

## **Participation in multi-criteria decisions: a software tool and a case study**

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**Abstract:** The paper describes AMACI, a software prototype supporting the decision process in the choice among alternatives. AMACI has been designed in the context of environmental assessment, considering participation essential to elicit interests and judgment parameters of the different groups involved in the decision. Therefore, the software makes possible a clear and transparent communication and supports the active involvement of the stakeholders. The main features of AMACI are the following: it provides a framework for the description of a decision problem and structures the decision making process for each decision-maker; it makes use of the classical multiattribute decision analysis, including tools to define utility functions; it computes the ranking of the alternatives; it helps a group of decision-makers in dealing with uncertainty and in managing the possible conflict. AMACI has been used to perform the Strategic Environmental Assessment of the local planning process of the Municipality of Trezzo sull'Adda (Italy). The main steps of the procedure and the use of AMACI are briefly described: identification of stakeholders (public, relevant authorities); definition of alternatives; identification of the evaluation criteria; elicitation of the decision-maker preferences; estimation of the effects of the alternatives; comparison between alternatives; sensitivity analysis.

**Keywords:** group decision support systems; multi-criteria analysis; strategic environmental assessment; participation; software.

### **1. INTRODUCTION**

AMACI is a software prototype developed to deal with the decision phase in the context of a Decision Support System (DSS) for environmental assessment (see Laniado et al. [2004] for a description of the whole DSS), which allows to involve both administrators and stakeholders with different opinions and interests. See Colomi et al. [1999] for a description of a previous basic version of the software. Within the philosophy of the DSS, key factors of AMACI are (1) identification and involvement of the interested subjects (decision-makers, stakeholders, etc.) in every phase of the process, and (2) support the communication with analyses and tools easy to understand.

AMACI enables to compare the alternatives on the basis of their impacts, in the framework of the Multi Attribute Value Theory by Keeney and Raiffa [1976], and to manage the conflict due to the presence of a variety of criteria, decision-makers and stakeholders, supporting the consequent negotiation.

AMACI has been used to support the Strategic Environmental Assessment (SEA) of a local planning process in the Municipality of Trezzo sull'Adda (Italy). The SEA procedure has been introduced by the 2001/42/CE European directive, which requires the public administration to define new plans and programs considering all the reasonable alternatives, and assessing them not only from a socio-economic and financial point of

view but also from an environmental one. The directive provides also that all the subjects interested (“the authorities that are likely to be concerned by the environmental effects of implementing plans and programmes and the public affected or likely to be affected by, or having an interest in, the decision-making”) are consulted in specific moments and that the general public is fully informed during the decision-making process.

The first part of the paper presents the features of AMACI, following the logical path of an evaluation: multi-criteria analysis (Section 2.1), sensitivity analysis (Section 2.2), and participation and conflict analysis (Section 2.3). The description is not exhaustive, focusing mainly on the aspects that make AMACI innovative according to the author’s opinion. The second part of the paper describes the case study of Trezzo sull’Adda and how the software has been used.

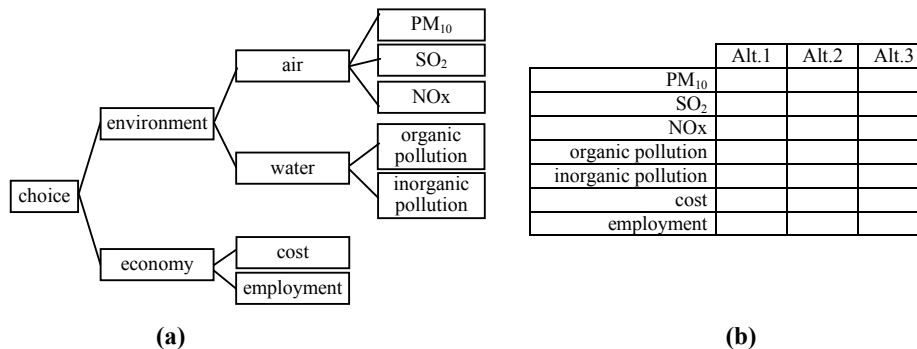
## 2. AMACI SOFTWARE

### 2.1 Multicriteria analysis

The use of AMACI by a single decision-maker is first presented, leaving to Section 2.3 the discussion of the case with multiple decision-makers.

First, the problem has to be formulated, defining alternatives, decision-makers and evaluation criteria. Each alternative is composed by a set of actions, interventions, policies which constitute a project or a plan; an alternative can differ from another one completely or just partly, for instance in a single action. The decision makers are all the subjects which can directly contribute to the decision. The criteria, used to evaluate the different effects of the alternatives, can be structured in a tree, thus making their logical structure clear, and helping to avoid problems like double counting some of the effects of the alternatives. See Figure 1a for a didactic example. Structuring the criteria in a tree also enables to obtain partial results and to perform sensitivity analysis for different aggregated levels of criteria.

The leaves of the tree are called indicators and constitute the rows of the evaluation matrix, to be filled with quantitative and qualitative impacts. See Figure 1(b) for an example. Each row is characterized by its measurement unit.



**Figure 1.** (a) A didactic example of criteria tree and (b) of a related evaluation matrix in a case with 3 alternatives. Each cell of the matrix has to be filled with the impact of the column alternative on the row indicator

Before proceeding with the classical multi-attribute analysis, AMACI allows to aggregate some of the indicators. For instance, if a number of indicators is defined to measure the noise generated by different working phases of a productive process, the user may want to consider a single noise indicator in the subsequent steps of the analysis (e.g. the maximum noise value generated throughout the process). Aggregations can be done using both analytical and logical operators.

The decision-maker has then to define a value function for each indicator, to transform it into a corresponding objective expressed on a [0-1] scale, 1 indicating the maximum satisfaction and 0 the maximum discontent. For instance the value function of a cost indicator has a decreasing shape, because low values of cost are preferred to high ones. On the other hand, the value function of the indicator “density of foxes in the natural park” has an increasing shape for low values of the indicator until the optimal density (which will depend also on the characteristics of the park) and then a decreasing shape. Value functions can be defined for both qualitative and quantitative impacts. They can be assigned analytically or by points. In the second case, AMACI allows to enter the coordinates numerically or to introduce and move the points directly on a chart using the mouse. The decision-maker defines how these points are to be considered, for instance as the only points where the value function is defined or as the points defining a piecewise linear function. Once all the value functions have been assigned, the objectives matrix is computed by the software.

The software allows an interesting representation of the objectives values through a spidergram, whose axes represent the criteria: each alternative is here represented by a colored line connecting the points corresponding to the scores of the alternative on each axe. The spidergram shows quite immediately if there are dominated alternatives, since the line representing a dominated alternative is entirely contained by the line of the alternative which dominates it.

The decision-maker has then to assign a vector of weights to the criteria, to express their relative importance. Weights can be assigned directly on the indicators list, but this can be quite unmanageable in a case with many different indicators, the rigorous procedure to assign weights is in fact quite difficult to follow in real cases. In order to facilitate this delicate step of the procedure, AMACI allows to assign weights on the criteria tree, comparing the relative importance of each “son” criterion from the point of view of its “father” criterion. For instance, from the point of view of the father *local air quality*, the decision-maker would have to set the weights for the sons *particulate matter*, *nitrogen oxides*, *sulphur dioxide* and *lead*. Generally speaking, at a high level of the tree, for instance between macro-sectors like environment, economy and social factors, weights are established at a political level, while at a low level weights are established by technicians, for instance a toxicologist for the weights to be assigned to different pollutants to estimate local air quality. Once the weights have been assigned at all the tree levels, AMACI computes the final weights of the indicators.

AMACI is now able to compute the global performance of the alternatives as weighted sum of their scores with respect to the objectives and to rank them. The results are represented in different ways, to allow a good comprehension. For instance, the numerical results can be seen on a pie chart, each sector representing an alternative and having the central angle proportional to the global score of the alternative. More information can be obtained visualizing a bar chart, each bar representing an alternative and having its length proportional to the global score of the alternative; in this case each bar is composed by segments of different colors, showing the contribution of each criterion to the global score. The user can choose the disaggregation level she want to see represented: for instance she may want to see the contribution to the global score coming from each indicator, or from a more aggregated level moving back on the criteria tree, for instance from each sector of analysis (air quality, water pollution, noise,...).

Partial results can also be obtained by selecting only a subset of indicators, for instance all those spreading from the same branch of the criteria tree, thus obtaining, if the tree has a sector or spatial disaggregation, rankings by sector or by region.

## 2.2 Sensitivity analysis

The elicitation of criteria weights is usually the most delicate step of the multi-criteria analysis, both because their attribution always implies some degree of arbitrariness and uncertainty, and because they reflect the decision-makers’ subjectivity, they are just meant to make his value system explicit. AMACI allows therefore to perform a sensitivity analysis on the weights, giving indications on the robustness of the ranking.

The simplest sensitivity analysis refers to each single weight. Please note that the weight can be referred to any level of the criteria tree, i.e. it can be the weight given to an indicator or to a sector of analysis, or to a region and so on. The software computes the minimum increase and decrease of the value of the weight such that a rank reversal with another alternative occurs. The result is presented in a table. AMACI also shows on a chart the trends of the global performances of the alternatives when varying a single weight value.

It is also possible to guide the analysis interactively: the interface presents two bar charts, one representing the weights values, the other the global performances of the alternatives as discussed in the previous section. The user can simply drag up or down the bar of the weight she want to vary and see how the global performances are affected. Numerical results are also shown on a table. The same analysis can be performed selecting more than one weight at the same time and increasing or decreasing their values simultaneously.

A further possibility consists in letting the proportion between all the weights vary without correlation: the software finds the vector of weights at minimum distance from the assigned one such that a rank reversal occurs. AMACI shows to the user the rank reversal vector and the rank reversal alternative. Solving this problem is not trivial, since most definitions of distance between vectors are unsuitable to weights vectors and, if adopted, give rise to misleading results (see Colomi et al. [2001] for a complete discussion of the problem). The weight vectors are defined via a linear normalization maintaining the ratios between the vector elements, hence the chosen distance must be invariant with respect to the normalization. Since the information the normalised vectors give is represented by the direction they define in the space of their components and not by a precise point in such a space, a correct way of measuring distances between such vectors is to measure the distance between their directions. A very simple distance which satisfies this requirement is the "angle distance", namely the angle that the two vectors form in the space of their components. AMACI makes use of the angle distance each time it has to compute the distance between weight vectors, both in sensitivity and conflict analysis.

### **2.3 Participation and conflict**

As regards the use in a participatory process, AMACI can ensure two essential requirements:

- Transparency: building a shared information on technical analyses and political decisions, necessary to make the interested subjects aware of what is going on.
- Repeatability: the documentation and the software implementation of every step of the process allow to change any element (according for example to newly available information), and easily go through the process again.

AMACI goes further taking into account the conflicts among the social groups involved, who usually voice different interests, opinions, and reference value systems. Of course conflicts cannot be solved analytically, but an analytical support to negotiation, consisting mainly in giving clear information, can be very helpful and constitute the basis for negotiation (see for example Kersten [1997]).

AMACI allows therefore to introduce different weight vectors for the indicators, each vector representing a different actor. For each actor, the final ranking is computed and statistics on the results are shown, e.g. the percentage of times each alternative classifies first, or in the first, second, third, or  $n^{\text{th}}$  position, according to all the actors; the same elaboration can be done attributing different importance to the actors, for instance weighting twice an actor representing two times the number of the people represented by each of the others.

AMACI obtains conflict indicators based on the distances between the actors weight vectors: all the distances between pairs of actors are computed and ordered in a matrix, and both global conflict indicators (e.g. the average distance among actors) and individual conflict indicators (e.g. which is the most disagreeing subject) are pointed out.

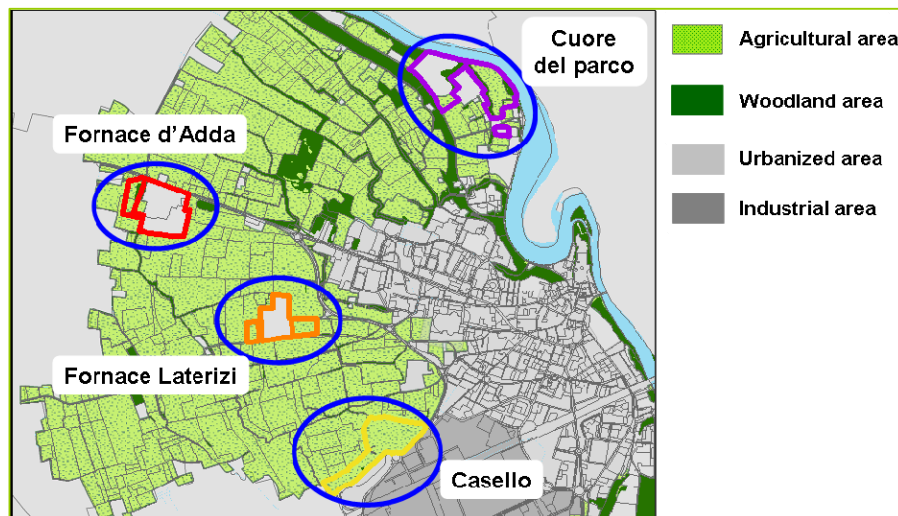
To give a basis to negotiation efforts, AMACI also computes the barycentric vector of weights, the one with minimum total distance from all the vectors assigned by the actors, and allows the actors change their original vectors, in an iterative way, until they possibly reach a consensus.

If the actors are willing to relax their hypothesis and assign the weights qualitatively, ranking them from the largest to the smallest without identifying their exact values, further negotiation margins open: in this case AMACI computes which are the alternatives (usually more than one) that can classify first for each actor. This allows to identify alternatives which are potentially less conflicting, i.e. those which can classify first for a high percentage of actors.

Pointing out the most critical and conflicting elements of the alternatives can also help to generate new alternatives, which can be similar to the previous ones (with some changes and/or mitigation measures), or totally different (see for instance Bana e Costa [2001]). Therefore, the process of choice among alternatives taking into account multiple criteria and involving multiple stakeholders and decision-makers becomes an iterative procedure, possibly converging to a consensus solution.

### 3. CASE STUDY

AMACI has been used to support the SEA of the Town-Planning Scheme of the Municipality of Trezzo sull'Adda. The SEA process started on July 2008, when private proponents submitted a proposal to set up and increase some productive and commercial activities. The parts of the municipality interested by the assessment, illustrated in Figure 2, are an agricultural area (*Casello*), two agricultural and productive areas (*Fornace d'Adda* and *Fornace Laterizi*), and a disused cava on the river Adda (*Cuore del parco*).



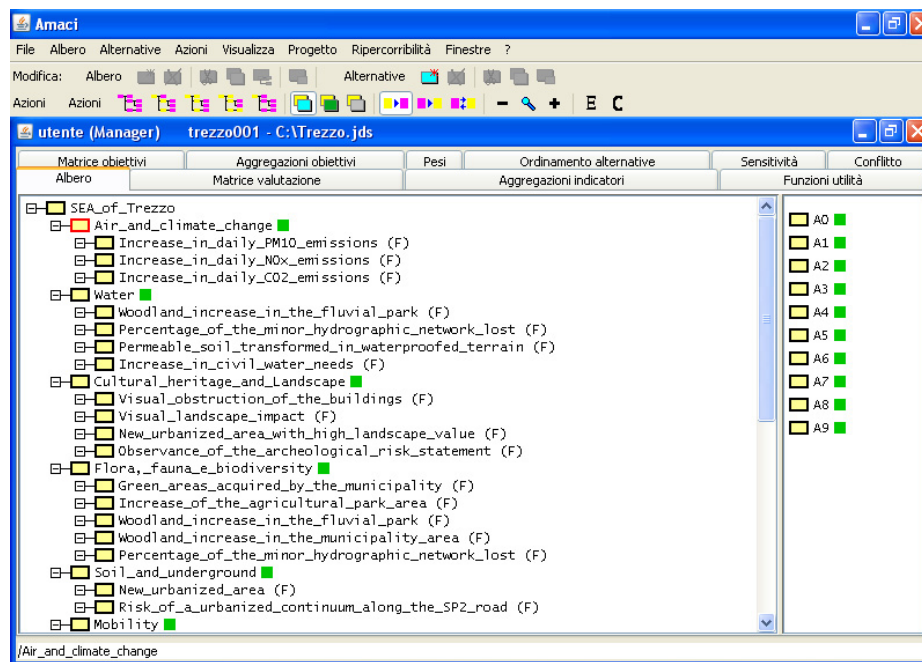
**Figure 2.** The areas interested by the Strategic Environmental Assessment of the Town-Planning Scheme of Trezzo sull'Adda.

One of the main objectives of the SEA process is to avoid to make a decision based on a few alternatives, maybe proposed only by a specific stakeholder (e.g. a private backer). In this case, the public would have no possibility to gain early influence in the way decisions are made. Consequently, on one hand the public would feel excluded from participating in decisions that affect them, on the other hand the public's reactions would become, from the perspective of the planning authority, just unproductive opposition. A public decision-making process should consider all the feasible alternatives identified and evaluated also with the participation of the stakeholders and the public, as pointed out by Steinemann [2001] and Valve [1999].

In the case study, the participation process actively involved citizens and associations through a set of public hearings and thematic participatory meetings on the effects on land-use, environment, mobility and socio-economy. Most of the people participated to all the meetings, creating a kernel of interested people that spread the results of the meeting to other citizens.

The alternatives taken into account in the Trezzo SEA are combinations of proposals coming from the private backers, the participation process, the planner of the municipality, and the analyst in charge of the SEA. The evaluation considers 10 alternatives, taking into account also the zero alternative (A0), which corresponds with maintaining the current territorial structure and land use. Alternative A4, for instance, coincides with the original proposal of the backers and maximizes the area for productive activities in the *Casello* and *Fornace d'Adda* areas. On the other hand, alternative A6, defined in coherence with observations of environmental associations and the public, transfers some of the proposed productive activities for *Fornace d'Adda* and *Casello* in a less environmental valuable zone and envisages agricultural land use for such areas. All the alternatives, except the A0, have positive effects on the recovery and re-naturalization of the *Cuore del parco* area.

The alternatives are evaluated on environmental, economic and social criteria, defined according to a tree structure. The criteria tree can be easily managed by AMACI. Figure 3, for instance, depicts the main interface to handle the tree and presents part of the criteria tree used for the case study.



**Figure 3.** The AMACI interface: the criteria tree (*left*), the alternatives (*right*), and the tabs that correspond to the main steps of the multi attribute value theory (*top*) (criteria tree, evaluation matrix, value functions, ...).

The utility functions and the criteria weights have been elicited from the town councilor for the environment, and have been presented during the public meetings. However, the elicitation of these parameters were not included in the participatory process. Figure 4 depicts the AMACI interface for the construction by points of the utility functions of a qualitative indicator (*Visual landscape impact*) and a quantitative one (*New urbanized areas*). The first indicator is defined only for 5 points, while the second one is defined in a range of values.

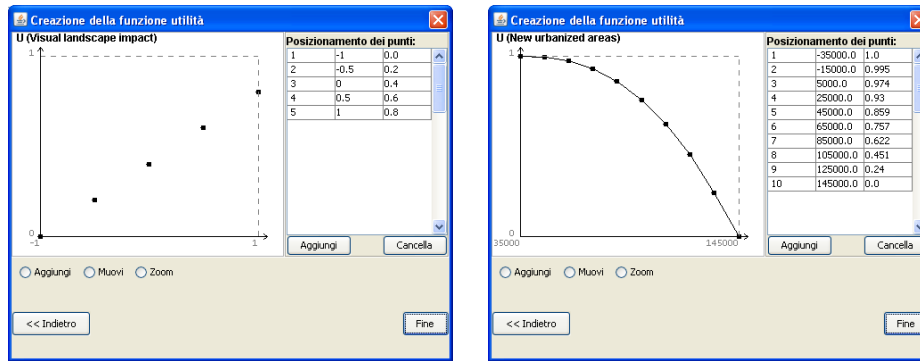


Figure 4. The AMACI interface for the utility function construction for the *Visual landscape impact* (left) and the *New urbanized areas* (right) indicators.

Figure 4 shows the global performance of the alternatives and the ranking. The software allows the user to select the level of aggregation for the results. For instance, if the user selects the criteria level indicated in Figure 3 by green squares, AMACI will present all the subsequent results on this set of elements (e.g. in Figure 4, the segments of different colors show the contribution of each selected criterion to the performance).

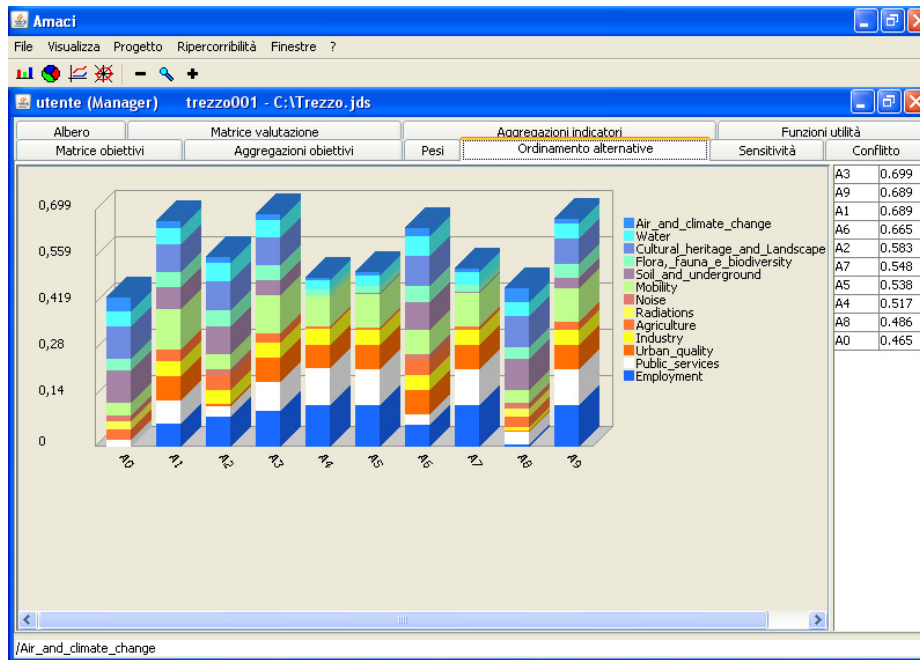


Figure 5. Ranking of the alternatives: the length of the bars is proportional to the global performance of the alternative.

Analyzing Figure 5, a preliminary result of the assessment could indicate that the first alternative in the ranking is A3, while the alternative initially proposed by the backers (A4) is in the third from last position. The result depends strongly on the preference expressed by the councilor. As already said, AMACI features a set of tools for the sensitivity analysis, in order to verify the robustness of the found solution. As an example, Figure 6 shows the AMACI interface for the sensitivity analysis on a single weight: the alternatives can be turned on/off (*on the right*), and the global performances of the turned on alternatives are plotted against the possible values – from 0 to 1 – that can assume the weight (*on the x axis*). The sensitivity analysis tools was useful also during a participatory meeting, letting the participants to change the weights. During the meeting, facilitators collected

suggestions to change the weights, and at the end of the meeting the analyst showed collectively (the participants did not have their own computer) the results in an interactive way.

At the end of the evaluation procedure (May 2009), the municipality council approved alternative A3, providing a set of prescriptions and compensation measures suggested by the SEA final report.

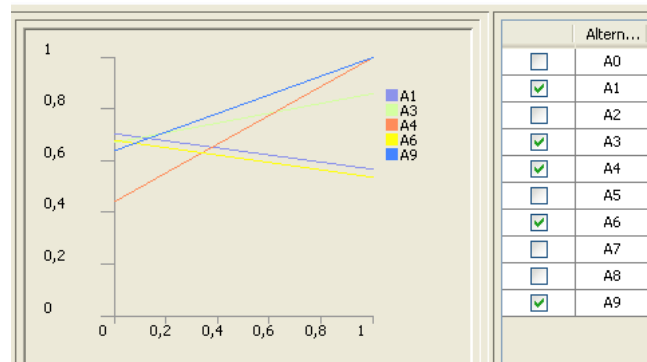


Figure 6. Results of the sensitivity analysis tool on a single criterion weight.

#### 4. CONCLUSIONS

The AMACI software described in this paper intends to make more transparent, repeatable and participated the decision-making process.

The town councilor that used AMACI judged positively the interface for the elicitation of his preferences. Moreover, he appreciated the possibility of re-assessing the alternatives in function of changes of the parameters (e.g. indicators' values, utility functions, criteria weights). The software has been evaluated effective both to make transparent to the public the weights used and to discuss the results on the basis of the sensitivity analysis. The possibility to display the results in different graphical ways and depending on different aggregation levels showed quite useful for the communication and comprehension of the decision process.

AMACI supported the decision-maker in understanding why a certain alternative is at the first or the last position of the ranking. The idea is to eliminate successively all the alternatives that are inferior because they are Pareto-dominated or too conflicting, or because they have critical impacts on a particular sector. This gradually narrows the problem and allows a more significant definition and evaluation of the remaining alternatives (Kersten and Mallory [1999]), so that the actual entity of the conflicts involved becomes more evident. A set of the best alternatives is selected, among which the decision-maker can make his choice. All the information on this decision-making process has to be provided to the public making more transparent the impacts and interests involved, and possibly leading to a more rational decision. Thus, SEA has to be considered not a procedure aimed at finding automatically the best alternative, but as a decision-making process, where a continuous participation of all the actors involved makes divergences due to subjectivity and contrasting interests emerge at an early stage of the analysis. Confrontation becomes therefore usually more constructive and the search for a compromise solution easier and less costly.

In Italy, this way of proceeding and structuring participation processes, eventually using a tool like AMACI, is not in the average cultural sensitivity; therefore the authors believe that the Trezzo SEA case represented a significant application.



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