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Selecting an Appropriate Multi-Criteria Decision Analysis Technique for Renewable Energy Planning

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This article develops a methodological framework to provide insights regarding the suitability of multi-criteria techniques in the context of renewable energy planning. The second section presents main characteristics of the particular decision-making process. The third section presents the main multi-criteria analysis methods, and the fourth section reveals the requirements of the techniques for renewable energy planning and the main attributes under which these methods should be evaluated. Subsequently, in the fifth section, a comparative matrix is created with the various appropriate multi-criteria techniques and their performance. Finally in the sixth section, we present our conclusions.

Keywords renewable energy planning, decision-making, multicriteria decision analysis

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The political, social, economic, and environmental importance of energy planning, to meet the ever-increasing energy demand with an adequate energy supply, renders the evaluation of different energy projects a major challenge for policy makers. This applies in particular for renewable energy sources (RES) because their particular features (decentralized production, localized and short-term cost, distributed and long-term benefits, involvement of many stakeholders, and multiple-evaluation criteria) entail the use of specific instruments to choose the optimum option.

The use of multi-criteria decision analysis (MCDA) techniques provides a reliable methodology to rank alternative RES projects in the presence of numerous objectives and constraints (Haralambopoulos and Polatidis, 2003; Huang et al., 1995; Lootsma et al., 1990; Siskos and Hubert, 1983). Despite, however, the large number of available MCDA methods, none of them is considered the best for all kinds of decision-making situations (Guitouni and Martel, 1998; Salminen et al., 1998; Simpson, 1996). There are no better or worse techniques, only techniques that fit better to a certain situation or not. Nevertheless, different methods, when applied to the same problem using similar data, often produce differing results. The main question is, therefore, how to choose the appropriate MCDA methodology in RES decision-making.

This article tries to address this question by developing a methodological framework to provide insights regarding the suitability of MCDA methods in the context of renewable energy planning. The second section presents the main characteristics of the decision-making process for RES. The third section presents the main families of MCDA methods, and the fourth section reveals the requirements of MCDA techniques for RES planning and the main attributes under which these methods should be evaluated. Subsequently, in the fifth section, a comparative matrix is created with the various appropriate multi-criteria techniques for RES projects and their performance. Finally in the sixth section, we present our conclusions.

Renewable Energy Sources Applications and Decision-Making

During the last decade, RES exploitation has gained a vast interest, and many countries have committed themselves to include them in their energy supply systems. This is due to the fact that RES are considered environmentally friendly and capable of substituting conventional fuels at competitive prices. Their contribution, however, to the current global energy supply is still small despite considerable technological advances in this field.

The main obstacles regarding the wide application of RES in the energy systems concern economic, technical, institutional, and social barriers that must be overcome. Moreover, RES exhibit localized environmental impacts such as landscape alteration, loss of amenity, extensive land and water use requirements, noise, etc.

A number of factors should therefore be taken into consideration. They emerge from the decentralized character of RES and the particularities imposed on the corresponding decision-making process (Figure 1). In most cases, these parameters could be operationalized through the inclusion of several technological, economic, social, risk, and environmental criteria in the planning exercise. The development procedure is even more complicated due to the involvement of stakeholders, influencing the decision-making process.

It goes without saying that these issues are in many cases not immediately compatible. The multidimensional nature of energy planning objectives and projects renders the application of conventional financial evaluation tools problematic. In the following section, different methodological MCDA schemes are presented shortly and proposed as an appropriate means for an integrated evaluation of RES projects.

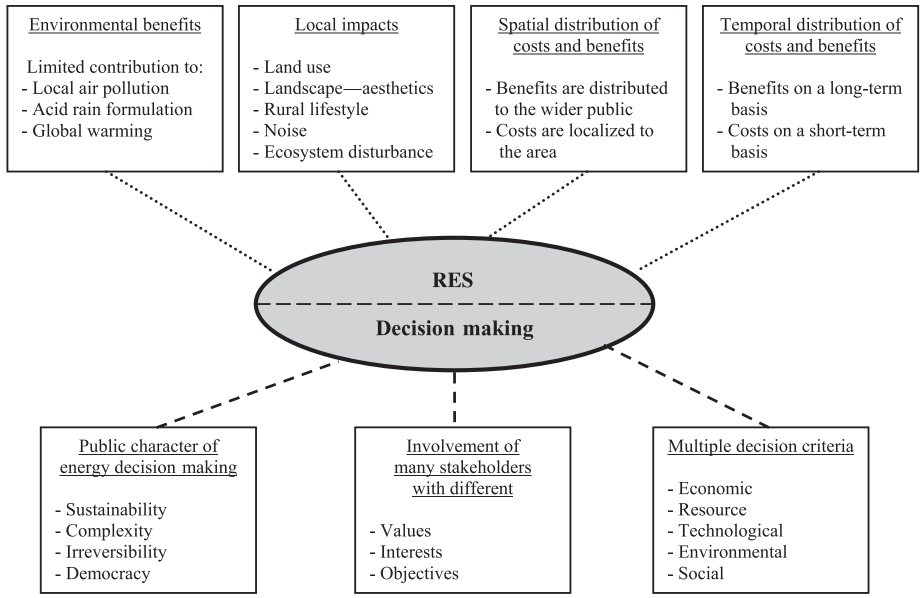

Figure 1. Renewable energy sources and decision making.

Multicriteria Methods

Different multicriteria methods have been applied to energy and environmental problems. The main approaches can be classified based on the type of decision model they apply to (Figure 2). In many situations, the alternatives that could be considered are originally infinite. The use of multiobjective programming methods to tackle these cases is far well known (Pokharel and Chandrashekar, 1998; Ramanathan and Ganesh, 1995). Nevertheless, these approaches face a considerable drawback: They sometimes end up with an

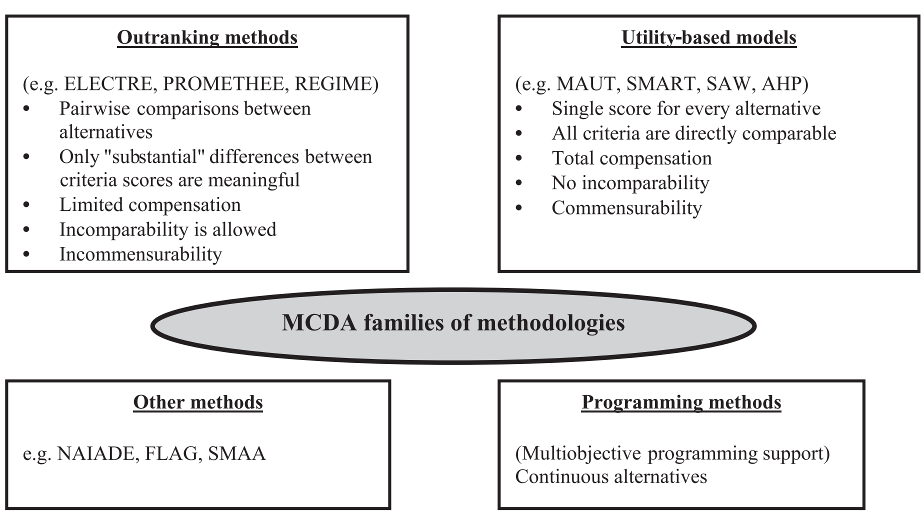

Figure 2. Multicriteria methods.

infeasible alternative. It is for this reason that we recommend discrete MCDA techniques for tackling energy planning issues. We give a concise overview of discrete multicriteria analysis methods in the next paragraphs.

The main families of methodologies include:

1. outranking methods, such as the Elimination Et Coix Traduisant la Realite (ELECTRE) family (Roy and Vincke, 1981; Vincke, 1992), the Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) I and II methods (Brans and Vincke, 1985), and Regime Method Analysis (Nijkamp et al., 1990);
2. value or utility function-based methods, such as the Multi-Attribute Utility Theory (MAUT) (Keeney and Raiffa, 1976); the Simple Multi-Attribute Rated Technique (SMART) (von Winterfeldt and Edwards, 1986); the Analytic Hierarchy Process (AHP) (Saaty, 1980); and the most elementary multicriteria technique, the Simple Additive Weighting (SAW); and
3. other methods like Novel Approach to Imprecise Assessment and Decision Environment (NAIADE) (Munda, 1995), Flag Model (Nijkamp and Vreeker, 2000), Stochastic Multiobjective Acceptability Analysis (SMAA) (Lahdelma et al., 1998).

A question arises of how one can choose an appropriate method in a specific decision situation? Table 1 lists specific operational requirements for a MCDA technique to be used in RES planning as they are disclosed from specific aspects of the decision-making process for energy and environmental problems.

Quite a lot of MCDA methods realize some of the previously listed requirements, but no method is capable of incorporating all at the same time. Especially the last condition of the time dimension in the analysis seems to have escaped from the attention of researchers. This is thought to reduce the applicability of MCDA methods in RES planning, given that energy and environmental issues stipulate all together short- and long-term consequences. To include the time-varying nature of the criteria weights, a framework incorporating integrated assessment, transition management, and multi-criteria analysis was recently proposed (Polatidis et al., 2003). Nevertheless, no explicit MCDA technique exists that originally operationalizes the dimension of time, and this topic is considered needing further research.

In addition, new methods could be developed to tackle the complex nature of energy and environmental decision making. An *ex-post* analysis of case studies' results could reveal what kind of additional technical components the techniques are missing (Figure 3). This process of creating—improving—MCDA techniques is ever-going by nature. The analysis of real applications could disclose the drawbacks of procedures and could imply alterations or new modules to be inserted to the methodologies.

Current techniques in use might need amendments in order to include, for example, the temporal dimension or to operationalize the *precautionary principle*. The latter is of high importance because, in energy and environmental decision making, the long time scales involved, combined with the uncertainties of global environmental impacts (climate change, biodiversity loss, etc.), enforce the view that humans should rely on scientific evidence only to the extent that no irreversible damage occurs. It seems prudent therefore to apply precaution and intuition in assessing the weights for the environmental criteria. This may be done by minimizing the risk-taking element and adopting only absolutely well-established facts.

One may say that the belief functions (Smets, 1988, 1997) may act as an indirect means to apply the precautionary principle to RES planning. Under an outranking approach, the Decision-Maker (DM) is usually asked to directly assess the weight factors

Table 1
Prerequisites of MCDA techniques for RES planning

Prerequisites of MCDA techniques	Justification
Weights elicitation	To provide preference information between the evaluation criteria
Critical threshold values, veto	To operationalize the assimilative capacity of the environmental, economic, resource, and social base
Comparability	To perform an integrated comparison between the different actions
Qualitative and quantitative information	To handle the mixed information usually present in problems of RES decision-making
Rigidity	To give robust results
Group decision-making	To include a diverse audience of stakeholders
Graphical representation	To render the outcome understandable
Ease of use	To familiarize the Decision Makers (DMs) with the decision-making process
Sensitivity analysis	To enhance the transparency of the procedure
Variety of alternatives	To incorporate all possible courses of action
Large number of evaluation criteria	To embrace all different aspects
Consensus seeking procedures	To reach up a global compromise
Incorporation of intangible aspects	To be capable of taking into account "hidden" dimensions of the problem
Incommensurability	To keep the decision criteria in their original units and provide a better decomposition of the issue
Treatment of uncertainty	To explicitly treat the imperfect data (uncertain, imprecise, missing, erroneous, etc.)
Partial compensation	To operationalize a strong sustainability conception
Hierarchy of scale	To decrease the ambiguities and provide for explicit consistency
Concrete meaning for parameters used	To improve the reliability of the process
Learning dimension	To acknowledge and accept new information revealed during the evolution of the procedure
Temporal aspects	To consider the emergency of the situation and clarify long- and short-term concerns

of the evaluation criteria. For the criteria with strong uncertainty (e.g., environmental criteria), the analysts could take the DM's weight factor and assume that this represents only part of the total weight, the credal part as described by Smets. Subsequently, by applying the Transferable Belief Model (Smets and Kennes, 1994), the computation of the whole weight can be realized as the additive performance of the creedal and pignistic integers. This process will result in higher power for environmental criteria where strong uncertainty, if not ignorance, prevails.

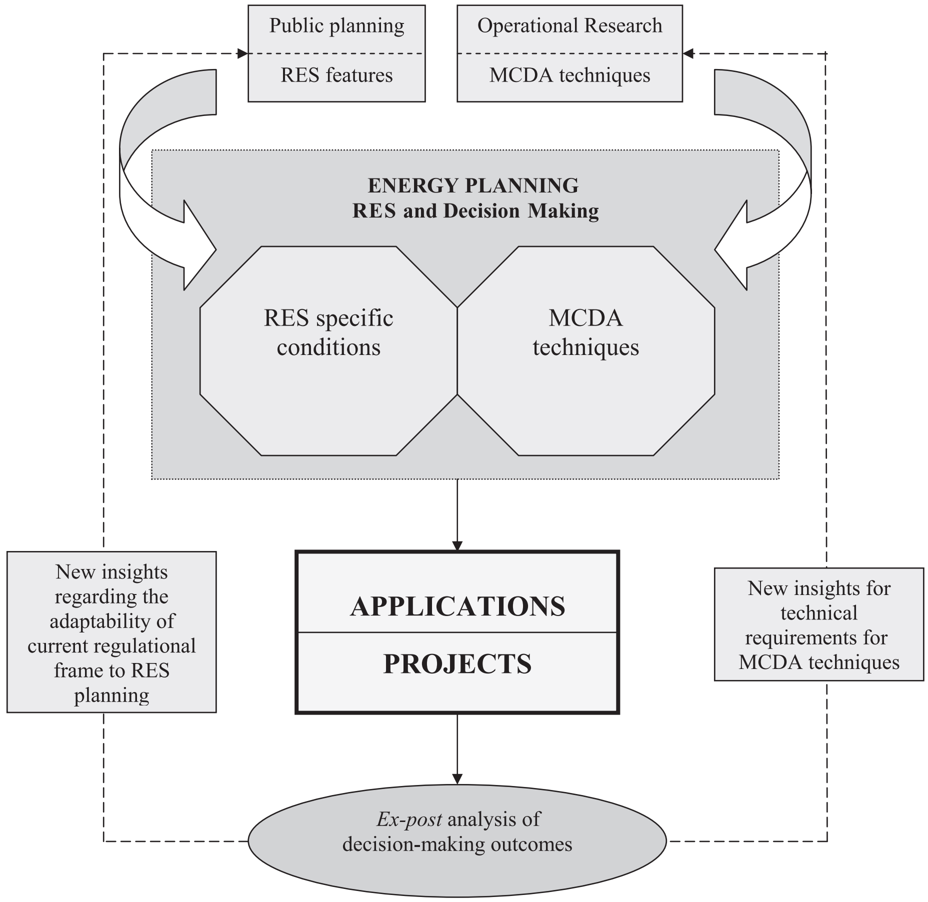

Figure 3. MCDA techniques for RES planning.

Multi-Criteria Decision Analysis in Renewable Energy Source Projects: Important Parameters

Next, a conceptual frame for articulating guiding principles to choose an MCDA method for RES projects can be formulated. It includes a multitude of aspects like:

- the operationalization of the *sustainability issue*,
- the modeling of DM's preferences,
- various technical features,
- the treatment of uncertainty, and
- several practical considerations.

The Sustainability Issue

Renewable energy planning constitutes a part of the wider issue of environmental policy focused on energy supply. As such, it has to address the general notion of sustainable development, meaning that it has to search for compromises between the diverse spheres of the economy, society, environment, and availability of resources.

The different methodologies display a diverse attitude toward the inclusion of strong or weak sustainability when deciding which RES project to be promoted. According to the degree of compensation allowed, weak or strong sustainability concepts can be operationalized. Figure 4 shows the gradual evolution of MCDA techniques regarding the compensability issue and the sustainability concept. Perhaps future techniques will be developed around these issues.

Clearly Cost-Benefit Analysis (CBA) imposes complete compensation between different criteria. This means that a relatively good performance of an action to one criterion can totally offset a relatively bad performance on some other criteria. Subsequently, a weak sustainability concept is omitted. For example, a project that displays good economic profitability for the developer could compensate for its severe ecological disturbance (e.g., a big hydro plan). The SAW method is merely a weighted CBA. Trade-offs between the different attributes are totally allowed, yet the rate of compensation depends on the weights of the corresponding criteria. This approach entails the existence of partial value functions for the criteria, although they are not explicitly stated. MAUT methods, with linear additive value functions, permit trade-offs between the different dimensions. The partial value functions for every decision criteria are explicitly stated. In fact, the analyst's responsibility is to reveal exactly these utility functions of each DM.

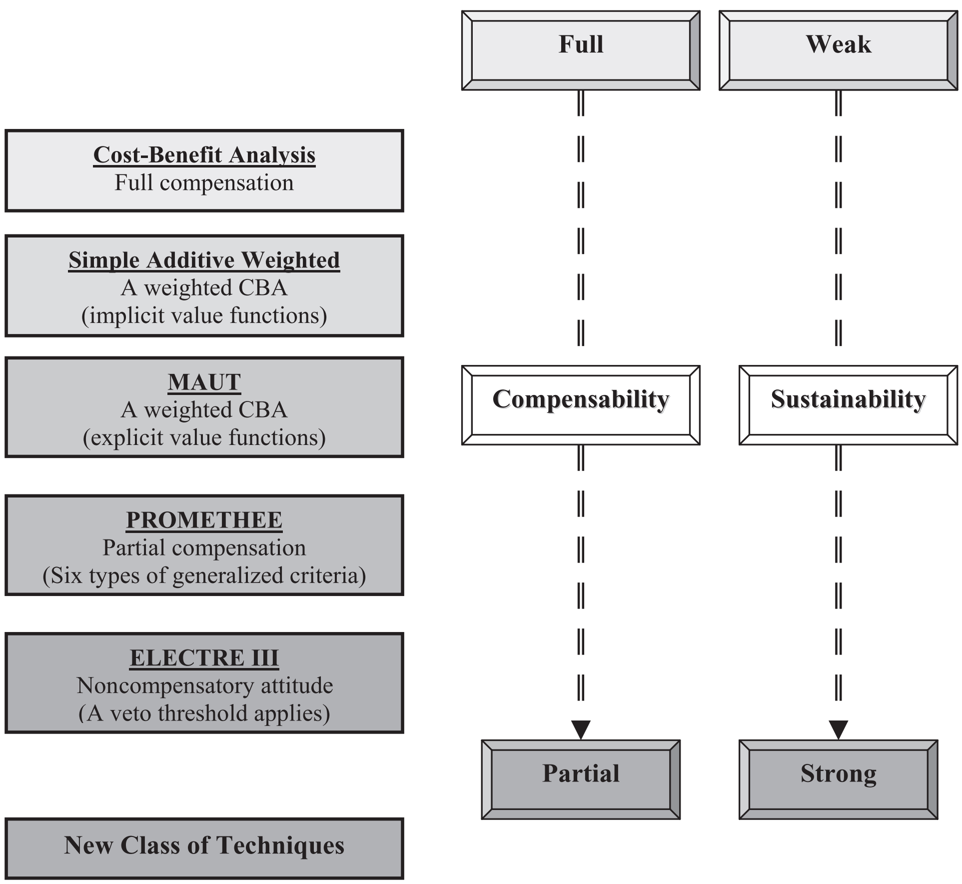

Figure 4. MCDA models facing compensability and sustainability.

Outranking methods typically do not authorize for complete compensation between different dimensions. The use of veto thresholds in the analysis explicitly limits the compensation between criteria, and indifference and preference thresholds do not render all differences between the criteria accountable for the overall ranking. By these means, a strong sustainability notion can be realized.

The adoption of the strong or weak sustainability notion has important consequences for RES planning. If we accept that there exist some ecological thresholds that cannot be exceeded, then we have to apply a decision-making method that operationalizes the strong sustainability concept. This is usually the case with areas that are about to host RES projects (remote mountainous areas with wild life and rich flora). Therefore, the inclusion of noncompensatory or partial compensatory methods seems to be a wiser approach for energy and environmental decision making.

Modeling Decision-Maker's Preference

In most multicriteria methods, a numerical value is assigned to each criterion expressing its relative importance. This reflects the corresponding criterion weight. The analysis of weights and their interpretation completely depends on the selected decision model.

Utility-based methods aim to establish an overall utility function that represents best the DM's preferences. This approach does not accept that there may exist good reasons to justify incomparability or the hesitation of preference between two alternatives. The estimation of weights is equivalent to that of substitution rates between the criteria. The DM has to provide answers to questions like "What is the gain with respect to one attribute allowing to compensate loss with respect to another?" and not in terms of "importance" of attributes.

In the outranking methods, because of their noncompensatory nature, the interpretation of weights is different than for a compensatory system such as MAUT. The weights used are not constants of scale, putting the different criteria values into the same measurements, but are simply a measure of the relative importance of criteria involved. The weight of a criterion could be linked with the number of votes given to a candidate in a voting procedure. However, in the PROMETHEE methods, weights can be seen more as trade-offs between criteria and not as coefficients of importance (Munda, 2003).

In renewable energy planning and decision-making, one is seldom able to use multicriteria methods requiring trade-offs from the DMs. They usually feel uncomfortable to provide explicit rates of compensation between, the criteria and they do not have sufficient time to devote to this procedure. Moreover, it is extremely expensive and time consuming for weights of criteria to be confirmed by consistency checks or by applying different procedures in the elicitation exercise. Therefore, it is desirable to use weights as importance coefficients—votes for the evaluation criteria. Of course, there always exists the option of no weighting for the criteria such as in the ELECTRE IV and NAIADE methods. However, it should be noted that the selection of a particular weighting scheme may have important ethical consequences (Munda, 2003).

Technical Features

Technical features can be divided according to three criteria: *input capabilities*, *the interaction with the method*, and the *hierarchy of scale* issue.

The *input capabilities* of the method concern the type of data accepted (required) by the decision model, i.e., the ability to handle both quantitative and qualitative information. In renewable energy decision-making problems, the information is usually of a mixed type; the economic criteria, for example, can usually be measured on a cardinal scale, while the environmental criteria on an ordinal one (aesthetic degradation, change in land use and rural lifestyle, global biodiversity effects, etc.). It is therefore prudent to use methods that can hold mixed information like the families of ELECTRE and PROMETHEE, the NAIADE, Regime Method, and Flag Model.

The *interaction with the method* reflects the number and/or nature of parameters that the DM has to assess in order to familiarize herself with the model. ELECTRE techniques demand the estimation of thresholds (three kinds in the general case) and weights. Moreover, the veto threshold is occasionally connected with the corresponding criterion weight (Rogers and Bruen, 1998). These factors however, sometimes help the DM to understand fully the problem and form his preferences consistently. Nevertheless, these features represent some abstract meaning. By those means, it seems that the PROMETHEE methods exhibit an advantage since the parameters needed have some concrete meaning for the DM.

Furthermore, it is thought that the explicit consideration of a *hierarchy-of-scale* issue is an attractive property for a MCDA technique that is used in an RES context. That familiarizes the DM with the different priorities from the early steps of the decision-making procedure. Therefore, she can have a better understanding of the value problems at hand. The only method, which explicitly deals with the hierarchy issue, is the AHP.

Uncertainty Treatment

In methods based on the utility function, the treatment of uncertainty is held using intervals or stochastic distributions. However, traditional probability theories work rather well only in the cases of *weak uncertainty*. It seems, though, that in the context of environmental problems, data are too imprecise and/or uncertain that probability distributions do not apply. Moreover, there exists no historical patterns for global environmental problems. Thus, it is not advisable to construct probability distributions for handling this kind of ambiguity. The concept of probability does not apply because we are not dealing with a stationary state being discovered; rather, the ecological-social-economic histories are being made and understood in time (Faucheux and Froger, 1995). This is considered another drawback of the utility-based methodologies, in the case of energy and environmental decision making.

On the other hand, in outranking approaches, the inaccuracy of criteria values can be modeled through indifference and preference thresholds. These intervals not only try to model the DM's preferences but also capture the uncertainty of data between them. Of course, threshold values must be assessed separately for each criterion and problem. It seems that this approach is better suited for energy and environmental problems.

Practical Considerations

There are some practical requirements for an MCDA method to be used in public (renewable) energy and environmental issues. They include:

- the ease of use,
- the ability to support a large number of DMs,
- the capacity to handle many criteria and alternatives,
- the ability to handle inaccurate or uncertain criteria (e.g., in RES projects, some of the information required is rather qualitative and other is just uncertain, like

the future unfolding of the liberalization in the EU and its effects upon prices and subsidies),
- low requirements on time and money, and
- the direct interpretation of parameters.

It is very difficult for any technique to satisfy concurrently all the previously discussed requirements. Nevertheless, the large number of DMs, alternatives, and criteria in public (renewable) energy and environmental problems is usually the norm. Moreover, the analysts often do not have enough time and/or economic resources to assess partial utility functions or perform pairwise comparisons of all alternatives and criteria with every DM. This leaves the MAUT and the AHP methodologies with a big disadvantage.

Additionally, the intangibles present in environmental issues impose severe obscurities to the DMs in their attempt to compare directly the significance of extremely dissimilar criteria. For example, specifying a tradeoff ratio between landscape degradation and employment may just be too hard to be defined. This is also a big drawback for the MAUT family.

Ease of use is also an important attribute for an MCDA technique to be used in RES decision making. The people who are going to use the method are not, in most cases, experts. They may feel being manipulated by a "black-box" methodology when they are unable to understand the way that the techniques operate. PROMETHEE seems then slightly easier to use than ELECTRE and AHP (Al-Shemmeri et al., 1997).

Usually an MCDA method requires that some parameters need to be set up. These factors, depending on the methodology applied, could be weights, thresholds, aspiration-reservation levels, etc. In some cases, these parameters have some concrete meaning while in others they are largely abstract notions. For example, in the PROMETHEE methods, the thresholds have some actual meaning for the DM, while the weights do not. This is also the case with AHP and the ELECTRE methods, which do not carry an axiomatic foundation of their weight attributes. However, in the MAUT case, the weights have a clear meaning as trade-offs between the criteria.

A Comparative Evaluation of MCDA Techniques for RES

In Table 2, MCDA methods are juxtaposed with their necessary identified attributes. The scale "+++/−−−" is ordinal in nature ("+" is more desirable than "−," "+++" is more desirable than "+" and "−−−" is less desirable than "−") and reflects the previous discussion and experience gained from our direct involvement in a number of real case studies (Munda et al., 1998; Polatidis and Haralambopoulos, 2003; Vreeker et al., 2002).

Table 2 demonstrates clearly a very important fact, i.e. there is *not one method* that can perform superiorly to all identified attributes. This leads to the main conclusion that the most important criteria must first be identified, and then appropriate methods should be chosen. Overall, ELECTRE III, NAIADE, Regime Method, and PROMETHEE II seem to perform better for the issue at hand.

Conclusions

In this work, a variety of decision analysis techniques for renewable energy projects was examined. Outranking methods including NAIADE and Regime Method were identified as a set of techniques better suited to the integrated appraisal of such complex projects. This is based on the fact that these techniques permit a general ordering of the

Table 2
Comparison of multicriteria techniques in the context of renewable energy problems

Attributes	Modelling DM's preference Weights as trade-offs Weights as importance coefficients	Strong–weak sustainability concept Compensability	Theoretical and technical features Input capabilities Interaction with the method Hierarchy consideration	Uncertainty treatment Probability distributions Fuzzy sets Thresholds	Practical requirements Ease of use Number of parameters to be estimated Interpretation of parameters Support a large number of DMs Support a large number of alternatives, criteria Time and resources needed
MCDA techniques					
MAUT	−−−	−−−	++	+	++
ELECTRE I	+++	+	+	−−	++
ELECTRE II	+	++	+	+	+
ELECTRE III	+	++	+	++	++
ELECTRE IV	−	++	+	+	+++
ELECTRE TRI	+	++	+	+	++
PROMETHEE I	+	+	+	++	++
PROMETHEE II	+	+	+	+	+++
Regime Method	+	+	+	++	++
AHP	−−−	−	++	+	+
NAIADE	−	+	+	+++	++
Flag Model	−	++	+	+	+++
SMAA	−	−	++	+	++
SMART	−−−	−	+	+	++
LEXICOGRAPHIC	−	−−	++	−	+++

alternatives while allowing individual pairs of options to remain uncompared when there is insufficient information to distinguish between them. In contrast, any additive method, such as MAUT or AHP, which generates a single score for each alternative, requires that all options be directly comparable with each other even when such comparisons are questionable because of lack of suitable data.

The main characteristics of RES and the particularities they impose on the relevant decision-making process have been revealed. In addition, the special technical features that an MCDA technique addresses were identified. There are multicriteria methods that fulfill *some* of these features, yet *none can satisfy them all*. In particular, the time dimension of energy planning and RES decision making has not found yet an operational representation in an MCDA technique. The normal period for a rolling time schedule is in the five-year range, during which criteria, weights, environmental pressures, priorities, etc., may change considerably.

Moreover, MCDA methods should be updated and adjusted to handle the ongoing complexity of energy and environmental policy. The *ex-post* analysis of real applications can provide an impetus towards the realization of specific amendments and/or new technical modes to be included in MCDA techniques. A new fine tuning of the outranking techniques could be the insertion of the so-called *belief functions* to model the DM's preference for environmental criteria as a way to integrate the precautionary principle in RES decision making.

The specific aspects that need be addressed by an MCDA technique for RES decision making are summarized as follows:

- the operationalization of the sustainability issue,
- the modeling of DM's preferences,
- the multitude of technical features,
- the treatment of the uncertainty, and
- the consideration of practical aspects.

The authors have tried to analyze further the previously discussed elements and to provide a decomposed approach in which the relative attitude of MCDA techniques towards these features is scrutinized. Since there are no better or worse MCDA methods, it is the overall framework of the energy-environment-economy interactions that is going to influence the evaluation process. Therefore, several MCDA methods are analyzed and ranked following their performance on a number of criteria. The final identification and the selection of the most suitable method was deduced from the relevant qualifications and shortcomings of each candidate scheme.

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