

Integrated sustainability assessments: a spatial multicriteria evaluation for siting a waste incinerator plant in the Province of Torino (Italy)

Valentina Ferretti · Silvia Pomarico

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Abstract The present paper proposes a spatial multicriteria approach for supporting decision makers in the siting process of a waste incinerator plant in the Province of Torino (Italy). Municipal solid waste management is an intrinsically complex problem because it involves different interconnected elements and must achieve objectives that are often in conflict. Given the spatial nature of the problem, a useful support is provided by a family of methods that are rapidly gaining traction for planning and policy-making, named multicriteria spatial decision support systems, which are based on geographical information systems and multicriteria analysis coupling. In the present study, a methodological framework is proposed for the integration of geographical information systems with a specific multicriteria analysis technique, named Analytic Network Process. The method is illustrated with reference to a case study in the Province of Torino. The purpose of the research is to generate a suitability map of the area under analysis in order to locate a municipal solid waste incinerator plant. The application allows the dependence relationships between the criteria to be assessed and the relative importance of all the elements to be evaluated. The results are obtained in the form of maps analyzed through the ILWIS 3.3 GIS software and have been further verified through a “what-if” analysis with reference to the clusters priorities in order to test the robustness of the model. The implementation of the spatial Analytic Network Process technique gives an originality value to the present research since it represents one of the first applications at both the national and international levels.

Keywords Waste management · Multicriteria spatial decision support systems · Multicriteria analysis · Analytic Network Process · Geographical information systems · Land suitability analysis

V. Ferretti (✉) · S. Pomarico
Politecnico di Torino, Department of Regional and Urban Studies and Planning (DIST),
Castello del Valentino, viale Mattioli, 39-10125 Turin, Italy
e-mail: valentina.ferretti@polito.it

S. Pomarico
e-mail: silvia.pomarico@polito.it

1 Introduction

The selection of the appropriate waste incinerator site can be viewed as a complex multicriteria decision-making problem that requires an extensive evaluation process of the potential locations and other factors as diverse as economic, technical, legal, social or environmental issues (Geneletti 2010). In other words, it represents a “weak” or unstructured problem since it is characterized by multiple actors, many and often conflicting values and views, a wealth of possible outcomes and high uncertainty.

Considering the risk of social opposition generally associated with undesirable facility location problems and the need for justification of the final choice, a useful support is provided by a specific family of decision support systems (DSS; Burstein and Holsapple 2008), named multicriteria spatial decision support system (MC-SDSS; Malczewski 1999), since they integrate the sustainability dimensions while offering a systematic approach able to prove the importance of “where” in addition to “what” and “how much”.

Spatial multicriteria decision analysis is a process that combines and transforms geographical data (the input) into a decision (the output). This process consists of procedures that involve the utilization of geographical data, the decision maker’s preferences and the manipulation of the data and preferences according to specified decision rules (Sharifi and Retsios 2004; Malczewski 2006).

This approach takes advantage of both the capability of geographical information systems (GIS) to manage and process spatial information and the flexibility of multicriteria analysis to combine factual information (e.g., soil type, slope, infrastructures) with value-based information (e.g., expert’s opinion, quality standards, participatory surveys) (Geneletti 2010).

The main rationale for integrating GIS and multicriteria analysis (MCA) is that they have unique capabilities that complement one another. On the one hand, GIS has great abilities for storing, managing, analyzing and visualizing geospatial data required for the decision-making process. On the other hand, MCA offers a collection of procedures, techniques and algorithms for structuring decision problems and for designing, evaluating and prioritizing decision alternatives (Malczewski 1999).

The most significant difference between spatial multicriteria decision analysis and conventional multicriteria techniques is the explicit presence of a spatial component. Spatial multicriteria decision analysis therefore requires data on the geographical locations of alternatives and/or geographical data on criterion values (Sharifi and Retsios 2004).

Moreover, spatial multicriteria analysis provides significant support for the generation and comparison of the alternatives through an active participation of the stakeholders involved in the decision-making process, thus becoming one of the most interesting evolution in the context of environmental assessment procedures (such as the Environmental Impact Assessment and the Strategic Environmental Assessment; Glasson et al. 2005) where the comparison of different alternatives represents a fundamental part of the whole process and where the complexity of the problems and the need for a technical support in the decision-making process are particularly real.

From the methodological point of view, the present application proposes the integration between GIS and a specific multicriteria analysis technique named Analytic Network Process (Saaty 2005), in order to assess the suitability of part of the Province of Torino (Italy) to host a waste incinerator (ATOR 2008). The ANP represents the generalization of the more well-known Analytic Hierarchy Process (AHP, Saaty 1980) to dependences and feedbacks and is particularly suitable for dealing with complex decision problems that are characterized by interrelationships between the elements at stake.

Since the incorporation of the AHP calculation block in the IDRISI 3.2 software package, it has become much easier to apply this technique to solve spatial problems. Applications of the spatial ANP are instead scarce, and only few examples can be found (Nekhay et al. 2009; Neaupane and Piantanakulchai 2006; Levy et al. 2007; Ferretti 2011b).

The present study thus represents one of the first experimentations at both the national and international levels.

After the introduction section, the paper is organized as follows: Sect. 2 offers a brief literature review regarding the application of decision support systems (DSS) and municipal solid waste management-related problems, and Sect. 3 presents the MC-SDSS approach. The application of the spatial ANP model to the study case is shown in Sect. 4. Finally, Sect. 5 proposes a “what-if” analysis, Sect. 6 discusses the main findings of the application, and Sect. 7 summarizes the conclusions that have been drawn from the study, highlighting the opportunities for expanding the work.

2 Municipal solid waste management (MSWM) and decision support systems (DSS): literature review

The problem of undesirable facility location selection has been extensively studied in the literature. Since 1960s, many works have been developed concerning the modeling of MSWM problems. The first applications referred to land-use models and had the aim of optimizing collection routes and facilities for the selection of a site, focusing only on financial criteria (Truitt et al. 1969).

Environmental consideration in 1980s and 1990s draws much attention to the potential of pollution due to waste disposal, which led to more restrictive environmental regulations and to stronger emphasis given to other criteria in the process of undesirable facilities location.

According to the sustainable development approach, a waste management system has to be environmentally effective, economically affordable and socially acceptable (Bottero and Ferretti 2011). Mention should be made to the fact that the environmental effectiveness is a measure that includes a full range of variables (e.g., air pollution, energy production, recycling, etc.), and it has been operationalized in a variety of ways (Poloni-Staudinger 2008).

Generally speaking, it can be said that a project is environmentally effective if it goes in the direction of minimizing the use of non-renewable natural resources and of optimizing the use of renewable natural resources. In this sense, an environmentally effective project will cause fewer negative intergenerational effects (Bottero and Ferretti 2011).

The mathematical models for problem-solving have evolved from the single-criterion, maximin models (maximizing the average or minimum distance between the customers and the facility) (Hale and Moberg 2003), to multicriteria models that include conflicting criteria in the analysis of the decision problem.

During 1990s, MSWM models started to consider the complexity that is intrinsic in decision problems, and some MCA applications were proposed (Caruso et al. 1993).

These models consider the full range of waste streams to be managed and view the available waste management practices as a menu of options from which to select the preferred solution on the basis of site-specific environmental and economic considerations. Many MCA models are available to address MSWM problems, including Analytic Hierarchy Process (AHP) (Dey and Ramcharan 2008), PROMETHEE (Khalil et al. 2004;

Queiruga et al. 2008), ELECTRE (Hokkanen and Salminen 1997; Norese 2006), Analytic Network Process (ANP) (Khan and Faisal 2008; Tuzkaya et al. 2007; Aragonés-Beltrán et al. 2010; Tseng 2010), GIS and fuzzy MCA (Changa et al. 2008).

Other models consider the whole life cycle of products, by means of life cycle analysis (LCA), with the aim of making a comprehensive assessment of the MSWM strategies' impacts on the environmental system (Barton et al. 1996; McDougall et al. 2001).

The siting process of undesirable facilities depends on an ever-increasing variety of factors, laws and regulations, and a large volume of spatial data should be evaluated and processed. Although GIS are very useful tools in siting experiences, they lack the ability to locate an optimal site unless an optimization arrangement is introduced (Sharifi et al. 2009).

In a preliminary screening stage, utilization of GIS normally involves employing a set of criteria in order to classify an area into defined classes by creating buffer zones around geographical features to be protected (Changa et al. 2008). All map layers are then intersected so that the resulting composite map contains two classes of area: suitable and unsuitable. With the aid of this functionality, GIS have been widely used in order to facilitate and lower the cost of the process of site selection for various purposes (Sharifi and Retsios 2004).

Higgs (2006) reported the potential of integrating multicriteria techniques with GIS in the specific context of waste facility location problems. The applications of spatial multicriteria analysis to solve location problems were few for many years, but in the past decade, presenting and solving multicriteria location problems have undergone a substantial growth and have opened windows to location science in different business (Farahani et al. 2010).

With particular reference to the social aspects of MSWM problems, the models have to be able to reflect the public's opinions concerning landfills and other waste management plants. The point of view of the population involved in the problem usually presents the characteristics of social opposition that affects the construction of undesirable facilities. This phenomenon is also known as NIMBY (not-in-my-back-yard), NOTE (not-over-there-either), LULU (locally-unacceptable-land-use) and BANANA (build-absolutely-nothing-anywhere-near-anything). An analysis of the literature pertaining to this context has highlighted a lack of models that are able to consider the three dimensions of sustainability together and to reflect the intergenerational effects of the proposed MSWM strategies (Morrissey and Browne 2004; Erkut et al. 2008).

3 Multicriteria spatial decision support systems: an integrated approach for land suitability analysis

3.1 State of the art

In the context of decision support systems (DSS), researchers have often ignored the importance of the graphical analysis of spatial information. One of the first experiences concerning the use of maps in decision-making processes refers to the work of McHarg (1969), where the basic concepts that would be later developed in geographical information systems (Charlton and Ellis 1991) are set forth. GIS provide an important way of enabling decision makers (DMs) to make better decisions by conducting spatial analysis and displaying spatial information. Whereas DSS and GIS can work independently to solve some

simple problems, many complex situations demand the two systems to be integrated in order to provide better solutions (Li et al. 2004).

Following this reasoning, it can be stated that the development of spatial decision support systems (SDSS) has been associated with the need to expand the GIS system capabilities for tackling complex, not well-defined, spatial decision problems (Densham and Goodchild 1989). The concept of SDSS evolved in the mid-1980s (Armstrong et al. 1986), and by the end of the decade, many works concerning SDSS were available (Densham 1991; Goodchild 1993; Densham and Armstrong 1987; Armstrong 1993). Over the course of the 1990s, there has been considerable growth in the research, development and applications of SDSS, and in recent years, these common decision support functions have been expanded to include optimization (Aerts et al. 2003; Church et al. 2004), simulation (Wu 1998), expert systems (Leung 1997), multicriteria evaluation methods (Feick and Hall 2004; Malczewski 1999; Thill 1999; Janssen and Rietveld 1990; Carver 1991; Eastman et al. 1993; Pereira and Duckstein 1993; Jankowski and Richard 1994; Laaribi et al. 1996), online analysis of geographical data (Bedard et al. 2001) and visual-analytical data exploration (Andrienko et al. 2003) with the aim of generating, evaluating and quantifying trade-offs among decision alternatives.

The field has now grown to the point that it is made up of many threads with different, but related names, such as collaborative SDSS, group SDSS, environmental DSS and SDSS based on spatial knowledge and on expert systems.

With specific reference to GIS-based multicriteria decision analysis, the full range of techniques and applications has been recently discussed in a very interesting survey developed by Malczewski (2006). From 2000, the number of studies has been increasing, and several applications can be found in different fields. Multicriteria spatial decision support systems are commonly applied to land suitability analysis in the urban/regional planning, hydrology and water management and environment/ecology fields (Malczewski 2006; Ferretti 2011a) and are usually based on a loose coupling approach and on a value focused thinking framework (Ferretti 2011a).

3.2 Methodological approach

A spatial decision support tool can be defined as an interactive computer system designed to assist the user, or group of users, to achieve high levels of effectiveness in the decision-making process while solving the challenge represented by semi-structured spatial decision problems (Malczewski 1999).

An MC-SDSS is thus a procedure to identify and compare solutions to a semi-structured spatial decision problem, based on the combination of multiple factors that can be, at least partially, represented by maps (Malczewski 2006). According to Sharifi et al. (2006), in a spatial decision problem, the options can be described by a defined set of maps providing information on each criterion. Therefore, the spatial decision problem can be visualized as a “table of maps,” which has to be transformed into one final ranking of alternatives.

According to the model proposed by Simon (1960, 1991) and considering the work of Steinitz (1993), Sharifi and Rodriguez (2002) have developed a framework for planning and decision-making process, which is shown in Fig. 1. In this model, there is a flow of activities from intelligence to design to choice phase as well as steps in each phase (Sharifi 2007). The framework highlights how each phase of the decision-making process involves the methodological contribution of both GIS and multicriteria evaluation methods. Particularly, the intelligence phase refers to the examination of the environment in order to identify problem or opportunity situation and includes the structuring of the problem,

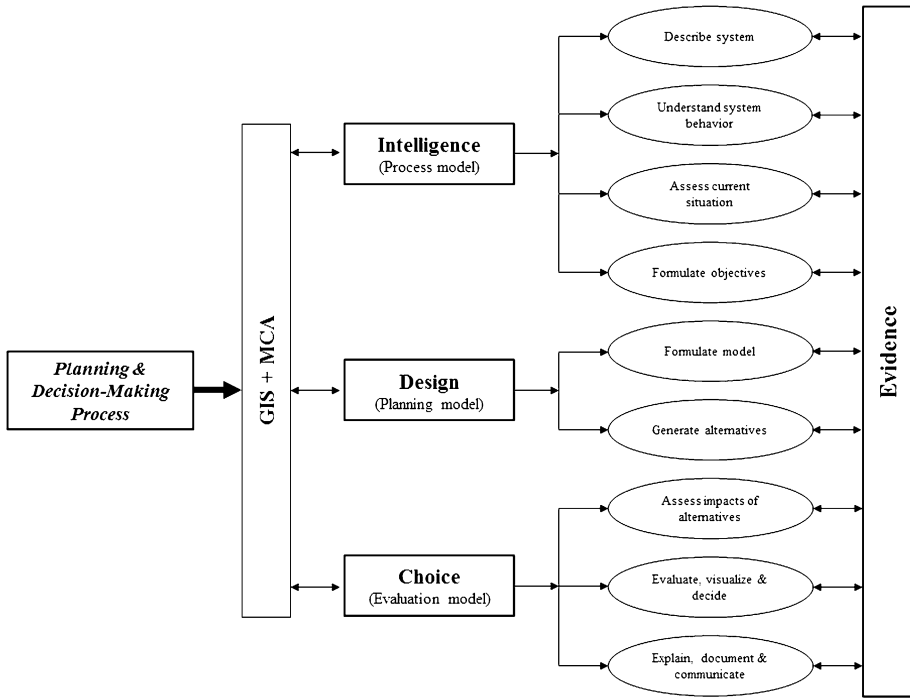


Fig. 1 Framework for planning and decision-making process (Source: adapted from Sharifi and Rodriguez 2002)

during which the system under consideration is defined and the objectives to pursue are explored. One or more criteria, or attributes, are then selected to describe the degree of achievement of each objective (Keeney 1992).

The design phase involves the development and analysis of possible courses of action. This phase is the innovative part of the process and refers to the data collection and processing, as well as to the development of multicriteria analysis through the definition of the relationships between objectives, attributes and preferences of the decision maker (Malczewski 1999). In this phase, the alternatives are generated performing a spatial multicriteria evaluation using the criteria structure and the set of constraints identified in the intelligence phase in order to produce a suitability map (Zucca et al. 2007).

During the choice phase, alternatives are evaluated and a selection of specific course of action is performed; furthermore, detailed analyses, such as the sensitivity analysis, are deemed appropriate in order to obtain some recommendations.

Finally, evidence is defined as the total set of data, information and knowledge at disposal of the planner, decision makers and analyst.

Spatial multicriteria analysis therefore represents a significant step forward compared to conventional MCA techniques because of the explicit spatial component, which requires both data knowledge and representation of the criteria (criterion maps), and the geographical localization of the alternatives. In fact, conventional non-spatial MCA techniques typically use the average or the total impact of an alternative on the environmental system, considering them appropriate for the whole area under consideration: in other words, conventional approaches assume spatial homogeneity within the study area. This assumption is clearly

unrealistic since the evaluation criteria, or rather the attributes that are used to measure them, vary spatially.

Compared to conventional MCA techniques, spatial multicriteria analysis requires information on the value of the criteria and geographical location of the alternatives, in addition to the preferences of decision makers. The spatial data are then processed using the computer potential of GIS and multicriteria analysis methods in order to support the decision-making process in solving a complex spatial problem.

4 Land suitability analysis for siting a waste incinerator

4.1 Analysis of the territorial context

The present paper illustrates the development of an MC-SDSS model in order to choose the most suitable area for the localization of waste incineration in the Northern Province of Torino (ATOR 2008), with particular attention to the environmental aspects related to the implementation of the new project.

The Province of Torino (Fig. 2), the capital of the Piedmont Region, has about 2.3 million inhabitants and covers a surface area of 6.829 km². Mention should be made of the presence of a wide hydrographic catchment area, both surface and underground. Until recently, widespread urbanization led to an intensive exploitation of agricultural, forest and breeding resources, which resulted in the complex arrangement of very small towns throughout the territory. The number of municipalities in the Province no fewer than 315 is in fact the highest in Italy.

The area under examination for the identification of the most suitable sites for the localization of the municipal solid waste incinerator is situated in the northeast part of the Province (Fig. 2), since the plant project, as stated by the Provincial Waste Management Program, will serve two municipal clusters in the same area.

4.2 Problem definition and decision model structuring

According to the aforementioned plan, the waste management in the area of the Province of Torino involves three main actors: the Regional Authority, which is in charge for the

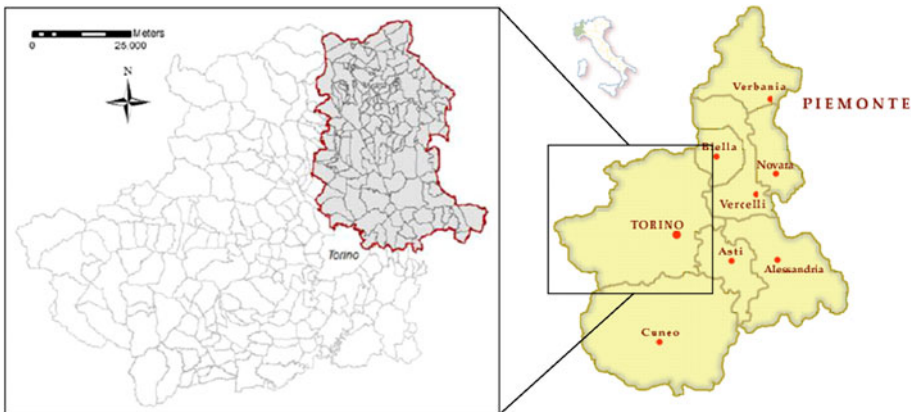


Fig. 2 Area under analysis

overall waste programming, the Provincial Authority, which is in charge for the management of the waste, and the ATOR, which is a public authority responsible for organizing and controlling the different facilities existing on the territory in the waste management context.

With specific reference to the location of waste management facilities, the plan requires a stepped procedure that can be described as follows:

– *Phase 1: macro-localization (competence of the Province)*

In this phase, the requirements coming from the legislation and the indication provided by the local planning tools are considered for identifying the potential sites. The result of this investigation is a classification of the areas in two classes: ‘non-suitable areas’ and ‘potentially suitable areas’.

– *Phase 2: micro-localization (competence of the ATOR)*

The potentially suitable areas are investigated in depth with reference to different parameters, such as preferential factors (accessibility, centrality ...), dimensional and geomorphologic characteristics of the area, etc. From this investigation, a set of candidate sites is obtained, which is further investigated through a more detailed analysis and specific surveys.

With specific reference to the case under investigation, the decision-making process concerns the early stage of the procedure.

Decision-making is a process involving a sequence of activities that start with the recognition of decision problem and ends with the recommendation for a decision (Zucca et al. 2007). Keeney (1992) identifies two major approaches: alternative-focused and value-focused. The alternative-focused approach starts with the development of alternative options, proceeds with the specification of values and criteria and then ends with the evaluation and recommendation of an alternative. Instead, the value-focused approach assumes the values as fundamental element in the decision analysis: it first focuses on the specification of values and then, considering the values, feasible options are developed and evaluated based on the predefined value and criteria structure (Sharifi 2007).

In this work, a value-focused approach based on the framework for planning and decision-making (Fig. 1) has been developed. According to Keeney (1992), the decision problem was structured by a value tree: starting from the overall objective of the analysis, which is the identification of the most suitable site for the location of a waste incinerator, a comprehensive set of evaluation criteria that reflect all the concerns relevant to the decision problem has been identified. Figure 3 shows this framework where the goal, the subobjectives according to which the problem has been structured, and finally the evaluation criteria that assess the achievement of the objectives are indicated.

Due to the aforementioned complexity of the problem under analysis and with the aim of finding the most significant aspects involved in the decision and the most suitable location for the project, the ANP method has then been used for the development of the model. As already mentioned, the choice to integrate GIS and the ANP method gives an originality value to the present paper because it represents one of the first experimentations at both the national and international levels. The reasons for using an ANP-based decision approach in the present analysis are as follows: (1) the assessment of the suitability for siting a waste incinerator plant is a multicriteria decision problem; (2) there are dependencies among groups of criteria and between these to be analyzed; (3) the detailed analysis of the inter-relationships between criteria forces the decision makers (DMs) to carefully reflect on their project priority approach and on the decision-making problem itself, thus helping DMs to gain a better understanding of the problem and to make a more

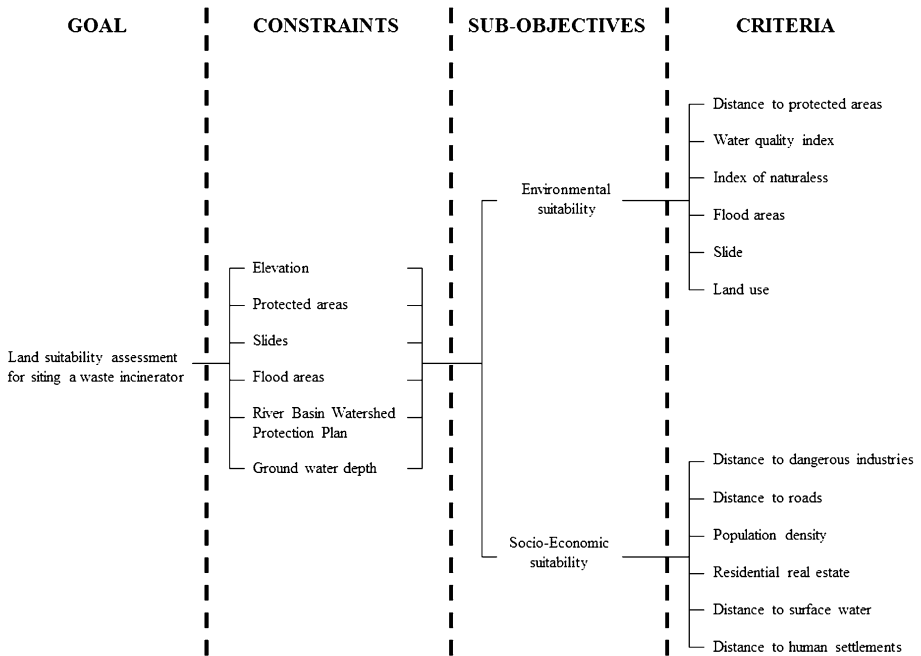


Fig. 3 Decision problem structuring according to a value tree

reliable final decision; and (4) the integration with GIS allows to investigate potentialities and limits of the innovative approach.

Particularly, the Analytic Network Process (ANP) is a decision support tool, belonging to the MCA family, that has recently been gaining popularity. Developed by T.L. Saaty (Saaty 2005) as the generalization to dependences and feedbacks of the more well-known Analytic Hierarchy Process (AHP) (Saaty 1980), the ANP represents a theory of relative measurement on absolute scales of both tangible and intangible criteria based both on the judgement of experts and on existing measurements and statistics needed to make a decision. By freeing us from the burden of ordering the components in the form of a directed chain as in the AHP hierarchy, the ANP represents any decision as a network and allows the structure to develop more naturally. The ANP represents therefore a better way to describe faithfully what can happen in the real world and is gaining merit as a useful tool to help technicians make their decision processes traceable and reliable. By including dependences and feedbacks and by cycling their influence by means of the supermatrix approach, the ANP is more likely to capture what happens in the real world, thus providing effective support for the kind of decisions needed to cope with the future (Zoffer et al. 2008).

From the methodological point of view, the ANP is based on five fundamental steps (Saaty 2005): (1) structuring of the decision-making problem; (2) clusters and nodes weighting by means of pairwise comparisons; (3) supermatrices formation; (4) elicitation of final priorities; and (5) sensitivity analysis.

As far as the problem structuring phase is concerned, the ANP approach involves identifying groups or “clusters” constituted by various elements (“nodes”) that influence

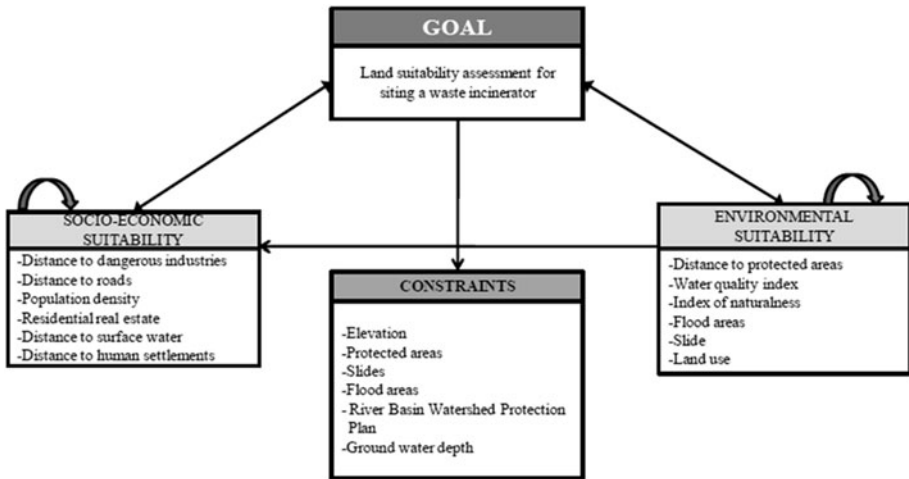


Fig. 4 ANP network structure for the case under examination

the decision. All the elements in the network can be related in different ways since the network can incorporate feedbacks and complex inter-relationships within and between clusters, thus providing a more accurate modeling of complex settings. The network construction represents an important and very creative phase in the problem-solving process.

In the present application, the model has been developed according to the simple network structure illustrated in Fig. 4. Mention should be made to the possibility of structuring the decision problem according to the complex network structure (Saaty 2005), which is usually based on four subnetworks: benefits, costs, opportunities and risks. These subnetworks allow all dimensions of the decision problem to be considered.

The network structure of the problem and the interdependences between the clusters were simulated using Super Decisions 1.6.0 software,¹ which automatically creates a list of the pairwise comparisons needed to run the evaluation.

It is necessary to highlight that the criteria considered in the present application were selected based on the requirements coming from the legislative framework in the field of waste management (Waste Management Plan of the Province of Torino; Provincia di Torino 2006), which provides a list of both exclusionary and non-exclusionary aspects to be considered for the location of waste facilities.

In the present study, 18 attributes are involved in the computation process, distinguished as exclusionary (6) and non-exclusionary criteria (12). These last are clustered in two main groups, including factors relevant to the socio-economic suitability and factors influencing the environmental suitability (Fig. 4).

According to the ANP methodology, once the network has been identified, it is necessary to represent the influences among the elements. It has been chosen to approach this task according to the following strategies. To start with, all the elements in the clusters are supposed to have an influence on the general goal. Further relationships have then been identified concerning the potential influences among the elements of each cluster. These

¹ www.superdecisions.com.

influences reflect the natural dynamics of the environmental and territorial systems, where link and interaction pathways exist between individual elements, which can, positively or negatively, affect each other (Bottero and Ferretti 2011). For example, the “index of naturalness” is influenced by the “land use” and by the “distance from natural areas” (Fig. 4).

The direction of the arrows in Fig. 4 indicates the interdependence relationships between the factors. A single-direction arrow shows the dominance of one factor by another. A double-direction arrow shows mutual influence between the factors. The loops indicate inner dependences.

In the next phase, evaluation criteria and constraints that score the potential sites were represented as thematic map layers in a GIS database.

It is worth specifying the difference between:

- constraints, which are non-compensatory criteria that determine which areas should be excluded from or included in the suitability analysis. The excluded areas will get a nil (0) performance value in the composite index map, while the remaining areas will obtain a value between 0 and 1. Constraints are thus expressed in the form of a Boolean (logical) map. They depend on standing legislation and on the characteristics of the area under analysis. In this study, they were selected in accordance with the legislation in the waste management field (Provincia di Torino 2006). The overall constraint map is calculated by multiplying all the constraint layers.
- Factors, which are compensatory criteria that contribute to a certain degree to the output (suitability). There are two types of factors: (1) benefit criteria and (2) cost criteria. A benefit criterion contributes positively to the output (the higher are the values, the better it is), while a cost criterion contributes negatively to the output (the lower are the values, the better it is). As opposed to constraints, which cannot be compensated, poor performance of a factor can be compensated by good performance of another factor. Using compensatory decision rules, such as the weighted sum, this can still lead to good overall performance in the composite index map (Zucca et al. 2007).
- Groups of factors. They define an intermediate goal.

The identification of alternative suitable sites to host the waste incinerator has been carried out by using the GIS software ILWIS 3.3 (ILWIS 2005).²

The study area was discretized using a grid cell size of 25 m × 25 m. Maps were computed through basic raster GIS operations (map overlay, buffering, distance mapping, spatial queries, etc.).

Figure 5 shows the criteria tree with the associated thematic maps for the case study under analysis.

4.3 Development of the model

As previously explained, each criterion is represented by a map of a different type, such as a classified map (forest, agriculture, etc.) or a value map (slope, elevation, etc.). In order to generate criteria maps, data collection was performed and basic raster GIS operations like map overlay, buffering, distance mapping, spatial queries, etc., were implemented. For decision analysis, the values and classes of all the maps should be converted into a common scale, which is called utility. Utility is a measure of appreciation of the decision

² www.itc.nl/ilwis.

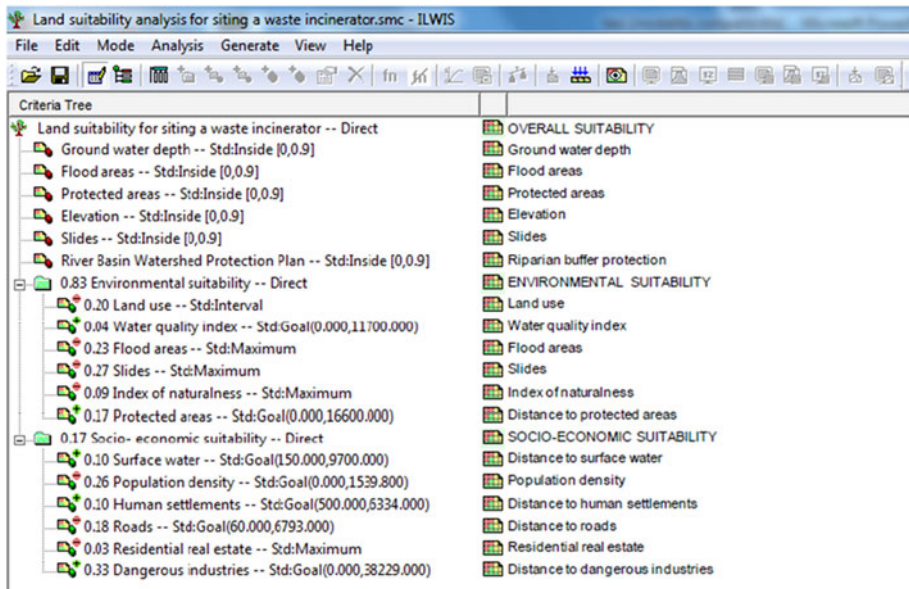


Fig. 5 Criteria tree used in the analysis. On the *left* are constraints, factors and associated weights with descriptors and on the *right*, the corresponding file names of the digital maps spatially representing constraints and factors. The interaction structure is from the ILWISs SMCE module (ILWIS 3.3 2005)

maker with respect to a particular criterion and relates to its value/worth (measured in a scale from 0 to 1). Such a transformation is commonly referred to as standardization (Sharifi and Retsios 2004).

In the present study, the standardization was performed by using linear functions that converted the original factor scores (each expressed in its own unit of measurement) into dimensionless scores in the 0 (worst situation) 1 (best situation) range.

This method assumes that a linear relationship exists between the impact scores and the perceived significance of the impacts. Furthermore, this method offers the advantage of keeping the ratio between the original impact scores and the standardized ones.

Table 1 explains how each criterion has been standardized in the present study.

With the aim of giving an example, Fig. 6 shows the source map (Fig. 6a), the standardized one (Fig. 6b) and the standardization function (Fig. 6c) for the factor “distance to surface water”.

After criteria map standardization, the next step of the analysis is to assign a weight to each factor. In fact, the methodology does not assign weight to the constraints, since, as already recalled, these last are non-compensatory variables that determine the areas to be excluded from the evaluation process.

The pairwise comparison method was applied to obtain factor weight, according to the Analytic Network Process (ANP) technique.

The comparison and evaluation phase, according to the ANP methodology, is divided into two distinct levels: the comparison between clusters, which is more general and strategic, and the comparison between nodes, which is more specific and detailed.

The comparison phase consists of the progressive formation of three supermatrices:

Table 1 Factors description and standardization

	Criteria	Description	Standardization
CONSTRAINTS	Ground water depth	Areas with ground water depth between 0 and 3 m are excluded from the analysis.	Depth 3m is standardized to 0; all other values are standardized to 1.
	Flood areas	Flood areas with return period less than 50 years are excluded from the analysis.	Flood areas with return period 50 years are standardized to 0; the remaining areas are standardized to 1.
	Protected areas	Protected areas are excluded from the analysis.	Natural protected areas are standardized to 0; the remaining areas are standardized to 1.
	Elevation	Areas with elevation higher than 1000 m are excluded from the analysis.	Areas with altitude 1000 m are standardized to 0; all other values are standardized to 1.
	Slides	Active slide areas are excluded from the analysis.	Active slides are standardized to 0; the remaining areas are standardized to 1.
	River Basin Watershed Protection Plan	Riparian buffer protection are excluded from the analysis.	Riparian buffer protection are standardized to 0; the remaining areas are standardized to 1.
FACTORS	Distance to surface water	The criterion represents the distance to surface water bodies since the proximity to the considered factor enhances the economic feasibility of the facility.	Distance 150 m (protection buffer provided by PPGR 2006) is standardized to 0; distance >150 m is standardized according to the linear function (the lower the distance, the higher the score).
	Land use	The criterion classifies the area in five classes: urbanized areas, agricultural areas, forests, wetlands and hydrological network.	Linear standardization (the higher the natural value of the area, the lower the score).
	Slides	The criterion classifies the area according to the following three classes of geological risk: medium, medium/high and very high.	Linear standardization (the higher the geological risk, the lower the score).
	Flood areas	The criterion classifies the area according to the floods return periods.	Linear standardization (the higher the return period, the higher the score).
	Distance to protected areas	The criterion maps the distance to protected areas.	Linear standardization (the higher the distance, the higher the score).
	Water quality index	The criterion maps the distance to the best performing classes of water quality index.	Linear standardization (the higher the distance from the high quality classes, the higher the score).

Table 1 continued

Criteria	Description	Standardization
Index of naturalness	The index of naturalness is calculated by assigning a value between 0 and 1 to each patch in the area under consideration (the higher the natural value of the area, the higher the score) and by multiplying this value for the area of the considered patch (OCS 2002).	Linear standardization (the higher the index, the lower the score).
Distance to roads	The criterion represents the road network system inside the area under examination in order to take into consideration the costs associated with transportation of waste to the plant and to prioritize locations with connection to the road existing road network.	Distance ≤ 60 m (protection buffer provided by PPGR 2006) is standardized to 0; distance > 60 is standardized according to the linear function (the higher the distance, the lower the score).
Population density	The criterion assigns to each Municipality the population density value (Comuni Italiani 2012). Prioritizing areas with low population density over densely populated areas allows to prevent problems with public opposition.	Linear standardization (the higher the population density, the lower the score).
Residential real estate	The criterion assigns to each Municipality the real estate value expressed in $/m^2$ (Agenzia del Territorio 2012) in order to provide a representation of the real estate property.	Linear standardization (the higher the real estate values, the lower the score).
Distance to dangerous industries	The criterion considers the presence of dangerous industries inside the area under examination in order to minimize risks effects.	Linear standardization (the higher the distance, the higher the score).
Distance to human settlements	The criterion considers the effects of siting a waste incinerator on the surrounding population in terms of noise, odors, traffic and visual impacts.	Distance ≤ 500 m (protection buffer provided by PPGR, 2006) is standardized to 0; distance > 500 m is standardized according to the maximum function (the higher the distance, the higher the score).

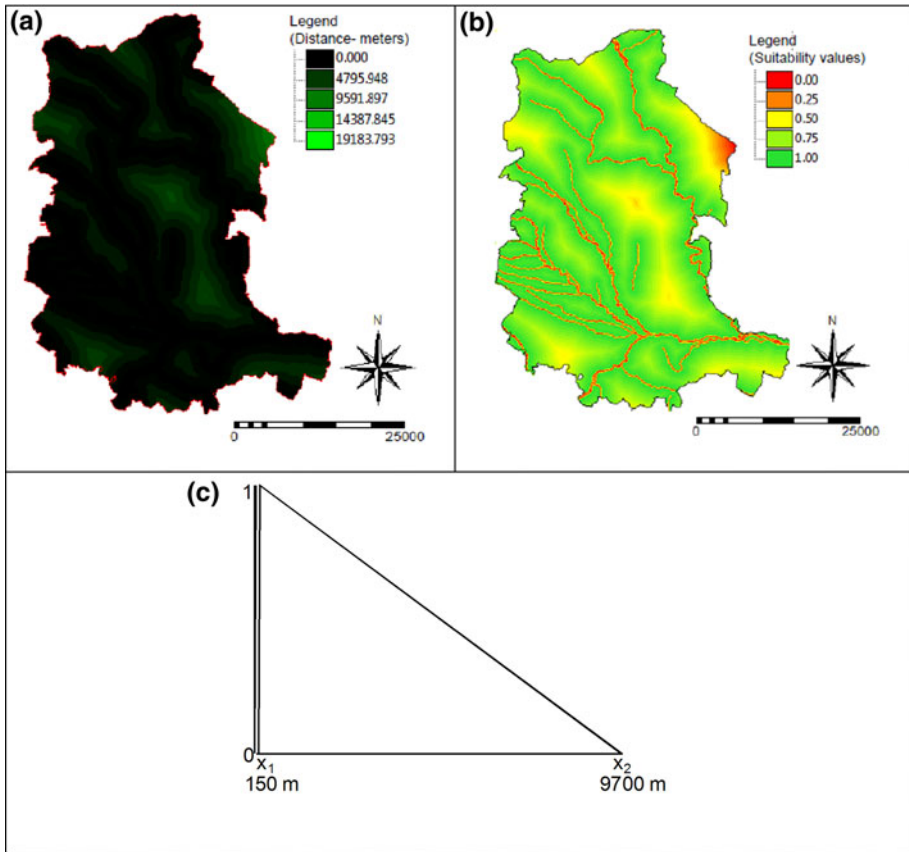


Fig. 6 Source map (a), standardization function (c) and standardized map (b) for the factor “distance to surface water bodies”

- the “initial supermatrix”, composed of all the eigenvectors that are derived from the pairwise comparison matrices of the model;
- the “weighted supermatrix” obtained by multiplying the initial supermatrix values with the pairwise comparison matrix obtained at the cluster level; and
- the “limit supermatrix” obtained by raising the weighted supermatrix to a limiting power, in order to converge and to obtain a long-term stable set of weights that represents the final priority vector.

Because both standardization of the maps and weighting of the criteria are largely subjective, a focus group has been organized where several experts have been involved in order to discuss and evaluate the general aspects of the problem simulating the decision-making process. With the aim of making up a multidisciplinary group able to approach the complexity of the problem under analysis, the focus group brought together experts in the field of spatial analysis, environmental engineering, landscape assessments and sustainability assessment procedures. The different experts worked together in order to achieve a consensus with reference to both the weighting of the elements involved in the decision and the standardization of each factor map.

Table 2 Priorities of the model elements

Clusters	Factors	Weight
Environmental suitability (0,830)	Flood areas	0,225
	Water quality index	0,036
	Index of naturalness	0,089
	Slide	0,273
	Land use	0,204
	Distance to protected areas	0,173
Socio-economic suitability (0,170)	Distance to dangerous industries	0,333
	Population density	0,264
	Distance to human settlements	0,104
	Distance to surface water	0,098
	Residential real estate	0,026
	Distance to roads	0,175

Table 2 represents the priorities of the factors (normalized with respect to the clusters) resulting from the limit supermatrix. These priorities are the starting point for the aggregation and the synthesis of the results of the model.

The weighting assignment shows the factors that most affect environmental suitability and socio-economic suitability. It was found that “slide” and “flood areas” had the biggest impact on environmental suitability, while “distance to dangerous industries” and “population density” were the two factors that had the greatest weight in determining socio-economic suitability.

4.4 Design of the suitability map

Once the maps have been obtained for each criterion and the factor weights have been established, it is necessary to combine all the information in order to obtain the overall suitability map. In this case, a weighted linear combination has been used that combines the factors and constraint maps according to the following formula:

$$S_j = \sum W_i X_i \Pi C_k \quad (1)$$

where S_j represents the suitability for pixel j for incinerator localization; W_i represents the weight of factor i ; X_i represents the criterion score of factor i ; C_k represents the criterion score of constraint k ; and Π is the product symbol.

As it can be seen from the formula, factors are combined by applying a weight to each followed by a summation of the results to yield a suitability map and then by multiplying the suitability calculated from the factors by the product of the constraints.

In this model, two intermediate suitability maps were generated: one for the environmental suitability of the area for incinerator localization and the other for socio-economic suitability, in order to better identify trends and factors that can influence the decision-making process providing an integrated assessment of the different aspects that characterize the spatial problem under examination. These two maps were then aggregated together with the constraints established in the model by the decision rule described above in order to produce the final suitability map of the territory.

The final suitability map returns results in a range from 0 to 1, where higher values correspond to the suitable areas for the incinerator localization and low suitability values correspond to areas unsuitable for the realization of this project.

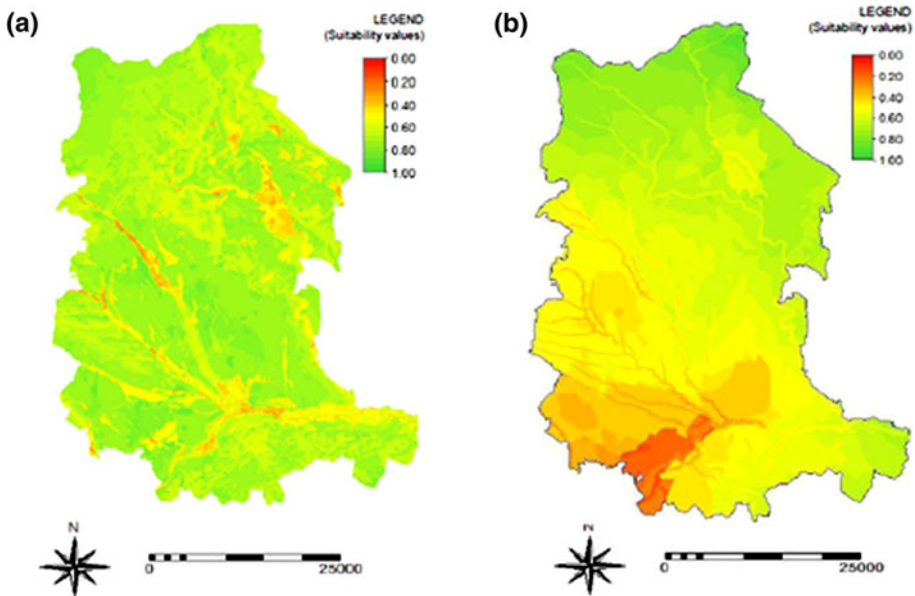


Fig. 7 Intermediate environmental and socio-economic suitability maps

Figure 7a shows the suitability for incinerator localization from the environmental point of view. From the results, there are no areas that are totally unsuitable for the establishment of the new plant, and the least suitable areas are those most affected by hydrogeological risk.

Figure 7b illustrates the suitability from the socio-economic point of view. There is a clear correspondence between socio-economic suitability and the distance of a site from areas of widespread urbanization: moving away from the neighboring municipalities of the city of Torino, sites became more suitable as the population density factor has considerable weight in the socio-economic aspects involved in the decision.

Finally, Fig. 8 shows the final outcome of the evaluation process. The map obtained represents a decision support tool in order to spatially identify suitable areas for the localization of the project.

5 “What-if” analysis

In order to simulate different decision-making behaviors, a “what-if” analysis was carried out. This type of analysis is concerned with a “what-if” kind of question to see how the final answer changes when the inputs, whether judgments or priorities, are revised. Particularly, in multicriteria decision models, the aim of the analysis is to see how these changes modify the final generation of alternatives.

In the present study, we generated three different suitability maps by changing each time the weight assigned to the two clusters in which the decision problem was divided: environmental suitability and socio-economic suitability. Table 3 summarizes the different weights assigned to environmental and socio-economic aspects for each simulation.

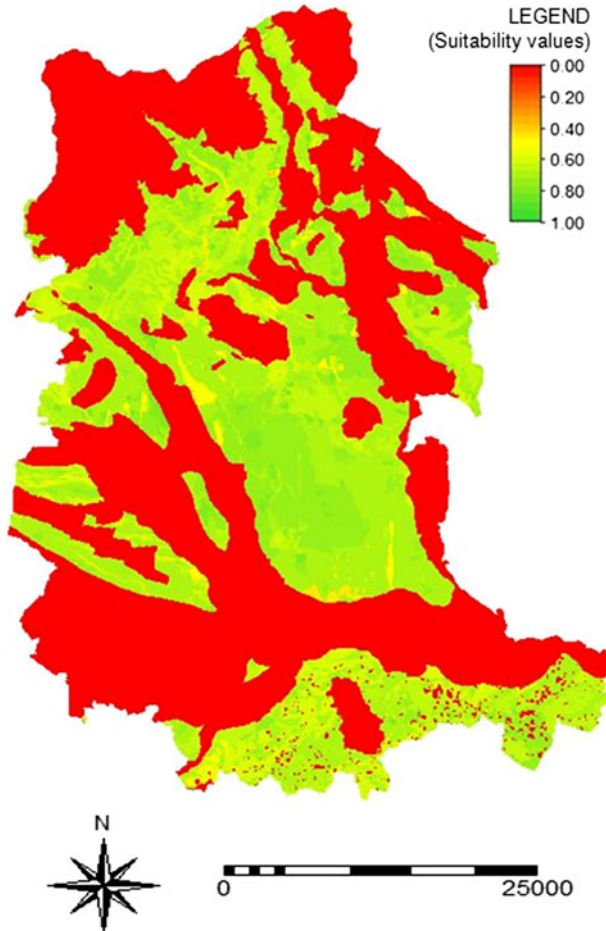


Fig. 8 Final suitability map

Table 3 Environmental and socio-economic aspects' weights for each simulation

	Weights	
	Environmental aspects (%)	Socio-economic aspects (%)
Simulation I	90	10
Simulation II	50	50
Simulation III	10	90

The first case shows the situation where environmental aspects weigh 90 % and socio-economic aspects the remaining 10 % in achieving the objective. The second simulation refers to the case in which both factors have equal weight in determining the most suitable areas for localization. Finally, the third represents the reverse situation in which socio-economic aspects have the greater importance.

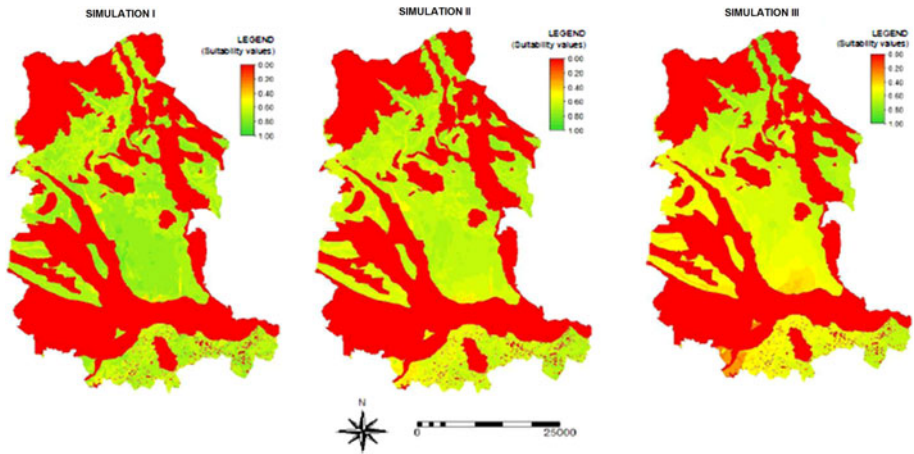


Fig. 9 Sensitivity analysis simulations. In the first simulation, environmental aspects weigh 90 % and socio-economic aspects the remaining 10 % in achieving the objective; in the second simulation, both factors have equal weight, and the third simulation represents the reverse situation, where socio-economic aspects have the greater importance

Figure 9 shows the results of the “what-if” analysis. It is clear that suitable areas for incinerator localization decrease when importance of socio-economic aspects increases. It is possible to see that suitable areas are limited in the northeastern part of the Province.

In the first simulation, where environmental factors have more influence, the final suitability map is almost unchanged. The equal weight case shows a slight decrease in suitable areas in southern part near the city of Torino as this area is characterized by high population density and by widespread urbanization. Change in results is evident in the last map shown in Fig. 9 (simulation III) where socio-economic aspects affect more land suitability. In this map, suitability values decrease in most of the area under examination except in the northern part.

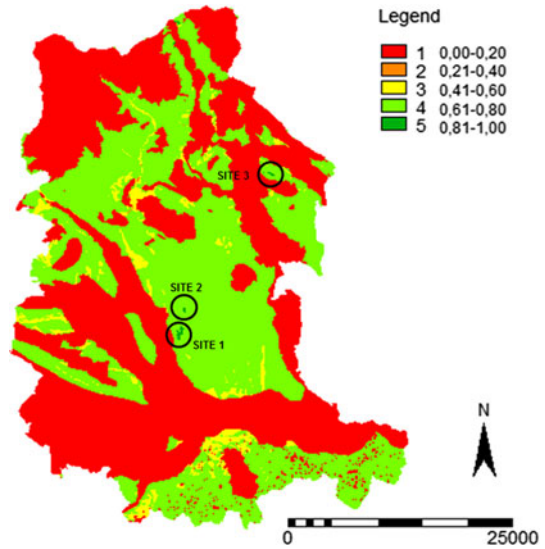
6 Discussion of the results

By weighting both the environmental and the socio-economic factors that positively and negatively affect the siting process of the waste incinerator, the final suitability map shown in Fig. 8 has been derived.

The results show that a relevant part of the territory is unsuitable for hosting a waste incinerator and that the areas with the highest suitability values are concentrated mainly in the central part of the area under examination. Analyzing Fig. 8, it becomes clear that constraints limit the number and the geographical extension of alternatives since, according to their definition, they represent the restrictions imposed on the decision-making space, thus determining the set of alternatives.

In order to gain a concise understanding of the results and a clear picture to be useful to DMs, the suitability values were aggregated into five classes, since too many value classes generate confusion and hamper the applicability of the results (Geneletti et al. 2007). The class thresholds were selected by subdividing the range of values that occur in the area under analysis into equal intervals. Another final suitability map has thus been generated

Fig. 10 Final map highlighting five suitability classes



and is illustrated in Fig. 10. From this map, it is clearly possible to identify three alternative sites that have the highest suitability values for siting the waste incinerator plant.

The present application has therefore highlighted that MC-SDSS offers significant support in the preliminary phase of the siting process (macro-localization phase), enhancing the efficiency of the performed analysis. Having the objective of identifying potentially suitable areas, the proposed model seems particularly appropriate for dealing with the initial phase of the waste incinerator siting process, as foreseen in the Waste Management Plan of the Province of Torino (Provincia di Torino 2006). The methodological approach adopted in this first phase of definition of the areas potentially more suitable provides a significant support to the evaluation and allows to obtain a useful knowledge base for the subsequent more detailed phase of the analysis (the micro-localization phase), in which it will be possible to select and compare the alternatives more suitable, shifting from the provincial scale of observation to the municipal one.

Interesting results are derived from the sensitivity analysis. The latter has proved to be an explanatory process by which the decision makers achieve a deeper understanding of the structure of the problem (Khan and Faisal 2008). As a matter of fact, knowledge of uncertainty factors is bound to increase the awareness of the decision makers about the merit of the different alternatives and consequently to orientate their strategy better (Geneletti et al. 2003). The role of MCA is to convey this information to the decision makers so that they can make a decision according, for instance, to their risk awareness.

All told, although the model can be considered stable since outputs do not change significantly while varying the cluster weights, it is worth mentioning a reduction in suitable areas for incinerator localization when the weight of the socio-economic aspects increases.

7 Conclusions and future developments

The research undertaken has proposed the development of a multicriteria spatial decision support system to assess the land suitability with reference to the siting process of a

municipal solid waste incinerator in the northern part of the city of Torino (Provincia di Torino 2006).

The study underlines the relevant role land suitability analyses play in spatial planning. In fact, these analyses allow us to determine and harmonize the guidelines for the various land-use types and intensities, as well as to assess potential conflicts between population needs and resource availability.

Furthermore, the paper highlights the advantages of GIS and MCA coupling with specific reference to their ability to support a decision-making process through a systematic, transparent and replicable approach, facilitated by the use of thematic maps.

Particularly, the results of the analysis performed show that the spatial ANP model is suitable to represent a real-world problem. In fact, the integrated approach provides the means by which to perform complex trade-offs on multiple evaluation criteria while taking the DM's preferences and the spatial variability of the criteria into account.

The main advantage of the GIS–MCA integration is the fact that decision makers can insert their own opinions (preferences with respect to evaluation criteria) into the decision-making process based on geographical information systems and receive feedback on their impact in policy evaluations through the visualization of specific maps.

In addition, these tools help to improve communication and comprehension within a group of decision makers, thus facilitating the achievement of consensus. Another advantage associated with MC-SDSS is their ability to provide a flexible problem-solving environment where it is possible to explore, understand and redefine a decision-making problem.

To summarize, decision makers expect MC-SDSS to provide decision-making support regarding two aspects: the first relates to the problem identification phase, to awareness enhancement and to the possibility of grasping the problem's fundamental characteristics and recognizing their main objectives, and the second relates to the support provided in generating different solutions to the problem, comparing these solutions and finally choosing the best one (Bottero et al. 2011).

Future opportunities for expanding the study refer to the possibility of performing a sensitivity analysis on the results by assigning different weight combination to the considered factors (Geneletti 2008; Aragonés-Beltrán et al. 2010).

Furthermore, it will be interesting to develop the present model according to the fuzzy sets theory (Zadeh 1965), which represents attribute values according to membership classes. As a matter of fact, uncertainty can be associated with fuzziness concerning the criterion weight assessment as well as the spatial attribute values (Malczewski 1999).

In order to refine and optimize the siting process during the micro-localization phase, further analyses are deemed appropriate. Based on the suitability values provided by the present study, alternative locations for the incinerator could be proposed. By developing a more detailed analysis at the municipal scale, it will be possible, for instance, to assess site visibility through viewshed analysis in a GIS which generates a map of the portions of landscape visible from each potential site. Moreover, considerations regarding the distribution of heat to settlement areas can be made at the municipal level in order to refine the model and the criteria. Further in-depth analysis could also take into account typical wind directions in order to assess the impact on the air quality of the pollutant and odor emissions from the incinerator.

Finally, considering that the failures in undesirable facility location are typically the result of strong public opposition, it is important to ensure participatory processes. To this end, it would be interesting to develop an online collaborative MC-SDSS (Borouhaki and Malczewski 2010).

Implementing GIS on the Internet and integrating its capabilities with MCA procedures provide a system that can potentially fill the gap between the general public and experts (Malczewski 2006). As a matter of fact, an online MC-SDSS enables the public to gain access to dynamic online maps and spatial decision-making processes via online communication tools where they can express and exchange their preferences and opinions regarding the decision problem. Online tools thus contribute to greater participation in democratic decision-making procedures (Carver 1999; Dragičević and Balram 2004; Jankowski 2009; Miller 2006; Boroushaki and Malczewski 2010). Nevertheless, it is worth underlying that developing a Web-based MC-SDSS is only one part for easing the participation. For an effective feasibility study, it is also necessary to consider and redesign such components of a public participation project as (1) advertising methodology (informing the general public of the spatial decision-making), (2) incentives for participation and (3) accessibility to the system (the computers and the Internet). Within this context, the sustainability of development projects depends, to a large extent, on the integration of local knowledge with scientific inputs from the experts (e.g., planners) in the decision-making process (Dunn 2007). Employing the concept of argumentation maps along with MCA techniques in a WebGIS environment provides a framework for exchanging information, ideas and preferences in a dynamic and interactive fashion (Ferretti 2011b).

In conclusion, any integration of MCA and GIS constitutes a very promising line of research in the field of environmental assessment procedures.

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