

An appropriate multiple criteria decision making method for solving electricity planning problems, addressing sustainability issue

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ABSTRACT: In the past, decision making within the energy sector, especially in Iran, was limited to economic analysis. Lately, multiple criteria decision making has gained great popularity. However, this is not enough to make a right decision by considering sustainability. This paper deals with designing an appropriate multiple criteria decision making method to address the multifaceted nature of such problems. This task is the second precondition to make a decision which meets the sustainability criterion. This is done by revealing new facts about quantitative and qualitative data and the degree of compensation between the criteria. Moreover, this paper illustrates the capability of different methods with regard to sustainable energy planning and management in two steps: 1) comparison of two main approaches in the strategic energy planning context; 2) evaluation of multi attribute decision making methods and combining them. Combining four methods including Analytical hierarchy process, Preference ranking organization method for enrichment evaluation II, geometric mean and weighted sum seems to result in designing an appropriate method which meets the sustainability criterion. These contributions are proposed for comparing the renewable energy technologies with non-renewable ones. Nevertheless, these seem to be applicable in any comparison between discrete alternatives in the energy sector.

Keywords: Analytical hierarchy process; Compensation; Decision analysis; Preference ranking organization method for enrichment evaluation II; Qualitative and quantitative data

INTRODUCTION

Nowadays, the important role of energy in improving welfare is undeniable as a strategic asset. This topic is a multifaceted and very complex matter. Existence of numerous structural (systems components) and procedural (systems functions) factors and their relations and dynamism cause such a complexity. From a structural point of view, an energy system is a combination of different subsystems with numerous actors within them. As an example, renewable energies are just a subsystem of the energy system, in which diverse actors, in public, university and business sectors, could be identified (Karapidakis *et al.*, 2010). One can understand this complexity from a process oriented point of view. As an example, Research and Development, resource mobilization and market formation are just some illustrations of essential processes in these systems. Moreover, these

processes have many sub-processes. On one hand, analysis of energy systems is impossible without restraining their complexity. On the other hand, making a right decision about a system is impossible without analyzing that system. Thus, using a rational procedure in taking a right picture of reality, then restraining complexity and as a consequence, making the right decision about the modeled system is necessary.

Analyzing every system depends on the purpose of analysis. Therefore, one can use different methods to solve a problem, based on its nature. There are various problems with varying dimensions in the energy context. Some examples of these problems are capacity expansion planning, transmission and distribution network planning, load management and comparison of electricity generation technologies. These problems, as a part of all problems in the energy context, have different facets and varying degrees of importance.

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In fact, deciding about each of them has a different level of impact on the energy system; some of them having a short time span and others having longer. Thus, one can classify energy related problems with respect to their effective time span. [Hobbs \(1995\)](#) introduces such a classification, in which energy related problems are classified into short-term, mid-term and long-term problems. Long-term problems usually last more than ten years. Thus, decision making for such problems is a part of strategic planning ([Tuzkaya, 2009](#); [Tuzkaya et al., 2009](#)). Mid-term problems are related to issues which are defined along several years or months like operational planning or designing power system plans with respect to existing facilities. When the time horizon is limited to several weeks or minutes, short-term planning is relevant. Such problems are related to minimization of operational costs. The longer the time span of a problem, the more complex it is and the larger is its scope.

The problem discussed in this paper is considered within the context of energy, specifically the context of electricity planning. This problem is related to deciding whether or not to make a significant investment in electricity generation from wind energy resources by the Iranian government. This is a sustainable alternative to develop the energy system. There are two approaches to answer this question:

- To compare the condition in which the government invests in the wind sector with the condition in which the government does not make such an investment;
- To compare electricity generation from wind energy resources with electricity generation from other competing resources.

The second approach seems to be more appropriate for answering the question, because even if the investment was feasible, there might be more profitable options to invest in. In other words, investment in the wind sector may divest Iran of some advantages. Therefore, the primal question could be refined and be rewritten as: what is the position of electricity generation from wind in comparison to other resources? Based on this refinement, the existing problem falls into an appraisal class with respect to specific purpose of energy problems ([Table 2](#)).

Actually, Iran, like any other country, faces the resource limitation problem. Moreover, this problem is very important, as Iran is a developing country. Also, it is obvious that decision making about government

investment in a subsystem of the energy sector has long-term effects on its energy system. Thus, this decision making problem falls into the category of long-term problems which increases the importance of the problem. This means that a right or wrong decision may lead to many advantages or disadvantages for Iran. This reasoning is justification of using a rational, clear and understandable decision making procedure.

To compare wind energy with other alternatives, it is necessary to see the problem from different points of view. In other words, considering different aspects is necessary for right decision making, which leads to sustainable development. The United Nations' World Commission on Environment and Development (WCED) defined sustainable development as: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" ([WEC, 1986](#); [WCED, 1987](#)). This concept is a multifaceted one, including environmental aspects in addition to economical, social and cultural ones. With sustainability in mind, making a decision necessitates including different criteria in decision making process. Thus, using a multiple criteria evaluation of alternatives can offer significant contribution towards sustainable development of energy sector ([Georgopoulou et al., 1997](#); [Afgan et al., 2000](#); [Zhou et al., 2006](#)). Moreover, such techniques are gaining popularity in sustainable energy management ([Huang et al., 1995](#); [Pohekar and Ramachandran, 2004](#)). There are two preconditions to make a decision which meets sustainability criterion:

- To define a set of sustainability indicators ([Afgan and Carvalho, 2002](#));
- To design an appropriate approach which results in choosing a sustainable alternative ([Polatidis et al., 2006](#))

There are numerous studies dealing with indicator definition, proposing guidelines and algorithms to choose a decision making method. However, few studies put effort into designing a method with sustainability considerations. Designing such a method is an important task, as the importance of environmental problems has risen owing to the green revolution ([Chien and Shih 2007](#); [Huang and Shih, 2009](#); [Tehrani et al., 2009](#); [2010](#)). It is the aim of this paper to design a method for Multiple criteria decision making (MCDM) with sustainability consideration. This is done based on illustrating some facts about the nature of qualitative

and quantitative data. This paper is the result of a research conducted in 2010 to provide a methodology for deciding on investment in the wind sector by the Iranian government.

This problem can be identified as a part of the Strategic energy planning and management (SEPM) procedure (section 2). To design an appropriate method, a two-leveled approach is introduced. At the first level, different approaches that may meet the problem are identified and compared with each other. In this paper, two approaches are identified: Energy planning (EP) and its models and Multiple attribute decision making (MADM). These two bodies of literature play an important role in solving energy related problems. After comparing these two approaches and choosing the more appropriate one, an appropriate method of the selected approach is designed to solve the problem. Finally, some concluding remarks are presented.

MATERIALS AND METHODS

Strategic energy planning and management

UN (2002) defines SEPM as “an approach by which Governments (and stakeholders) take a long-term view of trends in natural resource use and environmental and social quality (described as the ‘vision’), identify the changes necessary to bring these trends within sustainable limits and to establish a management

framework to encourage key groups in society to achieve these goals”. Thus, this approach consists of vision establishment with respect to sustainable development, designing strategies to meet the objectives and formulation of operational plans.

This approach is useful for determination of government strategies at macro levels in the energy sector and translating these strategies to operational plans. Thus, the Iranian government’s decision about considering a significant share of energy supply for wind energy will have an extensive effect on its strategies in the energy sector.

This approach is a process which consists of different steps (Fig. 1). The UN (2002) gives some guidelines in 8 topics related to these steps (Table 1). Decision making about investment in the wind sector by the Iranian government is a strategy of the energy sector. Therefore, this problem can be defined in the fifth step in the following table. To solve this problem, it is common to employ two approaches, including EP and MADM. To find the more appropriate approach it is necessary to compare these approaches. Thus, in the third and forth sections of this paper, these two approaches are briefly introduced. Based on presented discussions, section 5 deals with comparing these approaches as a tool for formulating a strategy (step 5 in Table 1).

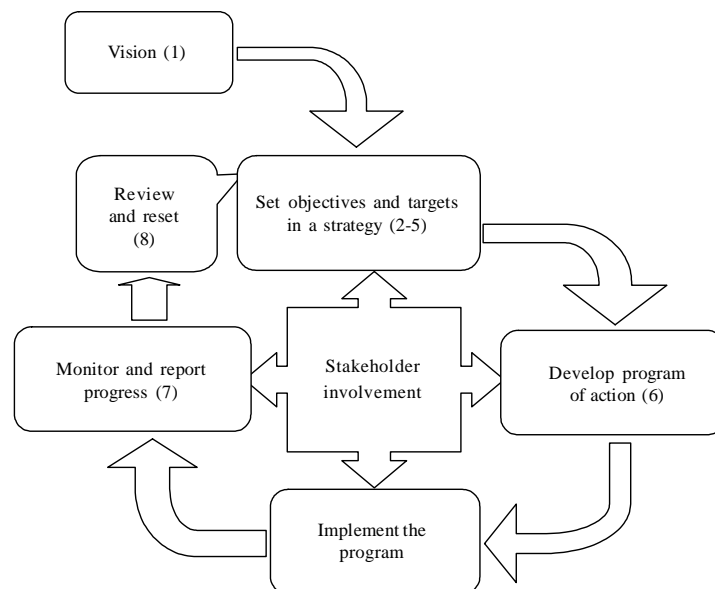


Fig. 1. Strategic energy planning and management approach (UN, 2002)

Table 1: Guidelines for using strategic energy planning and management approach (UN, 2002)

Code	Name	Remarks	Related step in SEPM approach
1	Vision	Define an optimistic, realistic and long-term goal which is not limited to the energy sector.	Vision
2	Driving forces	Identify macro trends affecting the energy sector, which may or may not be controllable.	Set objectives and targets in a strategy
3	Identifying the baseline	Identify system's situation at the beginning of the planning process.	Set objectives and targets in a strategy
4	Developing scenarios	Identify different probable conditions during development.	Set objectives and targets in a strategy
5	Formulating a strategy	Translate vision into goals, objectives and strategies of the energy system.	Set objectives and targets in a strategy
6	Formulating an action plan	Translate objectives and strategies into targets and activities.	Develop program of action
7	Monitoring progress and evaluation	Develop a monitoring system to develop confidence about meeting goals at the right time, using different methods like defining a set of indicators.	Monitor and report progress
8	Adjusting to new information	Identify changes in the system due to implemented plans and other factors to repeat the process.	Review and reset

Energy planning

EP at the energy sector level can be defined as a set of activities which find "a set of sources and conversion devices so as to meet the energy requirements / demands of all the tasks in an optimal manner" (Hiremath *et al.*, 2007). Thus EP is about coordinated planning of different stages of the energy supply chain. Thery and Zarate (2009) split the supply chain into three parts based on states of energy:

- Primary energy which has not yet entered the conversion process,
- Distributed energy or energy carrier which is the result of the energy conversion process, but is not yet in the desired form to be used by the consumer, and
- Delivered energy which can be used directly by the consumer.

Due to complexity of energy systems, using computers to analyze these systems is inevitable. Using computer's computational power, it is possible to include a large amount of data and information in the analysis. Therefore many EP models have been developed in recent years. The quantity and quality (degree of adjustment to the reality) of these models have increased as computers' by computational power increase. Although there are various forms of EP models, one can figure out their general structure. For a better understanding of EP models, one can classify them from different points of view. Different classifications have been proposed by various authors.

Among others, Pandey (2002); Schrattenholzer (2005); Jebaraj and Iniyar (2006); Hiremath *et al.* (2007); van Beeck (1999) have proposed different classifications of such models. van Beeck (1999) reviewed different classifications and described attributes of famous EP models according to these classifications. Table 2 summarizes a part of classifications proposed in the literature.

With respect to Table 2, in the refined question:

- Alternatives appraisal is the aim of the problem,
- with low degree of endogenization, low extent of the description of non-energy sector components and low extent of the description of energy end-uses; but high extent of the description of energy supply technologies,
- top-down analytical approach,
- multi-criteria methodology,
- at the national level and in the energy sector,
- for a long time span and
- using quantitative as well as qualitative data at an aggregated level.

Multiple attribute decision making

Decision making is choosing among alternatives. Varieties of methods have been developed to analyze decision making so far. A subset of these, named multiple criteria methods, is about incorporating different aspects of alternatives into the decision making problem. These methods, among other

Table 2: Energy models classification from different points of view (van Beeck, 1999)

Criterion	Sub criteria	Classes	Explanation	References
Purposes	General purposes	Forecasting	"To predict the future"	Hourcade <i>et al.</i> (1996)
		Scenario analysis	"To explore the future"	van Beeck (1999)
		Backcasting	"To look back from the future to the present"	
	Specific purposes	Energy demand analysis	"Focusing on demand as a function of changes in population, income, and energy prices"	van Beeck (1999)
		Energy supply analysis	"Focusing on technical (and perhaps financial) aspects of energy supply"	
		Impact analysis	"Analyzing impacts of using certain energy systems or enacting certain policy measures"	
		Appraisal	Comparing several options	
Structure	Degree of endogenization	A range from low to high	Incorporating parameters within the model equations as much as possible	Hourcade <i>et al.</i> (1996) van Beeck (1999)
	Extent of the description of non-energy sector components	A range from low to high	"Including investment, trade, consumption of non-energy goods and services, income distribution, and so on."	
	Extent of the description of energy end-uses extent of the description of energy supply technologies	A range from low to high		
		A range from low to high		
Analytical approach	Top-down		Can only be used "if historical development patterns and relationships among key underlying variables hold constant for the projection period"	Grubb <i>et al.</i> (1993) Hourcade <i>et al.</i> (1996) van Beeck (1999)
		Bottom-up	Are suited only "if there are no important feedbacks between the structural evolution of a particular sector in a strategy and the overall development pattern"	
	Econometric		"Applying statistical methods to extrapolate past market behavior into the future"	Berrie <i>et al.</i> (1985); Grubb <i>et al.</i> (1993); Hourcade <i>et al.</i> (1996); Kleinpeter (1995)
Underlying methodology	Macro-Economic		"Focusing on the entire economy of a society and on the interaction between the sectors"	World Energy Conference (1986)
	Economic equilibrium		"Focusing on the energy sector and its relations with the rest of the economy"	van Beeck (1999)
	Optimization		"Optimizing decisions for energy investment in the energy sector"	
	Simulation		"Reproducing a simplified operation of the system"	
	Multi-criteria		"Including other criteria than just economic criteria"	
Mathematical approach	Linear programming		With linear equations and continuous variables	Kleinpeter (1995) van Beeck (1999)
	Mixed integer programming		With linear equations and continuous or integer variables	
	Dynamic programming		Optimizing through splitting the problem into different stages	
Geographical coverage Sectoral coverage		Global, regional, national, local, or project uni-sectoral or multi-sectoral		van Beeck (1999) van Beeck (1999) Grubb <i>et al.</i> (1993) Thery and Zarate (2009) van Beeck (1999)
Time Horizon		Short, medium, and long-term		van Beeck (1999)
Data Requirements	Dependence on experts Level of aggregation	Quantitative (independent) or qualitative (dependent) aggregated or detailed		van Beeck (1999)

decision supporting systems and single objective decision making, form the decision analysis methods (Zhou *et al.*, 2006). MCDM methods can be grouped into two sets, based on their possible solutions:

- Discrete solutions: MADM
- Continuous solutions: Multi Objective Decision Making (MODM)

Generally, MADM methods are about comparing several discrete alternatives with respect to independent criteria. Therefore, assessment of alternatives with respect to each criterion and relative importance of criteria (or some information about it) are main inputs of these methods, while the output is evaluation of alternatives based on the criteria. MADM methods have the power of indentifying the structure of complex decision making problems and elucidating decision makers' preferences. These methods are also understandable and reliable for the decision makers. Having these features, MADM methods are being used more and more by analysts.

Haralambopoulos and Polatidis (2003); Linkov *et al.* (2004); Pohekar and Ramachandran (2004) and Wang *et al.* (2009) among others, introduced the MADM process. Summing up these studies, one can propose an MADM process. Table 3 contains some explanations about the MADM process.

Comparing approaches

In this section, similarities and differences between EP and MADM are discussed from three aspects which influence the proper approach selection. These aspects can be named as:

- Goals: Represent the purpose of using an approach. Based on the goal of the problem, one or more approaches can be used.
- Methodology: Describes underlying methodology of each approach.
- Extent: Includes level of analysis in each approach, and aspects that can be incorporated into the analysis by approach (inclusiveness).

A more detailed description of each aspect and comparing approaches with respect to them, is the subject of the remainder of this section.

Comparing approaches with respect to goals

The goal represents the purpose of using an approach. On one hand, a goal is sought to be reached by solving any problem. On the other hand, each approach is used to reach a goal. Thus, an approach whose goal is compatible with the problem's goal must be used. Some EP models seek to find optimum shares in energy supply in different regions based on the demand for a long time. Consequently, these models

Table 3: Steps in MADM

Stage	Step	Explanations
Problem's structure articulation	Precise definition of problem	Identifying problem causes, studying system boundaries, presumptions and stakeholders
	Identifying alternatives' requirements	Identifying minimum requirements which are expected from alternatives
	Setting goals	Identifying points which are desired to be achieved
	Identifying alternatives	Identifying options which are not in contradiction with problem definition, have minimum expected requirements and are close to goals as much as possible
	Identifying criteria	Identifying aspects which distinguish alternatives with respect to the goals
Decision making implementation	Selecting the appropriate decision making method	Knowing how different the methods work and choosing the one that is compatible with the problem's presumptions and goals, DM's preference and the one having the maximum complementary features
	Articulation of DM's preferences	Translating DM's preference into mathematical relations
	Using MADM method for evaluation	Feeding model with gathered data and obtaining output
	Implementing sensitivity analysis	Identifying the range in which by changing input data, output remains constant

determine the optimum share of each energy resource in energy supply, using quantitative criteria. Therefore, these models do planning based on some presumptions (such as previous decisions and policy measures).

MADM methods are used to compare different alternatives, using quantitative and qualitative criteria. Usually, an ordered set of alternatives is the output of such models. Using this approach, one can choose, rank, describe or sort a set of alternatives, considering different aspects. MADM involves general methods which can be used in different applications including the energy sector. Roy (1975, 1996, 2005) names four problematic issues for these methods: 1) Description, 2) Choice, 3) Sorting and 4) Ranking.

The aim of the present task is to study wind power justification by comparing it with other available power supply options. Therefore, the issue demands determining the position of wind power in relation with other independent options. Several points must be considered in this comparison. Some of these include economic, environmental and social security considerations. Focusing on these comparisons means to compare options in line with sustainable development in Iran. As it is clear in the task aim, the purpose of this study is not to determine the optimum flow of energy supply in different regions or to determine shares of different supply options. Rather, the qualitative and quantitative data are used together to solve this problem. Seemingly, MADM's goals match with the problem's goals. In addition, the EP approach (depending on the method used) can be used to answer questions other than questions related to the problem.

Comparing approaches with respect to methodology

The methodology used in each approach includes techniques that are used in it. Moreover, any technique uses a particular type of data. For example, some techniques use quantitative data; some other use qualitative data and some of them use a combination of them.

EP uses multi-objective decision making methods, such as linear and nonlinear programming to achieve its goals. These methods interact with continuous spaces. Most studies conducted in this context are based on complicated mathematical models and powerful decision support system software (Ferreira, 2007). As a result of extensive use of mathematical formalism, too much simplifying assumptions are incorporated in such methods.

The MADM approach does not describe objectives and constraints in the form of mathematical functions. It identifies characteristics of a limited set of alternatives to evaluate them and compare them with each other. The main power of these models is their ability in structuring issues that have been defined with ambiguity (Dialoulaki *et al.*, 2005). In this way, these methods provide a deep insight into alternatives. Part of planning in the energy context can be done based on the MADM approach to compare alternatives in this context, such as scenarios, strategies, technologies and so on (Ferreira, 2007). Then, proposed options are characterized by a set of criteria in different ways to aggregate all data. This approach often needs the participation of stakeholders and decision makers (DMs) in the weight assignment process, DM's preference elucidation and tradeoffs. Models used in this approach are able to offer options' characteristics to DMs. These points lead to a more transparent decision making process than when complex mathematical functions are used.

In the raised issue, it is not desired to use sophisticated mathematical techniques to solve the problem. Moreover, the most important advantage in using an approach is that it helps to structure the issue in order to understand the features of the alternatives. Besides, it is not reasonable to compare different options, using just quantitative data.

In conclusion, methodologies used in the energy planning approach deal with continuous spaces; while in the present matter, the answer space is discrete. Moreover, this approach typically uses sophisticated mathematical models, in which the development and validation for a country consumes much time and cost. The MADM approach identifies issues related to alternatives and characterizes them. This way, DMs (and stakeholders) can systematically compare alternatives. Therefore, methods used in the MADM approach are in compliance with conditions of the problem.

Comparing approaches with respect to extent

The extent of approaches is comparable from two perspectives. These two perspectives are the level of analysis and inclusiveness of each approach. In order to understand the concept of level, a hierarchy can be imagined (Fig. 2). In a hierarchy, by moving towards higher levels, more macro issues will be raised. In addition, by moving towards higher levels, issues'

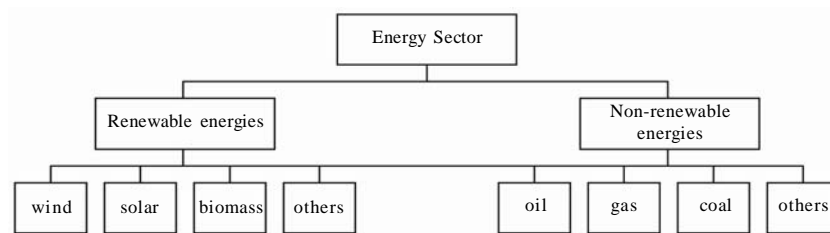


Fig. 2: A hierarchy in the energy sector

details will be reduced. Otherwise, the complexity of the subject will be increased. Inclusiveness means different aspects of the subject are incorporated. For example, some approaches have the ability of involving political considerations. In this example, the political considerations are one aspect to analyze the subject (along with other considerations such as economic, environmental and social).

Energy planning (depending on the aim of the model used) deals with the country's energy sector as a whole (renewable and nonrenewable) and its various parts (supply, carrier and so on). First, some models, focusing on one sector (e.g. electricity only) were developed and then more complex models were created. Also, in order to achieve EP targets, some considerations, such as demand growth rate and differences between different regions of the country are noted. However, some considerations in the context of EP gain little attention by EP models or are even missed.

The MADM approach performs decision making based on type and purpose of the problem (both at macro level and at lower levels). Due to the ability of this approach in solving specific types of problems (multiple criteria decision making in discrete spaces), some considerations raised in this approach are different from considerations raised by other approaches and other considerations that are common. For example, electricity demand growth and diversity of various geographic areas in supply and demand are not considered in MADM, since this approach is suitable for comparison and is not used for determining shares.

The raised issue is a relatively macro problem in the energy sector and needs meso level data (neither detailed data nor aggregated data) to be included in evaluating alternatives. Moreover, it is desired to consider different aspects (as much as possible) in

comparing alternatives. With respect to this aim, EP models are not compatible with the problem's requirements.

Proper approach

Based on comparing approaches from the three mentioned point of view, the MADM approach seems to be qualified for being used in the planning process. It is worth to mention that if the problem requires determining shares of energy supply alternatives, the EP approach would be more appropriate (again at the cost of missing some aspects). Therefore, MADM methods will continue to be studied in this paper.

RESULTS AND DISCUSSION

Appropriate MADM method

To design an appropriate MADM method, it is necessary to characterize the methods. Then, it will be possible to design an appropriate method with respect to the problem's conditions. Hence, in this section after characterizing most probable methods, the most suited one with problem conditions will be identified.

Generally, one can classify MADM methods into elementary and advanced. Elementary methods use a qualitative approach, while advanced methods use a quantitative approach in decision making. It must be noted that a qualitative approach means an approach with minimal mathematical operations, while a quantitative approach utilizes many more of such operations. Thereby, quantitative and qualitative terms are not relevant to input data. Table 4 includes a brief summary of each method.

On one hand, various MADM methods are being applied to the same data results in different outputs. On the other hand, each decision making method is suitable for some problem conditions. Therefore, based on the raised problem conditions, the most appropriate method must be chosen. As a consequence, a key question in every MADM problem is "what is the most

Table 4: Popular MADM methods

Type	Name	Summary	References
Elementary	Lexicography	First of all, alternatives are ranked with respect to the most important criterion. Then, alternatives in the same position are ranked with respect to the second most important criterion and this process goes on until alternatives are compared with respect to all criteria. Countries in Olympic Games are ranked based on numbers of gold, silver and bronze medals using this method.	Fishburn (1974, 1975)
	Pros and cons	A list of pros and cons is provided for each alternative. Then, an alternative which has more pros and less cons is chosen.	
	Maximin and maximax	The Maximin method is based on avoidance of bad performance as much as possible. Therefore, this method maximizes alternatives' minimum performance. Thus, an alternative whose weakest performance is better than other alternatives' weakest performance is chosen. The Maximax method uses a similar strategy, except that it maximizes the best performance.	Linkov <i>et al.</i> (2004)
	Conjunctive and disjunctive	First of all, a threshold value is determined for each criterion. Then, the conjunctive method removes alternatives which do not pass the threshold for all criteria. Also, the disjunctive method removes alternatives which do not pass the threshold for at least one criterion.	Linkov <i>et al.</i> (2004)
Advanced	(AHP)	Decision making begins by designing an analytical hierarchy tree. This hierarchy is a graphical representation of the real complex problem. On the top level, the problem's objective is mentioned while other levels are comprised of criteria and alternatives. Then in a bottom-up approach, DM(s) do a pairwise comparison for each factor in each level with respect to upper level factors. Different methods are introduced in literature to compute the final value of alternatives based on the Eigenvector.	Saaty (2000, 2005)
	(MAUT)	MAUT is a systematic method for identifying and analyzing several variables to provide a common basis for decision making. A key step in this method is characterizing a multi attribute utility function. To do this, identifying single attribute utility functions and their weights is necessary. Formulating a multi attribute utility function provides the possibility of computing each alternative's final value.	Dyer (2005)
	ELECTRE	This set of methods is based on a pairwise comparison and outranking relation. These methods, based on the chosen version, utilize preference, indifference and incomparable relations. An outranking relation is based on two basic concepts: "1) <i>Concordance</i> : For an outranking aSb to be validated, a <i>sufficient</i> majority of criteria should be in favor of this assertion. 2) <i>Non-discordance</i> : When the concordance condition holds, none of the criteria in the minority should oppose too strongly to the assertion aSb ."	Figueira <i>et al.</i> (2005); Roy (1990, 1991)
	PROMETHEE	In this set of methods, DMs' preference structure is articulated using a mathematical function based on the difference in values of alternatives. Then, based on distance between each pair of alternatives, their relative value is computed. The relative position of each alternative is characterized applying another mathematical function.	Brans <i>et al.</i> (1984, 1986); Brans and Mareschal (2005)
	Other methods	This set of methods includes QUALIFLEX, ORESTE, REGIME, ARGUS, EVAMIX, TACTIC and MELCHIOR methods. These methods, which implement the outranking concept, prevent DMs from quantification of qualitative values as much as possible. In these methods, alternatives are ranked or chosen utilizing a quantitative approach.	De Keyser and Peeters (1994); Martel and Matarazzo (2005); Paelinck (1976, 1977); Voogd (1982)

appropriate method for solving the problem?" Many models and methods have been developed in literature to answer this question. These models and methods focus on compatibility of MADM methods' objectives and attributes with the problem's objective and attributes. Some authors just introduce several guidelines for choosing a method as a part of the MADM process, while others focus on this subject. Reviewing studies done by both groups of authors provides a basis for designing an appropriate method of decision making.

Løken (2007) introduces validity of method (what it is supposed to measure) as the most important criteria in choosing an MCDM method for energy planning problems. Providing DMs with all the information they need, compatibility with the accessible data (appropriateness) and ease of use and understanding are also evaluated as important criteria by this author.

Polatidis *et al.* (2006) introduce prerequisites of the MADM methods and their justification. These prerequisites are the following capabilities: weight elicitation, using critical threshold values or veto, integrated comparability, handling qualitative and quantitative information, rigidity, handling group decision-making, graphical representation, ease of use, performing sensitivity analysis, incorporating a variety of alternatives and criteria, implementing consensus seeking procedures, incorporation of intangible aspects, incommensurability, treatment of uncertainty, allowing partial compensation, providing hierarchy of scale, providing concrete meaning for parameters used, acknowledging learning dimension and considering temporal aspects. It seems that some of these criteria are related to model input, some others are related to analytical processes and the rest of them are relevant to model output for DMs. This diversity in criteria somehow represents considering almost all aspects by these authors.

Guitouni and Martel (1998) mention several guidelines for choosing an appropriate MADM method. Their remarks are related to the following issues:

- Incorporating stakeholders in the decision making process
- Compatibility of method with DMs way of thinking
- Compatibility of method with desired problematic
- Ability of handling available data
- Compatibility of method with DMs expectations with respect to degree of compensation

- Compatibility with the problem's assumptions
- Existence of decision support system software

Deason (1984) introduces a set of descriptors of problem situation. Based on these descriptors an algorithm for choosing the appropriate method is proposed. Gershon (1981) proposes 27 criteria in order to choose the appropriate method. These criteria are classified into 4 groups which are named Mandatory binary criteria, Non-mandatory binary criteria, Technique dependent criteria and Application dependent criteria. Using these criteria, MADM methods are compared based on a distance metric.

Teale (1988) classifies 49 characteristics into four groups: describing the problem, describing the DM or analyst, describing the techniques, and describing the solution obtained. Teale (1988) also reviews and classifies 70 MADM methods. Due to the difficulty in evaluating all methods with respect to all the characteristics, this author evaluates 16 methods with respect to 24 characteristics.

As mentioned in previous sections, after defining the problem, identifying alternatives and criteria and characterizing the problem's objectives and condition, one can design the appropriate method. The previous subsection provided a picture in which different aspects of designing an appropriate method were included. This subsection represents efforts to design a well-suited method with raised problem, using gained insights. To do so, important aspects by which available methods must be compared are proposed based on reviewing the literature. Then, a well-matched method is identified.

It seems that the most important criterion in designing a method is its compatibility with the problem's objective. This criterion is explicitly mentioned in a set of criteria proposed by Guitouni and Martel (1998) and Løken (2007), while implicitly mentioned by other authors. In this paper, this criterion is defined based on the problematic concept. The raised problem in this study is justification of electricity generation from wind energy resources by comparing it with other alternatives. Wind energy is justified as it gains a winning position among others. To determine the relative position of wind energy, its rank needs to be identified. Therefore, the objective of this problem is to rank alternatives. Thereby, the designed method must have ranking problematic. Another requirement in the present problem is handling both quantitative and qualitative data. Almost all of the available methods

have the ability of accepting mixed data. This aspect is explicitly introduced by all reviewed studies. But there is a delicate point which is missed by authors. It is not sufficient to accept mixed data by a method to judge whether it is qualified or not. A relevant key question is "how does the method handle these data?" For more explanation, quality and quantity concepts must be described at first. A variable is called quantitative, if it can be measured by a reliable (without change) unit. So, different people have similar ideas about the amount of that variable (without considering error). Thus, quantitative variables are expert independent. An example is powerplant capacity. On the contrary, qualitative variables are expert dependent as it is impossible to define a reliable unit for them. Therefore, various people have different ideas about those variables. In such cases, analysts have no way to include such variables except to rely on expert opinion. A relevant example can be degree of political tension as a result of using a technology. In decision making problems, analysts try to transform qualitative variables into quantitative ones, using indicators. In some cases it is not possible to do so and some variables remain qualitative. As quantitative variables are measured based on units of measurement, it is possible to compute the distance between two alternatives with respect to quantitative criteria. But, it is not possible to compute the distance with respect to qualitative criteria due to lack of unit. For example, suppose that the capacity of powerplant A is 2000 MW and capacity of powerplant B is 1500 MW. Based on the unit of measurement one can say the capacity of powerplant A is 500 MW more than powerplant B. Now, assume that using technology A results in high tension but using technology B results in low tension. No one can say how much more tension is the result of using technology A instead of technology B. This is because there is no unit for measuring tension. Therefore, dealing with qualitative criteria, one can just tell approximately relative values of the two alternatives. To understand the result of this difference, the following example seems to be helpful.

A reality about the value of two options with respect to an aspect can be expressed in two ways. The first expression is "value of the first option is 2 and value of the second option is 4". The second expression is "value of the second option is twice greater than that of the first one". The first expression contains more data. The first type of expressions can be stated for

both quantitative and qualitative criteria, while it is impossible to use the second type for quantitative ones. Describing quality and quantity concepts helps to distinguish methods based on the way they deal with data. Relevance of this fact to designing an MADM method is the preference of DMs. As an explanation, it can be said that if DMs think based on the distance between two alternatives, a method which is based on distance must be used. This issue is relevant in a quantitative criteria set, as there is a unit defined for the quantitative one. But, as it is not possible to think based on distance with regard to qualitative criteria, methods based on relative judgment shall be used. This means that the decision must be made based on relative importance or utility of alternatives. In the mentioned example, one can say technology A results in high tensions, compared with technology B.

The next aspect is DMs' preference elucidation. This aspect is introduced by reviewed studies under different titles. At least three dimensions can be named for this aspect. The first one is the variety of relations defined for comparing alternatives. As an example, in some models just *I* (indifference) and *P* (preference) relations are used, while other methods utilize *R* (incomparable) relation as well. [Figueira et al. \(2005\)](#) provide a detailed description about these relations. The second dimension is about the evaluation method by DMs. For cases in which DMs prefer pairwise comparisons, using methods based on such comparisons are desired. The third one is related to degree of compensation allowed by the model. Utility methods are compensatory, while outranking methods are semi- or non- compensatory.

Another criterion which is not addressed by the authors is degree of using the method in the problem's context. In fact, the more a method is used in a context, the more it will be legitimized in that context from DM's point of view, because using a method which is used beforehand in the same context assures DMs that a right method is used. As a consequence, DMs rely on the method's results. As the second advantage of considering this criterion, continual use of a method in a context, provides experience about its application. This leads to fewer mistakes and more efficient implementation. For example, [De Keyser and Peeters \(1996\)](#) remark issues which must be noted for applying the PROMETHEE method.

Other criteria that must be noted in designing an appropriate approach are: ease of use and

understanding, degree of dependence on DMs, ability of supporting group decision making, rigidity, using meaningful parameters and availability of decision support system software. These criteria are remarked by the authors.

The mentioned criteria provide a basis for removing methods which do not have minimum expected criteria from the list of methods. In the problem raised, identifying the order of alternatives is desired. As complete ranking of alternatives is needed, the position of each alternative must be determined. Therefore, using *R* type relation is not relevant. This means, non-compensatory methods won't be used. All of identified methods except ORESTE and some versions of ELimination Et Choix Traduisant la REalité (ELECTRE) and PROMETHEE family of methods provide complete ranking (Guitouni and Martel, 1998).

Input includes the quantitative and qualitative data. Therefore, the designed method must handle both types of data. Among the mentioned methods, QUALIFLEX, REGIME, ORESTE and Achieving Respect for Grades by Using ordinal Scales (ARGUS) are not qualified. QUALIFLEX is well-suited when all criteria are qualitative. Due to normalization in the REGIME method, a large amount of data will be missed. ORESTE and ARGUS methods lead to similar results. From DM's point of view, a comparison between alternatives must be based on the distance between them with respect to quantitative criteria. For example, in comparing three alternatives with respect to their costs, it is assumed that alternatives A, B and C cost 2, 4 and 8 units respectively. From DM's point of view, relative utility of A in relation to B is more than that of B in relation to C. Thus, the relative value of alternatives is not linear with respect to the cost. As a consequence, methods which are not based on distance are not appropriate to be used in decision making with quantitative criteria.

As mentioned before, elucidation of DMs' preference is a 3-dimensional criterion. With respect to the first dimension, DMs do not use *R* relation as they want to see the complete ranking of alternatives. Thus, all utility based methods and those ranking methods that do not include *R* relation are qualified with respect to this dimension. According to the second dimension, QUALIFLEX, REGIME, ORESTE, ARGUS, EVAMIX, TACTIC, Méthode d'ELimination et de Choix Incluant les relation d'ORDre (MELCHIOR) and ELECTRE family must be removed. On one hand, these methods have complex mathematical

computation and some of them need further knowledge such as graph theory, linear algebra and quadratic programming. On the other hand, DMs in such a managerial level neither have such knowledge, nor have the time to learn them. As a consequence, they won't know what is occurring in the decision making process. Since they see these methods as a black box, they won't rely on their results (Løken, 2007). Moreover, some methods are not flexible enough to model DMs' preference. This makes a difference between PROMETHEE and Multi attribute utility theory (MAUT) with other methods, as they provide unlimited functions. In these methods, DM can choose a function which fits with its preference structure. In relation with the third dimension, Polatidis *et al.* (2006) recommend using methods with a lower degree of compensation as a consideration of sustainability issues. This approach for considering sustainability issues is also acknowledged in this paper. Among the survivor methods, those which have more supplementary features are more desired. Among MADM methods, "elementary" methods are not qualified as they are designed for simple problems. Simple problems are those in which few alternatives and criteria are included. Also, due to reasons mentioned above, among advanced methods, the "other methods" group and ELECTRE family seem to be inappropriate. The three remaining methods in the list are Analytical hierarchy process (AHP), PROMETHEE family and MAUT. An interesting matter is that these methods (as well as ELECTRE family) are the most frequently used in the energy sector (Dialoulaki *et al.*, 2005; Kahraman *et al.*, 2009; Pohekar and Ramachandran, 2004; Polatidis *et al.*, 2006; Wang *et al.*, 2009). Also, their problematic is ranking (Figueira *et al.*, 2005; Guitouni and Martel, 1998). Among these methods, MAUT is very time consuming and is highly dependent on DM's preference. These two reasons can be causes of its relatively reduced usage in recent years. This reduction is reported by Zhou *et al.* (2006).

As mentioned above, computing alternative values with respect to qualitative criteria based on their paired ratio is desired. This means determining how many times the *i*th alternative is more valuable than the *j*th alternative. Also, with respect to quantitative criteria, decision making must be based on the distance between alternatives. This means how greater the *i*th alternative is as compared to the *j*th alternative. As the AHP method is based on ratio and PROMETHEE family

is based on distance, they seem to be compatible with qualitative and quantitative criteria respectively. PROMETHEE family includes PROMETHEE I, II (Brans, 1982;), III, IV, V (Brans and Mareschal, 1995), GDSS (Macharis *et al.*, 1998), TRI and CLUSTER (Figueira *et al.*, 2005). Among the PROMETHEE family, PROMETHEE II is more desired as it provides complete ranking and is user friendly (Tuzkaya *et al.*, 2009; Behzadian *et al.*, 2010). Another issue raised in relation with implementing procedures is weighting the criteria. There are different methods for weighting the criteria. Usually, the weighting methods are applied in cases where weighting the criteria is not provisioned by the designed MADM method. In other words, in such methods, weights of criteria are input data. Since the AHP method is based on relative importance, it can be used to set the criteria weights. Another advantage of using AHP, is handling of group decision making. In this way, group decision making is provisioned by the method and there is no need to use any other methods. So, in this study, AHP is proposed to be used for weighting the criteria, handling group decision making and comparison of alternatives with regard to qualitative criteria. The PROMETHEE II method is also used for comparison of alternatives with regard to quantitative criteria because of its flexibility in decision modeling and appropriate handling of quantitative data (least amount of loss of information). Finally, it can be said that the experts would not choose alternatives with better economic performance criteria at the cost of environmental issues, security, political, and other criteria. This means the use of semi-compensatory decision making methods is desired. In this study, economic criteria are also quantitative and others are qualitative. Thus, in the comparison of alternatives with respect to both types of criteria, an equation which selects alternatives with fair performance with respect to all aspects should be used. For this reason, aggregation of alternative values with regard to qualitative and quantitative criteria can be computed using the following equation.

$$V_a = E_a^{w_E} \cdot N_a^{w_N}$$

Where, V_a is value of a . Also E_a , N_a , W_E and W_N represent the value of a with respect to quantitative criteria, value of a with respect to qualitative criteria, weight of quantitative criteria and weight of qualitative criteria, respectively. As this relationship is a geometric mean, those alternatives that perform fairly with respect

Table 5: Alternatives value computation, using geometric mean

Criteria	1 st criteria	2 nd criteria	Value
Criteria weight	0.5	0.5	
1 st alternative	0.1	0.9	0.3
2 nd alternative	0.5	0.5	0.5

to different criteria are more desired than ones that perform well with respect to some criteria and have bad performance with respect to some others. Table 5 can help to better understand this issue.

Therefore, an alternative with good performance with regard to all criteria is more desired than ones that perform well in several criteria and have bad performance with regard to others. If an arithmetic average were to be used to calculate values, the numbers obtained from both alternatives would be equal.

As an extension of this method, criteria can be classified into different categories so that existing criteria in each category can offset each other perfectly, but criteria in various categories cannot fully compensate each other (semi-compensatory). Three cases can be expected in relation to criteria for each category:

- 1) All criteria are qualitative: use AHP to compute the value of each alternative.
- 2) All criteria are quantitative: use PROMETHEE II to compute the value of each alternative.
- 3) Criteria are qualitative and quantitative: use PROMETHEE II to compute the value of each alternative with respect to quantitative criteria and AHP to compute values with respect to qualitative ones.

Then use the following equation to compute the final value of all criteria within the group:

$$V_{a:C_m} = W_E \cdot E_{a:C_m} + W_N \cdot N_{a:C_m}$$

Where $V_{a:C_m}$ is the value of a for criteria group C_m (criteria in the m th group). Also, $W_{E:C_m}$, $E_{a:C_m}$, $W_{N:C_m}$ and $N_{a:C_m}$ represent the sum weights of quantitative criteria belonging to the m th group, value of a with respect to quantitative criteria belonging to the m th group, sum of weights of qualitative criteria belonging to the m th group and value of a with respect to qualitative criteria belonging to the m th group, respectively.

Finally, the value of a can be computed using the following equation:

$$V_a = \prod_{i=1}^L V_{a:c_i}^{w_{c_i}}$$

Where V_a represents the value of a and $V_{a:c_i}$ and w_{c_i} are the value of a with respect to the i th group of criteria and weight of the i th group of criteria, respectively. It is assumed that all criteria are classified into L mutually exclusive groups. An implicit assumption in the above equation is that the compensation relation is a transitive one. This means, it is assumed that DM compares compensatory criteria in a reasonable manner. So, there will be no case where one criterion belongs to more than one group.

CONCLUSION

This paper dealt with designing an appropriate method for decision making regarding a given problem using a two-level approach. At the first level, two popular approaches were reviewed and were compared with each other from three perspectives. At the second level, different MADM methods were reviewed and compared.

During this review, some untapped aspects about quantitative and qualitative data and their relevance to the method designing task were revealed. It was clarified that quantitative data provides DMs with more information by doing analysis based on distance. Analyzing data based on ratio causes information gaps. Therefore, it is proposed that depending on which type of data is desired to be analyzed, different methods shall be used.

Based on a review of the literature and supplementary reasoning, the most important aspects in selection (one can say design, as the proposed method is made up of four MADM methods, named AHP, PROMETHEE II, geometric mean and weighted sum) of the appropriate method are introduced. Some of these aspects were new to the literature. Finally, the generalized method of decision making has been proposed using the four mentioned MADM methods by considering sustainability.

Since reasoning for design of the method was general enough, it seems to be applicable in similar cases (any comparison between discrete alternatives in any chain of energy sector) which meet the following conditions:

- 1) Sustainability issues are at the center of attention and DMs are serious to incorporate the sustainability aspect into decision making problems. This leads to designing methods with lower degrees of compensation.
- 2) The value of alternatives is not linear in relation with their quantities in quantitative criteria from DMs point of view.
- 3) DMs are not familiar with complex MADM methods and do not have enough time to learn how they work.

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