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Multicriteria Analysis

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Abstract

Despite great progress in the quantification of damage costs in recent years, determination of monetary values remains elusive for certain impact categories, including those related to ecosystem acidification, eutrophication, and reduced visibility.

One of the objectives of the ExternE-Pol project was to develop a framework based on multicriteria analysis or Multi-Criteria Decision Analysis (MCDA) that could be used for exploiting the preferences of decision-makers, stakeholders, or environmental experts (in the following simply referred to as “stakeholders”) to derive monetary values for impacts whose monetization has remained problematic.

The ultimate goal is to integrate multicriteria methodology into the wider frame of cost-benefit analysis (CBA) for supporting policy and decision-making, especially in the context of sustainable development. Both CBA and MCDA aim at broadening the decision making perspective beyond the limits set by the market mechanism, while both rely on values attached by people with multiple points of view. In traditional CBA, human values are either reflected in existing market prices or are produced by aggregating individual preferences drawn from methods of welfare economics, such as the Contingent Valuation Method (CVM). In contrast, in MCDA, values reflect human preferences and in particular the preferences of the stakeholders involved in the *specific* decision context.

In this report we summarize the tasks undertaken to develop an MCDA framework for indirect monetization of environmental goods, and present the results obtained from a case study using this framework.

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4. Multicriteria Analysis

4.1 Introduction

Despite great progress in the quantification of damage costs in recent years, determination of monetary values remains elusive for certain impact categories, including those related to ecosystem acidification, eutrophication, and reduced visibility.

An objective of the ExternE-Pol project was to develop a framework based on multicriteria analysis or Multi-Criteria Decision Analysis (MCDA) that could be used for exploiting the preferences of decision-makers, stakeholders, or environmental experts (in the following simply referred to as “stakeholders”) to derive monetary values for impacts whose monetization has remained problematic.

Hence, the ultimate goal is to integrate multicriteria methodology into the wider frame of cost-benefit analysis (CBA) for supporting policy and decision-making, especially in the context of sustainable development. Both CBA and MCDA aim at broadening the decision making perspective beyond the limits set by the market mechanism, while both rely on values attached by people with multiple points of view. In traditional CBA, human values are either reflected in existing market prices or are produced by aggregating individual preferences drawn from methods of welfare economics, such as the Contingent Valuation Method (CVM). In contrast, in MCDA, values reflect human preferences and in particular the preferences of the stakeholders involved in the *specific* decision context.

Recently, many authors have tried to integrate concepts of behavior and decision analysis in economic valuation [Kotchen and Reiling, 2000; Svedsater 2001]. In the case of environmental valuation, constructive approaches have been proposed [Gregory et al, 1993; McDaniels, 1996; Gregory and Slovic, 1997; McDaniels and Roessler, 1998; Kwak et al, 2001]. Motivating these constructive approaches, it is argued that people do not have well-ordered preferences for unfamiliar objects like ecosystem goods and services, which in addition involve a multiplicity of values. Thus, the elicitation process itself helps people form and express preferences in terms suited to the decision problem. Elicited preferences, and thus weights, would then be “*more stable and coherent because they have been arrived through informed and well considered value judgments*” [Sagoff, 1998].

MCDA relies on such preference elicitation, aiming at gradually constructing values for unfamiliar goods rather than revealing ‘true’ values hidden in human mind. In this sense, MCDA is particularly suited for decision situations involving environmental criteria. Literature highlights a number of advantages of MCDA:

- MCDA **directly involves the stakeholders** facing a particular decision problem in order to detect their preferences and values regarding the decision criteria. Hence, the extracted values better reflect concerns and priorities of the people directly affected.

- MCDA acts as an **interactive learning procedure**, motivating stakeholders to think harder about conflicts addressed by taking into account other points of view and opposing arguments [Martinez-Alier et al., 1998, Omann, 2000]. The decision is structured into manageable sub components, and new scientific insights find more easily their way into the policy debate and stimulate constructive revisions of existing positions [Hobbs and Horn, 1997; Toman, 1998]. Such a transparent and constructive procedure enables stakeholders to better understand the problem at hand and arrive at a better and commonly negotiated solution [Faucheux and Froger, 1995; Lahdelma et al. 2000].
- MCDA is a **multi-disciplinary approach** amenable to capturing the complexity of natural systems, the plurality of values associated with environmental goods and varying perceptions of sustainable development [Toman, 1997]. The stakeholders participating in a MCDA procedure have the possibility and the responsibility to take into account perspectives and information that may go beyond those considered in their own discipline.
- MCDA applications can **consider a large variety of criteria**, whether quantitative or qualitative, independent of the measurement scale. Hence, it allows for a more comprehensive analysis for sustainability, since it can include all aspects of sustainability rather than being restricted to marketed goods or monetized costs and benefits [Oman, 2000].
- MCDA is **less prone to biases and distributional problems** than WTP or WTA estimates. Individuals feel freer to express their preferences in the form of importance weights and decide on the necessary trade-offs when they are not restricted by their ability to pay [Joubert et al., 1997]. A better approximation of human preferences is facilitated, though the overly-precise specifications of weights conveys false certainty [Munda, 1996].

Below we summarize the tasks undertaken to develop an MCDA framework for indirect monetization of environmental goods, and present the results obtained from a case study using this framework.

4.2 The Multi-Criteria Decision Analysis background

MCDA has undergone an impressive development during the last 30 years, in part because it is amenable to handling today's complex problems, in which the level of conflict between multiple evaluation axes is such that intuitive solutions are not satisfactory. MCDA is not a tool providing the 'right' solution in a decision problem, since no such solution exists. The solution provided might be considered best only for the stakeholders who provided their values in the form of weighting factors, while other stakeholders' values may indicate another alternative solution. Instead, it is an aid to decision-making that helps stakeholders organize available information, think on the consequences, explore their own wishes and tolerances and minimize the possibility for a post-decision disappointment [Belton and Stewart, 2002].

Multiple MCDA methods are available, suitable for a wide variety of decision situations. Furthermore, several weighting techniques have been developed to help stakeholders involved in a MCDA procedure become aware and articulate their

preferences. However, certain structural elements are common to all decision situations, independent of the MCDA method used. These structural elements are briefly described in the following paragraphs.

Structural elements

The core elements in a MCDA problem are certainly the set of alternative actions and the set of criteria along which these actions have to be evaluated. However, there are a number of structural and external characteristics that go beyond an arithmetic definition of these basic elements. Several approaches are available to help approach these characteristics in a consistent and systematic way. One of the most convenient and comprehensive is the **CAUSE** checklist (Criteria, Alternatives, Stakeholders, Uncertainty, Environment) [Belton and Stewart, 2002].

➔ **Criteria** represent the decision maker(s) or other stakeholders' points of view along which it seems adequate to establish comparisons [Bouyssou, 1986]. There are two main approaches to determining the set of criteria, reflecting the two ways of building a MCDA problem. A top-down approach is compatible with 'value-focused thinking' where criteria are built in a hierarchical structure, known as 'value tree', leading from primary goals to main (fundamental) objectives, which in turn are further broken down to specific criteria [Keeney and Raiffa, 1976, Keeney, 1992]. The bottom-up approach supports 'alternative-focused thinking', where criteria are identified through a systematic elicitation process, and may subsequently be grouped in broader categories. In both cases, a coherent set of criteria presents the following properties:

- **Value relevance:** Criteria are linked to fundamental goals of the stakeholders enabling them to specify preferences.
- **Understandability:** The concept behind each criterion is clear and there is a common view about the preferred direction of the alternatives' performances.
- **Measurability:** The performance of alternatives can be expressed on either a quantitative or a qualitative measurement scale.
- **Completeness:** The set of criteria strives to cover all important aspects of the problem considered while still being concise and operational.
- **Non-redundancy:** No criteria reflects the same concept as another, thus avoiding double-counting and over-attributing importance of a single aspect.

Alternatives are usually thought of as 'given', in the sense that they are *a priori* and strictly defined. However, alternatives may result from the systematic exploration of the objectives pursued in the decision situation considered. Especially in problems of strategic nature, the challenge is to detect interesting alternatives not obvious or apparent at first sight- on the basis of the main concerns expressed during problem identification. In his work on "value-focused thinking" Keeney [1992] emphasises the importance of generating alternatives through creative thinking focused on the values of the people concerned. In other occasions, where decision makers face a large number of *a priori* defined alternatives, a first crucial step is to identify a manageable set of 'good' or 'interesting' or 'representative' alternatives. Screening or sorting techniques can facilitate the search for preferred alternatives. Finally, *t* alternatives may be implicitly defined as combinations of discrete actions. In such

cases, decision makers seek to determine the most attractive combination (portfolio) of the available actions.

- ➔ **Decision maker(s)** or other **stakeholders** involved in the decision situation are those identifying the nature of the problem and driving the solution procedure towards the preferred direction. Although the two terms are sometimes used interchangeably, for our purposes, decision makers are those assigned with the responsibility to take the final decision, whereas stakeholders is a much broader notion encompassing any single individual or group of people with an interest or concern in the examined problem. The decision makers are thus expected to take into account the stakeholders' point of view depending on their overall managerial behaviour, the type of the problem considered and the ability of stakeholders to assist or to hamper the solution's implementation. However, the involvement of stakeholders in the MCDA procedure is useful in capturing several aspects of the problem and getting a better insight to its potential consequences.
- ➔ Acknowledging **uncertainty** is another crucial element of MCDA problems. The main cause of uncertainty is limited knowledge about external parameters that may influence the performances of the considered actions. This type of uncertainty can be handled by constructing scenarios for various possible values of these uncertain parameters, as well as by the exploitation of probabilities in the treatment of stochastic events. In addition, decision makers have to handle internal uncertainty stemming from hesitations during the problem structuring process (which alternatives, how important are the criteria, etc.). The problem's solution depends greatly upon the way both external and internal uncertainties are taken into account and the techniques used to incorporate them into the analysis.
- ➔ **Environment** refers to all those parameters defining the decision context. They may include fiscal, legislative or cultural aspects, which may broaden or restrict the scope of the analysis and impose constraints in the decision making procedure. Even if all other elements are the same, the problem's solution might differ if the decision is taken in another location or time period.

4.2.1 Procedural steps

A MCDA approach proceeds step-wise, typically with active involvement of stakeholders as shown in Figure 4.1. The steps, described below, are interconnected in that backtracking and loops are often necessary before arriving at the final decision.

- ➔ **Problem identification:** This first step is to identify the issue under consideration, to agree on the focus and the scope of the analysis, and to recognise external constraints such as physical or legislative environment, or time and resources available. When working with multiple stakeholders, a common understanding of the problem should be achieved through the elicitation of ideas and the sharing of concerns and values. In these cases, generation of ideas is facilitated through a structured conversation process, one often supported by experienced co-ordinators (facilitators) able to stimulate thinking, as well as by software. The aim is to look

at all aspects of the target problem, which can be organised by identifying links and building clusters of common concepts.

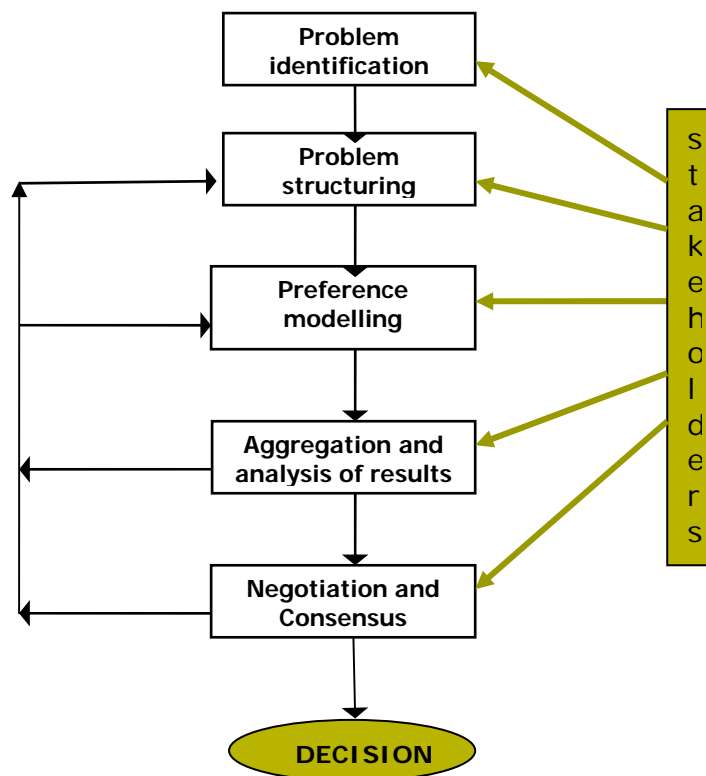


Figure 4.1: The steps in a MCDA procedure

- ➔ **Problem structuring:** Next, the decision maker or group of stakeholders should strive to formally express the detected aspects toward determining its main elements. This is a critical step for the subsequent analysis; it is often quoted that “a well structured problem is a problem half solved”. Following from an alternative-led or a value- focused thinking exercise, the set of alternatives and criteria is identified, and the degree of uncertainty faced is recognised and –if necessary- incorporated in the analytical procedure to be followed.
- ➔ **Preference modelling:** This task aims at capturing stakeholder preferences for the specific decision context. The difficulty here is that preferences cannot be considered as definite and *a priori* stored within human mind. Instead they are modelled during the decision aid process by means of specific techniques, often as a learning procedure, enabling decision makers to think and realise their aspirations. Two types of preferential information can be distinguished:
 - **Intra-criterion preferences:** judgements refer to relative values attached to different levels of performances. Depending on the aggregation method applied, this kind of preferential information is derived either by defining partial value functions reflecting the attitude of stakeholders in each particular criterion (risk neutral, risk averse or risk prone), or as indifference, preference or veto thresholds.

- **Inter-criterion preferences:** judgements refer to the relative importance attached to the information carried by each single criterion. Depending on the aggregation method, weights may represent scaling factors relating scores and their variation in one criterion relative to another criterion, or may denote the influence that each criterion has in building up the total preference relation. These two different types of weights have different meanings and are derived through different techniques.
- **Aggregation and analysis of results:** This step combines the scores alternatives with preferential information to arrive at a final solution that takes into account all evaluation criteria. A number of multi-criteria methods have been developed, each based on different ways of deriving preferential information and on different aggregation rules. Having arrived at the solution sought (by rank order, classification or efficient combination of variables), stakeholders have to think if this solution is satisfying.. Any stakeholder may realise ambiguities or false expression of his/her own values and possibly ask for a reconsideration of the problem's structure and/or his/her initial judgements.
- **Negotiation and consensus:** When there are multiple stakeholders, there are usually disagreements regarding the proposed solution. A structured discussion and negotiation process –often supported by specific computational techniques– aiming at discovering the main sources of divergence and at justifying or rejecting judgements, is usually of great help in getting better insight into the whole problem. This process enables revision of some structural elements and preferential aspects. Thus, it is possible to gradually arrive at a solution more apt to be commonly accepted by all stakeholders and be successfully implemented.

4.2.2 Review of MCDA methods

The strength of the MCDA methodology lies in the dynamic connection of all the steps described in the previous section, However, a formal description of the available methodological tools illustrates the modelling aspects related to elicitation of preferences and aggregation. Depending on the theoretical background and the key assumptions adopted in these two steps, MCDA methods can be divided into two broad categories, as follows:

- **Multi-Attribute Value Theory methods (MAVT)** aim to associate a unique number ('value') representing the overall strength of each alternative taking all criteria into account. If there is substantial uncertainty about the performances of alternatives, the term 'utility' is used to denote that the preferences of stakeholders against risk are formally included in the analytical procedure. To begin, partial value (or utility) functions are defined for each criterion for reducing performances, in the [0-1] interval. Partial values are then aggregated for deriving total values and for preordering examined alternatives. The transition from partial to global value functions (taking into account the whole set of criteria) implies the use of an aggregation formula together with the inter-criterion preferences provided by the decision maker. The simplest and most commonly used aggregation model is additive :

$$V(a) = \sum_i w_i \cdot v_i(a)$$

where, $V(a)$ is the total value associated with each alternative a , and w_i is the weight attached to each criterion i by the stakeholder.

In MAVT methods, weights play the role of scaling factors in the sense that they relate scores among the different criteria. By assigning weights denoting relative importance, stakeholders implicitly express what portion of one criterion they are willing to give up in order to improve the performance of another criterion by one unit. So, if the weight of criterion i is double the weight of criterion j , then the stakeholder values 10 units on criterion i , the same as 20 units on criterion j . In order for the stakeholders to more clearly express preferences in terms of the necessary trade-offs between criteria, weights are defined on initial natural scales and then taking into account the absolute level of performances and absolute differences in scores.

→ **Outranking methods** start by making pairwise comparisons of alternatives for each single criterion in order to denote partial binary relations, e.g. '*an alternative a is at least as good as alternative b* '. To make this comparison stakeholders provide intra-criterion preferential information in the form of indifference and preference thresholds. Partial binary relations are then synthesized over all criteria by taking into account the inter-criterion preferences expressed by weights denoting relative importance. Thus the strength of preferences between pairs of alternatives, rather than values of alternatives, are determined on a normalized scale, from 0 to 1, the former denoting no preference (including indifference) and the latter strict preference. Because of the vague determination of preferences, the key feature of the outranking methods is that they allow for two or more alternatives to remain incomparable if there is insufficient argument to support that one alternative outranks the other(s).

Weights in outranking methods have a different meaning than those in MAVT methods. In outranking methods, they do not represent trade-offs between criteria scores, since they are used to combine preference relations rather than scores of alternatives. They are measures of the degree to which each criterion influences a final statement of whether or not '*alternative a is equal or preferred to b* '. If this statement is valid for the most important criteria, this supports the validity of the assertion overall.

4.2.3 Comparative view on MCDA and CBA

To select which of these two broad categories of MCDA methods is more appropriate for indirect monetization we consider three important notions characterizing any multi-dimensional valuation procedure:

Commensurability, specifying if there is a common measure for aggregating several evaluation dimensions. **Strong** and **weak** commensurability can be distinguished [O' Neill, 1993]. The former holds if there is a common cardinal measure applying in all evaluation dimensions, while the latter assumes only an ordinal scale on which all different dimensions are gauged.

Compensation, specifying if a disadvantage in one evaluation dimension may be offset by an advantage in another dimension. It is here also possible to distinguish **full** and **partial** compensation, the latter implying the existence of thresholds in preference relations and thus disallowing the full substitutability between values.

Comparability, specifying if there is a single comparative term by which the actions under consideration can be ranked. **Strong** comparability indicates that there is a single comparative term by which all actions can be ranked, and **weak** comparability indicates that there are conflicts between the underlying dimensions restricting the possibility for a complete ranking [O' Neill, 1993].

These three notions are interconnected in the sense that a strong commensurability implies full compensation of criteria as well as strong comparability of the actions under consideration. This is the case of CBA, where all impacts, positive and negative, are valued in monetary terms and therefore, which can be aggregated, implicitly assuming that losses in one impact can be fully compensated by gains in another, while decision rules such as maximizing net present value (NPV) allow for a strong comparability of actions.

Incommensurability of values does not imply incomparability. Instead, incommensurability allows for weak comparability between options without their performance being measured on the same cardinal scale. The concept of weak comparability has been operationalized in Multi Criteria Decision Analysis approaches [(Martinez – Alier et al, 1998)]. Among MCDA approaches, the most suitable for use in CBA are the MAVT methods, because:

- Both CBA and MAVT are rooted in utilitarian theory, which assumes that there is a common measure of social welfare on which alternative actions can be gauged and compared. Although in MAVT methods strong commensurability is not *a priori* assumed, it can be achieved through value judgments or utility estimates of the stakeholders. Thus, a full compensatory model is applicable.
- Comparability in CBA is achieved by using linear aggregation models such as NPV, while in MAVT methods, linear additive functions are also the most widely used for aggregating partial values.

The commensurability assumption, whether directly (in CBA) or indirectly (in MCDA), adopted here is often disputed in the literature, especially for environmental goods. It has been argued that such a single super-value (either money or utility) cannot encompass all different dimensions of sustainability and the plurality of values connected with each environmental good [Rosenberger, 2001]. Arguments against money reductionism are a more serious charge. Considering all goods as commodities is often considered as an unrealistic, since several functions of natural systems have no economic value in themselves [Turner et al., 2000]. A broader perspective should recognize points of view outside of markets and see human preferences not exclusively linked with consumer behaviour [Funtowicz and Ravetz, 1994]. However, despite this criticism, it is conventionally argued that the market mechanism is the driving force of modern societies and that policy making becomes more effective if based on the signals markets are using to guide consumer and producer choices.

4.3 Elicitation of Preferences

4.3.1 Values and Preferences

Neo-classical economists consider human preferences as given and fixed. However, experimental results confirm that people do not have well-defined values regarding environmental goods, in part because they often lack essential information about their functions and possible services. In such cases it is argued that values can only be approximated through approaches that help people to construct their preferences when they are responding to survey questions [Sagoff, 1998].

Moreover, a large and growing literature from cognitive psychology, socioeconomics and decision behavioral analysis suggest that human preferences change over time and vary under particular contextual and framing conditions [Slovic, 1995, Dietz and Stern, 1995, Norton et al. 1998]. This means that in the mid- and long term preferences change under the influence of education, advertising, cultural conditions, technological change, evolution of social systems and the changing availability of environmental and other natural resources.

Such preference variability favours the use of constructive approaches to elicit human values [Gregory et al., 1993, Schade and Payne, 1994, Slovic, 1995]. It is namely argued that any attempt to derive human values for unfamiliar goods should be based on an interactive procedure of value construction, rather than on a neutral process of value discovery [Gregory and Slovic, 1997, Gregory et al., 1993].

In addition to the instability of human preferences, value theory distinguishes between *consumer* and *citizen* preferences. Consumer preferences reflect conceptions of welfare individuals seek for themselves, while citizen preferences reflect conceptions of what we ought to do as a society [Sagoff, 1998]. This distinction can be perceived as reflecting an *egoistic* versus *altruistic* attitude, respectively [Dietz and Stern, 1998, Russell et al, 2003]. Consumer preferences are considered to be relatively stable, while citizen preferences depend on the overall decision situation, its framing and description.

Market transactions focus on egoistic values. Similarly, CVM and other economic valuation techniques frame preferences in market-oriented terms and thus focus mainly on the egoistic dimension of preferences. Consequently, estimates may be biased to self-interest and people's altruistic concern underestimated [Dietz and Stern, 1998]. On the contrary, weighting methods used in the framework of MCDA methods facilitate the construction of values encompassing both egoistic and altruistic beliefs.

4.3.2 Weighting Methods

Weighting methods are usually divided in two categories: compensatory and non-compensatory. Since the additive aggregation model implemented in both CBA and MAVT methods assumes strong compensation between criteria, a combination of the two approaches should rely on a compensatory weighting method. This means that by assigning weights of relative importance, decision makers implicitly determine tradeoffs between the number of units of one criterion they are willing to give up in order to improve the performance of another criterion by one unit.

All compensatory weighting methods aim to highlight hidden dilemmas behind a number of mutually exclusive options evaluated across multiple criteria by making

stakeholders become aware of the potential gains and losses implied by their choice. However, each technique follows a different approach to elicit human preferences.

The most widely used compensatory weighting methods are the following:

➔ **TRADE-OFF method** [Keeney and Raiffa, 1976]:

The TRADE-OFF method is grounded in a rigid theoretical background and reveals the dilemmas posed to the stakeholders through pairwise examination of criteria. In each pair, two hypothetical alternatives are constructed, differing only in these two criteria. The first alternative has the best performance in one criterion and the worst in the other criterion, while opposite performances are assumed for the second alternative. Stakeholders are first asked to choose one of the two alternatives. Their choice thus indicates the most important criterion. In a second step, they are asked to define how much they are willing to give up in this criterion in order to improve the other at its best level. Their answer reveals directly the trade-off between the criteria. The minimum number of criteria comparisons is $n-1$, while a self-consistency check necessitates the examination of all possible combinations of criteria, thus of $n \cdot (n-1)$ comparisons.

➔ **SWING method** [von Winterfeldt and Edwards, 1986]:

The SWING method begins by constructing two extreme hypothetical Scenarios, W and B, the former presenting the worst performance in all criteria (worst score of the examined alternative options) and the latter the corresponding best performance. It is assumed that the stakeholder prefers the current Scenario W. The preference elicitation procedure consists in asking stakeholders to carefully look at the potential gains from moving from W to B and then to decide which of the criteria they want to first shift to Scenario B. Assuming that this first swing is valued with 100 units on a hypothetical value scale, the stakeholders are asked to assign a value (<100) to the second criterion moved to B, then to the third and so on until the last criterion is moved to Scenario B.

➔ **RESISTANCE TO CHANGE** [Rogers and Bruen, 1998]:

This method is based on Personal Construct Theory and has been recently adapted to estimate the relative importance of environmental criteria in outranking MCDA methods (e.g. ELECTRE). It has elements from the SWING method as well as from the pairwise comparison techniques. Each criterion is assumed to have two different poles of performance, a desirable (best) and an undesirable (worst) side. Assuming that all criteria are at the desirable side, stakeholders are asked to compare all the criteria between each other in pairs, and to choose which one they are willing to move from the desirable side to the undesirable side. The relative importance of each criterion is obtained from the number of times it was resistant to change in this process

➔ **MACBETH** (Measuring Attractiveness by a Categorical Based Evaluation Technique) [Bana e Costa and Vansnick, 1994].

MACBETH is a MAVT method integrating the weights elicitation procedure as an essential part of the overall evaluation approach. The method comprises SWING and TRADE-OFF elements, while comparisons include hypothetical reference scores characterized as good and neutral. It furthermore provides the necessary consistency tests for the coherency of the procedure.

➔ **CONJOINT or HOLISTIC approach**

This method is a typical example of a holistic procedure, requiring stakeholders to rank or rate the examined alternatives by taking into account their scores in the whole set of criteria. These holistic preferences are then disaggregated by using statistical regression analysis to derive single value functions and corresponding weights. The method is very convenient for stakeholders because of the simple preferential information required. However, people have the tendency to ignore or to misinterpret many attributes, even important ones, when ranking the multi objective alternatives, and treating them in an inconsistent way. In addition, participants are not forced to deliberate and thus become conscious of their own preferences, so the derived weights are less defensible and balanced [Hobbs and Meier, 2000].

4.3.3 Comparative assessment and selection of weighting method

The weighting techniques described above differ with respect to a number of properties that may significantly influence their capacity to translate human preferences into numerical values:

- **Simplicity and transparency:** TRADE-OFF and MACBETH are the most complicated methods, while the HOLISTIC approach is the simplest method, but follows a less transparent procedure and the obtained weights are not reliable. SWING and RESISTANCE TO CHANGE methods are considered as simple and transparent.
- **Degree of inconsistencies in the articulation of preferences:** more inconsistencies appear in the TRADE-OFF, the MACBETH method and the HOLISTIC approach and their resolution may be intricate and confusing. Inconsistencies are normally avoided in the SWING and the RESISTANCE TO CHANGE methods.
- **Ability to handle small or large number of criteria:** The TRADE-OFF and the MACBETH methods are the most difficult to apply in problems with a large number of criteria because of the increased number of pairwise comparisons needed. The HOLISTIC approach is prone to inconsistencies if the number of criteria increases. However, the RESISTANCE TO CHANGE method is not appropriate for problems with a small number of criteria because the less important criterion could be assigned with a zero weight. The SWING method is least sensitive to the number of criteria.
- **Sensitivity to impact range:** The more a preference elicitation procedure involves cross-attribute comparisons of impact range, the more sensitive will be the elicited weights to the range of attributes, and thus the more reliable for use as scaling factors. The TRADE-OFF and the MACBETH methods are the most sensitive to impact range and the HOLISTIC approach the least sensitive. The SWING and RESISTANCE TO CHANGE methods present an intermediate sensitivity to impact range.

The comparative assessment of the weighting methods above shows that the SWING and TRADE-OFF methods have most advantages. The SWING method is simpler, more transparent, better at avoiding inconsistencies, and applicable with practically any number of decision criteria, while the TRADE-OFF method is more sensitive to variations of impact range.

Preliminary tests we made showed that the SWING method was far preferred by most respondents, mainly because of the much simpler way of eliciting the stakeholders' preferences, as well as because of the reluctance of certain stakeholders to directly define trade-offs including ethical values (e.g. human health vs. cost). Our tests indicated that its sensitivity to impact range was comparable to that of the TRADE-OFF method.

4.4 The proposed MCDA framework

Given the theoretical background of MCDA methods and of preference elicitation techniques, we propose the following properties for a framework to monetize as yet unmonetized environmental impacts:

- Use a MAVT method, because of the similarities in the theoretical origin and axiomatic foundations MAVT has with CBA. The assumed full compensation principle allows stakeholders to express their preferences in the form of weights indicating acceptable trade-offs between the evaluation axes considered. Thus, in the presence of even a single monetized criterion it is possible to translate preferences in monetary terms.
- Use a compensatory weighting method for the elicitation of preferences. The SWING method was found to be the most appropriate, because of its simplicity, transparency, consistency, adaptability to varying number of criteria and sensitivity to impact range.

Fig. 4.2 shows in a diagrammatic way the developed framework.

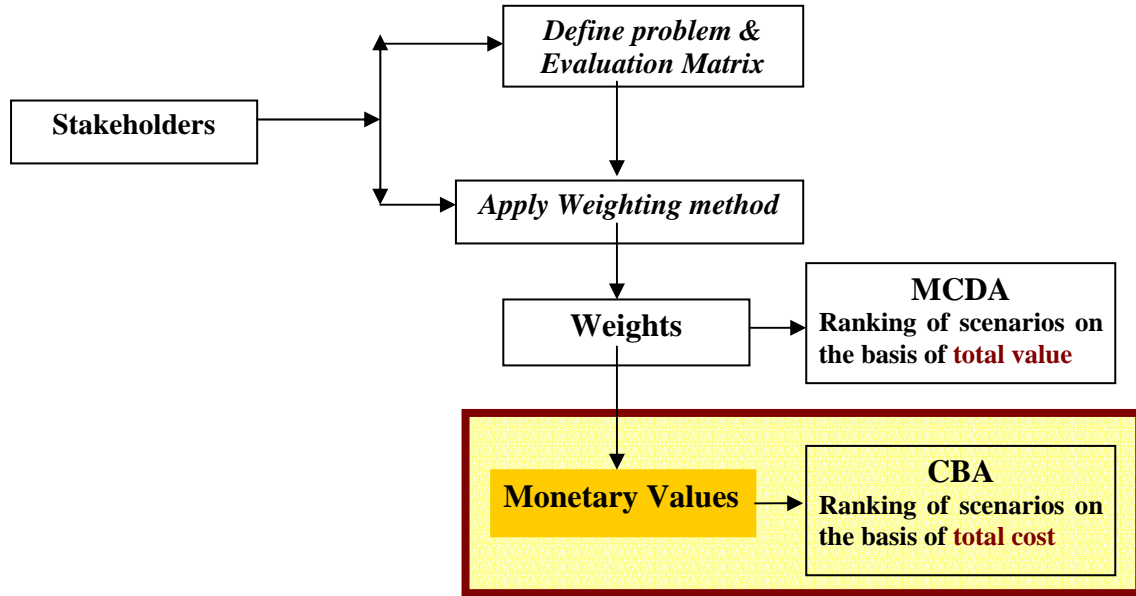


Figure 4.2: The developed MCDA monetization framework

As described in section 4.3.2, preferences of stakeholders in the SWING method are expressed as relative values v_i , with $v_i=100$ attributed to the most important criterion (the first swing from worst to best performance) and $v_j < 100$ assigned in a decreasing order to the other criteria from the second most important to the least important criterion.

This relative value scale v_i is then transformed to normalized weights w_i :

$$w_i = \frac{v_i}{\sum v_i}$$

Indirect monetization is based on the assumed equivalence of the stakeholder's relative preferences, relating the weight calculated for each physical impact to the weight of the cost criterion, both expressed on the corresponding impact scale:

$$\frac{w_i}{IR_i} = \frac{w_c}{IR_c}$$

IR_i and IR_c denote the impact range (i.e. the maximum potential gain) of the physical impact i and of the cost criterion, respectively. The underlying assumption is that the value functions for all impact categories are linear, e.g. improvements in the impact level are valued the same, independent of the absolute impact level. The linearity assumption reflects neutral behaviour against risk. This is a reasonable hypothesis given the limited range of impact levels under consideration. Hence, the per unit monetary value of the physical impact i , m_i , is calculated as::

$$m_i = \frac{IR_c \cdot w_i}{IR_i \cdot w_c}$$

For any pair i/c the higher the ratio of weights and/or the lower the ratio of impact ranges, the higher is the per unit monetary value implicitly assigned to the physical impact i .

This combined procedure has the following advantages identified above as strong points of MCDA approaches:

- The interactive participatory procedure typical of MCDA helps stakeholders to go deeper into the dilemmas posed, reach a better understanding of the problem and possibly revise their initial preferences.
- Conflicts are not solved in a mechanical, unreflective way on the basis of preferences expressed by other people facing possibly quite different decision situation.
- Stakeholders' preferences are not influenced by their ability to pay, so that distributional distortions are avoided.
- The process of deriving human preferences generally requires less time and effort than for contingent valuation or other valuation methods from welfare economics.

However, in order for such a procedure to provide reliable results the following **conditions** must hold:

- Non-monetized impacts should be measured on a cardinal scale. Otherwise trade-offs would lack sufficient meaning and monetary equivalents would be just rough estimates.
- The number and type of stakeholders should be carefully selected in order to gather opinions from all interested parties and secure in practice 'the democratic' character of the methodology.
- All stakeholders should be fully aware about the nature and relevance of the considered problem, while the significance of each single criterion and of the different performance levels should be made transparent.
- It is advisable to use more than one weighting technique in order to check for inconsistencies and guide stakeholders to think harder about the dilemmas faced.
- The analyst or facilitator should provide all necessary information, ease elicitation of preferences by using appropriate communication means (simple questionnaires, visual material etc.) and guide the whole procedure by indicating potential extreme positions or inconsistencies.

4.5 Case Study

4.5.1 Problem formulation

We conducted a case study aimed at monetization of acidification and eutrophication, two forms of ecosystem degradation that are causing major concern to policy makers at international and European levels. A preliminary investigation for other non-monetized impact categories (e.g. on visibility and cultural monuments) indicated that existing indicators are very site-specific, with quantification only feasible through a detailed and local analysis. Such analyses are out of the scope of the present project and of the specific exploratory task.

The selected policy problem refers to the choice among three possible scenarios for reducing emissions of NO_x, NH₃, SO₂ and VOC in Europe, relative to their levels in 1990. The reductions are described in terms of the corresponding physical impacts for acidification, eutrophication, mortality, and changes in agricultural production. Corresponding abatement costs, (i.e. the costs necessary to achieve the reductions) are also shown. The scenarios are drawn from IIASA [1999] and are defined as follows:

- CL: based on the anticipated reduction due to all current legislation and abatement plans, excluding the Gothenburg Protocol or the National Emission Ceilings Directive of the EU
- GP: based on the limits set by the UNECE Convention on Long Range Transboundary Air Pollution (Gothenburg Protocol)
- MFR: based on the Maximum Feasible Reduction resulting from the full application of currently available control technologies.

Table 4.1 presents the emission reduction assumed in each scenario.

Table 4.1: Emission reduction with respect to 1990 level for three tested scenarios

	CL	GP	MFR
NO _x	-48%	-50%	-79%
NH ₃	-12%	-13%	-40%
SO ₂	-71%	-75%	-91%
VOC	-49%	-53%	-72%

There is no single best scenario because lower emissions require higher abatement costs. Thus, the final choice depends on the relative weights that each stakeholder assigns to the considered criteria, which refer to levels of the following impacts:

- Abatement cost (billion €/yr)
- Acidification (km²)

- Agricultural loss (billion t of cereals & potato/yr)
- Eutrophication (km²)
- Mortality (YOLL/yr)

Data for environmental impacts and abatement costs are also drawn from IIASA [1999].

Table 4.2 presents the impact levels (as absolute rounded numbers and as relative indicators), both for 1990 and for each of the three reduction scenarios. Impact levels refer to the population and other receptors in EU-15.

Table 4.2: Impact levels of scenarios

IMPACTS in alphabetical order	Impact levels in 1990	Impact levels in 2010		
		REF	GP	MFR
Abatement cost (bil. €yr) (€yr per household)	0	58 380 €yr, hh	60 395 €yr, hh	101 665 €yr, hh
Acidification (1000 km²) (% loss of total ecosystems area)	370 24.80%	64 4.30%	53 3.60%	9 0.60%
Agricultural loss (bil.t of cereals & potato) (% loss of total agricultural production)	13 5.20%	10 4.00%	9 3.60%	6 2.40%
Eutrophication (1000 km²) (% loss of total ecosystems area)	667 55%	484 40%	476 39%	194 16%
Mortality (1000 YOLL/yr) (months/person per lifetime exposure)	3 300 7.8 months	1 900 4.5 months	1 800 4.3 months	1 100 (2.6 months)

4.5.2 Development and circulation of questionnaire

The questionnaire was developed in a simple EXCEL workbook based on the SWING method. It comprises the following sheets:

1. **Objective:** describes scope of survey and problem objectives
2. **Impact levels:** presents table WP.4.2. along with explanatory notes on the impact scale and the measurement units.
3. **The method:** presents the steps of the SWING method.

4. **YOUR PREFERENCES:** main part of the questionnaire, to completed by the stakeholders.
5. **Appendix:** provides additional information to put impacts in perspective, with reference to European totals for these impacts

The whole questionnaire is presented in Appendix 4.

The questionnaires are completed interactively. Namely, the respondent is directly informed about the monetary equivalents of his/her preferences and has the opportunity for revisions.

A pilot questionnaire was first tested by the project partners. In final form the questionnaire was sent by e-mail to 105 experts from several EU countries and the USA. Of these experts, 20 were involved in various phases of the ExternE project, while the other 85 respondents were experts in ecosystems modeling, environmental impact assessment and externalities assessment.

The number of returned questionnaires was 25 (24% response rate) with a much higher return rate for the ExternE participants (12 questionnaires or 60%). One questionnaire was excluded from further consideration due to the extremely low weight (1%) assigned to abatement cost that shifted all monetary equivalents to a different order of magnitude.

4.5.3 Analysis of results

The completed questionnaires were analyzed to determine the range of the weights attributed to the considered impacts and the implied monetary equivalents.

Table 4.3 gives the weights attributed by each respondent in the 24 consistent responses. The dispersion of responses is reflected in the standard deviation, which is about 50% of the average value of weight for abatement cost, eutrophication, and mortality. For acidification and agricultural loss, the standard deviations about about roughly 100% of the respective average weight.

Table 4.3: The weights of individual respondents

Respondent	Abatement Cost	Acidification	Agr. Loss	Eutrophication	Mortality
1	4%	38%	8%	15%	35%
2	44%	8%	8%	8%	31%
3	19%	7%	2%	38%	34%
4	21%	13%	4%	42%	21%
5	22%	4%	2%	27%	45%
6	4%	3%	0%	16%	78%
7	22%	7%	4%	30%	37%
8	27%	15%	7%	30%	21%
9	39%	4%	1%	16%	40%
10	27%	9%	5%	14%	45%
11	16%	20%	1%	31%	33%
12	65%	2%	1%	16%	16%
13	26%	19%	7%	37%	11%
14	30%	7%	3%	27%	33%
15	17%	14%	7%	28%	34%
16	16%	26%	13%	24%	21%
17	40%	0%	4%	8%	48%
18	33%	13%	3%	17%	33%
19	31%	3%	3%	31%	31%
20	19%	0.2%	0.4%	2%	78%
21	26%	7%	2%	31%	34%
22	29%	10%	6%	13%	42%
23	32%	2%	0%	35%	32%
24	15%	23%	23%	31%	8%
Average	26.1%	10.6%	4.8%	23.5%	35.0%
St. Deviation	13%	9%	5%	11%	17%

Table 4.4 shows the monetary equivalents for the considered impacts as derived by the weights attributed by each respondent in the 24 consistent responses.

Table 4.4: The monetary equivalents assigned by individual respondents (in 1000 €)

Respondent	Acidification per km²	Agr.Loss per kt	Eutrophication per km²	Mortality per YOLL
1	7818	14333	593	484
2	147	1344	28	37
3	297	717	297	97
4	521	860	593	1075
5	156	860	178	108
6	469	2150	297	54
7	261	1792	198	90
8	434	1991	165	42
9	80	146	61	55
10	261	1792	74	90
11	938	287	282	108
12	23	108	37	13
13	558	2048	212	23
14	174	796	132	60
15	625	2867	237	108
16	1303	8958	222	72
17	8	1075	30	65
18	313	1075	74	54
19	78	717	148	54
20	8	143	15	215
21	208	717	178	72
22	279	1536	64	77
23	43	40	165	54
24	1173	10750	297	27
Average	674	2379	191	130
St. Deviation	1562	3630	154	222

It can be seen that for 3 respondents (No 1, 16 and 24) the derived values for acidification and agricultural loss are extremely and unrealistically high, shifting average values and standard deviation to very high levels. Thus, these 3 questionnaires have been excluded from further consideration.

Nevertheless, it should be noted that for each impact category, the dispersion of values is higher than that of weights. This is because values depend on a combination of the weights assigned to abatement cost with the impact under consideration, and thus are very sensitive to small changes in the ratio of these two weights.

Figure 4.3 shows the spread of weights for the remaining 21 questionnaires, excluding the 10% lowest and 10% highest values. It can be seen that mortality is generally assigned with the highest weight, followed by abatement cost and eutrophication, while acidification and agricultural loss are generally assigned a lower weight.

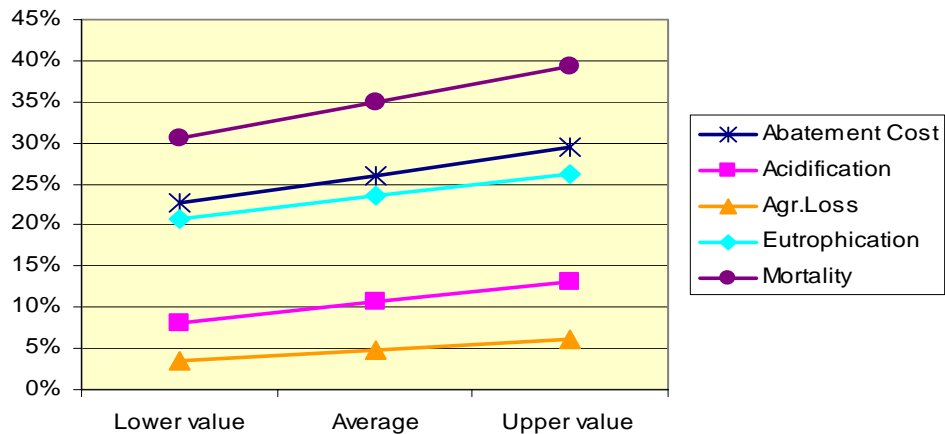


Figure 4.2: Spread of weights, excluding values in lowest and highest 10% of distribution

Figure 4.3 shows the corresponding spread of monetary equivalents indirectly assigned to the considered environmental impacts by the 21 respondents, again truncating the distribution at the 10th percentile of both upper and lower tails. As a consequence the average values shown in Fig. 4.4 are much lower than those included in Table 4.4. It can be seen that the highest variation of the estimated monetary values is observed in mortality and acidification impacts, while in the case of agricultural crops, the range of values is more restricted.

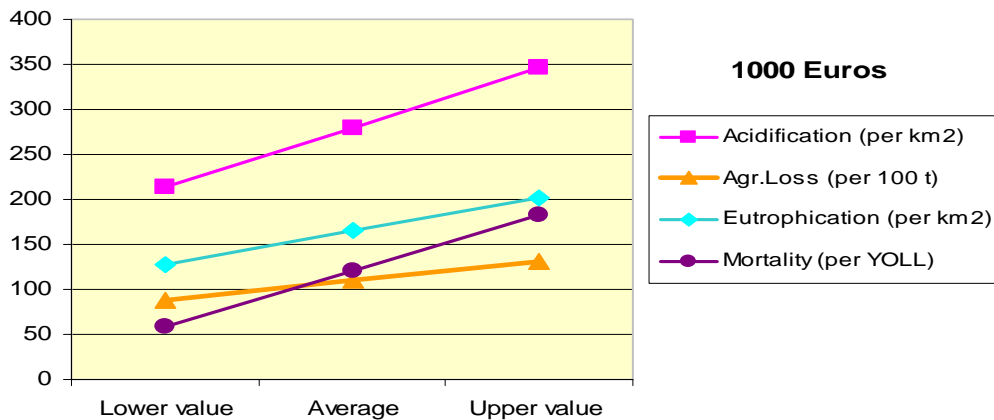


Figure 4.3: Spread of monetary equivalents, excluding values in lowest and highest 10% of distribution

Regarding the relevance of the obtained monetary equivalents, and focusing on the average values the following remarks can be made:

1. **For mortality impact**, the calculated average monetary value (120,000 € per YOLL) is of the same order of magnitude as values resulting from valuation approaches used in the ExternE project, although relatively higher than the last estimates agreed.

2. **For acidification and eutrophication**, the average monetary values amount to 280,000 and 165,000 € per km² (2800 and 1650 € per ha) which is one order of magnitude higher than found in recent valuation attempts [Vermoote and De Nocker, 2003; Pretty et al., 2003; Ruijgrok et al., 2004]. The difference between acidification and eutrophication might be attributed to the difference in the considered impact ranges.
3. **For agricultural loss**, the average monetary value (1050 € per ton) is around 6-7 times higher of the current market price for the considered crops.

These remarks should be interpreted under the limitations posed by the survey. Besides the small number of responses, the range of impact categories probably significantly influenced the obtained monetary values. This influence is clearly discernible in the values assigned to acidification and eutrophication, where despite the much lower weight attributed to acidification, the implied monetary equivalent per unit of ecosystems area is higher because the total area affected by acidification is much lower than the area affected by eutrophication.

Another factor that might have significantly influenced the obtained monetary values is the degree to which respondents were aware of values resulting from other valuation methods. To test this, we divided responses in two distinct groups:

- Group EXT, including 12 experts involved in various phases of the ExternE project, and
- Group EIA, including 9 experts in ecosystems modelling and environmental impact assessment.

It appears that the degree to which the respondents were likely to be familiar with monetization approaches and aware of existing monetary estimates may have substantially influenced the values derived for mortality impact. As shown in Figure 4.5, the average value for Group EXT (67000 €/YOLL) was about half the average value found for the groups combined, and about 1/3 of the value estimated by Group EIA. Group EXT's estimated value is very close to that agreed in the framework of ExternE project, suggesting that the weighting procedure has been shifted towards the existing estimates because of particular group of stakeholders involved in the test.

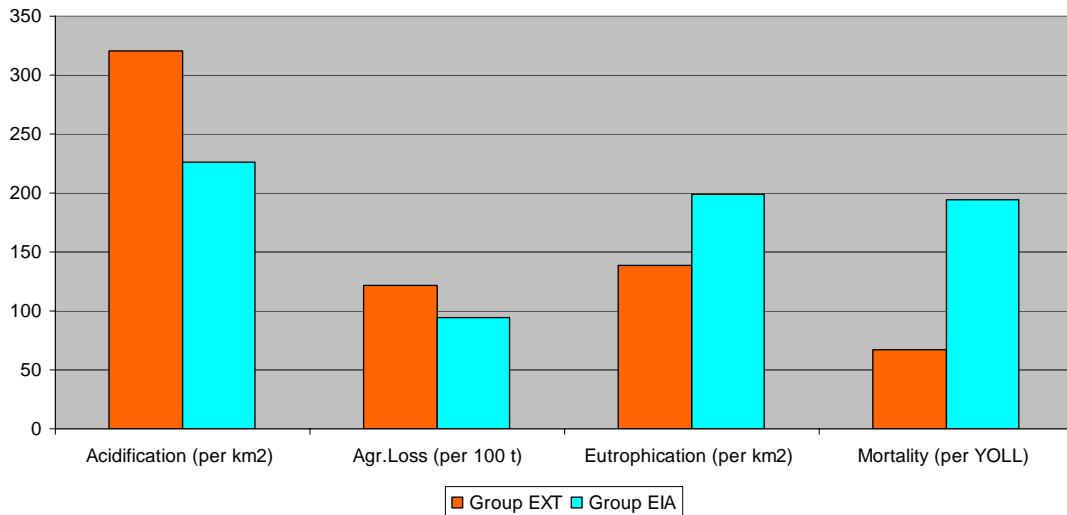


Figure 4.5: Average monetary equivalents for the two groups of respondents

Using the above presented weights and corresponding monetary equivalents, the (Pareto) optimal scenario for emissions reduction is the MFR scenario, which assumes the maximum feasible reduction in all pollutants. It is clear that this result is obtained in both MCDA (on the basis of the total value calculated for each scenario), and CBA (on the basis of the total cost associated with each scenario). It should also be noted that with the exception of one respondent 23 respondents agree on the predominance of scenario MFR. For respondent No 12, who assigned the highest weight to abatement cost and consequently the monetary values attributed to environmental impacts were very low, scenarios CL and GP were ranked first, while scenario MFR was the least preferred as presenting the highest total cost.

Figure 4.5 shows the total cost estimated for each scenario by taking into account the abatement cost and the cost of the associated environmental impacts calculated on the basis of the average monetary equivalents. The cost of agricultural loss was excluded because of the extremely high monetary value obtained.

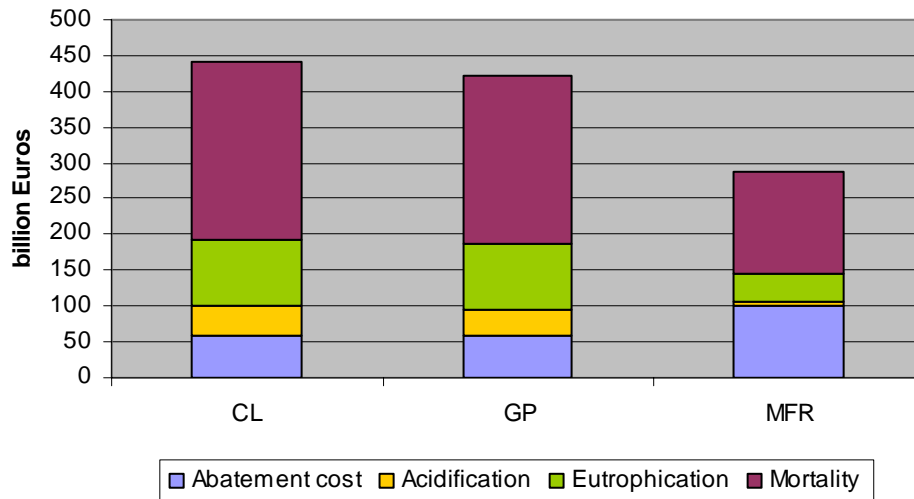


Figure 4.5: Average total cost of the examined emission reduction scenarios

4.5.4 A Greek case study

In order to test the proposed multicriteria monetization procedure, a parallel survey was conducted in Greece. The formulated problem consists of the evaluation of alternative scenarios for the expansion of the Greek electricity system. The main difference between these scenarios is the degree to which natural gas and/or renewable energy sources are introduced into the system up to 2010, respectively decreasing the share of lignite, which now dominates the electricity sector.

The examined impacts include mortality, CO₂ emissions, impacts on ecosystems, and agricultural loss, with the latter two estimated with the EcoSense model.

Two different weighting methods were used –SWING and TRADE-OFF- in order to check for the consistency of responses with different preference elicitation procedures. The formulated questionnaire was completed by 11 respondents (one of these rejected due to inconsistency) from ministries, utilities and research institutes including experts in energy and environmental management in the framework of individual interviews.

Figure 4.6 shows average weights and values assigned to the considered impacts. The respective monetary equivalents are presented in Table 4.5.

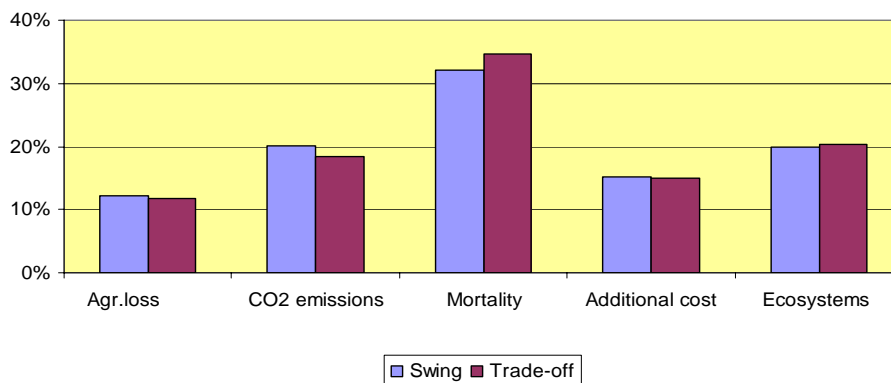


Figure 4.6: Average weights in the Greek case study

Mortality was assigned the highest weight, with a monetary equivalent very close to the ExternE estimate (with only 2 out of the 10 experts being aware of this value).

Table 4.5: Average values in the Greek case study

Impact	Swing	Trade-off
Agr.loss (€ per t of wheat)	495	498
CO2 emissions (€ per t of CO2)	23	22
Mortality (€ per YOLL)	56852	63970
Ecosystems (€ per km2)	44006	48408

The range of individual values is different for each impact, with the standard deviation being lower for CO₂ emissions and mortality (~30%) and higher (~80-100%) for agricultural loss and acidification. The variation of values for impacts on mortality and ecosystems are shown in Figure 4.8.

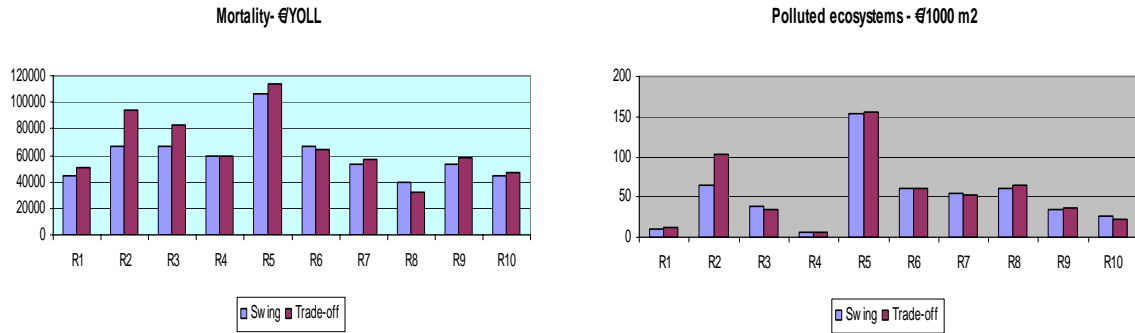


Figure 4.7. Variation of monetary values in individual responses

The two weighting methods give very similar results. It should be noted that all respondents found the SWING method easier and less time consuming to complete.

It can also be seen that the obtained monetary equivalents are much lower and more realistic than those obtained in the international survey, probably because of the following reasons:

- The respondents understood the presented problem well and were concerned about possible consequences of electricity generation.
- The personal contact helped in clarifying the various dimensions of the problem and the steps of the weighting procedure.

4.6 Discussion and conclusions

In the past, ExternE has been criticized as being unable to provide damage costs for impact types for which economists have not been able to determine appropriate monetary values. The methodology developed and implemented in this project is a promising approach to help fill this gap, as it can provide monetary values for such non-monetized impacts by extracting them from preference elicitation techniques used in MCDA.

We implemented this approach in order to derive monetary equivalents for acidification and eutrophication. Monetary equivalents were also derived for several impacts (mortality, CO₂ emissions) and market goods (agricultural crops) for which monetized values are already available, for checking and validating the proposed procedure.

One advantage of the proposed approach is that it directly involves the stakeholders facing a particular policy problem. Their preferences and the implied monetary equivalents are therefore specific to the given decision situation. This facilitates consideration of site-specific constraints and scarcity problems for particular goods, and the correspondingly affect of these considerations on resulting monetary values. In addition, the constructive preference elicitation procedure used facilitates building better awareness of the stakeholders' values. Moreover, MCDA is usually implemented in an open interactive procedure, where stakeholders have the possibility

to exchange ideas, and perhaps revise their initial preferences and converge to more reliable-realistic and legitimate monetary values.

In the present exploratory work, the European scale of the formulated policy problem did not allow for a clear definition of the impact categories, especially of the non-monetized impacts and hindered the articulation of preferences. This in addition to the absence of communication among stakeholders may explain the significant variation in the obtained monetary values as well as the overestimation of the considered impacts.

A further advantage of the multicriteria decision analysis is that it facilitates the free expression of preferences for environmental goods without restrictions due to the respondents' ability to pay. On the other hand, the unrestricted expression of interests can lead to an overestimation of the value of environmental goods in monetary terms, and thus, to unrealistic decision inputs.

The encouraging outcome of the work performed, along with the drawbacks detected in the obtained results, reveals the need to further investigate the possibility to exploit MCDA for deriving monetary values of non-monetized impacts. Particular emphasis should be given to the following objectives:

1. Examination of several site-specific problems in parallel in order to:
 - Obtain better estimates of the environmental impacts that matter
 - Involve stakeholders that are directly affected and more aware about the policy relevance of these impacts.
 - Compare and explain differences in value estimates on the basis of varying impact range and site-specific factors, including economic and cultural ones.
2. Organization of workshops to bring stakeholders together and facilitate exchange of information and convergence of preferences.
3. Comparison of monetary values derived from MCDA approaches and conventional CV methods, the former extracted through a series of group-based workshops with respondents from the CVM pool sample. Within the group-based deliberative workshops, the factors influencing group discussion would be necessary to be identified and explored.

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APPENDIX 4: The Questionnaire

Sheet 1: Objective

OBJECTIVE OF THE QUESTIONNAIRE

The purpose is to determine the **implicit monetary values** you assign to 4 impacts of air pollution: **acidification, eutrophication, loss of agricultural production and mortality**. The determination of such monetary values has remained problematic, and we have developed this questionnaire as a new approach, based on assessments by experts such as you. You will be presented with three possible scenarios for reducing the emission of NO_x, NH₃, SO₂ and VOC in Europe, relative to the base level of 1990. The reductions are described in terms of the corresponding physical impacts for acidification, eutrophication, mortality, and changes in agricultural production. The corresponding abatement costs are also shown, i.e. the costs necessary to achieve the reductions. There is no single best scenario because lower emissions require higher abatement costs, and your preferred choice depends on the relative weights you assign to the different criteria. You can do that in the Worksheet YOUR PREFERENCES designed for a simple multicriteria analysis of this problem. Since abatement cost is in monetary units, your choices imply monetary values for the other four (acidification, eutrophication, loss of agricultural production and mortality).

THE SCENARIOS

The three emission scenarios for 2010 are:

- ➔ **CL:** based on the anticipated reduction due to all current legislation and abatement plans (excl. Gothenburg Protocol)
- ➔ **GP:** based on the limits set by the UNECE Convention on Long Range Transboundary Air Pollution (Gothenburg Protocol)
- ➔ **MFR:** based on the Maximum Feasible Reduction resulting from the full application of currently available control technologies.

The data for the impacts and abatement costs are from "Economic evaluation of a Directive on National Emission Ceilings for certain atmospheric pollutants", a study for the EC by IIASA, Austria and AEA Technology, UK (1999).

Sheet 2: Impact levels

IMPACT LEVELS

The impact levels are shown (as rounded numbers) in the Table below, both as they were in 1990 and for each of the three reduction scenarios. They refer to the population and other receptors in EU-15.

- Abatement cost is shown as annual figures in the year 2010.
- Acidification and eutrophication are shown as the areas of ecosystems damaged by deposition of atmospheric pollutants exceeding critical loads.
- Agricultural loss is shown as the annual decrease in the production of cereals and potato which are among the most sensitive mass crops
- The unit for mortality is YOLL = years of life lost. Mortality is shown as the total YOLL lost in EU-15 each year.

Table 1. Impact levels.

CRITERIA	Impact levels in 1990	Impact levels in 2010		
		REF	GP	MFR
		-48% NO _x	-50% NO _x	-79% NO _x
-12% NH ₃	-13% NH ₃	-40% NH ₃		
-71% SO ₂	-75% SO ₂	-91% SO ₂		
-49% VOC	-53% VOC	-72% VOC		
Abatement cost (billion €yr)		58	60	101
(€yr per household)	0	(380 €yr per household)	(395 €yr per household)	(665 €yr per household)
IMPACTS				
in alphabetical order				
Acidification (1000 km²)	370	64	53	9
(% loss of total ecosystems area)	24,80%	4,30%	3,60%	0,60%
Agricultural loss (billion t of cereals & potato)	13	10	9	6

The table contains additional information to help you put the numbers in perspective.

→ The reduction of the emissions of each pollutant is indicated as % of the 1990 level.

→ For abatement cost the annual amount per household is also shown, assuming 2.5 persons/household.

Further information can be found in the Appendix.

→ For acidification the areas are also shown as % of the total area that could be affected by these impacts.

→ For agricultural loss the damage is given as

(% loss of total agricultural production)	5,20%	4,00%	3,60%	2,40%
Eutrophication (1000 km ²)	667	484	476	194
(% loss of total ecosystems area)	55%	40%	39%	16%
Mortality (1000 YOLL/yr)	3 300	1 900	1 800	1 100
(months/person per lifetime exposure)	(7.8 months)	(4.5 months)	(4.3 months)	(2.6 months)

percentage of the production of cereals and potatoes in 2000.

→ For eutrophication the areas are also shown as % of the total area that could be affected by these impacts.

→ Mortality is also expressed as the corresponding average loss of life expectancy per person if the population were exposed to this level for an entire lifetime.

Sheet 3: The Method

THE SWING Method for preferences elicitation

To specify your preferences, go to the worksheet YOUR PREFERENCES. You will be asked to rank and value the considered criteria by examining the potential improvement between two hypothetical (and unrealistic) Scenarios **W** and **B** shown hereafter. These scenarios are constructed by selecting the worst and the best performance levels in Table 1, respectively, for each of the criteria.

Table 2. The W and B scenarios.

Criteria	Scenario W (Highest Impact)	Scenario B (Lowest Impact)	Improvement	Potential gain
Abatement Cost (billion €)	101	58	43	285 € per household
Acidification (thousand Km ²)	64	9	55	3.7% of total ecosystems area
Agr. Loss (billion t of cereals & potato)	10	6	4	1.6% of total production of cereals and potato
Eutrophication (1000 Km ²)	484	194	290	24% of total ecosystems area
Mortality (thousand YOLL)	1900	1100	800	1.9 months per person, per lifetime exposure

STEP 1: Look at the potential gains between W and B

STEP 2: Specify rank order and value

1. Suppose that your starting position is scenario W and you are allowed to bring only one category to the level of scenario B:

- Type 100 in column VALUE on the line for the category you prefer to move (corresponding to 100 units on a hypothetical value scale).

2. Suppose now that you can also move a second category to Scenario B:

- In the corresponding line of column VALUE type the number that indicates the value you assign to this particular improvement on the scale from 0 to 100.

3. Continue this procedure for the remaining criteria, one after the other.

STEP 3: Observe the resulting monetary values (calculated by Excel)

STEP 4: Stop or revise your preferences

If you think that the monetary values do not adequately reflect your value system go back to step 2 and revise rank order and/or relative values.

Sheet 4: YOUR PREFERENCES

SWING METHOD

STEP 1) Study extreme values and potential gains

STEP 2) Specify relative values

Criteria	Scenario W (Highest Impact)	Scenario B (Lowest Impact)	Improvement	Potential gain	Value
Abatement Cost (billion €)	100	57	43	285 € per household	
Acidification (thousand Km2)	64	9	55	3.7% of total ecosystems area	
Agr. Loss (billion t of cereals & potato)	10	6	4	1.6% of total production of cereals and potato	
Eutrophication (1000 Km2)	484	194	290	24% of total ecosystems area	
Mortality (thousand YOLL)	1900	1100	800	1.9 months per person, per lifetime exposure	

STEP 3) Observe the results

Criteria	Weights	Monetary Values	thousand € per
Abatement Cost		1	
Acidification			km2
Agr. Loss			kt
Eutrophication			km2
Mortality			YOLL

STEP 4) Go to step 2 and revise your preferences - if necessary
 Otherwise the procedure is terminated.

Sheet 5: Background Information

APPENDIX: to help put the impacts in perspective

(note that the precise numbers in these scenarios do not matter for the purpose of eliciting your preferences; they only serve to provide a plausible and realistic menu of choices)

Air pollution mortality

If the air ambient concentration of air pollutants in Europe is reduced by 50% relative to today's levels, a reasonable policy goal for the coming decades, one can expect a life expectancy gain of about 5 months, averaged over the whole population (individual gains can be much larger or smaller). Loss of life expectancy is proportional to the incremental exposure, by contrast to the impacts on agriculture, acidification and eutrophication which are nonlinear in exposure.

To express the life expectancy change per person, divide by the total exposed population. The boundaries of the regional dispersion of pollutants are not sharp, but as a very rough indication we have divided by the population of EU15, 380 million. Whereas the YOLL number in Table 1 are annual impacts, it is perhaps more instructive to express them as loss per person if the exposure were constant at the respective level during an entire life of 75 yr. For example, the 3 300 000 life years lost at the exposure level of 1990 corresponds to $3300000 \cdot 75 / 380$ million = 0.65 yr = 7.8 months, as indicated in Table 1. Note that the emission levels and impacts in 1990 were very much higher than they are today.

Agricultural losses

For the purpose of this study, the impact on Agricultural Production that was expressed in monetary values has been translated into physical terms by assuming that the total damage affects cereals and potatoes (among the most sensitive crops to air pollution) and taking into account an average price of the corresponding products. This price is to be confirmed or considered as distorted by your answers. In EU-15 the total production of cereals and potatoes in 2002 is about 250 billion tons per year, meaning that, for example the loss for the REF scenario amounts to about 4%. Crop losses are a nonlinear function of incremental exposure, depending on background concentrations. At low background concentrations an increment of SO₂ or NO_x provides extra fertilizer that the plants can utilize. By contrast, O₃ exposure can only be harmful (the increment due to precursor emissions of VOC and NO_x has been taken into account).

Acidification and eutrophication

The areas damaged are compared with the total ecosystems area in EU-15 that is susceptible to acidification or eutrophication (1.4E6 km²) and for which critical load data exist. This area includes a large variety of ecosystems such as forests, grassland, lakes, freshwater catchment etc. For a brief description of acidification and eutrophication, see the following paragraphs.

Acidification

[From http://www.acidrain.org/acidification.htm](http://www.acidrain.org/acidification.htm)

Acidification is caused by emissions of sulphur dioxide, nitrogen oxides and ammonia. Sulphur makes the biggest contribution to acidification, although nitrogen compounds also contribute.

Acidification of water

Back in the fifties it was discovered that fish were disappearing from lakes and waterways in southern Scandinavia. Today, some 14,000 Swedish lakes are affected by acidification, with widespread damage to plant and animal life as a consequence. The damage is extensive in large parts of Scandinavia, but also occurs in parts of the United Kingdom and in the Alps.

Sensitivity to acidification is greatest in areas where the minerals in the soil weather slowly. When the soil becomes acidified its essential nutrients are leached out, which reduces the fertility of the soil. The acidification process also releases metals that can harm the micro-organisms in the soil that are responsible for decomposition, as well as birds and mammals higher up the food chain, including man.

Plants and animals disappear

The sensitivity of individual species to air pollutants and acidification varies. The most sensitive groups include fish, lichens, mosses, certain fungi and small aquatic organisms.

Forest damage

From the European survey of 1999 it appears that every fourth tree examined was damaged (the loss of leaves or needles exceeded 25 per cent). This damage to the forest has many causes, but most researchers agree that acidification of the soil and high concentrations of ground-level ozone are important contributing factors.

Eutrophication

[From http://www.epa.gov/maia/html/eutroph.html](http://www.epa.gov/maia/html/eutroph.html)

Eutrophication is a condition in an aquatic ecosystem where high nutrient concentrations stimulate blooms of algae (e.g., phytoplankton).

Why Should We Be Concerned?

Although eutrophication is a natural process in the aging of lakes and some estuaries, human activities can greatly accelerate eutrophication by increasing the rate at which nutrients and organic substances enter aquatic ecosystems from their surrounding watersheds. Agricultural runoff, urban runoff, leaking septic systems, sewage discharges, eroded streambanks, and similar sources can increase the flow of nutrients and organic substances into aquatic systems. These substances can overstimulate the growth of algae, creating conditions that interfere with the recreational use of lakes and estuaries, and the health and diversity of indigenous fish, plant, and animal populations.

Algal blooms hurt the system in two ways. First, they cloud the water and block sunlight, causing underwater grasses to die. Because these grasses provide food and shelter for aquatic creatures (such as the blue crab and summer flounder), spawning and nursery habitat is destroyed and waterfowl have less to eat when grasses die off. Second, when the algae die and decompose, oxygen is used up. Dissolved oxygen in the water is essential to most organisms living in the water, such as fish and crabs. Increased eutrophication from nutrient enrichment due to human activities is one of the leading problems facing some estuaries in the mid-Atlantic.