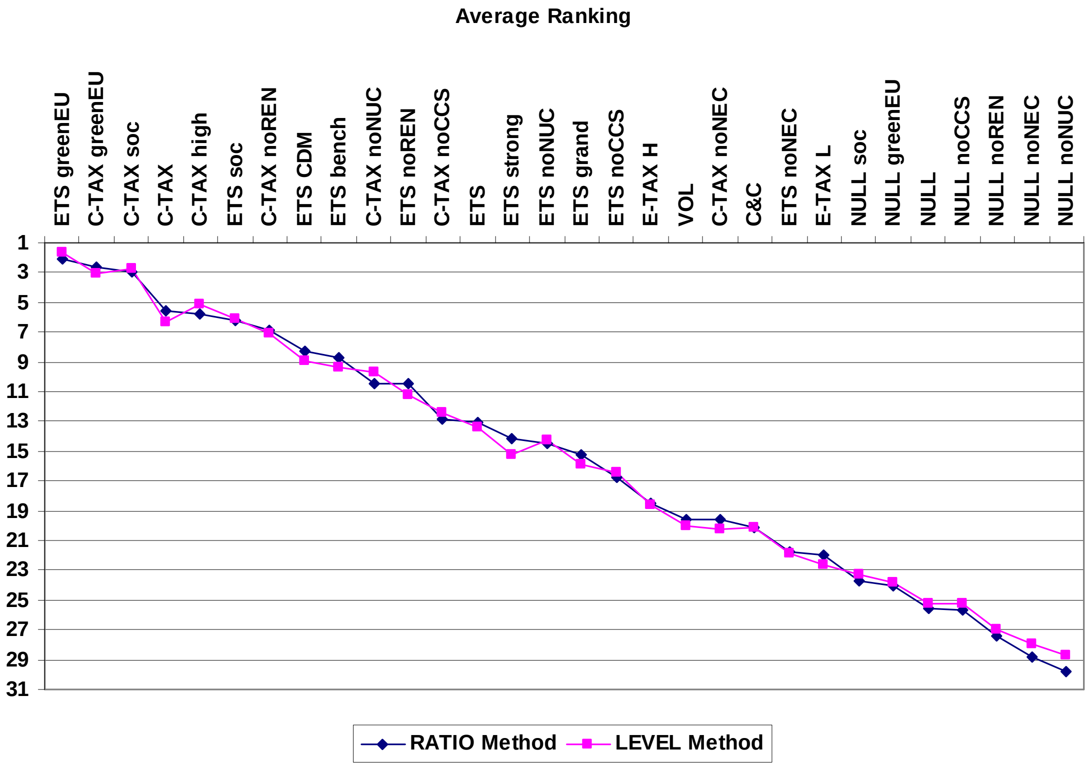

Figure 7: The final rankings of the policy instruments in policy problem A.

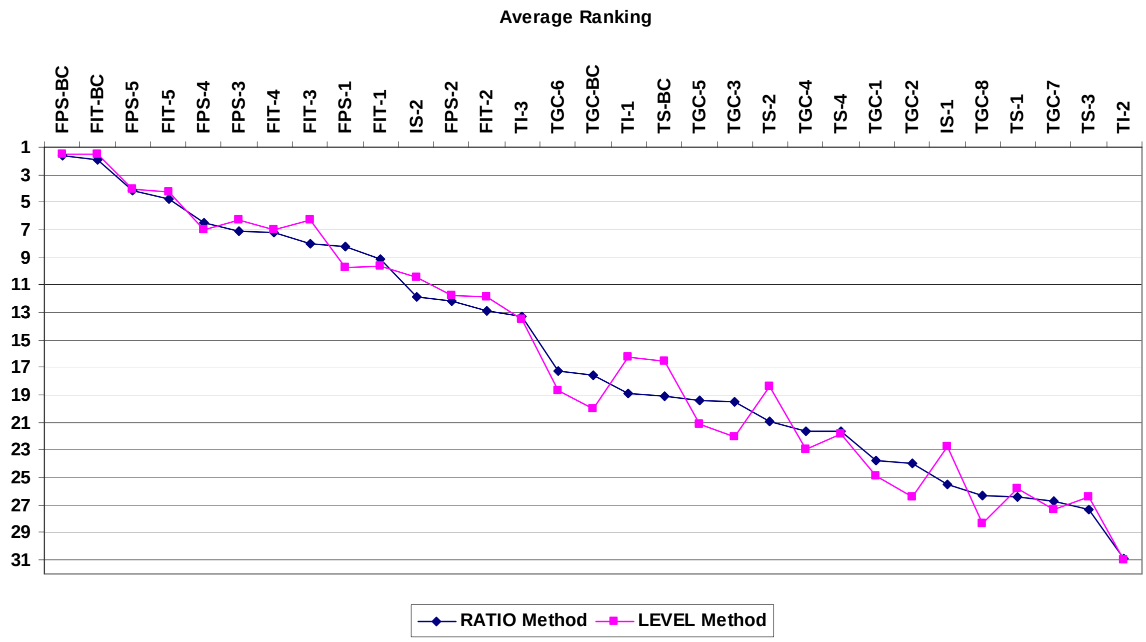

Figure 8: The final rankings of the policy instruments in policy problem B.

However, these permutations are practically non significant, since as already mentioned, the scores in policy problem B are so close, that reversals in the rank order of policy instruments by 1 or 2 places are not important for their overall assessment. Table 2 shows the mean deviation in the rank orders produced by the two weighting methods, D_R, calculated for each separate SH and for the average rankings of the whole group according to formula (7):

$$D_R(j) = \frac{\sum_i (|R_{RATIO\_ij} - R_{LEVEL\_ij}|)}{m} \quad (7)$$

where, R_{RATIO_ij} is the rank order of policy instrument i derived from RATIO method by the j stakeholder,

R_{LEVEL_ij} is the average ranking of policy instrument i derived from LEVEL method by the j stakeholder and

m is the total number of policy instruments in each policy problem

Table 2: Mean deviation of rank orders produced by the two weighting methods.

Stakeholder	Policy Problem A	Policy Problem B
SH1	2.2	2.3
SH2	0.5	0.8
SH3	0.7	0.8
SH4		
SH5	1.4	1.5
SH6		
SH7		
SH9	1.0	0.8
SH10	0.5	0.8
SH11		
SH13	0.5	1.2
SH14	0.2	1.1
SH15	0.6	2.5
SH16	0.3	2.2
SH18	2.6	1.7
SH19	0.7	1.0
SH20		1.6
SH22	0.2	0.9
SH23	0.2	0.6
SH24	0.4	0.3
SH25	0.9	2.6
SH26	1.8	5.5
SH27	1.1	2.8
SH29	0.5	0.7
SH33	0.6	6.5
SH35	2.5	
SH36	0.3	2.2
SH37	1.3	3.2
SH40	0.3	0.3
Average	0.4	1.2

4.3. Consensus between Stakeholders

4.3.1. Consensus on weights

The consensus within the group of SHs as regards the relative importance of criteria shows the degree each individual SH is represented by the derived average weights. The lower the deviation between SH's weights and average weights the higher is the consensus. Thus, a measure of conflict on weights, C_W, is calculated for each weighting method, the RATIO and the LEVEL method, according to the mean deviation formulas previously used, which are modified as follows:

$$C_{W\_RATIO}(j) = \frac{\sum_i (|W_{RATIO-ij} - W_{AvgRATIO\_i}|)}{n} \quad (8)$$

$$C_{W\_LEVEL}(j) = \frac{\sum_i (|W_{LEVEL-ij} - W_{AvgLEVEL\_i}|)}{n} \quad (9)$$

where, W_{RATIO_ij} and W_{LEVEL_ij} is the weight of criterion i derived from RATIO or LEVEL method by SH j,

$W_{AvgRATIO\_i}$ and $W_{AvgLEVEL\_i}$ is the average weight of criterion i calculated for the whole group of SHs, and

n is the total number of criteria in each policy problem.

Figures 9 and 10 show that the resulting mean deviation from average weights is relatively low in both policy problems for the majority of SHs. As expected, the LEVEL method leads to a lower conflict because of the smaller dispersion of weights already discussed in 4.2.1. With the RATIO method, for approximately 50% of SHs the deviation of their weights from average weights exceeds 3%. In policy problem A, the highest conflict is reported for SH4 and SH26, while in policy problem B, for SH5 and SH26.

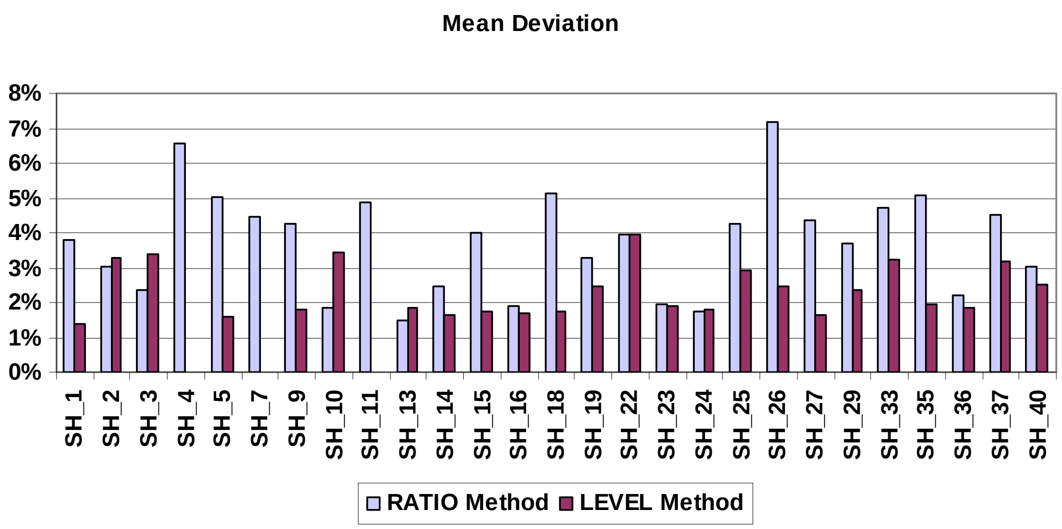

Figure 9: Mean deviation from average weights in policy problem A.

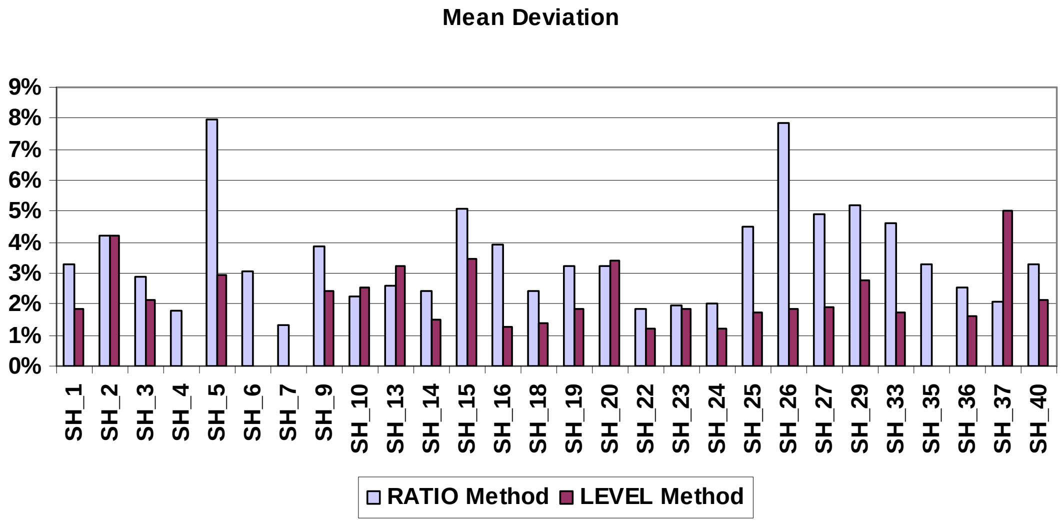

Figure 10: Mean deviation from average weights in policy problem B.

Table 3 shows the average consensus on weights for the whole group of stakeholders calculated by dividing individual indices with the number of participating stakeholders. It can be seen that consensus is almost the same in policy problems A and B, while the LEVEL method is clearly shown to facilitate consensus among stakeholders.

Table 3: Mean deviation from average weights for the whole group of stakeholders.

	Policy Problem A	Policy Problem B
RATIO Method	3.7%	3.5%
LEVEL Method	2.3%	2.2%

4.3.2. Consensus on rankings

The consensus within the group of SHs as regards the rankings of policy instruments shows the degree each individual SH is represented by the derived average ranking. The lower the deviation between SH's ranking and average ranking the higher is the consensus. Formulas (10) and (11) are derived from (8) and (9) by examining the deviations between rank orders instead of weights:

$$C_{R\_RATIO}(j) = \frac{\sum_i \left(\left|R_{RATIO-ij} - R_{AvgRATIO\_i}\right|\right)}{m} \qquad (10)$$

$$C_{R\_LEVEL}(j) = \frac{\sum_i \left(\left|R_{LEVEL-ij} - R_{AvgLEVEL\_i}\right|\right)}{m} \qquad (11)$$

where, R_{RATIO_ij} and R_{LEVEL_ij} is the rank order of policy instrument i derived from RATIO or LEVEL method by SH j,

$R_{AvgRATIO\_i}$ and $R_{AvgLEVEL\_i}$ is the average rank order of policy instrument i calculated for the whole group of SHs, and

m is the total number of policy instruments in each policy problem.

Figures 9 and 10 show that the resulting mean deviation from average rank order is relatively low in both policy problems for the majority of SHs and does not exceed 2 places for the majority of SHs. In accordance with the higher consensus on weights, the LEVEL method leads also to a higher consensus on the resulting rank orders. With the RATIO method, in policy problem A, the highest conflict is reported for SH11 while a considerable disagreement is found also for SH1, SH7 and SH18, while in policy problem B for SH5, SH26 and SH33.

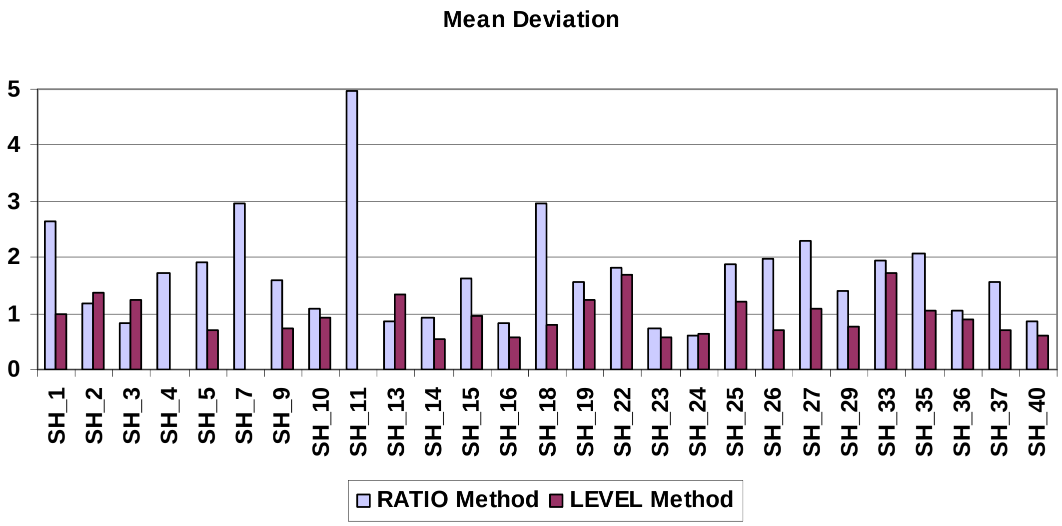

Figure 11: Mean deviation from average rank order in policy problem A.

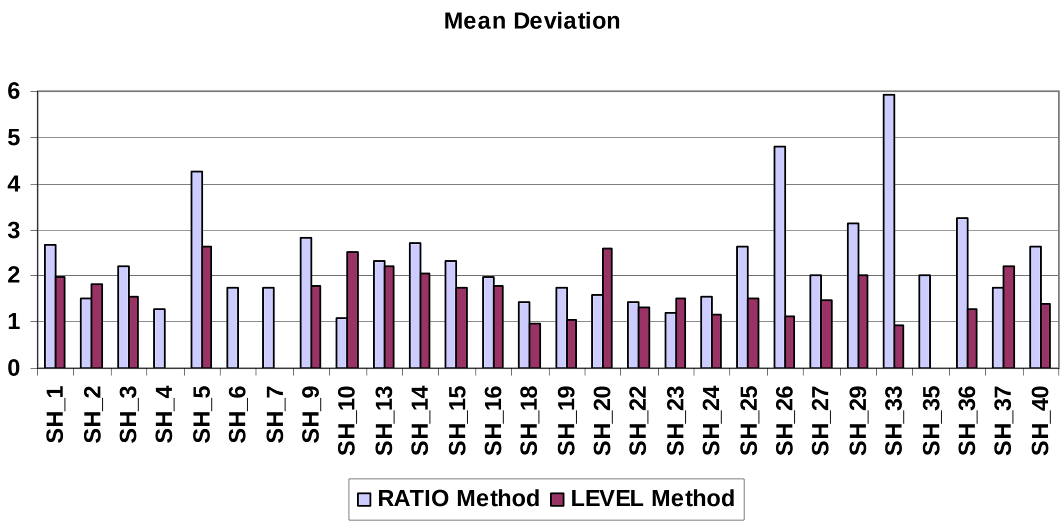

Figure 12: Mean deviation from average rank order in policy problem B.

Table 4 shows the average consensus on the ranking of instruments for the whole group of stakeholders calculated by dividing individual indices with the number of participating stakeholders. It can be seen that consensus is higher in policy problem A, while the LEVEL method is clearly shown to facilitate consensus among stakeholders.

Table 3: Mean deviation from average rank order for the whole group of stakeholders.

	Policy Problem A	Policy Problem B
RATIO method	1.7	2.3
LEVEL method	1.0	1.7

5. CONCLUSIONS

Multicriteria decision analysis can provide valuable assistance to managers, policy makers and other stakeholders facing complex decision situations in the energy sector, as proven by the rapidly growing body of relevant publications found in the literature. The policy assessment tasks implemented in the framework of the CASES project constitute an interesting case study for implementing MCDA in order to disclose the policy instruments that are most capable to internalise external costs in the electricity generation sector. To this purpose, two different sets of policy instruments, one for reducing CO_2 emissions and one for promoting renewable energy sources have been assessed by taking into account multiple evaluation criteria, as described in Deleverables D.8 and D.9, respectively.

The MULTI-CASES Tool has been developed in the framework of WP11 of the CASES project by integrating a reliable MCDA method and two weighting techniques, giving the SHs the opportunity to verify and confirm their judgement about the relative importance of the evaluation criteria. The MULTI-CASES Tool is available in a generic form and can be exploited in a variety of decision situations involving alternative options evaluated along a number of criteria. In the CASES project the MULTI-CASE Tool has been successfully implemented for ranking the above mentioned sets of policy instruments.

The analysis of results shows that the type of the weighting method can slightly influence the level and the dispersion of weights, although in the particular policy problems the observed deviations have not any significant impact on the derived rankings of instruments which appear to be particularly rigid. Moreover, it is found that with a few exceptions representing at maximum 15% of stakeholders there was a significant consensus on the relative importance of criteria and on the resulting average ranking of policy instruments.

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