74th Meeting of the European Working Group "Multiple Criteria Decision Aiding"

Towards an integration in sustainability assessment: the application of the Choquet integral for siting a waste incinerator

Marta Bottero [1], Valentina Ferretti [2], Giulio Mondini [3]

[1] Politecnico di Torino, Department of Housing and City (DICAS). marta.bottero@polito.it
[2] Politecnico di Torino, Land, Environment and Geo- Engineering Department (DITAG). valentina.ferretti@polito.it
[3] Politecnico di Torino, Land, Environment and Geo- Engineering Department (DITAG). giulio.mondini@polito.it

Multiple Criteria Decision Analysis (MCDA, Figueira *et al.,* 2005) is a valuable and increasingly widely-used tool to support decision-making processes where there is a choice to be made between different options. This approach is particularly useful in the context of sustainability assessment where a complex and inter-connected range of environmental, social and economic issues must be taken into consideration and where objectives are often competing.

It has been generally agreed that when dealing with sustainability issues neither an economic reductionism nor an ecological one is possible. Since in general, economic sustainability has an ecological cost and ecological sustainability has an economic cost, an integrative framework such as multicriteria evaluation is needed for tackling sustainability issues properly (Munda, 2005). In this sense, the analysis of the possible interactions among the elements is of particular importance for assessing the sustainability of a certain transformation.

Within this context, a very important role is played by the “non-additive measurement theory”, that makes use of the Choquet integral (Choquet, 1953; Sugeno, 1974). This last represents the generalization of the weighted average method and provides a computational structure for aggregating information taking into account interactivity between criteria.

The present paper proposes a multicriteria approach that is able to support Decision Makers in the choice of the best location for a new waste incinerator plant that has to be constructed in the Province of Torino (Italy). Three alternative sites have been compared based on different indicators that have been aggregated using the Choquet integral in order to obtain the global performance of each solution and to better highlight the tradeoffs between the aspects involved in the decision.

The aim of the analysis is to study the contribution that the Choquet integral offers in sustainability assessment of undesirable facilities location problems, paying particular attention to the use of quantitative indicators in the evaluation process. Mention should be made to the fact that the analysis takes into account the opinion of several experts in determining the importance of the different elements of the model.

The paper, which is thus based on an integrated approach able to aid the comprehension of complex phenomena, explores innovative MCDA models in the field of sustainability assessment of territorial transformations putting in evidence strengths and weaknesses of the methodological approach.

Keywords: Multiple Criteria Decision Analysis, Choquet integral, Environmental analysis, sustainability assessment, undesirable facilities location problems.

1. Introduction

It is well known that sustainable development is a multidimensional concept that considers different issues, such as socio-economic aspects, ecological factors, technical elements and ethical perspectives (World Commission, 1987). Measuring sustainability is often addressed through indicators able to represent the multidimensionality of the decision problem; these indicators must reflect the heterogeneous values that coexist in a resource and for this reason they are normally organized in specific sets and expressed by different measurement units (Boggia and Cortina, 2010).
Sustainability assessment requires therefore a Multicriteria-based approach. Generally speaking, the techniques belonging to the family of Multicriteria Decision Aiding (MCDA) are used to make a comparative assessment of alternative projects or heterogeneous measures (Roy and Bouyssou, 1995; Figueira *et al*., 2005). These methods allow several criteria to be taken into account simultaneously in a complex situation and they are designed to help Decision Makers (DMs) to integrate the different options, which reflect the opinions of the involved actors, in a prospective or retrospective framework. Participation of the DMs in the process is a central part of the approach.
Sustainability is often considered in terms of the three pillars of environmental, social and economic considerations and it has been generally agreed that policies, plans, programmes and projects should be prepared taking into account sustainability considerations. On the side of the evaluation procedures, which aim at assessing the overall sustainability of a territorial transformation project, mention can be made to the processes of Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA), which are defined at the European level by the Directives 1997/11/EC and 2001/42/EC, respectiverly. Both EIA and SEA over time have increasingly considered not only the environmental effects of plans and projects, but also social and economic effects; recently, some applications started to think about sustainability as an integrated concept (Morrison-Saunders and Therivel, 2006). There is no single definition of *integrated sustainability assessment* and several approaches are nowadays available with different levels of integration (Fig. 1).

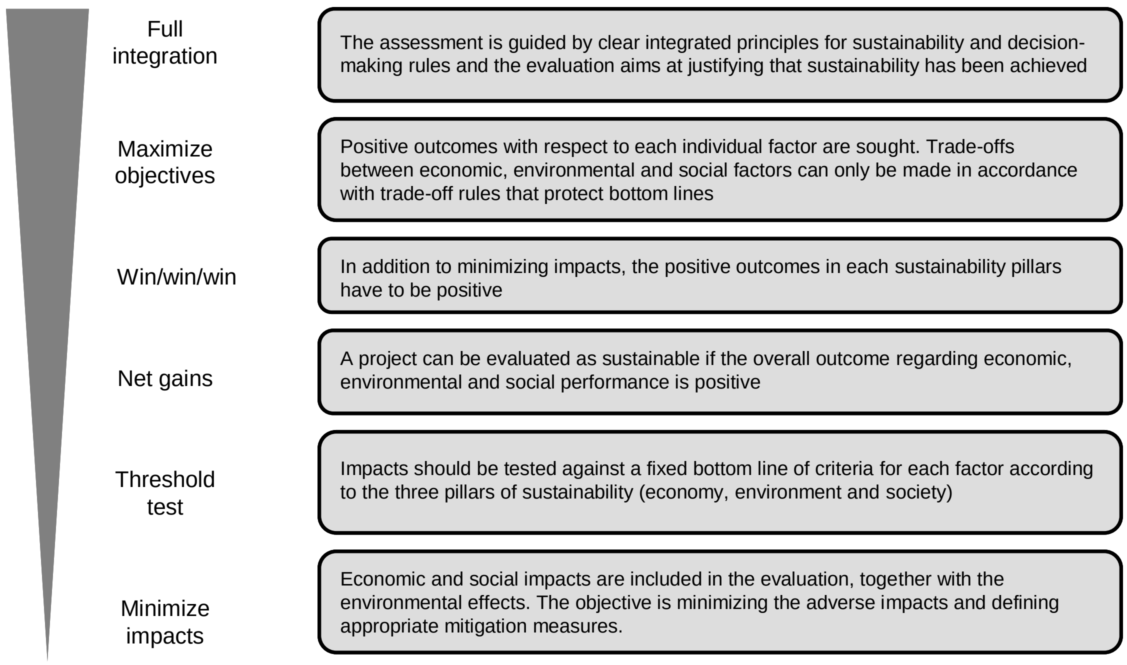

Figure 1 Existing approaches for addressing the issue of integrated sustainability assessment (source: adapted from Morrison-Saunders and Therivel, 2006)

When dealing with sustainability assessment in an integrated way, a critical issue is how to combine the different dimensions in the evaluation framework. Following the approach that has been proposed by Jesinghaus (1999), the performance of a certain strategy (plan, programme, project, policy etc.) in terms of sustainability can be computed by combining different criteria (or indicators) through a specific procedure that allows the original values to be aggregated in a composite index which reflects the overall sustainability of the topic under examination.
In this context, of particular importance is the degree of compensability between the different dimensions/aspects of the problem. In this sense, when dealing with sustainability issues it has been noticed that neither an economic reductionism nor an ecological one is possible (Munda, 2005). Since in general, economic sustainability has an ecological cost and ecological sustainability has an economic cost, an integrative evaluation framework is needed for tackling sustainability issues properly. From a computational point of view, the linear combination does not fit with the problem because the overall effect is not only the sum of the different effects; in other words, the principle of substitution cannot be applied in this context, where a good performance in one area (for example, the economic dimension) is not compensated by a poor performance in another area (for example, the environmental dimension) (Giove *et al*., 2010).
The work addresses the problem of the integration in sustainability assessment by means of the Choquet integral (Choquet, 1953; Sugeno, 1974), which provides a computational structure for aggregating information taking into account interactivity between the criteria. Starting from a real application concerning the location of a new waste incinerator plant that has to be constructed in the Province of Torino (Italy), the paper aims at exploring the contribution that the Choquet integral offers in sustainability assessment of urban and territorial transformation projects, paying particular attention to the use of quantitative indicators in the evaluation process.
After the introduction, the rest of the paper is organized as follows: section 2 provides the background methodology concerning Non-additive measures and Choquet integral; section 3 illustrates the performed application, considering the description of the study case, the structuring of the decision problem and the development of the model; section 4 discusses the main findings of the work and section 5 summarizes the conclusions that can be drawn from the research done.

2. Non-additive measures and Choquet integral

Criteria are used for evaluating decision-making problems. It has been noticed that in many decision problems criteria consist of interdependent and interaction characteristics and they cannot be evaluated and aggregated by conventional additive measures, such as the weighted average method.
In order to address this topic, many methods have been proposed in the Multi Attribute Value Theory context and they belong to the family of the Non-additive measures (NAM). It is widely recognized that the NAM approach satisfies many theoretical requirements and it is able to model many types of interactions in the preference structure of the DM.
The Choquet integral belongs to the NAM family and it represents a flexible aggregation operator being introduced by Choquet (1953) as the generalization of the weighted average method to interactions among criteria.
The Choquet integral method can be seen as a fuzzy integral method based on any fuzzy measure that provides an alternative computational structure for aggregating information.
The basic idea is to assign a weight to every possible set of criteria and to compute a weighted average of the values of all the subsets. This operation allows coalitions of criteria to be taken into account, instead of single criteria only, as in the weighted average method.

Note that the numerical complexity increases exponentially with the number of parameters involved. If *n* is the number of criteria, the Choquet integral requires the specification of 2^n parameters (which represent all the possible combinations of the *n* criteria).
Let 2^G be the power set of *G* (i.e. the set of all the subsets of the set of criteria *G*); a fuzzy measure (or capacity) on *G* is defined as a set function $\mu : 2^G \rightarrow [0,1]$ which satisfies the following properties:

1) $\mu(0) = 0; \mu(G) = 1$ (boundary conditions);
2) $\forall T \subseteq R \subseteq G, \mu(T) \leq \mu(R)$ (monotonicity condition).

In the framework of multicriteria decision problems, the value *μ(R)* given by the fuzzy measure *μ* on the set of criteria *R* is related to the importance weight given by the DM to the set of criteria *R* (Angilella *et al*., 2010).
A fuzzy measure is said to be additive if $\mu(R \cup T) = \mu(R) + \mu(T)$ for any *T, R* $\subseteq$*G* such that *T* ∩ *R*=0. Otherwise, the fuzzy measure is non additive and it can be super-additive if $\mu(R \cup T) \geq \mu(R) + \mu(T)$ or sub-additive if $\mu(R \cup T) \leq \mu(R) + \mu(T)$. For an additive measure, no interaction is possible among the criteria and the linear superposition holds. For a sub-additive measure, a redundant effect is modelled, while the contrary holds for a super-additive effect (synergic effect).
Given a non-additive measure *μ*, let us consider (x_1, x_2, …, x_n) the criteria values of a particular alternative. The Choquet integral of the vector (x_1, x_2, …, x_n) with reference to a capacity *μ* is given by the following equation:

$$Ch([x_1, x_2, \ldots, x_n], \mu) = \sum_{i=1}^{n} \left(x_{(i)} - x_{(i-1)}\right) * \mu\left(A_{(i)}\right) \qquad (1)$$

being (.) an index permutation so that $x_{(i)} \leq x_{(i+1)}$, *i*=1, 2, …*n*-1, $x_{(0)}$=0.
Figure 2 provides a geometrical representation of the Choquet integral.

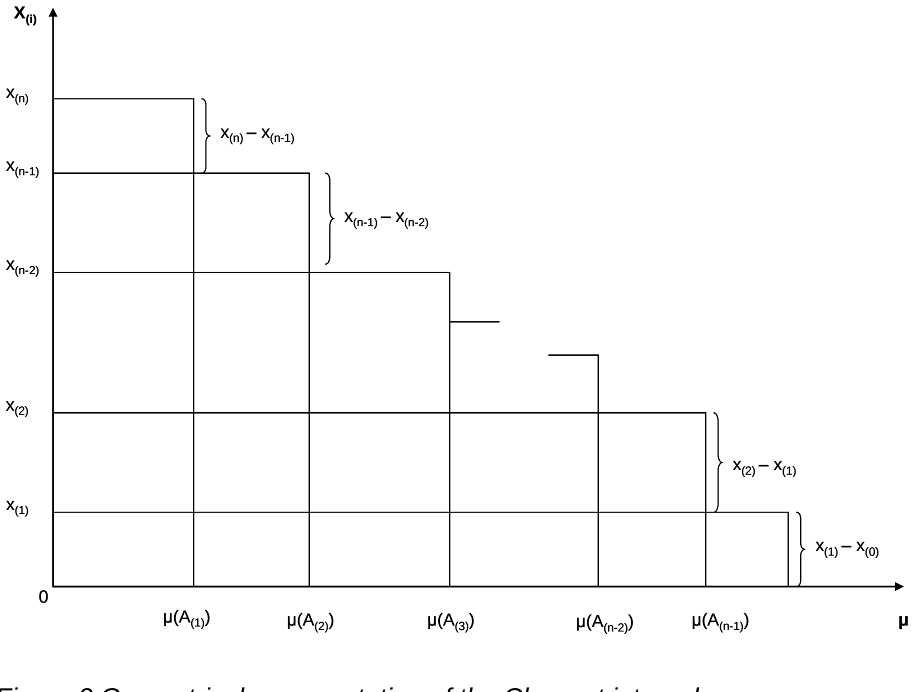

Figure 2 Geometrical representation of the Choquet integral

Several applications of the Choquet integral in MCDA exist in the literature, where it is possible to find a wide range of experimentations (Grabish and Labreuche, 2008). This framework has been

applied for addressing logistic processes (Demirel *et al.,* 2010; Berrah and Clivill, 2007; Tsai and Lu, 2006), economic evaluation (Heilpern, 2002), social analysis (Meyer and Ponthiere, 2011), while applications in sustainability assessment and environmental analysis are less consolidated (FEEM, 2009; Giove *et al*., 2010).
Mention should also be made to the adaptation of the Choquet integral in other MCDA techniques, such as Analytic Hierarchy Process (Lin, 2008; Hu and Chen, 2010; Lee *et al.,* 2011) and Analytic Network Process (Lang *et al.,* 2009; Yazgan *et al*., 2010) in order to consider the existence of interactions among criteria.

3. Application

3.1 Research objectives

The decision problem under analysis concerns the choice of the most suitable location for a waste incinerator plant, which has to be constructed in the Province of Torino (Italy). Mention should be made to the fact that the application performed in the present research is based on a scientific study that was developed by the Provincial Administration (ATOR, 2008) where different sites have been identified and investigated. Particularly, three alternative locations are presented and all the available information concerning the territorial context has been organized according to a qualitative/quantitative approach based on indicators.
The purpose of the present analysis is to experiment the application of the Choquet integral approach for the synthesis of the available data concerning the decision problem under examination. The baseline information that is used as input for the model has been directly derived from the aforementioned indicators system.
In particular, the specific objective of the application is to explore limits and potentialities of the Choquet integral approach in the context of undesirable facilities location problems, where several trade-offs exist among the conflicting aspects involved in the decision.
Taking into account technical elements that are measurable, and thus objectively comparable, is essential to build consensus around a decision, to reduce conflicts and consequently to pave the way to the location of undesirable facilities. This is why an approach based on indicators, most of which of quantitative nature and thus verifiable, has been adopted.

3.2 Description of the case study context

As already mentioned, the case study considered in this paper refers to the location of a waste incinerator plant that has to be constructed in the Northern part of the Province of Torino. At the moment, one incinerator plant is already under construction and it will service the Southern part of the Province. However, according to the Municipal Solid Waste Management provincial plan (ATOR, 2008), the construction of a second incinerator is necessary. The plant will have a capacity of about 290.000 tons/year and it will serve an area that includes 177 municipalities, for a total population of 530.000 inhabitants.
After a detailed study of the territory and of the land use plans of the different municipalities in the area, three potential plant locations have been identified on the basis of a technical decision process conducted by the Provincial Authority. The three sites are located in the municipalities of Ivrea, Rivarolo Canavese and Settimo Torinese (Fig. 3).

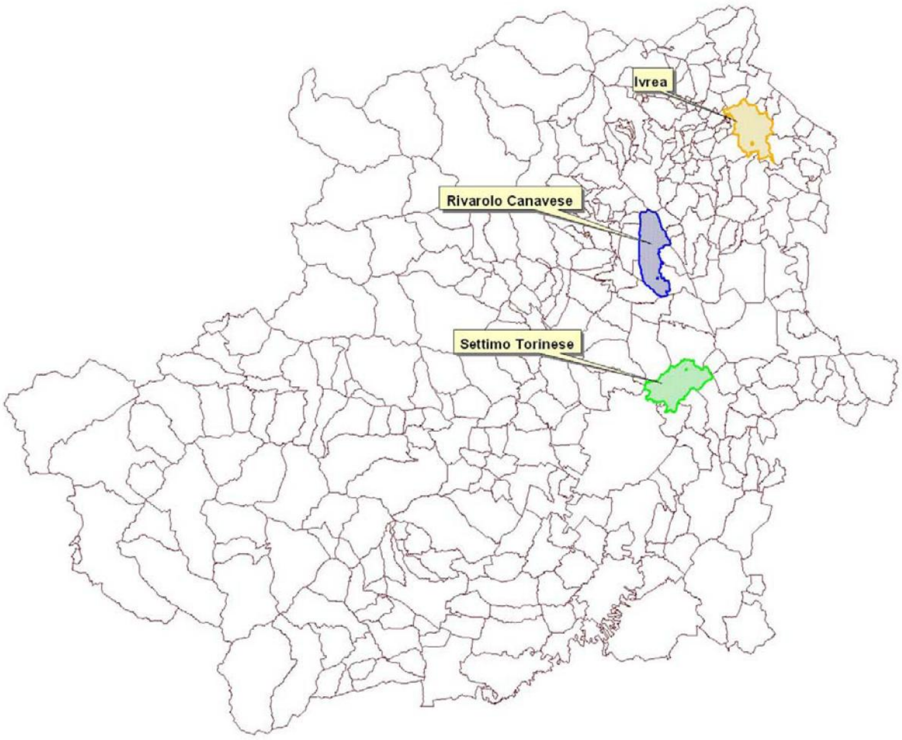

Figure 3 Representation of the three potential plant locations for the waste incinerator plant that has to be constructed in the Province of Torino (Italy)

3.3 Structuring of the decision problem

The problem definition overlaps the decision-making intelligence phase, which refers to the structuring of the problem, the identification of the objectives, and the selection of criteria or attributes to describe the degree of achievement of each objective (Simon, 1960).
The comparison of different sites for the location of a waste incinerator plant represents a complex planning problem in which the presence of interrelated elements and conflicting aspects suggests the use of a multicriteria approach that is able to provide a rational base for the systematic analysis of the alternative options. Due to the aforementioned complexity of the problem under consideration, and with the aim of explicitly considering the interrelationships and the trade-offs between the aspects involved in the decision, an approach based on Non Additive Measures and the Choquet integral has been applied.
Starting from the overall objective of the analysis, which is the identification of the most suitable site for the location of the new waste incinerator plant in the province of Torino, a comprehensive set of evaluation criteria that reflect all the concerns relevant to the decision problem has been identified (Fig. 4).
Taking into account the full range of aspects relevant to the decision problem enhances the quality of the final decision, allowing the totality of the effects of the transformation project to be considered and the negative externalities and the intergenerational effects to be minimized.
It is necessary to put in evidence that the criteria considered in the present application reflect the requirements coming from the legislative framework in the context of Environmental Impact Assessment (first of all, the European Directive 1997/11/CE). Further information for the structure of the decision model has been derived from the specific legislation in the field of waste management at both the national and local level. In this sense, of particular interest is the Waste Management Plan of the Province of Torino (ATOR, 2008), which provides a list of aspects to be considered for the location of waste facilities.

In the present study 29 attributes have been identified, clustered in three main criteria named "program frame", "project frame" and "environmental frame" (Fig. 4). Mention should be made to the fact that the three aforementioned frames constitute the basic components of the Environmental Impact Statement (EIS) (Glasson *et al*., 2005).
In particular, the "program frame" considers the coherence with the planning instruments in force at both the regional and local scale; the "project frame" refers to technical characteristics of the territorial transformation project that can positively or negatively orient the location of the waste incinerator (as, for instance, the water supply potentialities or the existence of positive concerns such as areas subjected to land reclamation). Finally, the "environmental frame" takes into account the presence of possible constraints from the point of view of the characteristics of the soil (e.g. hydro-geological risk, agricultural land, etc.), of the air quality (with reference to both the construction phase and the operation one), of the landscape and ecosystems and of the noise and electromagnetic fields components, paying also attention to the socio-economic aspects affected by the transformation project.
As previously stated, both quantitative and qualitative indicators concerning each EIS frame have been used based on the information made available in the Provincial Administration scientific study (ATOR, 2008).

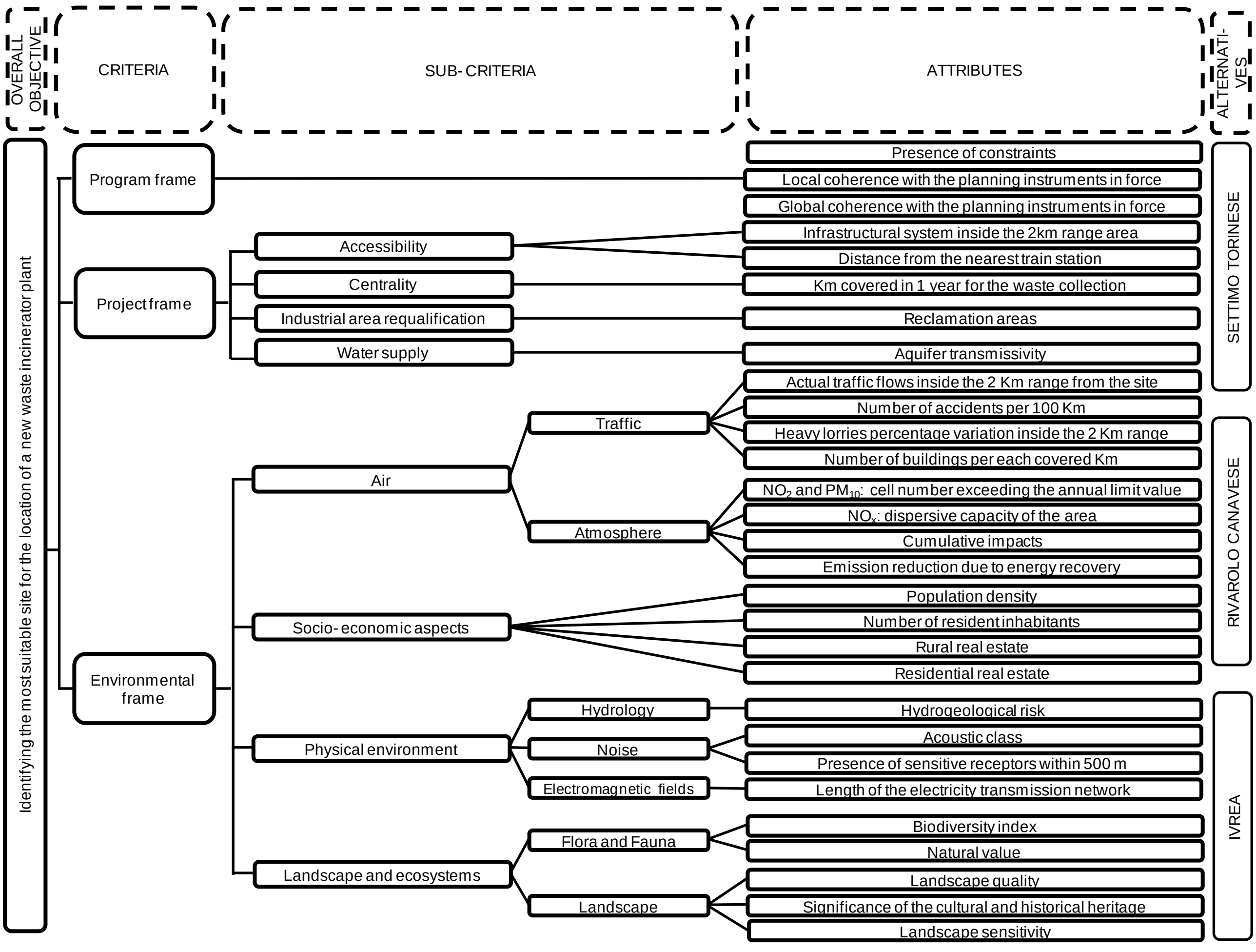

Figure 4 The decision tree for the analysis

It is important to underline that the analysis dimension concerns a 2 km range area from each site. In the context of undesirable facilities location problems, the aforementioned assumption leads to

identify more negative aspects (criteria to be minimized) than positive ones (criteria to be maximized) since the former spread more easily on the territory.
Mention should also be made to the fact that social opposition related indicators have not been considered in the structuring of the network, since they would have been equal for the three alternative sites.

3.4 Assessment of the alternatives

As highlighted in the OECD (2008) Handbook on constructing composite indicators, normalization is required prior to any data aggregation since the indicators in a data set often have different measurement units. Several normalization techniques exist in the literature and the choice among them should be made depending on the theoretical framework chosen.
The method that appeared better-suited for the present study consists in re-scaling the original values in a 0-10 range. The usefulness of the re-scaling procedure translates into a widening effect of the normalized indicators whose original values were extremely close, thereby enhancing even small differences. The problem with such a methodology is that it is greatly sensitive to extreme values, which tend to distort the normalized values (FEEM, 2009).
At a technical level, the raw values of each indicator for the three alternative sites have thus been translated into the 0- 10 scale, awarding 0 to the minimum value and 10 to the maximum value. Mention should be made to the fact that the problem under analysis involves both criteria that positively affects the decision (whose corresponding attributes have thus to be maximized) and criteria that negatively affects the decision (whose corresponding attributes have thus to be minimized). As a consequence, intermediate values between the minimum and the maximum have been converted through the following formulas (OECD, 2008), depending on the need to maximize or minimize the attribute, respectively:

$$Ii = \frac{x - x\min}{x\max - x\min}$$

$$Ii = \frac{x\max - x}{x\max - x\min}$$

in which I_i is the normalized index for each indicator and x indicates the raw value of the indicator.
The maximum and minimum values used for this type of normalization are the lowest and the highest values of a specific indicator. These values do not necessarily correspond to the best and worst possible values of that indicator in absolute terms and they do not represent value judgments. The reason why this technique has been chosen refers to the general objective of the present application which consists in the selection of the best performing alternative. The focus of the analysis is thus on the relative differences between the alternatives.
The results of the applied normalization procedure are shown in Table 1.

Table 1 Normalization of the attributes values

CRITERIA	SUB- CRITERIA	SUB-SUB-CRITERIA	ATTRIBUTES	IVREA	RIVAROLO	SETTIMO
Program frame			Presence of constraints	0	10	10
			Local coherence with the planning instruments in force	0	5	10
			Global coherence with the planning instruments in force	0	5	10
Project frame	Accessibility		Infrastructural system inside the 2 Km range area	10	0	10
			Distance from the nearest train station	10	10	10
	Centrality		Km covered in 1 year for the waste collection	0	6,9	10
	Industrial area requalification		Reclamation areas	0	5	10
	Water supply		Aquifer transmissivity	2,5	0	10
Environmental frame	Air	Traffic	Actual traffic flows inside the 2 Km range from the site	10	7,1	0
			Number of accidents per 100 Km	2,4	0	10
			Heavy lorries percentage variation inside the 2 Km range	0	5	10
			Number of buildings per each covered Km	10	7,5	10
		Atmosphere	NO_2 and PM_{10}: cell number exceeding the annual limit value	10	6,1	0
			NO_x: dispersive capacity of the area	0	8,8	10
			Cumulative impacts	10	6,3	0
			Emission reduction due to energy recovery	0	0	10
	Socio-economic aspects		Population density	0	10	5,3
			Number of resident inhabitants	6,7	10	0
			Rural real estate	10	0	6,2
			Residential real estate	0	10	3,6
	Physical environment	Hydrology	Hydrogeological risk	0	10	9,8
		Noise	Acoustic class	0	0	10
			Presence of sensitive receptors within 500 m	0	0	10
		Electromagnetic fields	Length of the electricity transmission network	10	7,6	0
	Landscape and ecosystems	Flora and Fauna	Biodiversity index	0	1,1	10
			Natural value	0	0	10
		Landscape	Landscape quality	0	5	10
			Significance of the cultural and historical heritage	0	10	5
			Landscape sensitivity	0	5	10

3.5 Identification of the measures and aggregation

With reference to the decision tree previously described, the elements have been aggregated at different levels. The result coming at the final node of the tree provides the overall sustainability value of the alternatives.

At each level of the decision tree, the procedure that has been followed in this application (Giove *et al.*, 2010) requires to attribute a weight to the coalition of attributes that belong to the same node. A matrix is then created, for each node of the decision tree, where all the possible combinations of attributes are embodied. The matrix is presented to a respondent, who is asked to express his/her preferences about the various scenarios. Particularly, the different combinations of attributes are evaluated in a 0-10 points scale where the value 0 means that the combination is not desirable at all, while the value 10 indicate a very attractive combination.

Mention has to be made to the fact that for the lower levels of the hierarchy the evaluation has been performed by individual experts in their proper field of expertise; in this case, different experts in the context of environmental engineering and sustainability assessment have been involved in the compilation of the matrixes.

As an example, Table 2 represents the questionnaire that has been submitted in order to evaluate the combinations of the elements belonging to the "project frame" criterion. Let us consider the sixth row of the matrix in Table 2. In this case, the question was of the type: "How do you evaluate an hypothetical scenario where accessibility and centrality are good, while industrial areas requalification and water supply are bad?" In this case, a synergy has been recognized by the respondent among the attributes and this leads to have a score of 8 for the combination of the elements 'accessibility' and 'centrality' that is higher than the sum of the single elements (second and third rows of the matrix in the Table 2). Following this example, Figure 5 shows in a geometrical way the calculation of the Choquet integral for the site of Rivarolo with reference to the "project frame" node. The initial scores of the Rivarolo site (300, 690, 500 and 0 for accessibility, centrality, industrial areas requalification and water supply, respectively) have been aggregated according to formula (1) by using the weights established in Table 2; the result of the calculations is 4160. Mention has to be made to the fact that in the aggregation procedure followed in the application the weights of attributes and criteria are given in a 0-10 points scale. According to this procedure, where no aggregation among the parameters of the model is required (i.e. there is only one attribute belonging to a node of the decision tree), the initial scores are multiplied for ten in order to obtain homogeneous values at each level of the decision tree.

Table 2 Scores attributed to the "Project frame" criteria

Accessibility	**Centrality**	**Industrial areas requalification**	**Water supply**	**Evaluation**
BAD	BAD	BAD	BAD	0
GOOD	BAD	BAD	BAD	3
BAD	GOOD	BAD	BAD	4
BAD	BAD	GOOD	BAD	1
BAD	BAD	BAD	GOOD	2
GOOD	GOOD	BAD	BAD	8
GOOD	BAD	GOOD	BAD	4
GOOD	BAD	BAD	GOOD	6
BAD	GOOD	GOOD	BAD	5
BAD	GOOD	BAD	GOOD	6
BAD	BAD	GOOD	GOOD	3
GOOD	GOOD	GOOD	BAD	8
GOOD	GOOD	BAD	GOOD	9
GOOD	BAD	GOOD	GOOD	8
BAD	GOOD	GOOD	GOOD	8
GOOD	GOOD	GOOD	GOOD	10

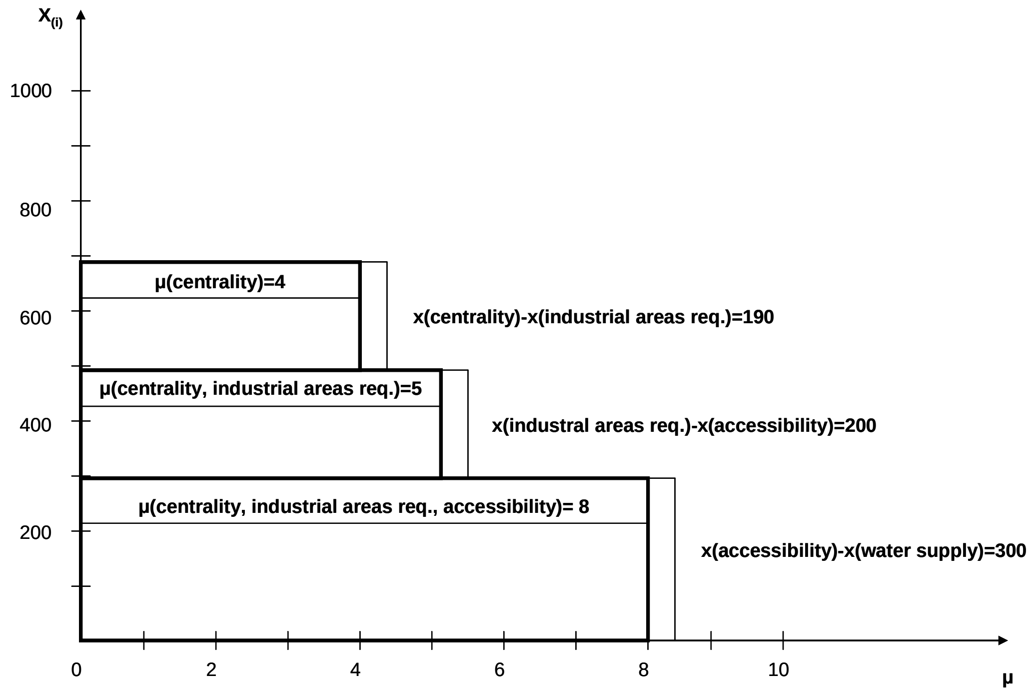

Figure 5 Geometrical representation of the Choquet integral for calculating the score of the Rivarolo alternative with reference to the "Project frame"

For the higher level of the hierarchy (i.e. the criteria level), the aggregation of the elements followed a different procedure. In this case, all the experts involved in the compilation of the questionnaire at the lower levels of the model have been asked to participate to a focus group where the general aspects of the decision problem have been discussed and evaluated. Table 3 represents the final result of the evaluation made by the focus group in order to address the topic of finding the most sustainable site for the location of the waste incinerator plant.

Table 3 Scores attributed to the "Sustainability" node

Program frame	Project frame	Environmental frame	Evaluation
BAD	BAD	BAD	0
GOOD	BAD	BAD	1
BAD	GOOD	BAD	4
BAD	BAD	GOOD	3
GOOD	GOOD	BAD	5
GOOD	BAD	GOOD	4
BAD	GOOD	GOOD	9
GOOD	GOOD	GOOD	10

Again in this case, different synergies among the criteria have been identified and the measure of the importance of some coalition turned out to be super-additive. This is the case, for example, of the coalition of project and environmental frames (seventh row of Table 3) where the measure 9 is higher than the sum of the importance of the single criteria (third and fourth rows of Table 3, respectively). This means that a positive interaction has been recognized between the two criteria and a scenario simultaneously characterized by a good performance in terms of project elements and environmental effects is considered very attractive.

4. Results and discussion

The application of the measures of Table 3 to the scores coming from the previous aggregation provides the final priorities of the alternatives. According to the calculations that have been made, the most suitable site for hosting the waste incinerator is Settimo (73,510), followed by Rivarolo (44,357) and finally Ivrea (23,884) (Table 4).

Furthermore, from the analysis of the partial scores of the alternatives considering the overall evaluation process (Table 4), it is possible to put in evidence some interesting findings.

The site of Ivrea has the lowest priorities according to the three considered criteria and the score for the program frame is nihil because of the presence of several constrains in the area. This lead to have a very low score in the final priority list of the alternatives.

The site of Rivarolo has more balanced scores with reference to the considered criteria, even if the value considering the project frame is low especially because the location is not easily reachable and central from the point of view of the overall collection area.

The site of Settimo has the highest priority with reference to all the considered criteria and the scores are very high considering the program and project frames. This leads to have the site at the first place in the final ranking of the alternative options.

The result is thus perfectly coherent with the findings coming from the Provincial Administration study (ATOR, 2008) and with those arising from the experimentation of other decision support systems implemented in the same study context (Bottero and Ferretti, 2011; Abastante *et al*., 2011). The real advantage coming from the application of the methodology proposed in the present study refers to the greater awareness gained by Decision Makers and Decision Analysts with reference to the compensability and interactivity among the elements being evaluated.

Table 4 Overall evaluation of the three alternatives

CRITERIA	SUB- CRITERIA	SUB-SUB-CRITERIA	ATTRIBUTES	IVREA					RIVAROLO					SETTIMO				
Program frame			Presence of constraints	0	0	0	0	23884	10	60	600	6000	44357	10	100	1000	10000	73510
			Local coherence with the planning instruments in force	0					5					10				
			Global coherence with the planning instruments in force	0					5					10				
Project frame	Accessibility		Infrastructural system inside the 2 Km range area	10	100	1000	3750		0	30	300	4160		10	100	1000	10000	
			Distance from the nearest train station	10					10					10				
	Centrality		Km covered in 1 year for the waste collection	0	0	0			6.9	69	690			10	100	1000		
	Industrial area requalification		Reclamation areas	0	0	0			5	50	500			10	100	1000		
	Water supply		Aquifer transmissivity	2.5	25	250			0	0	0			10	100	1000		
Environmental frame	Air	Traffic	Actual traffic flows inside the 2 Km range from the site	10	54.8	409	1776.8		7.1	57.1	427	4465.8		0	90	700	4702	
			Number of accidents per 100 Km	2.4					0					10				
			Heavy lorries percentage variation inside the 2 Km range	0					5					10				
			Number of buildings per each covered Km	10					7.5					10				
		Atmosphere	NO2 and PM10: cell number exceeding the annual limit value	10	20				6.1	21.2				0	40			
			NOx: dispersive capacity of the area	0					8.8					10				
			Cumulative impacts	10					6.3					0				
			Emission reduction due to energy recovery	0					0					10				
	Socio-economic aspects		Population density	0	26.7	267			10	60	600			5.3	33.8	338		
			Number of resident inhabitants	6.7					10					0				
			Rural real estate	10					0					6.2				
			Residential real estate	0					10					3.6				
	Physical environment	Hydrology	Hydrogeological risk	0	0	100			10	100	376			9.8	98	592		
		Noise	Acoustic class	0	0				0	0				10	100			
			Presence of sensitive receptors within 500 m	0					0					10				
		Electromagnetic fields	Length of the electricity transmission network	10	100				7.6	76				0	0			
	Landscape and ecosystems	Flora and Fauna	Biodiversity index	0	0	0			1.1	3.3	342			10	100	790		
			Natural value	0					0					10				
		Landscape	Landscape quality	0	0				5	65				10	65			
			Significance of the cultural and historical heritage	0					10					5				
			Landscape sensitivity	0					5					10				

5. Conclusions

The paper illustrates the application of an evaluation model based on the Choquet integral approach and on the data coming from a system of environmental and socio-economic indicators, to rank three sites for the location of a waste incinerator plant that has to be constructed in the Province of Torino.

Several applications are available concerning the integration of MCDA methods and indicators systems in the field of undesirable facilities location problems; in particular, mention can be made of a very recent experimentation of the ANP-BOCR approach for the same study context (Bottero and Ferretti, 2011). The results obtained in this paper are aligned with those coming from the aforementioned study and from the research done by the Provincial Authority (ATOR, 2008) and the findings have highlighted that a site is suitable for hosting a waste incinerator plant because of its position, which can maximize the positive factors that derive from the location and thus create added value. The negative drawbacks can in fact be minimized for all the alternative sites through the use of the best available technologies.

The results of the performed analysis show that the use of the Choquet integral based on a system of environmental and socio-economic indicators used as criteria ordered in a domain, some of which have to be maximized and others to be minimized, is suitable to represent the real problems of a territorial system and the complexity of the decision under examination, leading towards an integrated assessment.

Furthermore, the performed analysis provided a robust and transparent decision-making structure, making explicit key considerations and values and providing opportunities for stakeholders and community participation (Munda, 2005).

The procedure followed in the application seems to be suitable for dealing with real world problems from a practical point of view, showing a way for considering the whole range of available information and for taking into account experts opinions. Moreover, the results are precise and easy to be interpreted and communicated.

However, there are still several opportunities for expanding the study and for validating the obtained results. First, it would be of scientific interest to weight the criteria under consideration through multidisciplinary focus groups in order to move collaborative decision processes forward. In particular, future developments of the present application refer to the use of fuzzy weights (Zadeh, 1965), which represent attribute values according to membership classes.

The results of the model could be further validated by means of the application of the non-additive robust ordinal regression (Angilella *et al*., 2010) which explicits positive and negative interactions among criteria starting from the evaluation of the alternatives.

Given the spatial nature of the decision problem under analysis, future improvements of the work will also refer to the integration of the MCDA tool with Geographic Information Systems in order to develop a Multicriteria Spatial Decision Support Systems (MCSDSS) that will enable multi-purpose planning. In this sense, visualization techniques are of major importance in presenting and communicating the results to DMs and the interest groups (Malczewski, 1999).

Finally, It would be of scientific interest to test the model through sensitivity and robustness analysis and to investigate dedicated software for the computational process.

In conclusion, the application of the Choquet integral constitutes a very promising research line in the field sustainability assessments of territorial transformation projects and undesirable facilities location problems where trade offs and interactivity exist among the conflicting aspects involved in the decision.

The paper is the result of the joint effort of the three authors and the global responsibility for the work has to be equally shared between the three authors.

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