PROMITHEAS – 4

"Overview and selection of multi-criteria evaluation methods for mitigation/adaptation policy instruments"

Task Leader: *Prof. Agis M. PAPADOPOULOS (Part I)*

Aristotle University Thessaloniki

Dr. Popi KONIDARI (Part II)

National and Kapodistrian University of Athens

Greece, 2011

This report has been read, commented and approved by all members of the PROMITHEAS-4 Scientific Committee.
It was also disseminated for comments, through BSEC – PERMIS and BSEC – BC, to all relevant governmental and business authorities and partners before its finalization.
Partners from the beneficiary countries* of the consortium were encouraged to contact direct national authorities, agencies, institutions and market stakeholder for comments before the finalization of this report (Annex 1).

Members of the PROMITHEAS – 4 Scientific Committee:

1. Prof. Dimitrios MAVRAKIS, NKUA – KEPA (GREECE) -*Editor*
2. Dr. Popi KONIDARI, NKUA – KEPA (GREECE) – *Assistant to the editor*
3. Dr. Harry KAMBEZIDIS, NOA (GREECE)
4. Prof. Bernhard FELDERER, IHS (AUSTRIA)
5. Prof. Bilgin HILMIOGLU, TUBITAK – MAM (TURKEY)
6. Prof. Vahan SARGSYAN, SRIE – ESC (ARMENIA)
7. Prof. Dejan IVEZIC, UB – FMG (SERBIA)
8. Prof. Mihail CHIORSAK, IPE ASM (MOLDOVA)
9. Prof. Agis PAPADOPOULOS, AUT – LHTEE (GREECE)
10. Prof. Alexander ILYINSKY, FA (RUSSIA)
11. Prof. Anca POPESCU, ISPE (ROMANIA)
12. Prof. Andonaq LAMANI, PUT (ALBANIA)
13. Prof. Elmira RAMAZANOVA, GPOGC (AZERBAIJAN)
14. Dr. Lulin RADULOV, BSREC (BULGARIA)
15. Prof. Arthur PRAKHOVNIK, ESEMI (UKRAINE)
16. Prof. Sergey INYUTIN, SRC KAZHIMINVEST (KAZAKHSTAN)
17. Prof. Alvina REIHAN, TUT (ESTONIA)

**Turkey, Armenia, Serbia, Moldova, Russia, Romania, Albania, Azerbaijan, Bulgaria, Ukraine, Kazakhstan, Estonia.*

Acknowledgments: The Task Leader of this report acknowledges the contribution of Ms. Natalia Boemi, Ms. Frini Giama and Ms. Theodora Slini for the development of Part I of this overview.

Table of contents

Summary

The specific Task (W.P.4.1.) presents an overview and selection of multi-criteria evaluation methods for Mitigation/Adaptation policy instruments. The presented multi-criteria evaluation methods are already mature methods and are used, in some cases, for decades. Within the scope of this project, and in the frame of this deliverable, emphasis was placed on information referring to objectives, assumptions, methodology, advantages, disadvantages, applications, relevant software studies for the multi-criteria evaluation methods that have been used particularly for mitigation/adaptation policy instruments. The methods or families of methods, considered are AHP, ELECTRE, MAUT, SMART and AMS. The aforementioned methods are evaluated and compared. The most appropriate method for mitigation/adaptation policies that allows usage of available data and information from official national reports or official positions of national target groups has been selected.

PART I

Overview of multi-criteria evaluation method(s) for M/A policy instruments

by

Prof. Agis PAPADOPOULOS,

AUT- LHTEE (Greece)

Abbreviations

AHP	- Analytical Hierarchy Process
CBA	- Cost Benefit Analysis
CI	- Consistency Index
EEA	- European Environmental Agency
ELECTRE	- Elimination and Choice Expressing Reality
GHG	- Greenhouse Gas
IPCC	- Intergovernmental Panel for Climate Change IPCC
M/A	- Mitigation/Adaptation
MACBETH	- Measuring Attractiveness by a Categorical Based Evaluation TecHnique
MADM	- Multi-Attribute Decision Making
MAUT	- Multi-Attribute Utility Theory
MCA	-Multi Criteria Analysis
MCDA	- Multi-Criteria Decision Analysis
MCDM	- Multi-Criteria Decision Making
MODM	-Multi-Objective Decision Making
PIs	- Policy Instruments
PMs	- Policy Makers
SMART	- Simple Multi-Attribute Rating Technique
UK	- United Kingdom
UNEP	- United Nations Environmental Programme
UNFCCC	- United Nations Framework Convention for Climate Change
UTA	- UTilities Additives

Introduction

The EU's recommendations for future integrated policies on climate change, stress that there is an urgent need – pursuing a horizontal approach – to incorporate global warming and climate change as new parameters into all spheres and policies, taking into account the causes and consequences of global warming and climate change (EC, 2011 and 2010). Towards this direction Promitheas-4 cultivates knowledge transfer; identifies research needs for preparing mitigation/adaptation (M/A) policy portfolios for emerging countries and promotes cooperation at local and global level on actions to combat climate change for the post-2012 period.

The significance of decision support systems in policy-making, especially for climate change issues, is gradually acknowledged in the policy world (Grafakos et al., 2009), as stated at the Intergovernmental Panel for Climate Change (IPCC) at the third and the fourth assessment reports (IPCC, 2001 and 2007). However, given that diverse socio-economic characteristics enhance the implementation of different methods, it is obvious that there is not a single, widely accepted method. Identifying criteria for policy evaluation is a task that has progressively engaged both researchers and policy-makers who have developed various sets of criteria potentially applicable to climate policy assessment. However, there is no mutual agreement on precisely what criteria an optimal climate change policy should satisfy. The United Nations Energy Programme (UNEP, 1994) attempted to provide guidelines and analytical frameworks for consistent development of national greenhouse gases (GHGs) abatement scenarios, highlighting the significance of multi-criteria analysis (MCA) for ranking national alternatives and assessing M/A policy portfolios. Towards the same direction, United Nations Framework on Climate Change Convention (UNFCCC, 2002) stressed the need to apply MCA on certain cases, for example when costs and/or benefits cannot be quantified.

Decision-making for sustainable development and climate change policy, as aforementioned, is often characterised by a mixture of interactions, ignorance or/and uncertainty, conflicting interests and opinions. "*In order to understand how sustainability in environment interactions can be advanced (Stagl, 2007), it is first necessary to accept that:*

- *sustainable development and climate policies follow a multidimensional concept;*
- *the interface between science and policy is complex, and*
- *natural and human systems are adaptive*".

Secondly, it is important to choose appropriate assessment tools, efficient enough to address issues of incommensurability, complexity and adaptiveness.

Multi-criteria tools have the potential to consider the multidimensional, conflictual and uncertain properties of decisions, and at the same time to make available significant insight to a specified problem. Moreover, they can support decision-making process by clarifying conflicting values and conditions, increasing the transparency of the process.

Multi-Criteria Decision Making (MCDM) is a division of the broad family of Operations Research (OR) models which can solve a number of decision problems based on a specific set of decision criteria. This family is further divided into multi-objective decision making (MODM) and multi-attribute decision making (MADM) (Konidari and Mavrakis, 2007; Climaco, 1997).

During the last decades efforts were directed mainly in developing models to identify the relationship between climate, energy and economy supporting decision making in the climate policy sector (Meirer and Mubayi, 1983). As part of this effort, the increasing environmental concern added more value to the environmental parameter of the decision making process. In Figure 1, a synthesis of sustainable planning decision-making ingredient is presented. Specifically, sustainable planning is a complex and multi-criteria issue and should take into account economic parameters, GHG emissions, environmental concerns, social parameters.

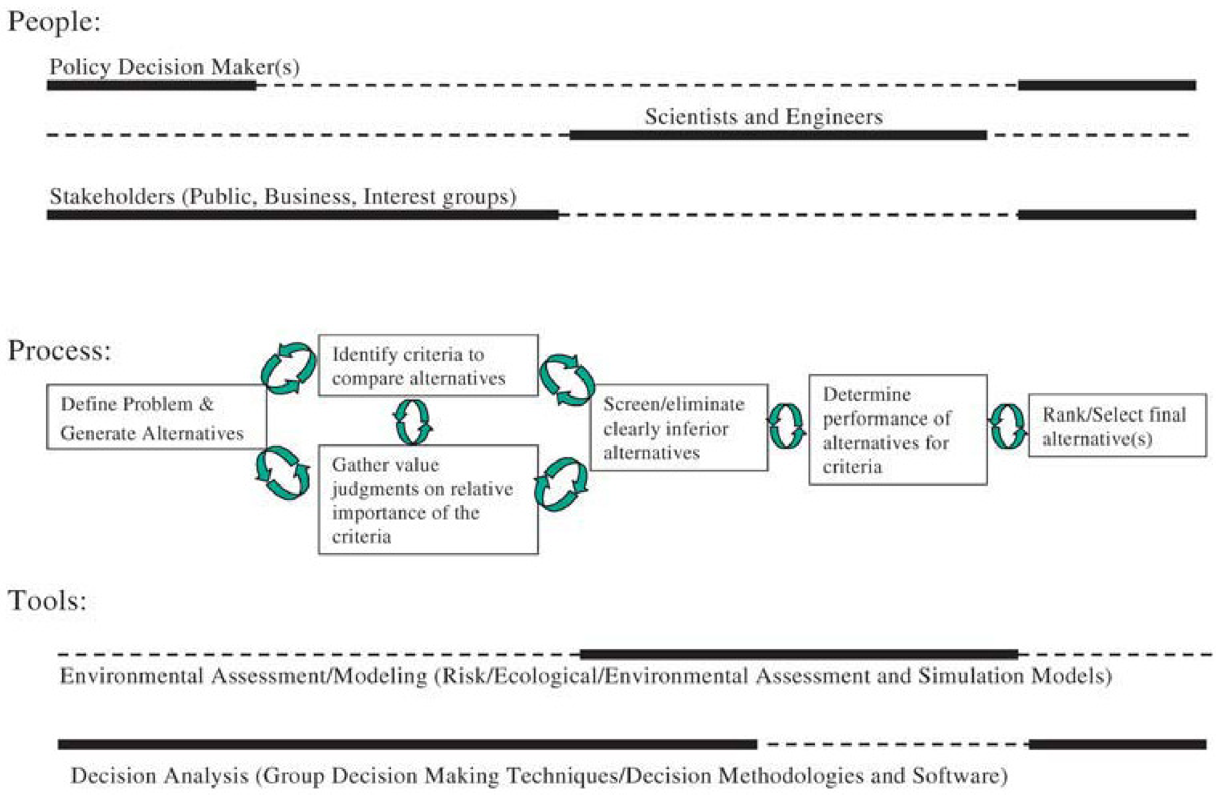

Figure 1: Synthesis of decision-making ingredients (Kiker, 2005).

MCA is also an efficient assessment tool for environmental planning able to consider numerous alternatives taking into consideration many different criteria, as well as the conflicting preferences of decision makers and various interest groups. The outcome of such a procedure is not unique, but rather an acceptable compromised solution (Lahdelma et al., 2000).

The core of the MCA and multi criteria evaluation methods is the decision model, which is a formal specification of how different kinds of information data are combined together to achieve a viable solution.

Aiming to appropriately describe the multi-criteria methods, it is essential to define the terms of criteria, alternatives and stakeholders. A discrete multiple criteria decision problem consists of a finite set of alternatives that are evaluated by means of multiple criteria. The criteria provide numerical measures for all relevant impacts and interactions of possible alternatives. The importance of different impacts depends mainly on stakeholders' points of view. It is necessary to clarify accurately how the performance of each alternative is measured in each criterion.

Usually, criteria are cumulative values derived from the principal factors, namely the assessment level. As Lahdelma et al. (2000) suggest*: "in environmental problems, alternatives can be divided into standard and innovative ones. Standard alternatives are obvious from the decision context alone: the actual project, the so-called zero alternative (rejection of the project), and other alternatives presented by the stakeholders. Innovative alternatives are those emerging through different kinds of negotiations during the process".* Moreover, the policy stakeholders can be classified into standard stakeholders and interest groups, all involved with the planning and decision process. Standard stakeholders include the decision makers, experts, planners and analysts responsible for the provision and the management the system, while the interest groups are political authorities, public organisations or inhabitants of the area under study. *"MCA can be used in order to clarify the planning process, to avoid various distortions and to manage all the information data, the criteria, as well as their uncertainties and importance"* (Lahdelma et al., 2000).

A major difference of the methods lies on how they combine the available data and alternatives. Formal techniques usually provide a weighting system for the different criteria. The key point of these techniques is to deal with the extensive amount of complex information in a consistent way.

"*The basic stages of applying a multi-criteria evaluation tool (DCLG, 2009) are summarised in the following:*

(a) Establishment of the decision issue:
- *establish aims of the analysis, and identify decision makers and other key players;*
- *design the socio-technical system for conducting the multi-criteria evaluation;*
- *determine the context of the assessment.*

(b) Detection of the alternatives to be evaluated;

(c) Detection of objectives and criteria:
- *identify criteria for assessing the consequences of each option;*
- *organise the criteria by clustering them under high-level and lower-level objectives in a hierarchy.*

(d) "Scoring". Determination of the expected performance of every alternative in relation to the criteria and the corresponding consequences of each alternative for each criterion.
- *describe the consequences of the alternatives;*
- *rank the alternatives on the criteria;*
- *examine the reliability of the rankings on each criterion.*

(e) "Weighting". Assign weight coefficients to each criterion for revealing its relative importance to the decision.

(f) Combination of the weight coefficients and scores for each option to derive an overall value.
- *calculate overall weighted scores at each level in the hierarchy;*
- *calculate overall weighted scores.*

(g) Examination of the results.

(h) Sensitivity analysis.
- *perform a sensitivity analysis: do other preferences or weights affect the overall ordering of the alternatives?*
- *check the advantage and disadvantages of selected alternatives, and compare pairs of alternatives;*
- *generate possible new alternatives that might be more suitable than those initially selected;*
- *repeat the above steps until a consistent model is obtained*".

Some of the most important advantages of MCA, as described by the European Environment Agency Report (EEA, 2003), follow:
- capability to compare scenarios with regards to contradictory objectives;
- facilitation of the process when many criteria are involved;
- bilateral learning between experts and interest groups;
- better understanding of the problem;
- storing all relevant problem information and setting the appropriate requirements for new information;
- increasing discussion between different stakeholders and activated non-participants.

Some of the main disadvantages of MCA are presented below:
- need for similar, comparable data;
- risk of overlapping selected criteria

- evident recognition and participation of the stakeholders to supply adequate and reliable information;
- uncertainty of the criteria set.

Climate change is a complicated strategy area with many interacting parameters. Aldy (2008) noted that the conceptual and empirical challenges are intensified by the lack of well-defined criteria as well as an objective process for defining weight coefficients to the considered criteria. Meanwhile, in order to select an optimum tool, the potential solutions should be first assessed with respect to the set of specific criteria of climate change issues. Otherwise there is a serious risk that a policy portfolio will be ineffective (Mickwitz, 2003).

Additionally, the IPCC (2001) as well as many European countries, e.g. Denmark (URL 1), Finland (SYKE, 2007; Solvari, 2010), Netherlands (Bonney, 2010, URL 2 and 3) and Sweden (URL 4), recommended (Betz, 2004; EEA, 2007,) a range of criteria and evaluated their use (U.S. EPA, 2009) to support decision makers in identifying optimal climate change policies.

Definitions of terms

For the better understanding of the multi-criteria evaluation methods and their different techniques, definitions of the often 'used' terms follows in Table 1.

Table 1: Explanation of common terms of multi-criteria evaluation methods.

Term	Explanation
Attributes	Evaluation criteria
Ease of use	Decision maker's familiarity towards the specific multi-criteria method
Hierarchy of scale	Decrease the ambiguities and provide explicity
Incommensurability	To keep the decision criteria in the original units so as to provide decomposition of the issue
Qualitative and quantitative information or data	To handle the mixed information usually present in complex decision problems
Score or performance	
Sensitivity analysis	To enhance the transparency of the procedure
Threshold values, veto	To operation the assimilative capacity of environmental, economic, resource and social database
Treatment of the uncertainty	To overcome the problem of the inadequate input data
Variety of alternatives	All possible aspects/options of a decision making problem
Weight coefficient or weight	Values or indicators showing preference (significance) among the evaluation criteria

1. Main categories of multi-criteria evaluation methods

There are several categories of multi-criteria methods, depending on the type of input data, the initial assumptions, the adapted method of analysis and the output result. Priority based, outranking, distance based and mixed methods are different kind of analysis applied to various problems. From another point of view, methods can be classified as deterministic, stochastic and fuzzy, while there are combinations of them keeping some of their major characteristics" (Greening and Bernow, 2004).

Belton and Stewart (2002) suggest the following widely accepted categorization of MCDM methods:

(a) value measurement methods or optimization methods;

(b) outranking methods;
(c) goal, aspiration or reference level models.

Apart from the above, Zopounidis and Doumpos (2002) suggest the following categories:

- multi-objective/goal programming;
- multi-attribute utility theory methods (AHP, MAUT, MACBETH etc.);
- outranking methods (ELECTRE, PROMETHEE, ORESTE etc.);
- preference disaggregation methods (UTA, UTADIS, MHDIS);
- rough set theory methods.

Throughout the years, different MCDA methods have been developed varying from simple ones to more complex ones. However, all methods follow the same decision process (Figure 2) and include:

(a) alternative solutions,
(b) different criteria,
(c) matrix of specific values for each criteria,
(d) weighting indicators for each criteria,
(e) an evaluation of each alternative solution in respect to other alternatives.

Even though there is a plethora of classifications, the multiple objective decision procedures always assume that a decision policy maker is involved at a certain point of the solution process. A widely accepted way to interfere the decision maker in the analysis is to employ an interactive approach (Keeney and Raiffa, 1976; Steuer 1986). Based on the role that the value function holds in the process, the following three solution principles can be disguised for resolving different types of MCDM problems by Korhonen et al. (1992):

(a) Assume the existence of a value function, and evaluate it explicitly.
(b) Assume the existence of a stable value function, but do not try to assess it explicitly. Instead, assume the general functional form of the value function.
(c) Do not make any assumption for the existence of a constant value function, either explicit, or implicit.

According to these solution principles, the following corresponding general approaches to solving multi-criteria problems can be detected.

Approach 1: A priori expression of preferences

This is a classical approach implemented in multi-attribute utility or decision analysis. Using Keeney-Raiffa (1976) type of interaction, the following steps can be identified:

(a) make hypotheses about the underlying value/utility function and its functional form;
(b) weigh up the parameters of the underlying value/utility function using complicated techniques;
(c) evaluate critical probability functions in case uncertainty exists;
(d) ensure the inner reliability of the decision maker’s aspects;
(e) score the alternatives in terms of value/expected utility.

Briefly, once an explicit value/utility function has been appraised, this function is used to rank order a finite number of the decision alternatives or optimize over the feasible decision space.

Approach 2: Interactive expression of preferences

(a) Based on an implicit value function.

In this case, decision maker aspects were used as a guide to the solution process in the direction of an optimal or widely accepted solution (in theory), under the hypothesis that the decision maker acts in accordance to some specific (but unknown) underlying value function (Hwang and Masud, 1979; Steuer, 1986; Shin and Ravindran, 1991). The stages describing this approach follow:

- make hypotheses about the underlying value function and its functional form;
- find an initial solution that is reasonable and efficient;
- cooperate with the decision maker and explore his/her reaction or response to the solution;
- revise the data about the underlying value function;
- generate an enhanced solution using the updated underlying value function;
- iterate until a preferable solution has been identified or the decision maker is satisfied with the solution.

(b) Based on no stable value function.

These approaches are typically based on projecting the decision makers' views in relation to the objectives of the study. This projection is generally achieved by minimizing the scalarizing functions (Wierzbicki, 1980; Steuer and Choo, 1983). Nevertheless, decision maker's value function is not defined. The stages describing this approach follow:

- exhibit a satisfactory solution and provide the decision maker with sufficient information about the non-dominated state, in particular in the vicinity of the presented solution;
- request the decision maker to provide preference data in the form of target levels, weights, etc.;
- employ the responses to produce a single or a set of non-dominated solutions for the decision maker's appraisal;
- iterate until the decision maker ends, or some specified termination criteria for the analysis have been reached.

In a sense, this approach intends to assist the decision maker to examine the set of competent solutions. Interactive software that implements such systems for a computer has been developed (Lewandowski et al., 1989; Korhonen, 1987, 1988). When such interactive algorithms (2a or b) are applied to real-world problems, according to Shin and Ravindran (1991), the most critical factor is the functional restrictions placed on the criterion functions, constraints, and the unknown value function.

Another important factor is the preference assessment or interaction style. Shin and Ravindran (1991) list the following eight typical interaction styles:

- binary pairwise comparisons;
- pairwise comparisons;
- vector comparisons;
- precise local trade-off ratios;
- interval local trade-off ratios;
- comparative trade-off ratios;
- listing the indices of the criterion functions to be improved or sacrificed; also specifying amounts of improvement or sacrifice;
- aspiration levels (reference points).

Approach 3: A posteriori expression of preferences

This approach produces non-dominated solutions and the decision maker is called to assess them. He/she is then expected to select the most favoured solution from the specific problem. No assumptions of the underlying value function are proposed. Typically, the following steps can be described by the following:

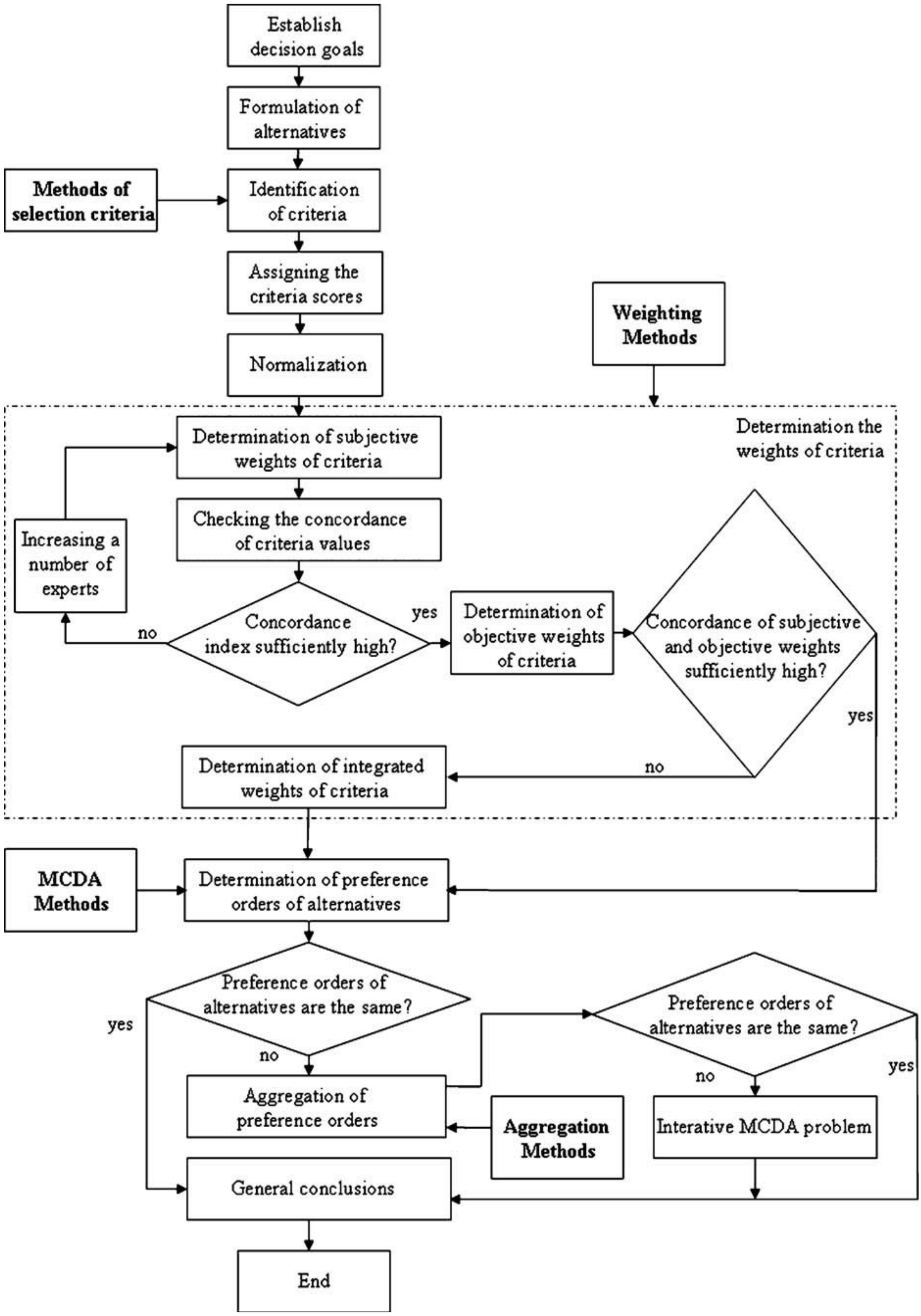

Figure 2: MCDA process in sustainable decision-making (Wang et al., 2009).

- produce a primary efficient solution;
- produce supplementary efficient solutions;

- present similar solutions in the criterion space to the decision maker and ask him/her to select the optimal.

The solutions (alternatives) are exhibited and envisaged according to the individual process, by means of appropriate systems, e.g. the ADBASE system (Steuer, 1986).

2. Multi-criteria evaluation methods for M/A policy instruments

The selection of the appropriate mitigation/adaptation policies and measures requires a sound of scientific knowledge of data and information. The objective will be the presentation and qualitative analysis of the MCA in order to select the most suitable for each emerging economy and the needs of the PROMHTHEAS-4 project.

Indicatively, within the framework of this project, the following five methods are described in detail: Analytical Hierarchy Process (AHP), Elimination and Choice Expressing Reality (ELECTRE), Multi-Attribute Utility Theory (MAUT), Simple Multi-Attribute Rating Technique (SMART) and AMS.

2.1. *Analytical Hierarchy Process (AHP)*

The AHP is a theory of measurement for dealing with quantifiable and/or intangible criteria that has found rich applications in decision theory, conflict resolution and in models of the brain, developed by Saaty (1980).

Methodology

AHP is a descriptive decision analysis that methodology calculates ratio-scaled importance of alternatives through pair-wise comparison of evaluation criteria and alternatives by means of the weighted sum method. The weights obtained in AHP method are introduced and, subsequently, each performance at the given level is multiplied with its weight and then the weighted performances are summed to get the score at a higher level. The procedure is repeated upward for each hierarchy, until the top of the hierarchy is reached. The overall weights with respect to goal for each decision alternative are then obtained. The alternative with the highest score is the best alternative (Wang, 2009). The decision applications of the AHP are carried out in two phases: hierarchic design and evaluation.

It is based on the decomposition of a complex problem into a hierarchic design with a goal (objective) at the top of the hierarchy, criteria and sub-criteria at levels and sub-levels of the hierarchy, and decision alternatives at the bottom of the hierarchy.

"*The evaluation phase is based on the concept of paired comparisons. The components at a given hierarchy level are compared in pairs to assess their relative preference with respect to each of the elements at the subsequent higher level*" (Pohekar and Ramachandran, 2004). This process of comparison generates a relative scale of measurement of the priorities or weights of the components. That is, the scale measures the relative standing of the components with respect to a criterion independently of other criteria or elements that may be considered for comparison. These relative weights sum to unity. The comparisons are performed for the components in a level with respect to all the components in the level above. The final weights of the components at the bottom level of the hierarchy are obtained by adding all the contributions of the elements in a level with respect to all the elements in the level above. This is known as the principle of hierarchic composition (Figure 3).

The hierarchical structure of AHP allows the decision maker to break the complex decision problem into smaller but related problems, in the form of goals, criteria, sub-criteria, and alternatives. Pair-wise comparison of elements enables the decision maker to focus on smaller sets of decisions and to compare between elements more efficiently. In this sense, the importance of each element (criterion) is clarified.

The decision maker first gives linguistic pairwise comparisons, then obtains numerical pairwise comparisons by selecting certain numerical scale to quantify them, and finally derives a priority vector from the numerical pairwise comparisons (Dong et al., 2008). While there is an infinite number of ways of combining the weights of the alternatives and the weights of the criteria, the additive aggregation rule of the AHP has the advantage of perceptive recognition of the distribution of the whole into its components.

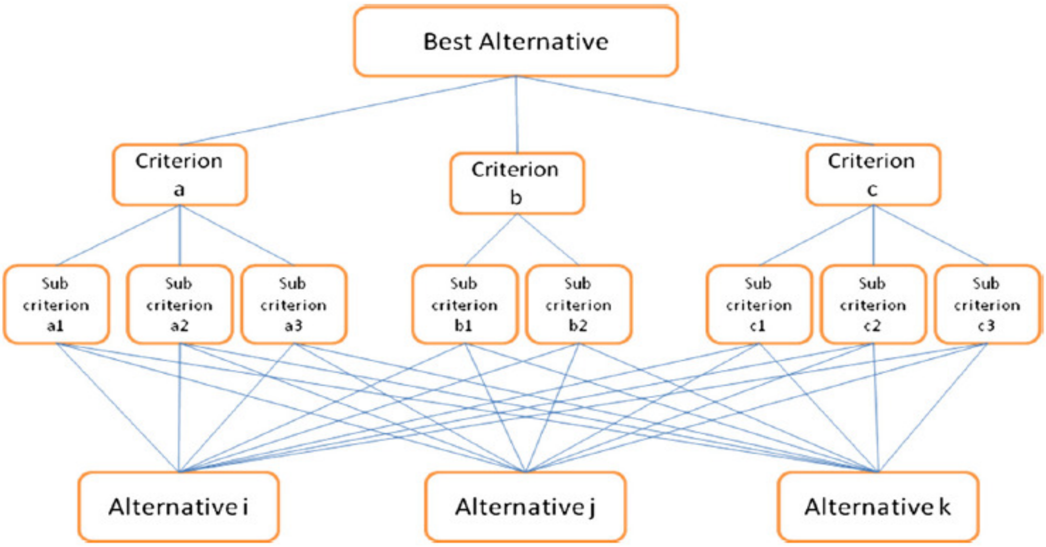

Figure 3: AHP structure (Theodorou et al., 2010).

Still, one has to keep in mind that, as hierarchies are not unique, their design requires experience and expertise of the problem considered. Furthermore, a group of people is needed to work together so as to reach consensus on both the hierarchy (design) and on the judgment and their synthesis (evaluation) and accomplish the initial purpose.

According to Saaty (1995), "the *axioms of the theory can be synopsized as follows:*

Axiom 1 - (Reciprocal Comparison): The decision maker must be able to make comparisons and declare the power of his/her preferences.

Axiom 2 - (Homogeneity): The preferences are represented via a bounded scale.

Axiom 3: (Independence). When preferences are expressed, criteria are assumed independent of the properties of the alternatives.

Axiom 4: (Expectations). For the purpose of making a decision, the hierarchic structure is assumed to be complete".

As he also comments, the relaxation of "*Axiom 1 indicates that the question, used to obtain the judgments or paired comparisons, is not clearly or correctly established. If Axiom 2 is not fulfilled then the components under comparison are not homogeneous and clusters may need to be formed. Axiom 3 implies that the weight coefficients of the criteria must be independent of the alternatives considered. A way to deal with a violation of this axiom is to use a generalization of the AHP known as the supermatrix approach. Finally, if*

Axiom 4 is not satisfied, then the decision maker is not using all the criteria and/or all the alternatives available or necessary to meet his/her reasonable expectations and hence the decision is incomplete".

Advantages - Disadvantages

A main advantage of the AHP is its applicability to the weighting of fuzzy criteria, along with solid ones, through ratio scales and scoring. In addition, by decomposing a problem or process in its components and combining them in a rational mode from the large, descending in regular steps, to the smaller, it is plausible to join via simple paired comparison judgments the lesser to the greater.

The strength of AHP lies in its ability to handle both quantitative and qualitative judgements (Macharis et al., 2004), while it employs a consistency test that can screen out inconsistent judgements, which makes the results reliable (Kablan, 2004). Additionally, the method calculates the inconsistency index as a ratio of the decision maker's inconsistency and randomly generated index. This index is important for the decision maker to assure him/her that his/her judgments were consistent and that the final decision is made well (Pohekar and Ramachandran, 2004). The success of the theory comes as a result of its simplicity and robustness (Vargas, 1990).

However, a major disadvantage of the method is that the number of pairwise comparisons to be made, may become very large increasing significantly the uncertainty of the process (Macharis et al., 2004). Furthermore, AHP has been criticised for its reliability based on the decision makers' beliefs and preferences.

Software

There are numerous available software for AHP which are described as quite user-friendly: MultCSync (Moffett et al., 2005), Expert Choice (ECPro, 2000), Logical Decisions (2003), Web-HIPRE (HIPRE 3+, Mustajoki et al., 2004), HIVIEW.

Applications

AHP has found uses in a wide range of fields, from simple personal decisions to complex and capital intensive ones.

The AHP method has been successfully applied to environmental planning, energy design, social sciences, agriculture and marketing as presented in Table 6. It is most often used when there is a small number of criteria and decision makers.

2.2. *ELECTRE*

Elimination and Choice Expressing Reality (ELECTRE) was developed by Bernard Roy in the mid-1960s. Today there exist several variations of the first method, namely ELECTRE I, ELECTRE II, ELECTRE III, ELECTRE IV, ELECTRE IS and ELECTRE TRI. All methods use an outranking methodology to solve problems.

Methodology

As far as the mathematical settings are concerned, any discrete multiple criteria decision-making problem is usually formulated by a set of alternatives $A = (x^1, x^2, \dots, x^n)$ and a set $(f_1, f_2, \dots, f_k)$ of criteria. The criteria are real-valued functions defined on the set A so that $f_l(x^j)$ represents the performance of the alternative x^j on the criterion f_l.

From the point of view of a decision maker, uncertainty of the data can also be dealt with in an easy and practical way by applying the so-called pseudo-criterion, which is a preference model including two

different thresholds: a preference threshold $p_l(f_l(x^j))$ and an indifference threshold $q_l(f_l(x^j))$ for each criterion f_l $(l = 1,..., k)$. These thresholds may be constants, linear or affine functions of $f_l(x^j)$.
For every criterion f_l, the double threshold model is the following:
It is valid that:
x^i is preferred to x^j if $f_l(x^i) > f_l(x^j) + p_l(f_l(x^j))$
x^i is weakly preferred to x^j if $f_l(x^j) + q_l(f_l(x^j)) < f_l(x^i) \leqslant f_l(x^j) + p_l(f_l(x^j))$, and
x^i is indifferent to x^j if $f_l(x^i) + q_l(f_l(x^i)) \geqslant f_l(x^j)$ and $f_l(x^j) + q_l(f_l(x^j)) \geqslant f_l(x^i)$
where $p_l(f_l(x^j))$ and $q_l(f_l(x^j))$ are preference and indifference thresholds, respectively and $p_l(f_l(x^j)) > q_l(f_l(x^j)) > 0$. Weak preference is supposed to describe the hesitation between indifference and preference (Papadopoulos and Karagiannidis, 2008).
Electre III is a typical and sophisticated method, using pseudo-criteria and taking the risk to a certain extent to establish outranking relations which can incorporate both criteria errors and uncertainties, as well as risk aspects' attitudes or sensitivities of decision-makers (Karagiannidis and Perkoulidis, 2009).
Although the ELECTRE family consists of some variations the basic concept and the mathematical setting does not differ dramatically although some variations are improved and some parameters are added to assist the decision making process.

ELECTRE I
Preferences in ELECTRE I method are modelled by using binary outranking relations, S, whose meaning is "*at least as good as*". Considering two actions a and b, four situations may occur (Rangel et.al., 2009):

- aSb and not bSa, i.e., aPb (a is strictly preferred to b).
- bSa and not aSb, i.e., bPa (b is strictly preferred to a).
- aSb and bSa, i.e., aIb (a is indifferent to b).
- Not aSb and not bSa, i.e., aRb (a is incomparable to b).

The method builds one or several (crispy, fuzzy or embedded) outranking relations. Note that using outranking relations to model preferences introduces a new preference relation, R (incomparability). This relation is useful to account for situations in which the decision maker and/or the analyst are not able to compare two actions.
Figueira and Roy (2004) constructed an outranking relation which is based on two major concepts:
(a) Concordance. For an outranking aSb to be validated, a sufficient majority of criteria should be in favor of this assertion.
(b) Non-discordance. When the concordance condition holds, none of the criteria in the minority should oppose too strongly to the assertion aSb.
The method as a concept is simple and it should be applied only when all the criteria have been coded in numerical scales with identical ranges. In such a situation, an action "a outranks b" (that is, "a is at least as good as b") denoted by aSb, only when two conditions hold.
This preference-indifference framework with the possibility to resort to incomparability, says nothing about how to select the best compromise action, or a subset of actions the decision maker will focus his/her attention on. In the construction procedure of ELECTRE I method, only one outranking relation S is matter of fact. The variations following came to improve and extent the application field of ELECTRE method.

ELECTRE II
"*The presentation of ELECTRE II may be of interest, both from a historical and a scientific point of view. This method was the first of the ELECTRE methods especially designed to deal with ranking problems according to Figueira*" (2002). Without going into further detail, it is important to point out that ELECTRE II was also

the first method to use a technique based on the construction of an embedded outranking relations sequence. The construction procedure is very close to the one used then by ELECTRE IV, in the sense that it is also a true-criteria based procedure. Hence, it is not surprising that the no veto condition remains the same. However, concordance condition is modified in order to take into account the notion of embedded outranking relations. There are two embedded relations: a strong outranking relation followed by a weak outranking relation. The ELECTRE III was designed as an improvement of ELECTRE II (Karagiannidis and Perkoulidis, 2009; Figueira and Roy, 2004).

ELECTRE III

ELECTRE III was an effort to improve the ELECTRE II method therefore deals with inaccurate, imprecise and uncertain data. This purpose was actually achieved, and ELECTRE III was applied with success during the last two decades on a broad range of real-life applications. The mathematical formula keeps the general concept of ELECTRE I. The new element of this method is the introduction of pseudocriteria instead of true-criteria. "*In ELECTRE III the outranking relation can be interpreted as a fuzzy relation and we could say that is a typical method using pseudocriteria and taking the risk to a certain extent to establish outranking relations which can incorporate criteria error and uncertainties as well as beliefs, risks and sensitivities of the decision makers*" (Figueira et al., 2004).

ELECTRE IV

The name ELECTRE IV was an unofficial name created for designating ELECTRE I with veto threshold (Figueira et al., 2004). This version of ELECTRE made it possible for analysts and decision makers to overcome the difficulties related to the heterogeneity of scales. Whichever the scales type, this method is always able to select the best compromise action or a subset of actions to be analyzed by decision makers. "*The ELECTRE IV introduced the veto threshold, vj, that can be attributed to certain criteria. The concept of veto threshold is related in some way, to the definition of an upper bound beyond which the discordance about the assertion "a outranks b" can not surpass and allow an outranking. In practice, the idea of threshold is, however, quite different from the idea of the disconcordance level like in ELECTRE I*" (Figueira et al., 2004). On what methodology structure concerns little changes occur from ELECTRE I to ELECTRE IV. The only new element is the 'no veto condition'.

ELECTRE TRI

ELECTRE TRI assigns a set of actions, objects or items to categories. "*Let us assume from the worst (C1) to the best (Ck). Each category must be characterized by a lower and an upper profile. Let C = {C1, . . . ,Ch, . . . ,Ck} denote the set of categories. The assignment of a given action a to a certain category Ch results from the comparison of a to the profiles defining the lower and upper limits of the categories; bh being the upper limit of category Ch and the lower limit of category Ch+1, for all h = 1, . . . , k. For a given category limit, bh, this comparison rely on the credibility of the assertions aSbh and bhSa. This credibility (index) is defined as in ELECTRE III. In what follows, we will assume, without any loss of generality that preferences increase with the value on each criterion*" (Figueira, 2004).

The objective of the exploitation procedure is to define the above binary relations. The role of this exploitation is to propose an assignment. This assignment can be grounded on two well-known logics based on Figueira (2004).

(a) The conjunctive logic in which an action can be assigned to a category when its evaluation on each criterion is at least as good as the lower limit which has been defined on the criterion to be in this category. The action is hence assigned to the highest category fulfilling this condition.

(b) The disjunctive logic in which an action can be assigned to a category, if it has, on at least one criterion, an evaluation at least as good as the lower limit which has been defined on the criterion to be in this category. The action is hence assigned to the highest category fulfilling this condition.
With this disjunctive rule, the assignment of an action is generally higher than with the conjunctive rule. This is why the conjunctive rule is usually interpreted as pessimistic while the disjunctive rule is interpreted as optimistic. This interpretation (optimistic-pessimistic) can be permuted according to the semantic attached to the outranking relation.
ELECTRE TRI is a generalization of the two above mentioned rules.

Advantages – Disadvantages
The main advantage of the ELECTRE method is that the comparison of the alternatives can be achieved even if there is not a clear preference for one of those therefore, and compared to other methods which are sensitive to the decision maker's beliefs, it is more reliable. Moreover, it has the ability to handle both quantitative and qualitative judgements. On the other hand it is a rather complex decision making method and requires a lot of primary data.

Software
Not so many software tools are developed exclusively based on ELECTRE methods. More software tools are developed taking into consideration the methodology structure of different methods, for instance, the CSMAA software (Tervonen, 2007) is a user friendly tool which is based on ELECTRE III and ELECTRE TRI methodology structure with some variances.
Another software tool based on the synthesis of different methods' structure is MCDA (Polatidis et.al., 2006) which is specialised to solve renewable energy sources' problems. The software tools are based on ELECTRE III, NAIADE and PROMETHEE II methodology.

Applications
The ELECTRE family multi-criteria methods are used by researchers in engineering and infrastructure investments studies, in environmental assessment as well as in multi-option problems within the environmental appraisal process. "*Through ELECTRE it became possible to determine not only the threshold values, but also values for noise, air, water impact criteria, as well as realistic values of indifference, preference and veto thresholds for various environmental criteria*" (Figueira et al., 2004).
The ELECTRE family methods applications concern environmental impact assessment, environmental as well as energy planning, renewable energy sources' problems, energy systems technology and waste management.

2.3. *Multi-Attribute Utility Theory (MAUT)*

MAUT (Keeney and Raiffa, 1976) determines the "*utility*" of various factors, over a given range of levels, based on decision-maker's preference. The result of this approach is a utility curve for each factor. The factor levels can be categorical, ordinal, or interval type values. Once the utility curves are extracted, each alternative can be evaluated on each factor and an overall score would then be derived by summing these factor utilities.
MAUT widens the classic utility theory so as to it can be applied to multidimensional problems, though persevering a strong theoretical foundation among MCDA methods.

Methodology
The basic steps to the required solution, as Sarkis and Sundarraj (2000) describe, are:

- identification of fundamental objective, of sub-objectives and attributes of sub-objectives;

- assessment of attributes' scores and weights;
- calculation of overall utility–most favourable choice–using weights and scores;
- sensitivity analysis to examine how a change in an attribute's value or weight influence the overall utility.

The objective of MAUT is to model and represent the decision maker's preferential system into a utility/value function U(.). The utility function is a non-linear function defined on the criteria space, such that:

$U(a_j) > U(a_k) \Leftrightarrow a_j > a_k$ (a_j is preferred to a_k)

$U(a_j) = U(a_k) \Leftrightarrow a_j \sim a_k$ (a_j is preferred to a_k)

The most commonly used form of utility function is the additive one:

$U(a_j) = p_1u_1(g_{j2}) + \ldots + p_nu_n(g_{jn})$

where, $u_1; u_2; \ldots ; u_n$ are the marginal utility functions corresponding to the evaluation criteria.

The process for extracting an additive utility function is accomplished via the collaboration between the researcher and the decision maker and involves the specification of the criteria trade-offs and the form of the marginal utility functions. The calculation of these parameters is accomplished via interactive procedures, e.g. the mid-point value technique suggested by Keeney and Raiffa (1976). Each marginal utility function defines the utility/value of the alternatives for each individual criterion g_i . The parameters $p_1; p_2; \ldots ; p_n$ are constants standing for the trade-off that the decision maker is willing to obtain on a criterion in order to gain one unit on criterion g_i. These constants are often considered to represent the weights of the criteria and they are defined such that they sum-up to one.

The utility/value can be defined by determination of single attribute utility functions followed by verification of preferential and utility independent conditions and derivation of multi-attribute utility functions.

Generally, the utility functions can be either additively separable or multiplicatively separable with respect to single attribute utility. The multiplicative form of equation for then utility value is defined as follows:

$$1 + ku(x_1, x_2, \ldots, x_n) = \prod_{j=1}^{n}(1 + kk_j u_j(x_j)) \qquad (1)$$

where j is the index of attribute,

k is overall scaling constant (greater than or equal to -1),

k_j is the scaling constant for attribute j,

u(.) is the overall utility function operator,

$u_j(.)$ is the utility function operator for each attribute j (Pohekar and Ramachandran, 2004).

Advantages – Disadvantages

MAUT is used to mainly help decision makers gain further knowledge and understanding of the problem (parameters, criteria, etc).

The method is a rather complex method, which can hardly be preferred for solving energy planning problems. However, and despite its complexity as a method, it is often used to help decision makers to understand better the objective of the problem, the sub- objectives, the weights and scores and the sensitivity analysis.

Software
Available software programs that support MAUT are the following: Logical Decisions (2003), Web-HIPRE (HIPRE 3+, Mustajoki et al., 2004), HIVIEW, 1000Minds (URL 5).

Applications
The applications of MAUT method concern, electric utility planning, renewable energy planning and environmental impact assessment problems.

2.4. *Simple Multi-Attribute Rating Technique (SMART)*

SMART was originally described in 1977 by Edwards as the whole process of rating alternatives and weighting criteria and is a simpler form of MAUT.

Methodology
The decision makers are asked to rank the importance of the changes in the criteria from the worst criteria levels to the best levels. Then 10 points are assigned to the least important criteria, and increasing number of points (without explicit upper limit) is assigned to the other criteria to address their importance relative to the least important criteria. The weight coefficients are calculated by normalizing the sum of the points to one.
Thus, the performance of an alternative "a" is calculated as:

$$U_a = \sum_{j=1}^{n} w_j r_{aj} \Big/ \sum_{j=1}^{n} w_j \qquad (2)$$

where r_{aj} is the rating of alternative a under the jth attribute with a numerically comparable scale. This is the simplest form of the MAUT where scores are standardized to a 0-1 scale, where 0 representing the worst expected performance on a given criterion and 1 representing the best expected performance (Salminen, 1998; Olson, 2001).

Edwards and Barron (1994) stressed that weights should clearly be related to the criteria ranges and presented an improved version, SMARTER. The idea of SMARTER is to use the centroid method so that the weight of a criterion ranked to be i*th* is

$$w_i = \frac{1}{n}\sum_{k=1}^{n}\frac{1}{k}$$

Edwards and Barron (1994) questioned the possible mistakes that happened during the elicitation process, as they considered with skepsis the existing trade-off between the consequences of the modelling mistakes and the mistakes generated in the elicitation process. In this sense they consider the modelling mistakes as the cost of the simplifications done through the hypotheses of linearity of the one-dimensional utility functions and of addictivity. However, the consequences of the elicitation mistakes are just identified when the decision maker does not consider the measures obtained as a reflex of his subjective preferences.

"*While MAUT allows greater flexibility in preference trade-off functions, if a linear MAUT model is used, transformation as applied in SMART yields precisely the same result. In MAUT, weights reflect both scale and importance. In SMART, scales are transformed to a common basis, so weights reflect importance. SMART does not request preference or indifference judgment among alternatives, as it is requested in most of MAUT derived methods*" (Edward and Barron, 1994). Edwards also affirms that hypothetical judgments

are unreal and they don't represent the real preferences, and it bores decision makers non instructed, leading them to reject the elicitation process or to accept any answer with the intention of finishing the questionnaire faster (Edward and Barron, 1994).
In SMART, one should consider (Salminen, 1998) that:

- all differences in criteria values are taken into account;
- uncertainty is dealt with probability distributions;
- additive model is used for assumed values/utilities;
- possibility is used to assume various forms for value/utility functions;
- complete order is employed.

Advantages – Disadvantages

The SMART method is a simple, utility based method with the ability to handle both quantitative and qualitative data. The method is more preferable for simplified decision making problems as for more complex problems other methods are more popular.

Software

The Smart-Swaps (Mustajoki and Hamalaninen, 2007) is a useful tool to employ the SMART method.

Applications

The applications of SMART method concern more environmental impact assessment problems.

2.5. *AMS*

AMS is a new evaluation method developed in Greece named from the initials of the three standard Multi-Criteria Analysis (MCA) methods that it incorporates. AMS consists a family method which combines three standard multi-criteria methods: the Analytical Hierarchy Process (AHP), the Multi-Attribute Utility Theory (MAUT) and the Simple Multi-Attribute Ranking Technique (SMART) (Konidari and Mavrakis, 2006; Konidari and Mavrakis, 2007).

Methodology

The method consists of four (4) basic steps:

(a) Creation of the criteria-tree.

(b) Determination of weight coefficients for criteria/sub-criteria.

(c) Grading of the instrument's performance under a criterion/sub-criterion.

(d) Collection of the previously produced grades and formation of the aggregate grade of each evaluated instrument. Consistency and robustness tests are performed within the relevant steps.

(a) Any potential user of the method will have to create the criteria – tree that corresponds better to the needs of the respective decision context. The identification of those parameters that matter mostly and specifically for climate policy evaluations were sought initially at previous evaluation cases performed by three groups actively involved in climate policy issues, policy makers (PMs), researchers and target groups (Konidari and Mavrakis, 2007). The aim was to record and recognize all the criteria that were used in these cases. Even if these evaluations referred to different types of climate change policy instruments there were commonly used criteria and these were included in the final set of criteria for the AMS method.
Any criteria or significant factors used by PMs for evaluating instruments were sought at the EU-25 National Communications to UNFCCC. Climate policy research experts' preferences in criteria were included since their work aims to assist the PMs. Target groups are the entities to which the policy

instruments are imposed by the PMs. PMs take into consideration their comments (in public discussions and position papers) before the implementation of a new instrument (Konidari and Mavrakis, 2007).

For the first level concerns the primary objective of all climate policy mitigation instruments. The goal of these instruments is to be effective in mitigating climate change through GHG emissions reductions. At the second level three criteria are included: environmental performance, political acceptability and feasibility of implementation. Their definitions, along with those of the corresponding sub-criteria that support them and form the third level, are quoted as follows.

Environmental performance is defined as the overall environmental contribution of the policy instruments towards the goal. Assessment under this criterion is based on the sub-criteria:

- Direct contribution to reduction of GHG emissions - synthesis and magnitude of GHG emissions reductions directly referred to and attributed only to the policy instruments;
- Indirect environmental effects - ancillary outcomes attributed only to the policy instruments.

Political acceptability is defined as the attitude of all involved entities towards the policy instruments. Assessment is facilitated through its sub-criteria:

- Cost effectiveness - property of the PI to achieve the goal under the perspective of a financial burden acceptable and affordable by the involved entities (target groups);
- Dynamic cost efficiency - property of the PI to create, offer or allow compliance options that support research projects, incremental and radical pioneer technologies and techniques, and institutional or organizational innovations leading to GHG emission reductions (Christiansen, 2001);
- Competitiveness - capacity of the entity to compete, under the particular PI, via price, products or services with other entities and maintain or even increase the magnitude of specific indicators describing its financial performance (Sinner, 2002);
- Equity - fairness of the PI in distributing emission rights, compliance costs and benefits among entities (countries/sectors) for accomplishing GHG emission reductions (Vaillancourt and Waaub, 2004). For international instruments two types of equity are considered, international (global) and inter-generational (IPCC, 2001). The first concerns equity among countries, while the second refers to the time horizon of the PI for confronting climate change. National PIs are examined for intra-country equity, which is equity within the country. Intra-country equity is divided into sector and social equity. Sector equity is the perceived fairness between different national sectors regarding the GHG emission reduction burden. Social equity is the perceived equity between different groups of society;
- Flexibility - the property of the PI to offer a range of compliance options and measures that entities are allowed to use in achieving reductions under a time frame adjusted according to their priorities;
- Stringency for non-compliance and non-participation - level of rigidity determined by provisions of the PI towards emitters that failed to comply or did not participate to its implementation.

Feasibility of implementation (or enforcement) is defined as the aggregate applicability of the PI linked with national infrastructural (institutions and human resources) and legal framework. Assessment is based on:

- Implementation network capacity - ability of all national competent parties to design, support and ensure the implementation of the PI. The capacity of the network is based on its trained personnel, technological infrastructure, credibility and transparency. The trained personnel concern the national human resources capable in supporting implementation of the PI. Technological infrastructure is the set of available technologies and techniques within the country that can be used for supporting implementation. Credibility is defined as the accuracy and consistency that characterize its activities, mainly measurements and elaboration of data necessary for implementation, promotion and steering of national compliance efforts. Transparency is defined as the openness of the implementation network towards target groups in providing them with clear information for the implementation of the PI and methods of operation.

- Administrative feasibility - aggregate work exerted by the regulatory implementation network during the enforcement of the PI;
- Financial feasibility - property of the PI to be implemented with low overall costs by the pertinent regulatory authorities.

(b) For the second step, the values for the weight coefficients of the aforementioned criteria/sub-criteria are those calculated in previous work of Konidari and Mavrakis (2007). More specifically, weight coefficients for attributes were defined in this step using the AHP procedure and based on the expressed preferences of the three groups actively involved in climate policy issues, policy makers, researchers and target groups. European Union stakeholders are the majority of these groups.

(c) The third step concerns the grading of the instrument's performance. The effectiveness of the j*th* instrument, denoted as U_j, is a function of its performances $U_{ji}(x_i)$ under the i criteria, denoted as x_i. $U_{ji}(x_i)$ are in turn a function of its performances under the respective sub-criteria (attributes). The performance of the j*th* instrument on a specific sub-criterion is graded through MAUT utility functions in the case that there are credible and available data.

The j*th* instrument is assigned a grade $u(v_{jik})$ (utility) under each k sub-criterion of the i criterion, because of its actually measured performance v_{jk}. Utilities for this paper are considered independent and linear for simplicity (Ananda et. al., 2005; Schaefer, 2001; Zeevaert et. al., 2001; Ahmed et. al., 1978).A linear function $u(v_{jik}) = a\, v_{jik} + b$, is used to calculate $u(v_{jik})$ in the scale of [0,100]. Coefficients a and b are defined for each k sub-criterion separately, solving a system with the following requirements. Grade $u(v_{jik})$ is equal to 100.0 (best) when the instrument has the highest v_{ijk} measured performance and equal to 0.0 (worse) for the lowest v_{ijk} measured performance (Pohekar and Ramachandran, 2006; Suslic et. al., 2001).

In the case that there are no credible and available data, the performance of the instruments on a specific sub-criterion is graded using SMART instead of MAUT. This preference in SMART is explained. $u(v_{jik})$ can not be determined due to the absence of data and another approach was sought for grading the performances. Direct assessment from decision makers is preferred, but since decision maker's opinion is based on his/her subjective judgement and on unintentional comparisons between evaluated objects, an attempt was made to incorporate this situation. SMART is closer to MAUT since they both belong at the same family of MCDA methods and reflects this situation better. Direct assessments are converted to normalized grades expressing the relative importance (prefer ability) that a decision maker shows in performances of evaluated objects as in the case of weight coefficients of criteria.

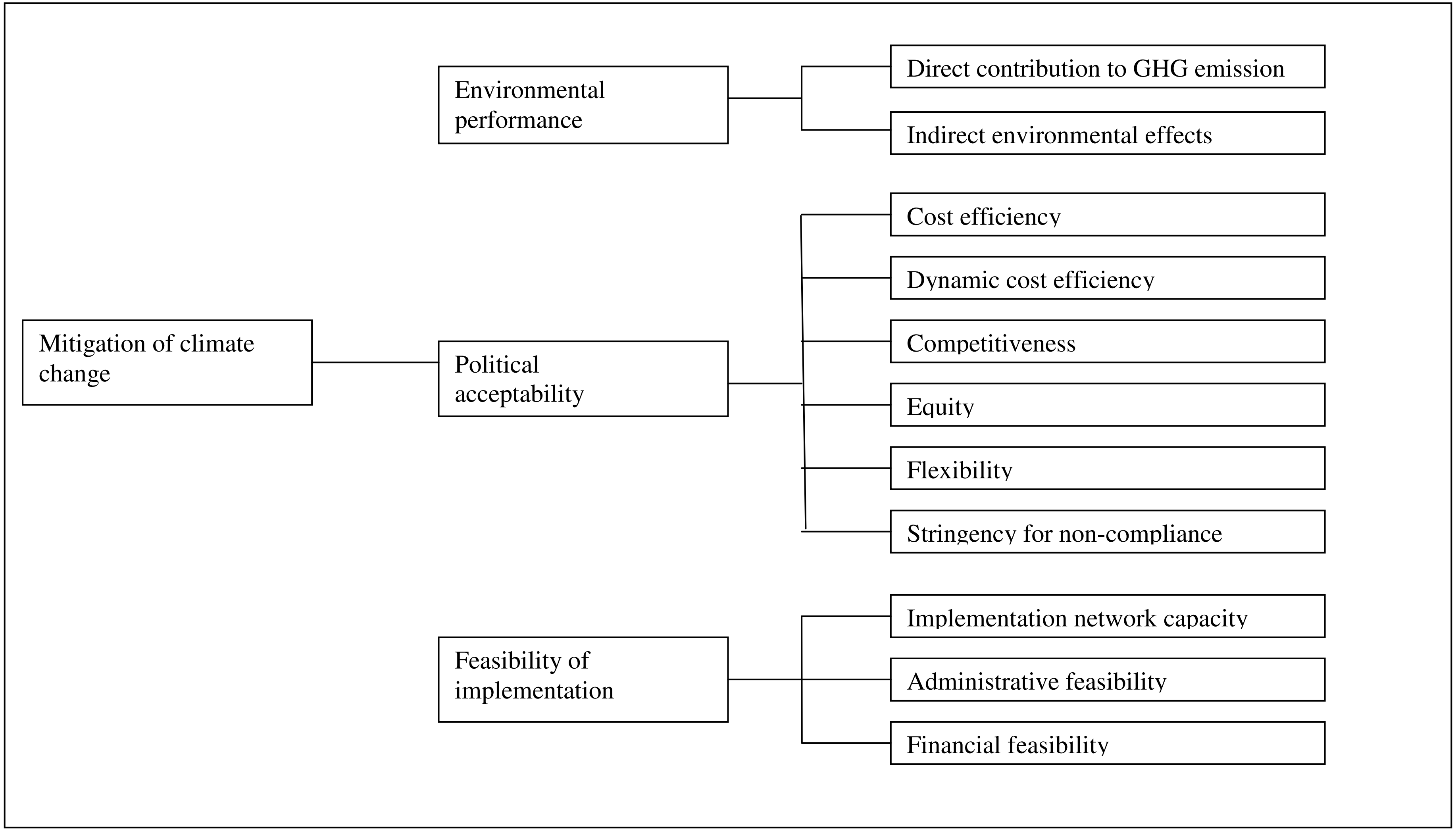

Figure 4: The AHP hierarchy.

The decision maker is asked to grade the performance of the instrument on a particular sub-criterion using scale. Taking m_k to stand for the grade assigned by the decision maker to the instrument for its performance at the k sub-criterion, $(\sqrt{2.51})^{m_k}$ is its un-normalized grade according to SMART (Lootsma, 1993; Lootsma and Barzilai, 1997). The normalized grades are calculated based on equation

$$normalized\ grade = \frac{(\sqrt{2.51})^{m_k}}{\sum_{k=1}^{n}(\sqrt{2.51})^{m_k}} \cdot 100$$

where n is the number of evaluated instruments under the k sub-criterion. Number 2.51 is used instead of number 2 of the SMART method, because 2.51 is the solution of equation $(\sqrt{x})^{10} = 100$. Using number 2.51, grade 10 corresponds to grade 100 of the MAUT scale.

(d) For the fourth step a grade (commonly measured performance) - determined in third step - of the assessed PI for a certain sub-criterion is multiplied with the respective weight coefficient of the sub-criterion. All products (concerning all sub-criteria) are added and form the grade of the criterion that is supported by these sub-criteria. The sum of these products is the grade of the PI under the criterion. This criterion grade is multiplied with the respective weight coefficient of the criterion.

All new products are added and form the final grade, which expresses the effectiveness of the evaluated PI.

More specifically:

$$U_j = w_1 U_{j1}(x_1) + w_2 U_{j2}(x_2) + w_3 U_{j3}(x_3) = \sum_{i=1}^{3} w_i U_{ji}(x_i)$$

The instrument or policy mix with the highest grade is the most effective.

Testing consistency of weight coefficients

Consistency of weight coefficients is tested using two different approaches. The first approach is based on the consistency index of the AHP method by Saaty. The index is calculated as

$$CI = \frac{\lambda_{max} - n}{n-1},$$

where CI is the consistency index,

λ_{max} is the maximum eigenvalue of the matrix and n is the rank value of the matrix. The random ratio of consistency is obtained using equation $CR^* = \frac{CI}{CR}$ where CR is the corresponding mean random index of consistency. CR receives the following values; 0 for a 2x2 matrix, 0.58 for 3x3, 0.90 for 4x4, 1.12 for 5x5, 1.24 for 6x6, 1.32 for 7x7, 1.41 for 8x8 and 1.45 for 9x9. A matrix is consistent if CR*<0.10. Otherwise, the matrix is not consistent and its value should be adjusted.

The second approach was developed by Peláez J.I. and Lamata M.T. in 2002. The consistency index CI is now a function of the matrix size and not of its entries. More specifically the CI of a M_{nxn} matrix is given by the average of consistency indexes of the matrix transitivities, ie

$$CI(M_{nxn}) = \begin{cases} 0, & if \ \ n<3 \\ \det(M_{nxn}), & if \ \ n=3 \\ \dfrac{1}{NT(M_{nxn})} \sum_{i=1}^{NT(M_{nxn})} CI(\Gamma_i), & if \ \ n>3 \end{cases}$$

where NT(M_{nxn}) is the number of different transitivities given by $NT(M_{nxn}) = \begin{cases} 0, & if \ n=3 \\ \dfrac{n!}{3!(n-3)!}, & if \ \ n>3 \end{cases}$

and CI(Γ_i) is the consistency index of the transitivity Γ_i. The last is a weak order preference structure on a set of three alternatives A_i, A_j, A_k (criteria/sub-criteria for this paper) ie

	A_i	A_j	A_k
A_i	1	a_{ij}	a_{ik}
A_j	$1/a_{ij}$	1	a_{jk}
A_k	$1/a_{ik}$	$1/a_{jk}$	1

Calculated CIs are assessed against the produced by 100.000 simulations CI values of Peláez J.I. and Lamata M.T. for different matrices and percentiles. A percentile of distribution is the critical value of the consistency index CI of this approach. The selected percentile is 0.10 (respectively to that of Saaty's method). The CIs values are 0.166 for a 3x3 matrix, 8.303 for a 6x6 matrix.

Testing robustness and uncertainty

Potential users perform sensitivity analysis (SA) for checking the robustness of the results.

Software

Clim-AMS is an integrated software tool used for evaluations within the area of climate change policy. The purpose of developing this tool is to facilitate policy makers in their decisions since it is designed for ex-ante selection and ex-post assessment based on the aggregate efficiency of policy instruments. It measures the effectiveness of climate policy instruments under the aforementioned set of criteria applicable for all types of climate policy instruments (Konidari, Thomaidis, 2006).

The user is guided through the whole software with help buttons available in all window forms and error messages appearing in case of inappropriate inputs. No specific knowledge or effort is required from the user regarding the background calculations, but only his/her effort in providing the relevant data and assessments.

Clim-AMS has incorporated the set of weight coefficients produced under the aforementioned procedure. The user may accept the values of these weight coefficients or re-calculate them. In the second case the consistency of the new weight coefficients is tested against two indexes of Saaty and of Peláez J.I. and Lamata M.T..

Advantages – Disadvantages

AMS is a simple, reliable, flexible, utilitarian and convenient evaluation tool that can satisfy the needs of climate policy evaluation. The tool is simple, because it requires the minimum inputs and efforts from the perspective of MCDM. Also, it is reliable because the proposed set of criteria is based on the official expressed preferences of three stakeholder groups involved in climate policy issues. The disadvantage is that it is a recently developed method, compared to the others, therefore it doesn't count so many applications.

Applications

The method has been applied for evaluating the performance of EU-ETS in eight EU member States[1] and the overall interaction of two pairs of climate policy instruments, EU-ETS and IPPC, EU-ETS and RES under the Hellenic framework. AMS method was adjusted properly for assessing aggregately climate change policy interactions or relevant policy mixes.

1 Denmark, Germany, Greece, Italy, Netherlands, Portugal, Sweden and United Kingdom (UK)

References

Akash BA, Mamlook R, Mohsen MS., 1999. Multi-criteria selection of electric power plants using analytical hierarchy process. Electric Power Systems Research 52, pp 29–35.

Aldy J. E., Ley E., Parry I., 2008. A Tax-Based Approach to Slowing Global Climate Change. Resources for the Future, Discussion Paper, pp 08-26.

André F.J., Riesgo L., 2007. A non-interactive elicitation method for non-linear multiattribute utility functions: Theory and application to agricultural economics. European Journal of Operational Research 181, 2, pp 793-807.

Aras H, Erdogmus S, Ko E., 2004. Multi-criteria selection for a wind observation station location using analytic hierarchy process. Renewable Energy 29, pp 1383–1392.

Bana e Costa C.A., Correa E.C., De Corte J.M., Vansnick J.C., 2002. Facilitating bid evaluation in public call for tenders: a socio-technical approach. Omega 30, pp 227 – 242.

Barzilai, J. 1997. Deriving weights from pairwise comparison matrices, Journal of the Operational Research Society 48, pp 1226–1232.

Beccali M., Cellura M., Mistretta M., 2003. Decision making in energy planning-application of the Electre method at regional level for the diffusion of renewable energy technology. Renewable Energy 28, pp 2063-2087.

Belton S. and Stewart T.S., 2002. Multiple Criteria Decision Analysis. An Integrated Approach, Kluwer Academic Publishers, Massachusetts.

Betz R., Eichhammer W., Schleich J., 2004. Designing national allocation plans for EU emissions trading - A first analysis of the outcomes. Energy and Environment 15, 375-425.

Bonney M., 2000. Climate Change Policies in the Netherlands: Analysis and Selection. Workshop on Best Practices in Policies and Measures, 11 – 13 April 2000, Copenhagen, Denmark.

Brugha CM., 2004. Phased multicriteria preference finding. European Journal of Operational Research 158, pp 308-316.

Chattopadhyay D, Ramanathan R. 1998. A new approach to evaluate generation capacity bids. IEEE Transactions on Power Systems 13, pp 1232–1237.

Chatzimouratidis AI, Pilavachi PA., 2009. Technological, economic and sustainability evaluation of power plants using the Analytic Hierarchy Process. Energy Policy 37, pp 778–787.

Christiansen A.C., 2001. Climate Policy and dynamic efficiency gains. A case study on Norwegian CO_2-taxes and technological innovation in the petroleum sector. Climate Policy 1, pp 499-515.

Climaco J., 1997. Multicriteria analysis. New York. Springer-Verlag.

Department for Communities and Local Government (DCLG), 2009. Multi-criteria analysis: A manual. London, U.K., ISBN: 978-1-4098-1023-0.

Dong Y., Xu Y., Li H., Dai M., 2008. A comparative study of the numerical scales and the prioritization methods in AHP. European Journal of Operational Research 186, pp 229-242.

Edwards W., 1977. How to use multiattribute utility measurement for social decision making. IEEE Transactions on Systems Man and Cybernetics, SMC–7, pp 326–340.

Edwards W., Barron F.H., 1994. Smarts and Smarter: Improved Simple Methods for Multi Attribute Utility Measurement. Organizational Behaviour and Human Decision Processes 60, pp 306-325.

Ehrhardt J, Shershakov VM., 1996. Real-time on-line decision support systems (RODOS) for off-site emergency management following a nuclear accident - Final Report. Luxemburg: European Commission.

Expert Choice, 2000. Expert Choice 2000 2nd Edition for Groups. http://www.expertchoice.com

Elkarni F, Mustafa I.,1998. Increasing the utilization of solar energy technologies (SET) in Jordan: analytic hierarchy process. Energy Policy 2, pp 1978–1984.

European Community (EC), 2010. Combating climate change European Parliament resolution of 11 March 2009 on an EU strategy for a comprehensive climate change agreement in Copenhagen and the adequate provision of financing for climate change policy. Official Journal C 87E, 1.4.2010, pp 90–94.

European Community (EC), 2011. Opinion of the European Economic and Social Committee on the ‘Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions — International climate policy post-Copenhagen: Acting now to reinvigorate global action on climate change’ COM(2010) 86 final. C 51, 17.2.2011, pp 69–74.

European Environment Agency (EEA), 2003. Assessment of information related to waste and material flows. A catalogue of methods and tools. Prepared by: D. Fatta and S. Moll. European Topic Centre on Waste and Material Flows, Technical Report 96. Copenhagen, Denmark. ISBN: 92-9167-577-6.

European Environment Agency (EEA), 2007. Fifth Specific Agreement EEA Research Foresight for Environment and Sustainability. Final Report. Framework Contract No. EEA/AIR/04/007. Prepared by: W.Sheate, T.Zamparutti, S.Bennett, M. Rogeli, 15 November.

European Environment Agency (EEA), 2010. The European environment – state and outlook 2010.

Figueira J. and Roy B., 2002. Determining the weights of criteria in the ELECTRE type methods with a revised Simos' procedure. European Journal of Operational Research 139, pp 317-326.

Georgopoulou E., Sarafidis Y., Diakoulaki D., 1998. Design and implementation of a group DSS for sustaining renewable energies exploitation. European Journal of Operational Research 109, pp 483-500.

Georgopoulou E., Sarafidis Y., Mirasgedis S., Zaimi S., Lalas D.P., 2003. A multiple criteria decision-aid approach in defining national priorities for greenhouse gases emissions reduction in the energy sector. European Journal of Operational Research 146, pp 199–215.

Golabi K, Kirkwood CW, Sicherman A., 1981. Selecting a portfolio of solar energy projects using multiattribute preference theory. Management Science 22, pp 174–189.

Gómez-Limón A.J. Martínez Y., 2006. Multi-criteria modeling of irrigation water market at basin level: a Spanish case study, European Journal of Operational Research 173, pp. 313–336.

Grafakos S., Flamos A., Oikonomou V., Zevgolis D., 2010. Multi-criteria analysis weighting methodology to incorporate stakeholders' preferences in energy and climate policy interactions. International Journal of Energy Sector Management 4, 3, pp 434-461.

Greening L.A., Bernow S., 2004. Design of coordinated energy and environmental policies: use of multi-criteria decision-making. Energy Policy 32, pp 721–735.

Hamalainen RP, Lindstedt M, Sinkko K. 2000. Multi-attribute risk analysis in nuclear emergency management. Risk Analysis 20, pp 455–468.

Hamalainen RP, Kettunen E, Ehtamo H. 2001. Evaluating a framework for multistakeholder decision support in water resources management. Group Decision and Negotiation 10, pp 331–353.

Heuberger R., Sutter C., Santos L., 2003. Host Country Approval for CDM projects in Uruguay: Application of a Sustainability Assessment Tool.
http://www.up.ethz.ch/publications/documents/CDM_Sustainability_ETH_Uruguay.pdf

Hwang C.-L., Masud, A.S.M., 1979. Multiple Objective Decision Making-Methods and Applications. Lecture Notes in Economics and Mathematical Systems 164. Springer, Berlin.

Hobbs B.F., Horn G.T.F., 1997. Building public confidence in energy planning: a multimethod MCDM approach to demand-side planning at BC gas. Energy Policy 25, pp 357-375.

IPCC, 2001. Climate Change 2001: Mitigation, Contribution of Working Group III to the third assessment report of the Intergovernmental Panel of Climate Change, IPCC.

IPCC, 2007. Climate Change 2007: Mitigation, Contribution of Working Group III to the fourth assessment report of the Intergovernmental Panel on Climate Change, IPCC.

ISO/IEC 9126, 1991. Information technology – Software product evaluation – quality characteristics and guidelines for their use. Geneva.

Jayanath A. and Gamini H., 2005. Evaluating public risk preferences in forest land-use choices using multi-attribute utility theory. Ecological Economics 55, pp 408-419.

Jones M, Hope C, Hughes R. 1990. A multi-attribute value model for the study of UK energy policy. Journal of Operations Research Society 41, 10, pp 919–29.

Kablan M.M., 2004. Decision support for energy conservation promotion: an analytic hierarchy process approach. Energy Policy 32, pp 1151-1158.

Karagiannidis A. and Perkoulidis G., 2009. A multi-criteria ranking of different technologies for the anaerobic digestion for energy recovery of the organic fraction of municipal solid wastes. Bioresource Technology 100, pp 2355-2360.

Keeney R.L. and Raiffa H., 1976. Decisions with multiple objectives. New York: Cambridge University Press.

Kiker G.A., Bridges T.S., Varghese A., Seager T. P., Linkov I., 2005. Application of Multicriteria Decision Analysis in Environmental Decision Making. Integrated Environmental Assessment and Management 1, pp 95–108.

Konidari P. and Mavrakis D., 2006. Multi-criteria evaluation of climate policy interactions. Journal of Multi-Criteria Decision Analysis 14, pp 35 – 53.

Konidari P. and Mavrakis D., 2007. A multi-criteria evaluation method for climate change mitigation policy instruments. Energy Policy 35, pp 6235-6257.

Konidari P., Thomaidis F., 2006. Clim-AMS, the software tool for climate policy evaluations. MCDA64, Euro Working Group of & Multi-criteria Decision Aiding, September 28-29 2006, Larisa, Greece.

Korhonen P., Moskowitz H., Wallenius J., 1992. Multiple criteria decision support - A review. European Journal of Operational Research 63, pp 361-375.

Lahdelma R., Salminen P., Hokkanen J., 2000. Using multicriteria methods in environmental planning and management. Environmental Management 26, pp 595-605.

Logical Decisions, 2003. Logical Decisions for Windows. Version 5.1. http://www.logicaldecisions.com.

Lootsma F.A., 1993. Scale sensitivity in the multiplicative AHP and SMART. Journal of Multi-criteria decision analysis 2, pp 87-110.

Lootsma F.A. and Barzilai J., 1997. Power relations and Group Aggregation in the Multiplicative AHP and SMART. Journal of Multi-criteria decision analysis 6, pp 155-165.

Macharis C., Springael J., De Brucker K., Verbeke A., 2004. PROMETHEE and AHP: The design of operational synergies in multicriteria analysis. Strengthening PROMETHEE with ideas of AHP. European Journal of Operational Research 153, pp 307–317.

Marttunen M, Hamalainen RP. 1995. Decision analysis interviews in environmental impact assessment. European Journal of Operational Research 87, pp 551–563.

McDaniels TL, 1996. A multiattribute index for evaluating environmental impact of electric utilities. Journal of Environmental Management 46, pp 57–66.

Meirer P. and Mubayi V., 1983. Modelling energy-economic interactions in developing countries-a linear programming approach. European Journal of Operations Research 13, pp 41-59.

Mickwitz, P., 2003. A Framework for Evaluating Environmental Policy Instruments. Evaluation 9, 415–436.

Moffett A., Garson J., Sarkar S., 2005. MultCSync: a software package for incorporating multiple criteria in conservation planning, Environmental Modelling and Software 20, pp 1315–1322.

Mustajoki J. and Hämäläinen R. P., 2007. Smart-Swaps — A decision support system for multicriteria decision analysis with the even swaps method. Decision Support Systems 44, 1, pp 313-325.

Mustajoki J., Hämäläinen R.P. Marttunen M., 2004. Participatory multicriteria decision support with Web-HIPRE: a case of lake regulation policy. Environmental Modelling and Software 19, pp 537–547.

Nijcamp P. and Volwahsen A., 1990. New directions in integrated energy planning. Energy Policy 18, 8, pp 764-773.

Olson D.L., 2001. Comparison of three multicriteria methods to predict known outcomes. European Journal of Operational Research 130, pp 576-587.

Ossadnik W. and Lange O., 1999. AHP-based evaluation of AHP-Software. European Journal of Operational Research 118, pp 578-588.

Peláez J. I. and Lamata M. T., 2002, "A new measure of consistency for positive reciprocal matrices", Computers & Mathematics with Applications, Volume 46, Issue 12, December 2003, Pages 1839-1845

Papadopoulos A.M. and Karagiannidis A, 2008. Application of the multi-criteria analysis method ELECTRE III for the optimization of decentralized energy systems. Omega 36, pp 766-776.

Pohekar S.D. and Ramachadran M., 2004. Application of multi-criteria decision making to sustainable energy planning – A review. Renewable and Sustainable Energy Reviews 8, pp 365-381.

Pohekar S.D. and Ramachandran M., 2006. Multi-criteria evaluation of cooking devices with special reference to utility of parabolic solar cooker (PSC) in India. Energy 31, pp 1215-1227.

Polatidis H., Haralambopoulos D., Munda G., Vreeker R., 2006. Selecting an Appropriate Multi-Criteria Decision Analysis Technique for Renewable Energy Planning. Energy Sources, Part B, 1, pp 181-193.

Prato T. 2003. Multiple-attribute evaluation of ecosystem management for the Missouri River system. Ecological Economics 45, pp 297–309.

Ramanathan R. 2001. A note on the use of the analytical hierarchy process for environmental impact assessment. J Environmental Management 63, pp 27–35.

Ramanathan R. and Ganesh L.S., 1990. A multi-objective programming approach to energy resource allocation problems. International Journal of Energy Research 17, pp 105–119.

Rahman S. and Frair L.C., 1994. A hierarchical approach to electric utility planning. International Journal of Energy Research 8, pp 185–196.

Ramanathan R. and Ganesh L.S., 1995. Energy resource allocation incorporating quantitative and qualitative criteria: an integrated model using goal programming and AHP. Socio Economic Planning Sciences 29, pp 197–218.

Rangel L.A.D., Gomes L.F.A.M., Moreira R.A., 2009. Decision Theory with Multiple Criteria: an Application of Electre IV and Todim to Sebrae/Rj. Pesquisa Operacional 29, pp 577-590.

Rogers M, Bruen M. 1998. Choosing realistic values of indifference, preference and veto thresholds for use with environmental criteria within ELECTRE. European Journal of Operational Research 107, pp 542–551.

Saaty, T.L., 1980. The analytic hierarchy process. New York: McGraw-Hill.

Saaty, T.L., 1985. Transport Planning with Multiple Criteria: The Analytic Hierarchy Process Applications and Progress Review. Journal of Advanced Transportation 29, I, pp 81-126.

Salminen P., Hokkanen J., Lahdelma R., 1998. Comparing multicriteria methods in the context of environmental problems. European Journal of Operational Research 104, pp 485-496.

Sarkis J. and Sundarraj P., 2000. Factors for strategic evaluation of enterprise information technologies. International Journal of Physical Distribution & Logistics Management 30, pp 196-220.

Sinner, J., 2002. Addressing competitiveness impacts of climate change policies. A report to the Ministry of Economic Development, pp 1. http://www.med.govt.nz/upload/20940/competitiveness.pdf

Shin W.S. and Ravindran A., 1991. An interactive method for multiple-objective mathematical programming problems, Journal of Optimization Theory and Applications 68, pp 539-561.

Sorvari J., 2010. Application of Risk Assessment and Multi-Criteria Analysis in Contaminated Land Management in Finland. Finnish Environment Institute, Helsinki, Finland. ISBN 978-952-11-3800-3.

Stagl S., 2007. SDRN rapid research and evidence review on emerging methods for sustainability valuation and appraisal. SDRN, London, U.K.

Steuer R.E.. 1986. Multiple Criteria Optimization: Theory, Computation and Application, John Wiley, New York, pp 546.

Steuer, R.E. and Choo, E.-U., 1983. An interactive weighted Tchebycheff procedure for multiple objective programming. Mathematical Programming 26, pp 326–344.

Suslick S. and Furtado R., 2001. Quantifying the value of technological, environmental and financial gain in decision models for offshore oil exploration. Journal of Petroleum Science and Engineering 32, pp 115-125.

SYKE, Finnish Environment Institute, 2007. Assessing the adaptive capacity of the Finnish environment and society under a changing climate: FINADAPT. Summary for policy makers written by Timothy R. Carter, Helsinki.

Theodorou S., Florides G., Tassou S., 2010. The use of multiple criteria decision making methodologies for the promotion of RES through funding schemes in Cyprus, A review. Energy Policy 38, pp 7783–7792.

Tzeng G.H. and Tsaur S.H., 1990. Application of multicriteria decision making to old vehicle elimination in Taiwan. International Conference on MCDM Taipei. Book of proceedings, vol 4, pp 268–283.

UNEP, 1994. UNEP Greenhouse Gas Abatement Costing Studies – Phase Two, UNEP collaborating centre on Energy and Environment, Riso, Denmark.

UNFCCC, 2002. "Input of the least developed countries expert group on the improvement of the guidelines for the preparation of national adaptation programmes of action", FCCC/SBI/2002/INF.14, United Nations Office Geneva, Geneva, Switzerland.

URL1: Denmark's National Allocation Plan 2008-12, 12 March 2007.English courtesy translation of Denmark's National Allocation Plan notified to the European Commission 7 March 2007.
http://193.88.185.141/Graphics/Energipolitik/dansk_energipolitik/CO2_kvoter/allokering/NAP2_godk_eng.pdf

URL 2: National Assessment and Best Climate Change Policy Practices of the Netherlands, http://www.worldenergy.org/documents/wec_ecc_study_national_assessment_netherlands.pdf.

URL 3: Nederlands nationaal toewijzingsplan broeikasgasemissierechten 2008-2012. Plan van de Minister van Economische Zaken en de Minister van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer Vastgesteld op 16 mei 2007 Geconsolideerde versie (Stcrt. 2008, nr. 132), in Dutch.
http://www.senternovem.nl/mmfiles/NAP-II%20Definitief%20geconsolideerde%20versie%20juli%202008%20%28Stcrt.%202008%2C%20nr.%20132%29%20v2_tcm24-283768.pdf

URL 4: Sweden's national allocation plan for emission allowances 2008-2012. 31 August 2006. Ministry of Sustainable Development. Courtesy translation 15 September 2006. **http://www.sweden.gov.se/content/1/c6/06/97/78/9ab84663.pdf**

URL 5: http://www.1000minds.com.

URL 6: http://www.catalyze.co.uk/products/hiview.

U.S. Environmental Protection Agency (EPA), 2009. Development and Evaluation of Sustainability Criteria for Land Revitalization. Revitalization Research Program
National Risk Management Research Laboratory Office of Research and Development. EPA/600/R-09/093, July.

Vargas L.G., 1990. An overview of the analytic hierarchy process and its applications. European Journal of Operational Research 48, pp 2-8.

Vaillancourt, K. and Waaub, J.-P., 2004. Equity in international greenhouse gases abatement scenarios: a multicriteria approach. European Journal of Operational Research 153, pp 489–505.

Voropai N.L. and Ivanova E.Y., 2002. Multicriteria decision analysis technique in electric power system expansion planning. Electrical Power and Energy Systems 24, pp 71–78.

Wang J.J., Y.-Y. Jing, C.-F. Zhang, J.-H. Zhao, 2009. Review on multi-criteria decision analysis aid in sustainable energy decision-making. Renewable and Sustainable Energy Reviews 13, pp 2263–2278.

Wang X. and Feng Z., 2002. Sustainable development of rural energy and its appraisal system in China. Renewable and Sustainable Energy Reviews 6, pp 395–404.

Wakeman JS., 2003. Milltown reservoir sediment/Clark Fork River superfund site focused feasibility study. U.S. EPA.

Wierzbicki A.P., 1980. The use of reference objective in Multiobjective Optimization. In: Fandel, G., Gal, T. (Eds.), Multiple Criteria Decision Making, Theory and Application. Springer, Berlin, pp 468–486.

Yedla S. and Shreshtha R.M., 2003. Multicriteria approach for selection of alternative option for environmentally sustainable transport system in Delhi. Transportation Research part A, 37, pp 717–29.

Zanakis S.H., Solomon A., Wishart N., Dublish S., 1998. Multi-attribute decision making: A simulation comparison of select methods. European Journal of Operational Research IO7, pp 507-529.

Zong W. and Zhihong W., 1997. Mitigation assessment results and priorities for China's energy sector. Applied Energy 56, pp 237–251.

Zopounidis C. and Doumpos M., 2002. Multi-criteria Decision Aid in Financial DecisionMaking: Methodologies and Literature Review. Journal of Multi-Criteria Decision Analysis 11, pp 167–186.

PART II

Selection of multi-criteria evaluation method(s) for M/A policy instruments

by
Dr. Popi KONIDARI,
NKUA-KEPA (Greece)

Abbreviations

AHP	- Analytical Hierarchy Process
AMS	- Combination of **A**HP, **M**AUT and **S**MART
CDM	- Clean Development Mechanism
DM	- Decision Maker
ELECTRE	- Elimination Et Choix Traduisant le REalité
GWP	- Global Warming Potential
LEAP	- Long-rang Energy Alternatives Planning System
M/A	- Mitigation/Adaptation
MAUT	- Multi-Attribute Utility Theory
MAVT	- Multi-Attribute Value Theory
MCDA	- Multi-Criteria Decision Analysis
NAMAs	- Nationally Appropriate Mitigation Actions
NPV	- Net Present Values
PROMETHEE	- Preference Ranking Organization METHod of Enrichment Evaluation
SMART	- Simple Multi-Attribute Rating Technique

1. Description of the problem

The development of a policy portfolio mixture for climate change mitigation/adaptation raises the issue of its evaluation. Furthermore the development of a number of these portfolios at regional level among countries with different profiles raises the issue of their comparative evaluation and through them the selection of the optimum alternatives.

In this concept the aim of this chapter is to conclude with the optimum method among those already used in the international scientific bibliography to fulfill both two issues.

Each M/A policy portfolio for a selected country is evaluated against a number of criteria/subcriteria that reflect environmental, financial, social and administrative requirements using as a tool a selected Multi-Criteria Decision Analysis (MCDA) method in order to conclude with the most efficient one.

To achieve this aim, the method should contain justifications regarding success or failure under each sub-criterion based on the available national data and information and the outputs of the energy model that is used for constructing each scenario/policy portfolio. Therefore, sub-criteria need to be linked with certain model outcomes; while for those not available information and data from national reports and the databases are to be used.

The most effective policy portfolio has to have the best performance compared to the other ones, while strengths and weaknesses should also be identified and commented providing preferable policy interactions between the policy instruments that form it. The outcomes of the method need to be in such a form that any Decision Maker (DM) – without knowing in depth the methodological background of the method - to be able to understand and use it.

In conclusion the evaluation aims to support the implementation of the post-2012 climate change agreement by identifying the most effective M/A policy portfolios for each country under consideration and among of a group of countries. A final M/A policy portfolio will be also compared and evaluated with similar portfolios of other countries.

2. Comparison and selection of a multi-criteria evaluation method

There are a large number of MCDA methods. None of them is appropriate for all types of decision making problems, but certain methods fit better in assisting a DM towards a specific problem (Polatidis H. et al., 2006; Joubert A.R. et al., 1997). As Roy B. pointed out in 1985 the principle aim is not to discover a solution but to construct or create something, which is likely to help "*an actor taking part in a decision process to shape and/or to argue and/or to transform his preferences or to make a decision in conformity with his goals*". This view has been adopted by other researchers also (Browne D., Ryan L., 2010; Salgado P.P. et al., 2009). The multi-criteria evaluation method that will be selected needs to fulfill the requirements as they were quoted in the "Description of the problem".

In facilitating the selection of the most appropriate MCDA method for the specific evaluation, AHP, MAUT, SMART, AMS, ELECTRE and PROMETHEE[2] are compared against the following elements:

(a) Objectives;

(b) Assumptions;

---

[2] PROMETHEE is presented at the end of the chapter. This method was included since a number of published research work for climate change policy issues uses it (see Table 1).

(c) Methodology;

(d) Advantages-Disadvantages;

(e) Relevant software.

The method that fulfils successfully most of these elements will be used.

2.1. *Objectives*

At the end of the procedure, one M/A policy portfolio will be characterized as most effective according to the specific national framework of an examined country. The selected method needs to satisfy the objectives of this evaluation though its: i) Outcomes; ii) Set of criteria/subcriteria; iii) Ability to incorporate model outcomes.

Outcomes

All methods are able to identify the "best" alternative out of a set of possible scenarios/policy portfolios. They share common mathematical elements since scores are assigned to the alternatives for a number of criteria/sub-criteria, then multiplied with the respective weight coefficients and finally combined to produce the total score. The methods differ on how the scores and the weight coefficients are assigned and combined. The followed processes require different forms of data and information while the total scores have different mathematical properties and slightly different meanings (Huang I.B. et al., 2011). Multi-attribute utility methods (AHP, MAUT, SMART, AMS) aggregate all points of view into a unique function which is to be optimized, while outranking methods (ELECTRE, PROMETHEE) construct and exploit a synthesizing relation based on the decision maker's preferences (Gamper C.D., Turcanu C., 2007).

As already mentioned, the main concept of the ELECTRE family methods is a system of binary outranking relations between the alternatives. Sometimes ELECTRE is unable to identify the preferred alternative and produces only a core of leading alternatives, due to a not necessarily complete system (regarding the use of the three thresholds) (Huang I.B., et al., 2011; Wang J.J. et al., 2009; Georgiou P. et al., 2008; Gilliam S. et al., 2005; Pohekar S.D., Ramachandran M., 2004). Some of the alternatives may remain incomparable due to an inadequate number of arguments to support the hypothesis that one alternative is as good as the other (Georgiou P. et al., 2008). This family of methods is convenient when encountering few criteria and a large number of alternatives because it offers a clearer view of the alternatives by eliminating the less favorable ones (Wang J.J. et al., 2009; Pohekar S.D., Ramachandran M., 2004; Beccali M. et al., 2003; Georgopoulou E. et al., 2003).

PROMETHEE belongs in the same category with ELECTRE and is able for partial or full ranking of the alternatives. Its outcome is a ranking of the best to the worst alternatives showing which more are preferred if all criteria are taken into consideration (Wang J.J, Yang D.L., 2007; Diakoulaki D. et al., 2007). Additionally, there are applications showing that it has the same results with SMART, MAUT and AHP (Geldermann J. and Rentz O., 2005; Ayoko G. et al., 2004; Salminen P. et al., 1998).

AMS has been designed especially for climate change policy evaluations. Its outcomes provide a full ranking of the alternatives exhibiting strengths and weaknesses. For fulfilling completely the need to conclude with the "most efficient" M/A policy portfolio by taking into consideration the type and level of emerging policy interactions only AMS has been used for such an approach (Konidari P., Mavrakis D., 2007).

Set of criteria/sub-criteria

Although each country has its own needs and priorities, the aim of the under discussion policy instruments is common; confronting and adapting to climate change. Out of all presented methods only AMS has already a complete set of criteria for evaluating climate change policy instruments and their interactions. The hierarchical order of this set has been verified and used for one least developed country, Trinidad & Tobago (Blechinger P., Shah K., 2011). For the other methods – apart from AHP - any set of criteria/sub-criteria needs to be defined and adjusted properly.

Ability to incorporate model outcomes

Depending on the set of criteria/subcriteria that is to be used the outcomes of an energy model need to be incorporated appropriately. There are cases at which an energy model was combined with a multi-criteria evaluation method particularly for M/A policy issues. The combination of AHP and MAUT has been used in evaluating a number of developed through the LEAP model policy scenarios (Phdungsilp A., 2010; Phdungsilp A., 2006). AMS has been used in combination with the Green-X model for evaluating policy scenarios regarding the penetration of RES-E in Greece (Kampezidis H. et al., 2011). No other combination between any of the particular six multi-criteria evaluation methods and energy models has been mentioned (Ishizaka A., Labib A., 2011; Behzadian M. et al., 2010).

Conclusion for objectives

AMS appears most suitable for complying with the objectives of this evaluation compared to the other methods. AMS has been designed particularly for M/A policy issues. It exhibits the alternative with the highest performance and simultaneously weaknesses and strengths can be identified. It is the only method out of the six presented that is used specifically for evaluating policy interactions.

2.2. *Assumptions*

All methods use certain mathematical processes in concluding to their results. Under "Assumptions" the methods are compared against their basic mathematical elements and how these comply with the needs of the evaluation.

Mathematical background

All MCDA methods have their mathematical background presented and established through the respective published work. Several papers can be found supporting this argument.

AHP is justified mathematically (Kablan M.M., 2004). It is a mathematical theory of value, reason and judgment, based on ratio scales (Eakin H., Bojorquez-Tapia L.A., 2008).

MAUT has the soundest theoretical structure of all the multi-criteria techniques (Gomez-Limon J.A., Martinez Y., 2006). It allows complete compensation[3] among all the attributes, while the multi-attribute utility functions incorporate preferences and uncertainties over all attributes explicitly. "*The tradeoffs among the different attributes are made explicit by the derivation of the scaling constants.*

[3] "*Compensability refers to the existence of trade-offs i.e. the possibility of offsetting a disadvantage on some criteria by a sufficiently large advantage on another criterion, whereas smaller advantages would not do the same. Thus a preference relation in non-compensatory if no trade-off occurs and is compensatory otherwise. The use of weights with intensity of preference originates compensatory multi-criteria methods and gives the meaning of trade-offs to the weights.*" (Munda G., 2006, http://www3.aegean.gr/environment/energy/mcda/library/Deliverables/del_20/A_NAIADE_based_approach_for_sustainability_benchmarking.pdf

Hence this method has an advantage over lexicography[4] *where no tradeoffs between the attributes are allowed*" (Ananda J., Herath G., 2009).

SMART is a trade-off method that can be used for up to sixteen criteria (Oltean-Dumbrava C., Ashley R., 2006). Due to its compensatory characteristic it can hide unacceptable scores for criteria. Its results are considered as robust and replicate decisions from more complex MAUT analysis with a high degree of confidence (Linkov I. et al., 2004).

ELECTRE III is a non-compensatory MCDA method, using mathematical functions to indicate the level of preference of one alternative over the others (Rogers M., Bruen M., 1998). It has a solid scientific background (Theodorou S. et al., 2010).

The basic assumptions and their consequences for the PROMETHEE method were presented in the initial paper of Brans J.P. et al. in 1986 and of Keyser De Wim, Peeters Peter in 1996. Brans J.P. et al. showed also that this method is more stable than ELECTRE. It offers a sound scientific procedure for leading to its outcomes (Theodorou S. et al., 2010).

Each method has its advantages and drawbacks. Their combination aims to make use of the strengths of the selected methods and create operational synergies or their use in parallel to get a broader decision basis for the DM (Browne D. et al., 2010; Theodorou S. et al., 2010; Ananda J., Herath G., 2009; Macharis C. et al., 2004). Furthermore, the mathematical background of each one of them is used appropriately in these combinations. Problems in AHP related with the inclusion of new alternatives and criteria can be solved when SMART is implemented (Gilliams G. et al., 2005). The combination of AHP and SMART is considered as better suited for quality evaluation, while the simple value functions are best suited for determining the scores of the alternatives (Tsvetinov P.E., 2003). The choice of a linear function as the value function is in most cases sufficient (Tsvetinov P.E., 2003). In AMS the authors used the mathematical background of all three methods (AHP, MAUT and SMART). They reduced the time for applying the procedure and the complexity that AHP exhibits when used for criteria and alternatives without affecting its credibility. The scales for the scores assigned to the alternatives for their performance against the sub-criteria are positive.

Cases of combined methods are encountered in several applications: AHP and MAUT were combined for evaluating reforestation chain alternatives of a forest stand (Kangas J., 1993). AHP and SMART in evaluating and selecting service offers (Tsvetinov P.E., 2003) or measuring decisional power in groups (Honert Van Den R.C., 2001). AHP and PROMETHEE were used for outsourcing information systems (Wang J.J., Yang D.L., 2007); selecting the best module design for ultra filtration membrane in dairy industry (Pirdashti M., Behzadian M., 2009); ranking of enterprises (Babic Z., Plazibat N., 1998).

Weight coefficients, parameters, thresholds, indexes

A big drawback for the MAUT family is the difficulty that a DM has when trying to specify a tradeoff ratio between two different criteria such as "landscape degradation" and "employment" (Polatidis H. et al., 2006). In AMS this problem is handled. The main criteria are three; each one of which has sub-criteria that are evaluated on how they contribute to the main one. Additionally, the preferences of three (3) main stakeholder groups are taken into consideration and through the AHP procedure the weight coefficients are determined. Psychologists argue that it is easier and more accurate to express one's opinion only on two alternatives that simultaneously on all (Ishizaka A., Lablb A., 2011).

Additionally, "*The AHP approach employs a consistency test that can screen out inconsistent judgments, which makes the results reliable.*" (Kablan M.M., 2004). Two consistency indexes are used in the AMS method. The application of both indexes showed that the incorporation of the

[4] "*In the lexicographic decision-making method attributes are first rank-ordered in terms of importance. The alternative with the best performance on the most important attribute is chosen*." (Linkov I. et al. 2004).

stakeholders' preferences regarding the assigned importance to criteria/sub-criteria is well done and reasonable. The values of both indexes are within the numerical limits specified by the developers of these indexes indicating that results are reliable.

The main characteristic of ELECTRE TRI is the assignment of alternatives to pre-defined categories (Karakosta C. et al., 2009; Dias L. et al., 2002). Taking into consideration that some countries have not implemented climate change adaptation policy instruments, it is difficult at this phase to assign potential actions into pre-defined categories such as high, low priority or not recommended options. Furthermore, apart from the thresholds (common for all ELECTRE forms), upper and lower limits of the categories need to be defined (Malekmohammadi B. et al. 2011; Karakosta C. et al., 2009). This process is usually difficult – not only for ELECTRE TRI, but for the other types as well - particularly when decision makers are unsure of which values each parameter (thresholds and limits for the categories) should take (Malekmohammadi B. et al. 2011; Dias L. et al., 2002). Simultaneously they need to have a "*clear global understanding of the implications of these values in terms of the output of the method* (Malekmohammadi B. et al. 2011). In ELECTRE methods the thresholds are usually appealing, but they are not clearly defined with a physical or psychological interpretation (Theodorou S. at al., 2010).

PROMETHEE does not have a certain mathematical procedure for defining weight coefficients (Wang J.J, Yang D.L., 2007; Brans et al., 1986). Indifference and/or preference thresholds can be defined by the decision maker for each criterion (Diakoulaki D. et al., 2007). This procedure may be difficult to be completed particularly by an inexperienced DM (Patlitzianas K.D. et al., 2007; Wang J.J, Yang D.L, 2007).

Conclusion for assumptions

AHP and AMS fulfill better the needs of the evaluation under "Assumptions". AHP offers guidelines in defining the weight coefficients and has a consistency index for verifying their consistency. Due to these advantages it has been used in combination with other methods also. AMS has incorporated the AHP procedure.

2.3. *Methodology*

The main steps in structuring a general MCDA procedure are the following (Kambezidis H. et al., 2011; Phdungsilp A., 2010; Konidari P., Mavrakis D., 2007; Gamper C.D., Turcanu C., 2007; Joubert A.R. et al., 1997):

- Step 1: Characterization of the context and the type of the recommendation needed (e.g. ranking, choice etc);
- Step 2: Selection of the main criteria and sub-criteria;
- Step 3: Development of measurement scales for the sub-criteria;
- Step 4: Determination of the weight coefficients for the main criteria and sub-criteria;
- Step 5: Definition of decision actions/alternatives/scenarios;
- Step 6: Accession of the performance of the decision actions/alternatives/scenarios against the criteria/sub-criteria;
- Step 7: Aggregating scores;
- Step 8: Conducting sensitivity analysis;
- Step 9: Analysis of results and making decisions.

Under "Methodology" the methods will be compared against these steps and how they correspond to them so as to fulfill the evaluation needs.

Understanding the problem

The main objective for climate change policy instruments is the mitigation of greenhouse gas emissions and adaptation towards the negative impacts of climate change. A number of factors need to be taken into account when evaluating such instruments. In most emerging economies only the first component of climate change policy has been developed due to the investment opportunities created by the Clean Development Mechanism (CDM) and the recently emerged need to submit the Nationally Appropriate Mitigation Actions (NAMAs)[5] to the UNFCCC. Additionally, there is a need to understand what types of policy instruments perform better under the particular framework of these countries.

From all the described methods AHP presents better the problem. The main advantage of AHP is the decomposition of the problem into elements (Ishizaka A., Labib A., 2011; Berrittella et al., 2008). This advantage is justified also by the fact that AHP has been combined with almost all the other methods as mentioned earlier. Its hierarchical structure of criteria allows users to focus better on specific criteria and sub-criteria when determining the respective weight coefficients through the pairwise comparisons (Ishizaka A., Labib A., 2011).

Decision hierarchy in SMART can be set up in the same way as in AHP (Kangas J., Kangas A, 2005). AMS has incorporated this advantage in its methodology. Usually in ELECTRE all criteria or criteria of the same group are considered as of equal importance (Papadopoulos A., Karagiannidis A., 2006; Diakoulaki D., Karangelis F., 2006; Salminen P. et al., 1998). PROMETHEE does not provide the possibility of structuring the problem. In the case of many criteria, it is difficult for the DM to "*obtain a clear view of the problem and to evaluate the results*" (Wand J.J, Yang D.L., 2007).

Selecting criteria/sub-criteria and determination of their weight coefficients

It is of critical importance the selection of the criteria against which alternatives are assessed and the weights that are assigned for each criterion. Consequently, it is important to include the relevant stakeholders to elicit such information (Browne D. et al., 2010).

AHP may be impractical for a survey with a large sample size of as 'cold-called[6]' respondents, because they may have a great tendency to provide arbitrary answers, resulting in a very high degree of inconsistency (Wong K.W.J., Li H., 2008).

Only AMS exhibits a complete set of criteria/subcriteria for M/A policy issues. The majority of the commonly used criteria for mitigation/adaptation policy instruments formed its criteria/sub-criteria tree. This was based on the preferences of three (3) different groups of stakeholders all active for climate policy issues. Blechinger P. and Shah K. (2011) confirmed the criteria/sub-criteria tree of the AMS method based on the preferences of policy makers whom they interviewed. The main advantage of this set is that it is common for developed and developing countries.

This approach - used in AMS - is encountered in practice. Ananda J. and Gamini H. in 2003 incorporated preferences of six (6) different groups of actively involved stakeholders (timber industry, conservation movement, agricultural enterprises, tourism industry, aboriginal groups and the general community). In their conclusions they consider that "*AHP allows the participation of more than one person as a decision maker, which is important in dealing with several stakeholders groups*". Braunschweig T. in 2000 worked with two (2) groups. The first one included project leaders, research managers, individuals responsible for biotechnology and the second one experts from

5 Cancun Agreements – December 2010.

6 A telephone call or visit made to someone who is not known or not expecting contact.

different institutions. He considers as a shortcoming the fact that the end users (farmers, providers, processors and exporters) were not included so as to have a broader participation.

Measurement scales and assessment of the performance

AHP allows qualitative and quantitative approaches for solving a problem (Wong J.K.W., Li H., 2008). A number of studies have used MAUT without probability distributions, but with utility functions (Ananda J., Herath G., 2009). Olson D.L. in 2001 showed that MAUT and SMART are equivalent when using transformed measure scales (standardized to have the worst performance measured with 0 and the best with 1) regarding data with precise measures and known outcomes. In the same work he concluded that SMART and PROMETHEE exhibit the same accuracy.

Some of the input data for the method will come from the energy model LEAP and will have their own measurement scales. LEAP can calculate the individual and combined Global Warming Potential (GWP) of one or more greenhouse gases. The user can choose among two (2) measurement units: Carbon (C) equivalents and Carbon Dioxide (CO_2) equivalents. This outcome will be used in the first criterion of AMS, the "Environmental performance". Using the MAUT procedure scores - ranging from 0 up to 100 - will be assigned properly through utility functions (Konidari P., Mavrakis D., 2006).

LEAP provides cost-specific outcomes. It calculates the total social Net Present Values (NPV) of a computed scenario against a pre-specified baseline scenario. It does not specify the actual costs accruing to different groups, i.e. it deals with costs rather than prices. However, the NPV can be split up to determine the streams from each sector (households, industry, transport, services, electric supply, etc.). These outcomes will be used for the sub-criteria of AMS "cost effectiveness", "competitiveness" and "equity". LEAP can calculate the percentage of RES penetration, as well as the penetration of energy efficient technologies. This outcome can be used for "dynamic cost efficiency". Finally, administrative costs can be included optionally, provided that the necessary data is included. This result can be used for "financial feasibility".

For the other sub-criteria that no model outcomes are available, information and data from national reports and databases can be used with the MAUT and SMART procedures during the AMS application. AMS can handle qualitative and quantitative forms of data.

In order to apply ELECTRE III a detailed knowledge of energy and economic background of the examined countries is necessary which is not all the time available (Papadopoulos A., Karagiannidis A., 2008).

PROMETHEE methods can handle data with a reasonable degree of accuracy and fixed numerical values (Behzadian M. et al., 2010; Olson D.L., 2001).

Sensitivity analysis

Sensitivity analysis is included for testing the robustness of the results (Berrittella M. et al., 2008). Some researchers consider it necessary (Papadopoulos A., Karagiannidis A., 2008). Additionally, this analysis is useful in situations where uncertainties exist in the definition of the importance of different factors (ie criteria weights) (Awasthi A., Chauhan S., 2011). Almost all applications of the aforementioned methods use it.

Conclusion for methodology

AMS complies better with the requirements of the evaluation.

2.4. *Advantages-Disadvantages*

The following factors were taken into consideration: ease of use; low requirements on time and money.

Ease of use

An end-user will have more confidence in the outcomes of a MCDA method if each step is understandable (Loken E., 2007; Gilliams S. et al., 2005). Since multi-criteria evaluation methods have not been used for M/A policy instruments in emerging economies, then the selected method needs to be easy of understanding and use.

Comparative analysis of MCDM approaches has indicated AHP to be the most popular compared to other methods due to its simplicity, ease to use and great flexibility (Ho W. et al., 2010; Babic Z., Plazibat N., 1998). It is an easier technique - with the exception of the eigenvalue calculations used to derive the local priorities of the elements in a cluster of the hierarchy and which remain actually hidden from the end-user - compared to MAUT and SMART and with less required cognitive skills compared to MAUT/MAVT and SMART (Ananda J., Herath G., 2009; Petkov D. et al., 2007).

Multi Attribute Utility Theory (MAUT) was cognitively more difficult to understand but the Simple Multi Attribute Rating Technique (SMART), which belongs to the same group of methods, was found to be easy (Petkov D. et al., 2007). For MAUT a drawback is the requirements of interactive decision environment in formulating utility functions, complexity of computing scaling constants using the algorithm (Pohekar S.D., Ramachandran M., 2004).

Other researchers consider MAUT and SMART as more easy to use compared to other methods which are characterized as more complex, less transparent to the user and of less use in participatory approaches to decision-making (Joubert A.R. et al., 1997).

For AMS Blechinger P. and Shah K. in 2011 mention that the method is user-friendly and transparent in the calculation process; usable without knowing in detail its methodological background.

"*Some versions of the ELECTRE methods (e.g. ELECTRE III) are considered complicated and therefore are not easily understood by DMs"* (Bojkovic N. et al., 2010). More specifically, the elicitation of preferential parameters used in these methods may be a complex task particularly when a group of DMs are involved or there is a need of using a greater number of categories (Brito A. J. et al. 2010). In the case for defining national priorities for GHG emissions reduction in the Hellenic energy sector a veto threshold was not applied because it was very difficult (or even undesirable) for the DMs to define it (Georgopoulou E. et al., 2003). The aggregation procedure is characterized as opaque and technically complicated for most DMs (Theodorou S. et al., 2010).

PROMETHEE seems easier to be understood by DMs and simpler to be managed by the analyst compared to ELECTRE III (Behzadian M. et al., 2010). It is characterized by decreased complexity (Wang J.J. et al., 2009).

Both ELECTRE and PROMETHEE as outranking methods allow the introduction of new criteria or alternatives at any time during the analysis or the adjustment of the values of their thresholds (Linkov I. et al., 2004). This is a flexibility of these methods compared to MAUT and AHP.

Low requirements on time and money

Using pairwise comparison for the determination of the weight coefficients of the criteria and for the assessment of the alternatives is time-consuming and exhausting for the DM, particularly when their number is large (summing up the number of criteria and alternatives) (Loken E., 2007; Konidari P., Mavrakis D., 2006). One of the disadvantages mentioned for AHP "*is its inability to reflect the human cognitive process because it does not cope with the uncertainty and ambiguity, which occurs in decision maker's judgments* (Shen Y.C. et al., 2010)". This disadvantage can be overcome by techniques such as fuzzy approach and the sensitivity analysis (Shen Y.C. et al., 2011).

SMART is usually quicker for a DM to implement since less ratings are required compared to the same number of pairwise comparisons (Honert Van Den R.C., 2001).

In the AMS method this procedure is limited only to the criteria and to the sub-criteria level of each criterion. This restriction reduces the number of pair wise comparisons.

The advantage of the ELECTRE method is that the tradeoffs among multiple attributes are compensatory, and the information contained in the decision matrix is fully utilized (Qin X.S. et al., 2008). ELECTRE techniques demand the estimation of thresholds (three kinds in the general case) and weights. These factors however sometimes help the DM to understand fully the problem and form his/her preferences consistently. Nevertheless, these features represent some abstract meaning (Polatidis H. et al., 2006). In the aforementioned case for defining national priorities for GHG emissions reduction in the Hellenic energy sector the researchers considered that the application of a veto threshold would have required an "*exhaustive discussion between DM*" which was not decided in the framework of the specific study (Georgopoulou E. et al., 2003).

Conclusion for advantages-disadvantages

AMS complies better to the evaluation needs.

2.5. *Applications*

For the particular use in M/A climate change policy issues there seem to be a limited number of relevant research works. The authors selected papers that:

- Concerned evaluation of a climate change policy goal, strategy, instrument, action or measure with the usage of one of the six (6) multi-criteria evaluation methods. Cases of policy scenarios or of policy instruments whose objective (primary or secondary) refers to the reduction of greenhouse gas emissions were included;
- Described fully the whole procedure of applying a MCDA method.

Papers linked with climate change, but referring to the evaluation of projects, technologies or RES/energy efficiency capacities were not included (Ali H.H., Nsairat F.Al S., 2009; Karakosta C. et al., 2009; Doukas H. et al. 2006; Diakoulaki D. et al., 2006; Papadopoulos A., Karagiannidis A., 2006; Heuberger R. et al., 2003; Beccali M. et al., 2003; Goumas M, Lygerou V., 2000).

Table 1 is the outcome of this search that aims to understanding the popularity of multi-criteria methods in M/A policy issues. It is worth mentioning that evaluation of M/A policy issues though the use of MCDA methods for emerging economies is at low levels compared to other topics (Ishizaka A., Labib A., 2011; Behzadian M. et al., 2010).

Conclusion for applications

AHP is the most popular method used in such applications, followed by PROMETHEE, ELECTRE and AMS. It should be noted that AMS is a rather new method compared to the other ones, but has already applications in this area.

Table 1: Application of multi-criteria evaluation methods for M/A climate policy issues.

No.	Evaluated alternatives	Used method(s)	Authors
1.	Three policy goals linked with RES in Taiwan	AHP	Shen Y.C. et al., 2011
2.	Three subsidy schemes for promoting Photovoltaic technology in Cyprus	AHP, ELECTRE, PROMETHEE	Theodorou S. et al., 2010
3.	Twelve policy scenarios for low-carbon development in Bangkok (Thailand)	AHP and MAVT	Phdungsilp A., 2010; 2006
4.	Six transport policy options	AHP	Berrittella M. et al., 2008
5.	Thirty five options in three sectors (energy, transportations, forestry) of Peru	AHP and PROMETHEE	Borges P.C., Villavicencio A., 2004
6.	EU-ETS performance in eight EU member States	AMS	Konidari P., Mavrakis D., 2007
7.	Two pairs of instruments for climate policy interactions for Greece	AMS	Konidari P., Mavrakis D., 2006
8.	Three policy scenarios for the penetration of RES-E in Greece	AMS	Kampezidis H. et al., 2011
9.	Twelve GHG Emission Mitigating Policy Instruments for Trinidad and Tobago	AMS	Blechinger P., Shah K., 2010
10.	Six adaptation actions for mitigating increased water consumption for Georgia basin in Canada	ELECTRE III	Qin X.S. et al., 2008
11.	Twenty seven CO_2 reduction measures for the period 2000–2010 in the Greek energy sector	ELECTRE TRI	Georgopoulou H. et al., 2003
12.	Twenty four energy efficiency initiatives	ELECTRE TRI	Neves L.P. et al., 2008
13.	Five scenarios for the increased use of RES in Austria	PROMETHEE	Madlener R. et al., 2007
14.	Four scenarios for the power generation sector in Greece	PROMETHEE	Diakoulaki D, Karangelis F., 2007

Relevant software

As presented in the respective sessions when describing the methods, there is available software for all of them.

3. Conclusions

Conclusions from previously conducted research works regarding the comparison of the methods are similar. SMART, which is derived from MAUT (Multiple Attribute Utility Theory), is regarded to be very similar to PROMETHEE, but ELECTRE offers additional options for thresholds when defining criteria models. On the other hand, PROMETHEE is a more refined method than ELECTRE in that the former quantifies the degree of preference of an object as compared with another for each criterion (Ayoko A.G. et al., 2004).

In the context of environmental problems, Salminen et al. (1998) considered PROMETHEE, SMART, and ELECTRE III to be particularly suitable (Ayoko A.G. et al., 2004). ELECTRE-2, PROMETHEE-2, AHP, Compromise Programming and EXPROM-2 were used to select the best reservoir configuration for the Chaliyar river basin in Kerala, India. Although following different approaches, analysis showed that all methods indicated the same preference strategy (Ananda J., Herath G., 2009).

Geldermann J. and Rentz O. in 2005 applied PROMETHEE, MAUT, and AHP to the same decision table with identical alternatives, criteria, scores, and weight coefficients. The results, regarding the ranking of the examined alternatives, did not diverge significantly, exhibiting the same groups of best and worst alternatives.

The outcomes of comparisons through objectives, assumptions, methodology, advantages-disadvantages, relevant software and applications are presented in Table 2. AMS fulfils successfully the requirements of the “Description of the problem”.

Table 2: Comparison of methods. Three scales are used with three levels each High (High+, High 0, High -), Moderate (Moderate +, Moderate 0, Moderate -) and Low (Low+, Low 0, Low -).

	AHP	MAUT	SMART	AMS	PROMETHEE	ELECTRE
Objectives						
Outcomes	High +	High +	High +	High +	High -	High -
Set of criteria/subcriteria	Low -	Low -	Low -	High +	Low -	Low -
Ability to incorporate model outcomes	High 0	High 0	Low -	High 0	Low -	Low -
Assumptions						
Mathematical background	High -	High -	Moderate +	High -	High +	Moderate +
Weight coefficients, parameters, thresholds, indexes	High -	Moderate +	Moderate +	High +	Moderate +	Moderate +
Methodology						
Understanding the problem	High +	Moderate -	Moderate +	High +	Moderate -	Moderate +
Selecting criteria/sub-criteria and determination of their weight coefficients	High +	Moderate -	Moderate -	High +	Moderate -	Moderate -
Measurement scales and assessment of the performance	High -	High 0	High 0	High 0	Moderate +	Moderate +
Sensitivity analysis	High -	High 0	High 0	High -	High +	High -
Advantages - Disadvantages						
Ease of use	High -	High +	High +	High +	Moderate +	Moderate -
Low requirements on time and money	Moderate -	High -	High -	High +	Moderate -	Moderate -
Applications	High +	Low +	Low -	Moderate -	Moderate -	Moderate -
Relevant software	High 0	High 0	High 0	High 0	High 0	High 0

Annex I

PROMETHEE

Description

PROMETHEE was developed by Brans (1982) and further expanded by Vincke and Brans (1985) (Behzadian M. et al., 2010; Wang J.J. et al., 2009). It uses the outranking principle to rank the alternatives like ELECTRE. PROMETHEE I is used for partial ranking of the alternatives and PROMETHEE II for their complete ranking. There are also PROMETHEE III, IV, V and VI (Behzadian M. et al., 2010).

Assumptions

The method uses the preference function P_j (A_i, A_k) which is a function of the difference d_j between two alternatives A_i and A_k for any criterion j. This difference is mathematically expressed as

$$d_j = f(A_i, j) - f(A_k, j) \quad (1)$$

with f(A_i,j) and f(A_k,j) denoting the values of the two alternatives for the specific criterion j.

PROMETHEE has six basic types of preference functions[7] P_j (A_i, A_k) to be used for the comparison of two alternatives against criteria: 1. usual criterion, 2. U-shape criterion, 3. V-shape criterion, 4. level criterion, 5. V-shape with indifference criterion and 6. Gaussian criterion (Brans et al., 1986).

For each preference function (or generalized criteria), the value of an indifference threshold, q; the value of a strict preference threshold, p; and the value of an intermediate value between p and q, s, have to be also determined (Behzadian M. et al., 2010). Two alternatives are indifferent for criterion j as long as d_j does not exceed the indifference threshold q. If the difference is greater than p there is a strict preference expressed with the selected function.

Multi-criteria preference index for a pair of alternatives A_i and A_k is defined as

$$\pi(A_i, A_k) = \frac{\sum_{j=1}^{n} w_j p_j(A_i, A_k)}{\sum_{j=1}^{n} w_j} \qquad (2)$$

where P_j (A_i,A_k) is the preference functions for alternatives A_i and A_k.

The incoming (or positive) flow is calculated as

$$\varphi^+(A_i) = \sum_{k=1}^{m} \pi(A_i, A_k), k = 1, 2, \ldots m \quad (3)$$

and the outcoming (or negative) flow as

[7] They are also called generalized criteria functions (Wang J.J. et al., 2009).

$$\varphi^{-}(A_i) = \sum_{k=1}^{m} \pi(A_k, A_i), k = 1,2,...m \quad (4)$$

For the net ranking of alternative A_i

$$\Phi(A_i) = \varphi^{+}(A_i) - \varphi^{-}(A_i) \quad (5)$$

The maximum $\Phi(A_i)$ indicates which is the best alternative.

Methodology

The basic concept of PROMETHEE is the pairwise comparison of the alternatives along each criterion. Its implementation requires information about the weight coefficients and the preference function. PROMETHEE II assumes that the DM is able to assign the weight coefficients appropriately, at least when the number of the criteria is not too large (Behzadian M. et al., 2010).

The basic steps of the method are: i) Determination of differences d_j based on pair-wise comparisons ii) application of the preference function for each criterion; ii) calculation of the multi-criteria preference index (or global preference index); iv) calculation of the outranking flows and v) calculation of net outranking flow - completion or partial ranking of the alternatives based on the defined preference structure (Behzadian M. et al., 2010; Ananda J., Herath G., 2009).

Software

Two software packages have been developed: DECISION LAB and PROMCALC[8] (Behzadian M. et al., 2010; Macharis C. et al., 2004). The first one is currently used for implementing PROMETHEE.

Applications

The method has been used in energy and environmental management and planning, hydrology and water management, business and financial management, chemistry, logistics and transportation, manufacturing and assembly, social and other topics (education, design, government etc) (Theododou S. et al., 2010; Behzadian M. et al., 2010).

8 http://www.promethee-gaia.net/software.html

References

Ali H. Hikmat, Nsairat F. Al Saba, 2009, “Developing a green building assessment tool for developing countries – Case of Jordan”, Building and Environment 44, pp. 1053-1064.

Ananda Jayanath, Herath Gamini, 2009, “A critical review of multi-criteria decision making methods with special reference to forest management and planning”, Ecological Economics 68, pp. 2535-2548.

Ananda Jayanath, Herath Gamini, 2003, “The use of Analytic Hierarchy Process to incorporate stakeholder preferences into regional forest planning”, Forest Policy and Economics 5, Pages 13-26.

Awasthi Anjali, Chauhan S. Satyaveer, 2011, “Using AHP and Dempster – Shafer theory for evaluating sustainable transport solutions”, Environmental Modelling & Software 26, 787-796.

Ayoko A. Godwin, Morawska Lidia, Kokot Serge and Gilbert Dale, 2004, “Application of Multicriteria Decision Making Methods to Air Quality in the Microenvironments of Residential Houses in Brisbane, Australia”, Environ. Sci. Technol. 38, 2609-2616.

Babic Zoran, Plazibat Neli, 1998, “Ranking of enterprises based on multicriterial analysis”, Int. J. Oroduction Economics 56-57, pp. 29-35.

Beccali M., Cellura M., Mistretta M., 2003, “Decision-making in energy planning. Application of the Electre method at regional level for the diffusion of renewable energy technology”, Renewable Energy 28, pp. 2063-2087.

Behzadian Majid, Kazemzadeh R.B., Albadvi A., Aghdasi M., 2010, “PROMETHEE: A comprehensive literature review on methodologies and applications”, European Journal of Operational Research 200, pp. 198-215.

Berrittella Maria, Certa Antonella, Enea Mario, Zito Pietro, 2007, “An Analytic Hierarchy Process for The Evaluation of Transport Policies to Reduce Climate Change Impacts”, Fondazione Eni Enrico Mattei Working Papers 61.

Bettali M., Cellura M., Mistretta M., 2003, “Decision-making in energy planning. Application of the Electre method at regional level for the diffusion of renewable energy technology”, Renewable Energy 28, pp. 2063-2087.

Blechinger P. and Shah K., 2011, “A Multi-Criteria Analysis Approach to Comparing of GHG-Emission Mitigating Policy Instruments in the Power Generation Sector of Trinidad & Tobago” - available at: http://www.cehi.org.lc/cef5/conf_pres.htm

Bojkovic Natasa, Anic Ivan, Pejcic-Tarle Snezana, 2010, “One solution for cross-country transport – sustainability evaluation using the modified ELECTRE method”, Ecological Economics 69, pp. 1176-1186.

Borges C. Pedro, Villavicencio Arturo, 2004, “Avoiding academic and decorative planning in GHG emissions abatement studies with MCDA: The Peruvian case”, European Journal of Operational Research 152, pp. 641–654.

Brans J.P., Vincke Ph. And Mareschal B., 1986, "How to select and how to rank projects: The PROMETHEE method", European Journal of Operational Research 24, pp. 228-238.

Braunschweig T., 2000, "Priority setting in Agricultural Biotechnology Research – Supporting Public Decisions in Developing Countries with the Analytic Hierarchy Process", Report paper 16, ISNAR, available at: **http://pdf.usaid.gov/pdf_docs/PNACL205.pdf**.

Brito J. Anderson, de Almeida Adiel Teixeira, Mota M.M. Caroline, 2010, "A multicriteria model for risk sorting of natural gas pipelines based on ELECTRE TRI integrating Utility Thoery", European Journal of Operational Research 200, pp. 812-821.

Browne David, Ryan Lisa, 2010, "Comparative analysis of evaluation techniques for transport policies", Environmental Impact Assessment Review 31, pp. 226-233.

Dias Luis, Mousseau Vincent, Figueira Jose, Climaco Joao, 2002, "An aggregation/disaggregation approach to obtain robust conclusions with ELECTRE TRI", European Journal of Operational Research 138, pp. 332-348.

Diakoulaki D., Georgiou P., Tourkolias C., Georgopoulou E., Lalas D., Mirasgedis S., Sarafidis Y., 2007, "A multi-criteria approach to identify investment opportunities for the exploitation of the clean development mechanism", Energy policy 35, pp. 1088-1099.

Diakoulaki D., Karangelis F., 2007, "Multi-criteria analysis and cost-benefit analysis of alternative scenarios for the power generation sector in Greece", Renewable and Sustainable Energy Reviews 11, pp. 716-727.

Doukas Haris, Patlitzianas D. Konstantinos, Psarras John, 2006, "Supporting sustainable electricity technologies in Greece using MCDM", Resources Policy 31, pp. 129-136.

Eakin Hallie, Bojorquez-Tapia Luis A., 2008, "Insights into the composition of household vulnerability from multicriteria decision analysis", Global Environmental Change 18, pp. 112-127.

Gamper C.D., Turcanu C., 2007, "On the governmental use of multi-criteria analysis", Ecological Economics 62, pp. 298-307.

Geldermann Jutta and Rentz Otto, 2005, "Multi-criteria Analysis for Technical Assessment – Case Study from Industrial Coating", Journal of Industrial Ecology, Volume 9, Number 3, pp. 127-142.

Georgiou P., Tourkolias C., Diakoulaki D., 2008, "A roadmap for selecting host countries of wind energy projects in the framework of the clean development mechanism", Renewable and Sustainable Energy Reviews 12, pp. 712-731.

Georgopoulou E., Sarafidis Y., Mirasgedis S., Zaimi S., Lalas D.P., 2003, "A multiple criteria decision-aid approach in defining national priorities for greenhouse gases emissions reduction in the energy sector", European Journal of Operational Research 146, pp 199–215.

Gilliams S., Raymaekers D., Muys B., Van Orshoven J., 2005, "Comparing multiple criteria decision methods to extend a geographical information system on afforestation", Computers and Electronics in Agriculture 49, pp. 142-158.

Gomez-Limon J.A., Martinez Y., 2006, "Multi-criteria modeling of irrigation water market at basin level: A Spanish case study", European Journal of Operational Research 173, pp. 313-336.

Goumas M, Lygerou V., 2000, "An extension of the PROMETHEE method for decision making in fuzzy environment: Ranking of alternative energy exploitation projects", European Journal of Operational Research 123, pp. 606-613.

Heuberger Renat, Sutter Christoph, Santos Luis, "Host Country Approval for CDM projects in Uruguay: Application of a Sustainability Assessment Tool", 2003, http://www.up.ethz.ch/publications/documents/CDM_Sustainability_ETH_Uruguay.pdf.

Ho William, Xu Xiaowei, Dey K. Prasanta, "Multi-criteria decision making approaches for supplier evaluation and selection: A literature review", European Journal of Operational Research 202, pp. 16-24.

Honert Van Den R.C., "Decisional power in Group Decision Making: A Note on the Allocation of Group Members' Weight in the Multiplicative AHP and SMART", Group Decision and Negotiation 10, 2001, pp. 275-286, Kluwer Academic Publishers.

Huang B. Ivy, Keisler Jeffrey, Linkov Igor, 2011, "Multi-criteria decision analysis in environmental sciences: Ten years of applications and trends", Science of the Total Environment, article in press.

Ishizaka Alessio, Labib Ashraf, 2011, "Review of the main developments in the analytic hierarchy process", Expert Systems with Applications 38, pp. 14336-14345.

Isiklar Gulfem, Buyukozkam Gulcin, 2007, "Using a multi-criteria decision making approach to evaluate mobile phone alternatives", Computer Standards & Interfaces 29, pp. 265-274.

Joubert R. Alison, Leiman Anthony, de Klerk M. Helen, Katua Stephen, Aggenbach J. Coenrad, 1997, "Fynbos (fine bush) vegetation and the supply of water: a comparison of multi-criteria decision analysis and cost-benefit analysis", Ecological Economics 22, pp. 123-140.

Kablan M.M., 2004, "Decision support for energy conservation promotion: an analytic hierarchy process approach", Energy Policy 32, 1151-1158.

Kangas Jyrki, Kangas Annika, 2005, "Multiple criteria decision support in forest management – the approach, methods applied, and experiences gained", Forest Ecology and Management 207, pp. 133-143.

Kangas Jyrki, 1993, "A multi-attribute preference model for evaluating the reforestation chain alternatives of a forest stand", Forest Ecology and management, 59, pp. 271-288.

Karakosta Charikleia, Doukas Haris, Psarras John, 2009, "Directing clean development mechanism towards developing countries' sustainable development priorities", Energy for Sustainable Development 13, pp. 77-84.

Keyser De Wim, Peeters Peter, 1996, "A note on the use of PROMETHEE multicriteria methods", European Journal of Operational Research 89, pp. 457-461.

Konidari Popi, Mavrakis Dimitrios, 2007, "A multi-criteria evaluation method for climate change mitigation policy instruments", Energy Policy 35, pages 6235-6257.

Konidari Popi, Mavrakis Dimitrios, 2006, "Multi-criteria evaluation of climate policy interactions", Journal of Multi-Criteria Decision Analysis, 14, pages 35 – 53.

Kampezidis H., Kasselouri B., Konidari P., 2011, "Evaluating policy options for increasing the RES-E penetration in Greece", Energy Policy 39, 5388-5398.

Linkov I., Varghese A., Jamil S., Seager T.P., Kiker G., Bridges T., 2004, "Multi-criteria decision analysis: a framework for structuring remedial decisions at contaminated sites", Comparative Risk Assessment and Environmental Decision Making, pp.15-54, Kluwer Academic Publishers.

Loken Espen, 2007, "Use of multicriteria decision analysis methods for energy planning problems", Renewable and Sustainable Energy Review 11, pp. 1584-1595.

Macharis Cathy, Springael Johan, Brucker De Klaas and Verbeke Alain, 2004, "PROMETHEE and AHP: the design of operational synergies in multicriteria analysis. Strengthening PROMETHEE with ideas of AHP", European Journal of Operational Research 153, pp. 307-317.

Madlener Reinhard, Kowalski Katharina, Stagl Sigrid, 2007, "New ways for the integrated appraisal of national energy scenarios: The case of renewable energy use in Austria", Energy Policy 35, pp. 6060-6074.

Malekmohammadi Bajram, Zahraie Banafsheh, Kerachian Reza, 2011, "Ranking solutions of multi-objective reservoir operation optimization models using multi-criteria decision analysis", Expert Systems with Applications 38, pp. 7851-7863.

Munda Giuseppe, 2006, "A NAINADE based approach for sustainability benchmarking", Int. J. Environmental Technology and Management, http://www3.aegean.gr/environment/energy/mcda/library/Deliverables/del_20/A_NAIADE_based_approach_for_sustainability_benchmarking.pdf

Neves Luis Pires, Martins Gones Antonio, Antunes Henggeler Carlos, Dias Candido Luis, 2008, "A multi-criteria decision approach to sorting actions for promoting energy efficiency", Energy Policy, Volume 36, Issue 7, pp. 2351-2363.

Olson L. David, 2001, "Comparison of three multicriteria methods to predict known outcomes", European Journal of Operational Research 130, pp. 576-587.

Oltean-Dumbrava Crina and Ashley Richard, 2006, "Assessing the relative sustainability of management solutions using multi-criteria techniques", IABSE Henderson Colloquim, Cambridge, 10-12 July 2006, Factor 10 Engineering for Sustainable Cities.

Papadopoulos Agis, Karagiannidis Avraam, 2008, "Application of the multi-criteria analysis method ELECTRE III for the optimization of decentralisedenergy systems", Omega 36, pp. 766-776.

Patlitzianas D. Konstantinos, Ntotas Konstantinos, Doukas Harris, Psarras John, 2007, "Assessing the renewable energy producers' environment in EU accession member states", Energy Conversion and management 48, pp. 890-897.

Petkov D., Petkova O., Andrew T., Nepal T., 2007, “Mixing Multiple Criteria Decision Making with soft systems thinking techniques for decision support in complex situations”, Decision Support Systems 43, pp. 1615-1629.

Phdungsilp Aumnad, 2010, “Integrated energy and carbon modeling with a decision support system: Policy scenarios for low-carbon city development in Bangkok”, Energy Policy 38, 4808-4817.

Phdungsilp Aumnad, 2006, “Energy Analysis for Sustainable Mega-Cities”, Licentiate Thesis, School of Industrial Engineering and management Department of Energy Technology, Royal Institute of Technology, Stockholm, Sweden.

Pirdashti Mohsen, Behzadian Majid, 2009, “Selection of the Best Module Design for Ultrafiltration (UF) Membrane in Dairy Industry: An Application of AHP and PROMETHEE”, International Journal of Engineering, Volume 3, Issue 5, pp. 116-142, ISSN: 1985-2312.

Pohekar S. D., Ramachandran M., 2004, “Application of multi-criteria decision making to sustainable energy planning – A review”, Renewable and Sustainable Energy Reviews 8, pp. 365-381.

Polatidis Heracles, Haralambopoulos Dias, Munda Giussepe, Vreeker Ron, 2006, “Selecting an Appropriate Multi-Criteria Decision Analysis Technique for Renewable Energy Planning”, Energy Sources 193, Part B, 1:181-193, ISSN: 1556 – 7249 print/1556-7275 online, DOI: 101080/009083190881607.

Qin X.S., Huang G.H., Chakma A., Nie X.H., Lin Q.G., 2008, “A MCDM-based expert system for climate-change impact assessment and adaptation planning – A case study for the Georgia Basin, Canada”, Expert Systems with Applications 34, 2164–2179.

Rogers Martin, Bruen Michael, 1998, “A new system for weighting environmental criteria for use within ELECTRE III’, European Journal of Operational Research 107, pp. 552-563.

Roy, B., 1985. Méthodologie Multicritère d'Aide à la Décision. Economica, Paris.

Salgago P. Paneque, Quintana S. Corral, Pereira A. Guimardes, Ituarte L. del Moral, 2009, “Participative multi-criteria analysis for the evaluation of water governance alternatives. A case in the Costa del Sol (Malaga)”, Ecological Economics 68, pp. 990-1005.

Salminen Pekka, Hokkanen Joonas, Lahdelma Risto, 1998, “Comparing multicriteria methods in the context of environmental problems”, European Journal of Operational Research 104, pp. 485-496.

Shen Young-Chi, Chou James Chiyang, Lin T.R. Grace, 2011, “The portfolio of renewable energy sources for achieving the three E policy goals”, Energy 36, pp. 2589-2598.

Theodorou Savvas, Florides Georgios, Tassou Savvas, 2010, “The use of multiple criteria decision making methodologies for the promotion of RES through funding schemes in Cyprus, A review”, Energy Policy 38, pp 7783–7792.

Tsvetinov Petco E., 2003, “Pre-negotiations over Services –A Framework for Evaluation”. Available at: http://eprints.qut.edu.au/1202/

Wang Jiang-Jiang, Jing You-Yin, Zhang Chun-Fa, Zhao Jun-Hong, 2009, “Review on multi-criteria decision analysis aid in sustainable energy decision-making”, Renewable and Sustainable Energy Reviews 13, 2263–2278.

Wang Jian-Jun, Yang De-Li, 2007, “Using a hybrid multi-criteria decision aid method for information systems outsourcing”, Computers & Operations Research 34, pp. 3691-3700.

Wong K.W. Johnny, Li Heng, 2008, “Application of the analytic hierarchy process (AHP) in multi-criteria analysis of the selection of intelligent building systems”, Building and Environment 43, pp. 108-125.