New spatial decision support systems for sustainable urban and regional development

Patrizia Lombardi and Valentina Ferretti
Interuniversity Department of Regional & Urban Studies and Planning, Politecnico di Torino, Torino, Italy

Received 26 July 2014
Revised 20 October 2014
7 December 2014
Accepted 5 January 2015

1. Introduction

The scientific debate on the limits of growth that followed the oil crisis in the 1970s has revealed the close interactions between environmental issues, economic and social development and energy security. Since then, the rise of climate change concerns on the public agenda has accelerated the need for quantitative and qualitative assessments of related strategies and policies.

At the level of "Districts and Built Environment," one of the main challenges is to reduce energy use, environmental impact and carbon footprints, which entails competitive industries for jobs and growth and at the same time ensures societal and social development and the well-being of citizens. Currently our existing building stock plays a major role in energy consumption (40 percent of EU final energy demand). This stresses the need for affordable and sustainable retrofit solutions on a large scale. According to the European Commission (2014), a major challenge in this area is to give stakeholders (industry, cities, operators, etc.) the tools needed to take appropriate systemic or individual decisions and facilitate scaling up solutions. The focus does not stop with the building, rather it addresses urban planning processes and "place-making" with people, in communities within cities.

At the level of "Cities and regional systems," new integrated, inclusive decision-making processes are required across a large number of actors and sectors. These are required because cities are dynamic living organisms that are constantly evolving. When addressing the complex problems of city management and planning it is not sufficient just to be concerned with the physical structure of the city; the interplay of intangible economic, social and environmental factors needs to be considered in an holistic way as well. This presents a big challenge.

Recent research findings highlight that decisions on urban and regional planning should be supported by collaborative and inclusive processes, otherwise they will fail. Current methods and tools for supporting decisions in the field of urban planning and design seem unable to tackle the problem as they cannot take a holistic approach or a full account of actors. Therefore, new mechanisms and approaches need to be found to ensure that citizens understand the issues and options and can express their preferences. Furthermore, a great deal of social science research is still needed to understand the interaction between city design, social preferences, economic issues and policy incentives.

This paper aims to present a new generation of evaluation systems to support decision making in planning and regeneration processes which involve expert participation. These systems ensure network representation of the issues involved and visualization of multiple scenarios. In particular, it highlights the potentialities of an innovative spatial decision support system (SDSS) by illustrating a collection of three case studies in which the proposed method has been applied to support environmental decision-making in separate but related contexts.

The paper is organized as follows. The next section discusses the need for new decision support systems (DSS) for tackling the problem of territorial transformations in order to achieve sustainable development in cities and the built environment. These systems are based on a new multicriteria method named Analytic Network Process (ANP; Saaty, 2005) which is able to represent the decision problem more effectively. Finally, Section 3 reviews this new generation of DSS and Section 4 illustrates three case studies. The first case study shows the potentialities of using spatial multicriteria evaluation for ecological landscape design, the second application is related to undesirable facility location problems and the third application to strategic planning of complex territorial systems. In the last section some conclusions are provided.

2. Role of SDSS in the field

Policy makers are specifically challenged with the need to achieve sustainable development in cities and regions, promoting a transition that radically decarbonizes energy sources without undermining well-being and patterns of consumption.

This transition process requires appropriate support and attention by all societal, technical, economic and political stakeholders in order to be delivered in a way which does not affect social well-being and urban sustainability. It requires new ways of "governing" cities that enable, on the one hand, more efficient management and, on the other, more integrated, inclusive decision making across a large number of actors and sectors.

A decision problem is defined as a situation where an individual or a group perceives a difference between a present state and a desired state and where: the individual or group has alternative courses of action available; the choice of action can have a significant effect on this perceived difference; and the individual or group a priori is uncertain as to which alternative should be selected. All territorial transformations are recognized as complex decision-making problems due to the presence of competing objectives, unavoidable trade-offs and possible outcomes. They require appropriate methodologies or approaches for supporting decisions and empowering stakeholders.

At an international level, many evaluation methods and tools have been developed in order to facilitate the integration of environmental values into planning and urban design (De Roo *et al.*, 2004; Rotmans *et al.*, 2000; Runhaar *et al.*, 2009; Wang *et al.*, 2013, 2014). These methods have been classified by Brandon and Lombardi (2011) as "Post-Brundtland" because they seem able to tackle the whole life cycle management of an urban project. A list of these methods and tools is also provided in Lombardi and Cooper (2009). Their aim is to identify and evaluate both the spatial and the technical aspects of the built environment. Although they are useful to guide the urban planning/design process according to environmental principles, they are not able to deal with all the complex issues involved in a planning design process. Furthermore, these systems are not able to describe urban dynamics as a network distribution of issues at different scales (but which are closely related to each other).

In the context of sustainability, evaluation does not merely involve appraising the feasibility and profitability of the future asset on the market, or checking some technical requirements and/or some environmental issues (e.g. risk analysis, static control, etc.). It also involves an integrated assessment of all aspects related to the built environment, and its performance, at different stages, from the earliest conception of the project's development to its final approval.

A number of problems faced in decision making related to urban planning are illustrated in the literature. Finco and Nijkamp (1999) identified the following issues: the information or data available always contains an element of uncertainty; the data or information may be stored in different databases that may be difficult to access, manipulate, compare and study; a large set of – often conflicting – objectives or targets has to be taken into account; the decision-making process itself might be influenced by power relations or selfish motivations; a decision-making process has to take place within the shortest time possible to avoid negative effects.

Although these are recognized critical issues that can plague a decision-making process, a major problem faced in planning evaluation for sustainability is the lack of a common language among the different stakeholders and urban actors (Brandon and Lombardi, 2005). This is required because planning evaluation is generally based on both technical and subjective values, expert judgements and opinions. In order to be effective, therefore, decision making for sustainability should be enlarged to include participation of stakeholders and concerned citizens. In addition, it requires a more realistic and effective representation of the problem involved.

Today a number of powerful techniques are available which can support this task, such as visual and geo-referenced information systems, DSS, virtual reality tools, etc. These tools are very effective in storing and organizing information but not very effective in structuring problems. Decision-making processes for sustainability require structure and a flexible guide which can support the argument and the communication among stakeholders.

In this context, collaborative SDSS and Multicriteria Spatial Decision Support Systems (MC-SDSSs) based on spatial knowledge and expert systems seem more appropriate to tackle the problem. In the next section, a detailed presentation of the state-of-the-art in this field is presented.

3. State of the art for SDSSs

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 Geographic Information Systems (GIS; Charlton and Ellis, 1991) were set forth.

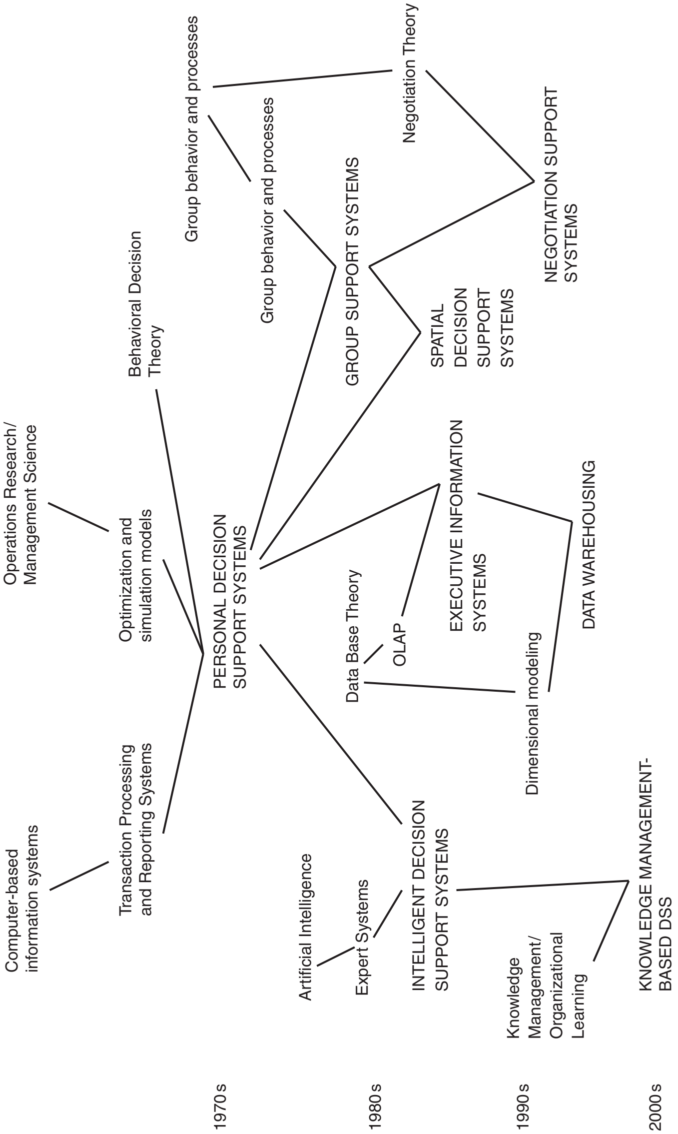
Whereas DSS and GIS can work independently to solve some simple problems, many complex situations demand the two systems be integrated in order to provide better solutions (Li *et al.*, 2004).

Arnott and Pervan (2005) trace and describe the development of the DSS field by identifying several sub-groupings of research and practice, as depicted in Figure 1.

In this context, it can be stated that the development of SDSS was 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 about them were available (e.g. Densham, 1991; Goodchild, 1993; Densham and Armstrong, 1987; Armstrong, 1993). Over the course of the 1990s there was considerable growth in the 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) online analysis of geographical data (Bedord *et al.*, 2001) and visual-analytical data exploration (Andrienko *et al.*, 2003), with the aim of generating, evaluating and quantifying trade-offs among decision-making alternatives (Spatial Decision Support Knowledge Portal, 2014).

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, MC-SDSS, environmental DSS and SDSS based on spatial knowledge and on expert systems. With specific reference to the MC-SDSS sub-group, the full range of techniques and applications has recently been discussed in an interesting survey developed by Malczewski (2006).

The amount of papers on MC-SDSS was limited for many years, but in the past decade, there has been substantial growth in the application of these tools for presenting and solving spatial multicriteria problems, thus stimulating research in different fields. A detailed analysis of the state of the art of these tools is beyond the scope of the present paper; the reader is referred to Ferretti (2013) for a classification of the scientific international literature highlighting the most recent global trends of the research in the MC-SDSS field.



Source: Adapted from Arnott and Pervan (2005, p. 69)

Figure 1.
Evolution of
the DSS field

In particular, MC-SDSS are most commonly applied to land suitability analysis in the urban/regional planning, hydrology and water management and environment/ecology fields, and are usually based on a loose coupling approach and on a value-focused thinking framework (Ferretti, 2013).

The rapid increase of the volume of MC-SDSS research can be attributed to different factors, ranging from the recognition of decision analysis and support as an essential element of GIS science, to the availability of low-cost and easy-to-use MCDA software and modules in spatial analysis software (Lami and Ferretti, 2014; Malczewski, 2006).

Within the MC-SDSS family, a new evaluation system has recently been developed which proposes the integration between GIS and a specific multicriteria analysis technique, the ANP (Saaty, 2005, 2013). This technique, which represents the generalization of the more well-known Analytic Hierarchy Process (AHP, Saaty, 1980) to dependences and feedback, is particularly suitable for dealing with complex decision-making problems which are characterized by inter-relationships among the elements at stake. From a methodological viewpoint, structuring an ANP decision-making process involves the definition of the main objective and the identification of groups or "clusters" which include various elements ("nodes") that influence the decision, and alternatives or options from which to choose. All the elements in the network can be related in different ways since the network can incorporate feedback and complex inter-relationships within and between clusters, thus providing more accurate modeling of complex settings. Comparative or relative judgments are then made on pairs of elements to ensure accuracy. Finally, by means of the super-matrices approach, a final priority vector is obtained for all the elements considered in the analysis.

The three case studies presented in the next section highlight the potential of this new ANP-SDSS tool for supporting complex decision making at the urban and regional planning level.

4. Case studies

4.1 Case study 1:MC-SDSS and land suitability analysis for ecological corridors 4.1.1

Setting. This first case study illustrates the development of a spatial multicriteria analysis to evaluate the ecological connectivity of the Piedmont region in Italy (a full description of the case study can be found in Ferretti and Pomarico, 2013).

Nature conservation is a very important issue in the sustainability assessments and spatial planning context. Knowledge of the suitability of the land to behave as an ecological corridor thus provides significant input to land use planning.

In particular, ecological corridors are areas or structures that enable the spreading, migration and exchange of species between core areas and nature development areas inside an ecological network (Jongman and Pungetti, 2004). The two primary components of ecological networks are hubs, or areas that are known to have ecological value, and links, which are the corridors that connect the hubs to each other. Knowledge of ecological networks can thus be used to support conservation-related land use decisions.

The purpose of this application is to generate a comprehensive map representing the ecological connectivity index of each area in the region under analysis. The added value of this map is the possibility to be used as a decision variable in spatial planning.

In particular, the territory of the region is divided in three areas: the mountain area, which surrounds the region on three sides and occupies most of the land (43.3%); the hilly area (30.3%); and finally the plain area (26.4%) situated in the central part of the region which corresponds to the hydrographic catchment of the

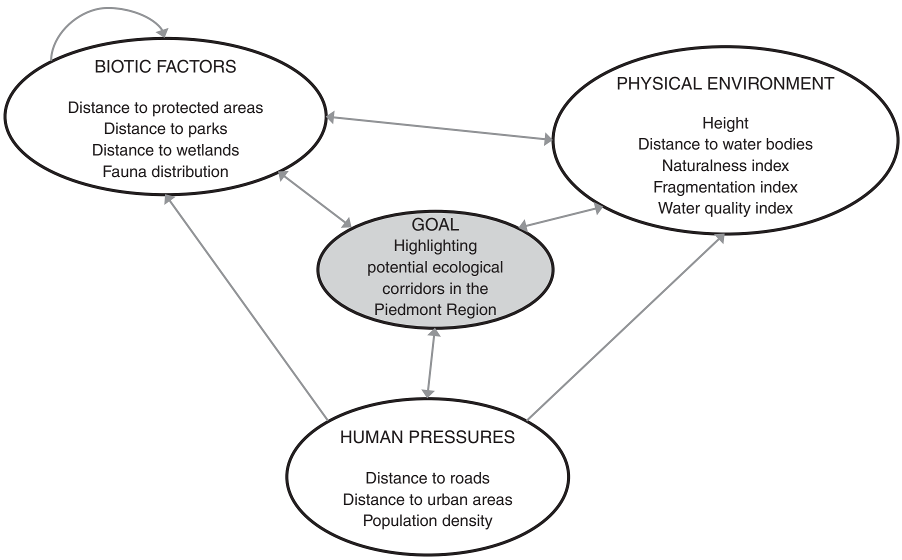
Po river and its many tributaries. Furthermore, it is important to highlight that the region is characterized by a significant number of natural protected areas. The regional law has established 63 protected areas which cover a total surface of 210,625 ha (7.6% of the territory). This aspect gives to the region a relevant environmental and ecological value to be protected and enhanced.

4.1.2 Methods. This case study represents one of the first experimentations of the ANP in a spatial domain.

The objective of the analysis was to identify potential ecological corridors, which ensure continuity between areas with high environmental and ecological value and stepping stones inside the region under analysis. In particular, this study develops a decision-making support model based on land use data and information on significant ecological areas, including important habitats for target species, wetlands, infrastructural impacts and human pressures in order to identify areas of ecological priority and potential ecological connections.

Starting from the overall objective of the analysis, a comprehensive set of evaluation criteria that reflect all the concerns relevant to the decision problem has been identified according to a value-focused thinking approach, which assumes the values as fundamental elements in the decision analysis and, based on the values and criteria structure, develops and evaluates feasible options (Keeney, 1992).

The criteria considered in the present application were selected based on the legislation on protected areas and on sustainability assessments (i.e. Habitats Directive, Birds Directive, European Directive on Strategic Environmental Assessment) which provide a list of aspects to be considered for the protection of ecological networks. Particularly, the selected criteria refer to quantitative ecological and environmental indicators and have been clustered in three main groups including factors relevant to the physical environment, biotic factors and human pressures (Figure 2).



Source: Ferretti and Pomarico (2013)

Figure 2.
The ANP model for assessing the ecological connectivity in the region

Given the spatial distribution of the considered elements, every criterion has been associated to a geographic map where each pixel has a suitability value.

The criterion map thus represents the spatial distribution of the criterion performance in reaching the objective. These maps were derived from basic raster GIS operations (map overlay, buffering, distance mapping, spatial queries, etc.), starting from public data available on the online database of the Regional Authority.

After criteria identification and mapping, standardization was required to make factors comparable and was performed by using value functions, i.e. curves that express the corresponding value score with reference to the level of objective achievement (Beinat, 1997). This operation converts the source map factor scores into a given value ranging between 0 (minimum suitability and low objective achievement) and 1 (maximum suitability and high objective achievement).

In environmental decision-making processes based on the use of SDSS, the interaction between stakeholders/experts and the analyst mainly occurs during the value functions and weights elicitation step. While the former step is more technical and thus requires the involvement of experts in different fields, the latter step could be opened to participation of different actors in order to take into account different perspectives on the decision problem under analysis.

In the present study, standardization was performed by means of a focus group of experts and by using both linear functions and sigmoidal monotonically decreasing functions (Eastman, 2006). With the aim of building a multidisciplinary team able to approach the complexity of the problem under analysis, the focus group brought together experts in the fields of spatial analysis, environmental engineering, landscape assessments and sustainability assessment procedures. The different experts discussed together in order to achieve a consensus with reference to both the standardization of each factor map and the weighting of the elements involved in the decision. In particular, the process was facilitated by the analyst and consisted in three subsequent phases. During the first phase the panel of experts discussed and validated the standardization functions of each factor map; during the second phase the experts brainstormed all together about the relative importance of the clusters considered in the analysis and finally, during the third phase, each expert answered an individual questionnaire about the relative importance of the nodes in the cluster belonging to his field of expertise.

Figure 3 presents the standardized maps obtained for all the criteria considered in the model while Table I summarizes the final priorities of the factors resulting from the evaluation, using the ANP.

The result of the participative procedure adopted for weighing the elements highlights that the most important factors in determining the suitability of the land to behave as ecological corridor are the "distance to urban areas" (0.22) in the "human pressures" cluster and "elevation" (0.20) in the "physical environment" cluster.

4.1.3 Results and lessons learned. Once the maps were obtained for each criterion and the weights were established, all the information was combined in order to obtain the overall suitability map according to the linear weighted combination aggregation rule.

In the present study, in order to test the stability of the results and improve the decision makers' awareness with reference to uncertainties and risks associated to the decision problem, we generated three different suitability maps by changing each time

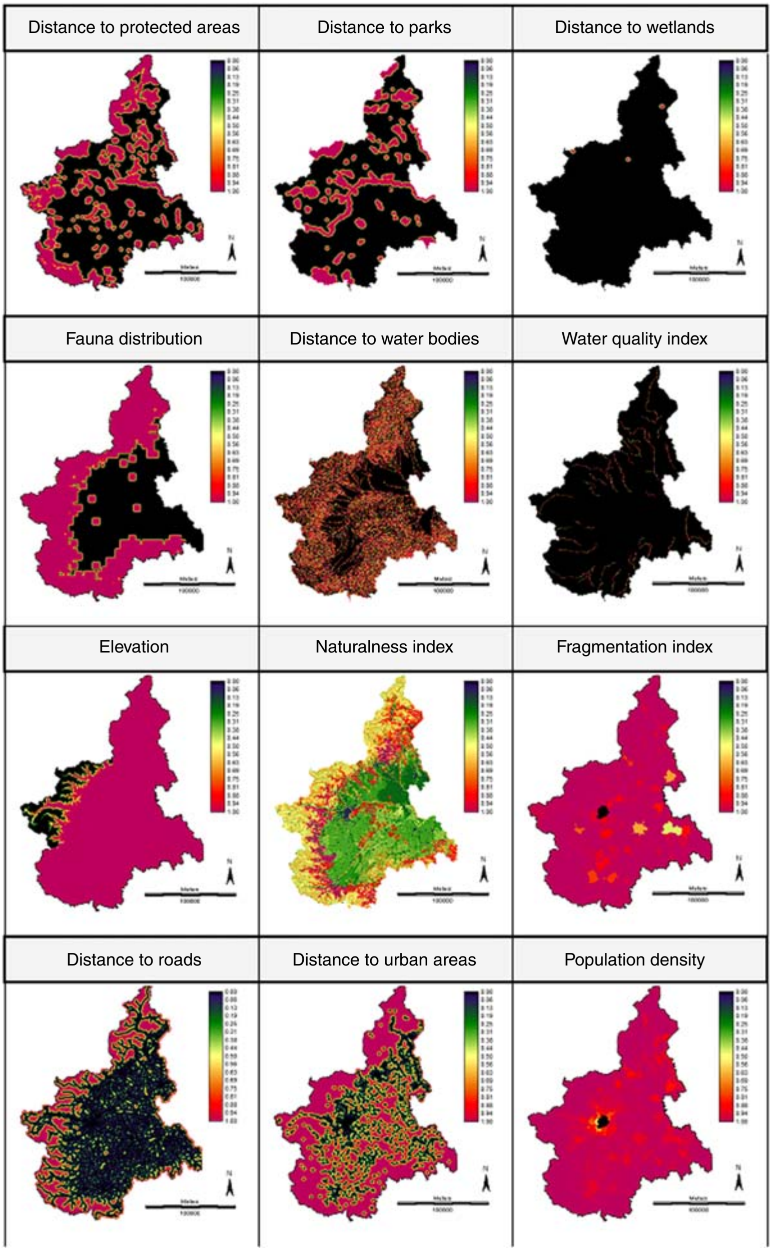


Figure 3.
Standardized factor maps

Source: Ferretti and Pomarico (2013)

the importance assigned to the three main clusters considered in the decision problem. The new set of weights for each simulation was defined and discussed during the focus group; in particular, the different experts were asked to simulate different points of view in order to have each time one cluster predominant over the others.

	Elements	Weights
Clusters		
Biotic factors (0.16)	Distance to protected areas	0.07
	Distance to parks	0.02
	Distance to wetlands	0.04
	Fauna distribution	0.05
Physical environment (0.54)	Elevation	0.20
	Distance to water bodies	0.03
	Naturalness index	0.10
	Fragmentation index	0.07
	Water quality index	0.06
Human pressures (0.30)	Distance to roads	0.08
	Distance to urban areas	0.22
	Population density	0.06

Table I. Priorities of the elements in the model

The first simulation (Figure 4a) shows the situation where the physical environment-related aspects have the greatest weight in determining the most suitable areas to host ecological corridors; in the second simulation (Figure 4b), biotic factors have the greatest importance and, finally, in the third simulation (Figure 4c), the human pressure cluster represents the most important aspect. Figure 4 shows the results of this "what-if" analysis.

The proposed methodology has thus generated cartographic results to be used as decision-making variables during planning procedures.

This result contributes to a better understanding of wildlife dispersal in fragmented landscapes, thus providing effective tools for conservation planning (Vuilleumier and Prélaz-Droux, 2002).

Moreover, by using the resulting index map as a means of analysis, it is possible to identify, for the sake of nature conservation, some critical areas needing mitigation measures. In addition, areas with high ecological connectivity values can be identified and monitoring procedures can therefore be planned.

In conclusion, the proposed methodological approach for aggregating multiple ecological and environmental indicators allowed to:

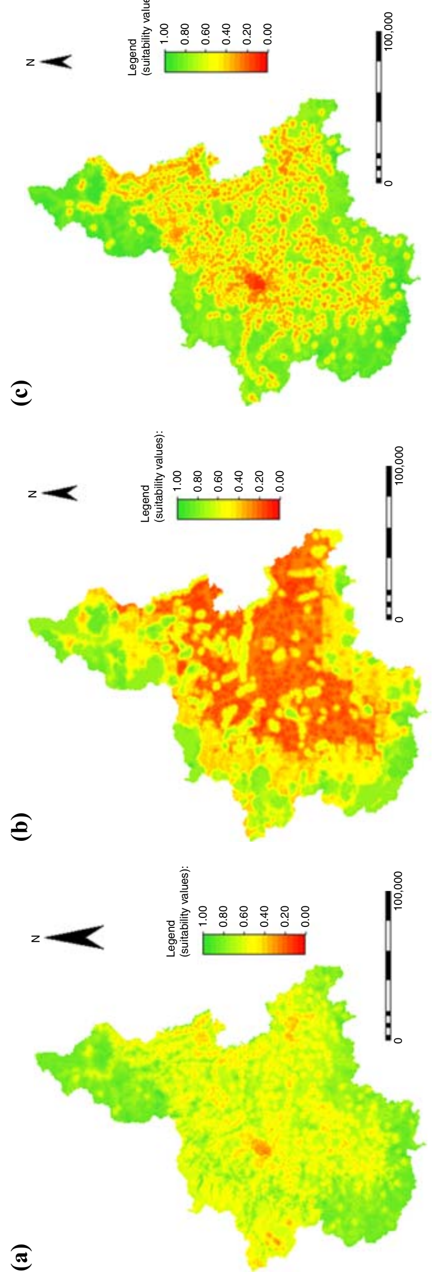
1. facilitate a better understanding of patterns that emerge from decision alternatives involved in the decision-making process; and
2. provide a mechanism with which complex issues can be thoroughly explored and immediate feedback to decision makers can be provided (Geneletti and Ferretti, 2014).

4.2 Case study 2: MC-SDSS for undesirable facility location problems

4.2.1 Setting. The location of undesirable facilities represents a complex decision-making problem due to the presence of different interconnected elements and of multiple and conflicting objectives.

Considering the risk of social opposition generally associated with undesirable facility location problems and the need for justification of the final choice, MC-SDSS play a fundamental role in this context 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."

Figure 4.
What-if analysis simulations



Source: Ferretti and Pomarico (2013)

When dealing with sustainability assessment in an integrated way, a critical issue is how to combine the different dimensions in the evaluation framework given the existence of influence mechanisms between the evaluation criteria. Indeed, in urban and territorial planning, long-term and negative impacts are very often the consequence of an underestimation of the interactions between criteria related to economic sustainability and ecological cost as well as to ecological sustainability and economic cost. A very promising tool for dealing with the existence of interaction mechanisms is the ANP (Saaty, 2005) since it allows to take into account dependencies and feedbacks between criteria in order to better reflect the natural dynamics of the environmental and territorial systems, where links and interaction pathways exist between individual elements, which can, positively or negatively, affect each other (e.g. water, air, soil, flora and fauna, etc.).

The present case study illustrates a spatial multicriteria approach to support decision makers in the siting process of a waste incinerator plant in the Province of Torino (Italy) (a full description of the case study can be found in Ferretti and Pomarico, 2012).

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 and is characterized by a very intensive land use due to residential expansion, industrial and tourism development, transportation infrastructures and agriculture. Urban settlements, infrastructures, agriculture and natural areas all compete for space. To complicate matters even further, geomorphologic constraints reduce the areas suitable for new construction.

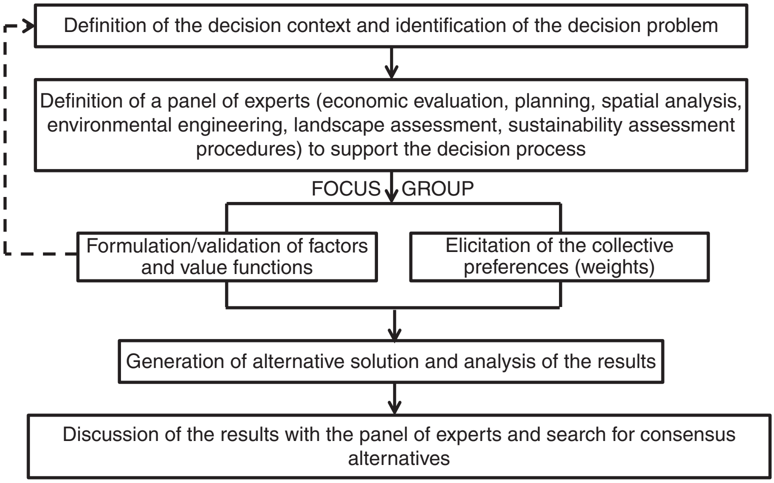
According to the Regional Law 24/2002 (Regulations for waste management), the Provincial Authorities are responsible for the identification of suitable areas for the location of waste disposal and for the recovery of municipal waste. Particularly, the procedure for finding a suitable site to host waste disposal facilities is articulated into five phases, named "planning," "localization at the macro level," "localization at the micro level," "project" and "authorization."

The objective of this study was to show the contribution of spatial multicriteria analysis to support the macro-localization phase, which aims at mapping the "unsuitable areas" and the "potentially suitable areas." In particular, the study made use of the public data available on the cartographic web database of the Regional Authority and simulated the decision-making process for the elicitation of the preferences of the decision makers. The objective of the study was thus to provide a preliminary analysis of the land suitability to host the facility.

4.2.2 Methods. In order to generate a suitability map of the area under analysis for the location of the municipal solid waste incinerator plant, the present application followed the process summarized in Figure 5.

In particular, from the methodological point of view, the ANP requires a network structure to represent the problem, as well as pairwise comparisons to establish the relationships within the structure. In the present application, the model has been developed according to the simple network structure illustrated in Figure 6.

As shown in Figure 6, 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. The considered criteria were selected based on the relevant international literature (e.g. Kontos *et al.*, 2003; Buenrostro



Source: Geneletti and Ferretti (2014)

Figure 5.
Flow chart of the decision support process

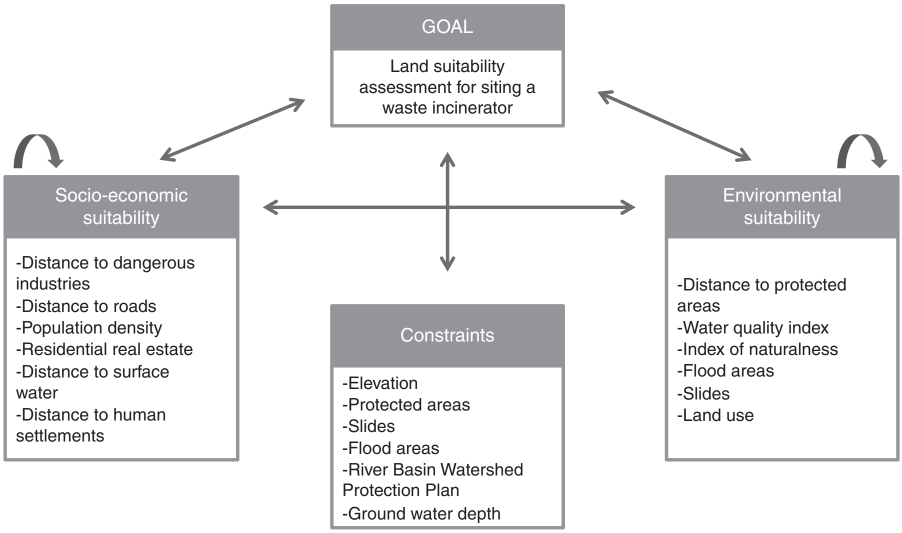


Figure 6.
The ANP network structure for the decision problem under analysis

Delgado *et al.*, 2008; Sumathi *et al.*, 2008; Wang *et al.*, 2009; Geneletti, 2010; Ferretti, 2011) and 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 aspects to be considered for the location of waste facilities.

The core of the process consisted in the standardization and weighting of all the factor maps. Because both the operations 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. Particular attention has been paid to the composition of the team of experts. In order to have a balanced group, different expertise were thus involved, ranging from regional planners, to environmental engineers, economists and spatial analysts. Given the high number of pairwise comparison questions generated by the ANP model, the process was facilitated by an analyst and the weighing phase was organized according to two levels: the clusters' level, for which the experts discussed together in order to reach a consensus on the clusters' weights; and the nodes' level, for which each expert answered an individual questionnaire.

The priorities obtained for the clusters and for the elements considered in the analysis are shown in Table II.

4.2.3 Results and lessons learned. The results are obtained in the form of a final suitability map with values ranging from 0 (unsuitable areas for the realization of the project) to 1 (most suitable areas for the incinerator localization).

In particular, a relevant part of the region was unsuitable for the location of the waste incinerator and the areas with the highest suitability values concentrated mainly in the central part of the region under examination. As a matter of fact, 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.

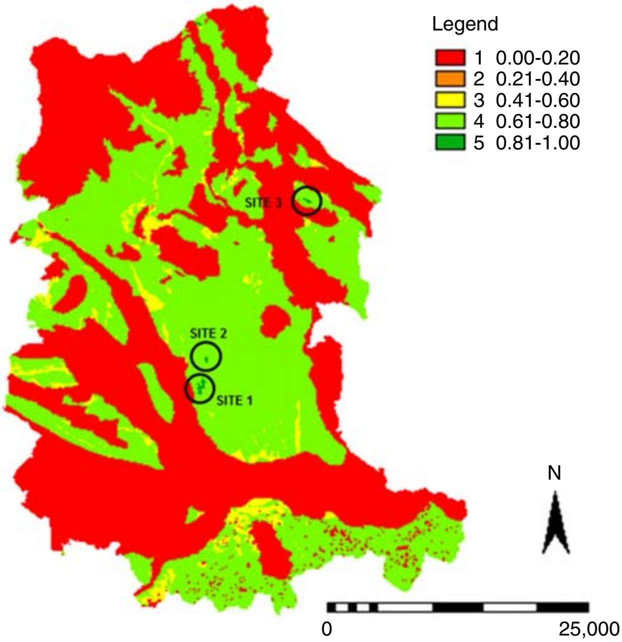
In order to gain a concise understanding of the results and a clear picture to be useful for decision makers, the suitability values were aggregated into five classes, since too many value classes generate confusion and hamper the applicability of the results (Geneletti *et al.*, 2007). The class thresholds were selected by subdividing the range of values that occur in the area under analysis into equal intervals. The final suitability map has thus been generated and is illustrated in Figure 7.

The conclusions that can be drawn from the proposed application can thus be summarized as follows:

(1) The present study has highlighted that MC-SDSSs offer significant support in the preliminary phase of the siting process (i.e. macro-localization phase), thus enhancing the efficiency of the performed analysis. The methodological approach adopted in this first phase of definition of the potentially more suitable areas provides a significant support to the evaluation and allows to obtain a useful knowledge base for the subsequent more detailed phase of the

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 II. Final priorities of the decision elements (the most important elements are highlighted in italics)



Source: Ferretti and Pomarico (2012)

Figure 7.
Final map highlighting five suitability classes

analysis (i.e. the micro-localization phase), in which it will be possible to select and compare the most suitable alternatives, shifting from the provincial scale of observation to the municipal one.

(2) Particular attention needs to be paid to the facilitation of the decision process given the high number of pairwise comparison questions that the ANP methodology generates. To this end, recent research trends refer to the use of facilitated modeling techniques (Franco and Montibeller, 2010) in order to better support the decision process for real world problems.

4.3 Case study 3: MC-SDSS for exploring opportunities and vulnerabilities of complex territorial systems

4.3.1 Setting. In the current debate regarding sustainability assessment and integrated approaches, the spatial analysis of the opportunities and vulnerabilities associated to a territorial context plays a critical role in supporting land use planning and management. The purpose of this third case study is to briefly illustrate the potential of the integrated spatial ANP approach for the definition of future opportunities and vulnerabilities in a mountain area in Northern Italy (a full description of the case study can be found in Ferretti *et al.*, 2014).

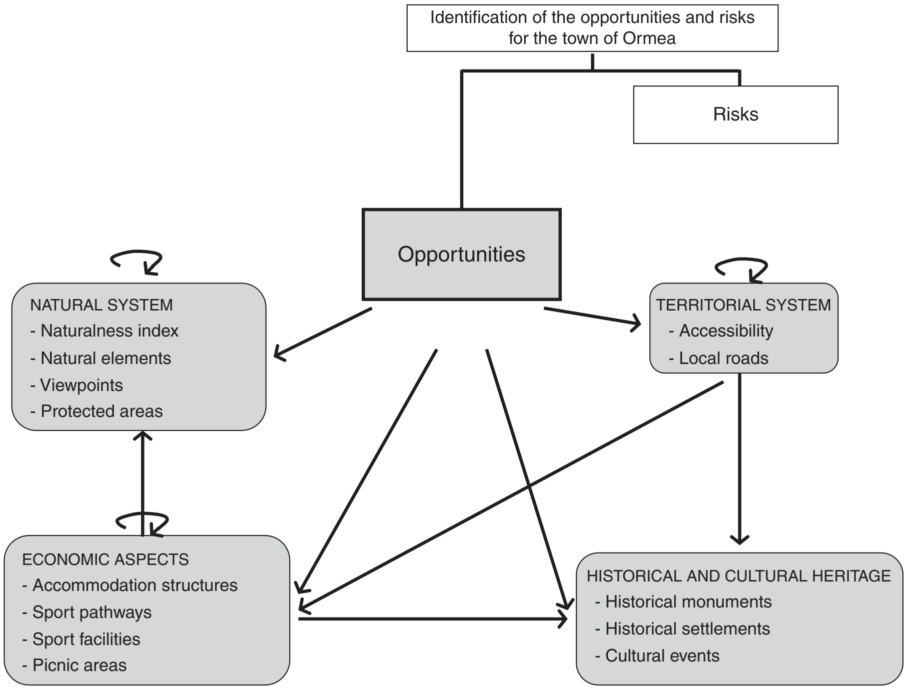
In particular, the case study considered in the application refers to a small town named Ormea. This town has a population of 1,750 inhabitants and is located in the Alpine territory of the Piedmont region, on the border with the Liguria region and with France.

In the past, the city used to be very important from the point of view of the industrial activities concerning the production of wool and paper. Moreover, thanks to the presence of the railway line, the town was an important tourism center at the international level. Nowadays, due to the abandonment of mountain areas, many economic activities have been relocated and the tourism sector is suffering. As a result, the town is experiencing a deep crisis and new strategies for the development of the area are needed (Ferretti *et al.*, 2014).

4.3.2. Methods. Starting from the overall objective of the analysis, which refers to the definition of the opportunities and vulnerabilities for the territory of Ormea, a comprehensive set of evaluation criteria that reflect all the concerns relevant to the decision problem has been identified according to a value-focused thinking approach (Keeney, 1992). In this case, opportunities and vulnerabilities have been considered, respectively, as positive and negative aspects of the transformation in the long time period, for which it is difficult to make any prevision. The spatial distribution of each element considered in the analysis has been derived from publicly available data on the area under analysis.

Figure 8 represents the ANP decision model framework with a focus on the opportunities sub-network.

In the present study, standardization and weighting were performed by means of a focus group of both experts in different fields (i.e. economic evaluation, environmental engineering and landscape ecology) and real stakeholders coming from the Ormea municipality. The advantage was that training a panel of experts allows to overcome



Source: Ferretti *et al*. (2014)

Figure 8. The opportunities sub-network in the ANP model for the problem under analysis

some difficulties and biases which characterize the decision processes based on a single expert.

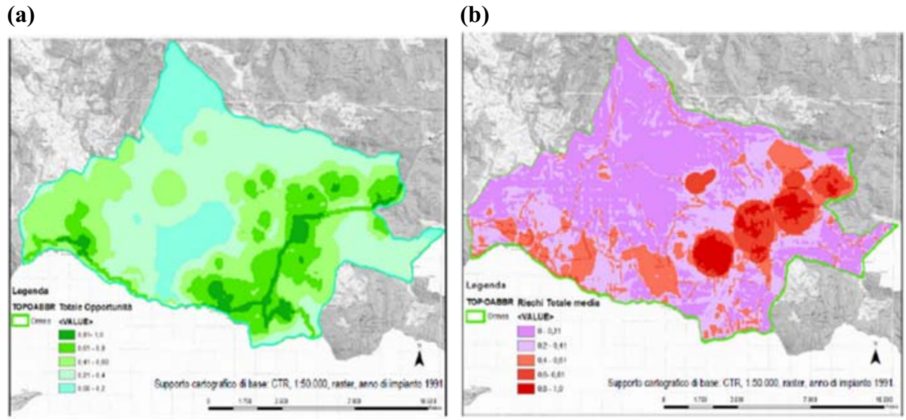
Through the active participation of all the experts and stakeholders the control points used for the standardization of each criterion have thus been defined and all the criteria maps have been translated in the 0-1 suitability range. In the subsequent phase, weighting was performed on all the considered aspects.

4.3.3 Results and lessons learned. The results of the proposed study are represented by two maps highlighting the spatial distribution of opportunities and vulnerabilities within the area under examination. These maps represent a first synthesis of negative and positive aspects for the region under analysis (Figure 9(a) and (b), respectively) and allow to derive useful indications with reference to warning spots needing specific mitigation or monitoring measures. As it is possible to notice from the results of the analysis, the opportunities and vulnerabilities seem to concentrate in the South-Eastern portion of the area under investigation, where the city center is located.

The conclusions that can be drawn from the proposed application can thus be summarized as follows:

(1) One of the most significant strengths of the adopted methodological approach is represented by the fact that the evaluation is organized in a learning perspective. The decision maker thus gains more awareness with reference to the elements at stake while structuring the model (by means of standardization functions and trade-offs elicitation) and thus learns about the problems throughout the decision process (Boerboom and Ferretti, 2014; Ferretti *et al.*, 2014).

(2) By identifying opportunities and vulnerabilities for the area under analysis, the adopted approach also allows to foresee different future strategies (scenarios) for the management and valorization of the entire area. Consequently, different policy strategies could then be studied and evaluated in order to select the most sustainable one.



Source: Ferretti *et al*. (2014)

Figure 9.
Overall distribution of the opportunities (a) and vulnerabilities (b) for the area under analysis

5. Conclusions

This paper has discussed the increasing amount of literature on MC-SDSS as a way of solving problems in different fields, including land suitability analysis in the urban/ regional planning, hydrology and water management and environment/ecology fields (Malczewski, 2006; Ferretti, 2013).

The three case studies presented in this paper involved the ANP method for representing and solving the problem. Many decision-making problems cannot be structured hierarchically because they involve the interaction of higher level elements with lower level ones. In other words, the feedback structure does not have the linear top-to-bottom form of the hierarchy but looks like a network, with cycles connecting its clusters of elements and with loops that connect a cluster to itself.

In a network model, usually not only does the importance of the criteria determine the importance of the alternatives but also the importance of the alternatives themselves determines the importance of the criteria. However, in general, if there is no feedback, and to reduce complexity, the alternatives can be excluded and the influence mechanism between the remaining clusters may be examined.

One of the most significant strengths of the ANP-SDSS methodology proposed in this paper is the awareness of the decision-making elements gained by the actors involved in the process. This leads to the generation of a learning effect and to an increased sense of involvement with the problem under analysis. Despite the advantages observed, the development and use of MC-SDSS also present some difficulties, such as the effective integration between GIS and MCA. As a matter of fact, the presence of both tangible and intangible aspects related to the sustainable development of the built environment and the need to integrate this heterogeneous information within the same spatial framework represents a key challenge in the practical use of these tools.

Moreover, another challenge associated to the use of MC-SDSS in participative processes stems from the operational difficulties of synthesizing a large number of (often conflicting) value judgments and thus of proposing inclusive recommendations.

In conclusion, all three case studies highlight the benefits in using this new ANP-SDSS tool for making appropriate systemic decisions and guaranteeing transparency and replicability to the overall evaluation/planning process. In particular, the results obtained in the three case studies have shown that the proposed method is suitable to represent the complexity of modern territorial systems, where interaction pathways and feedback exist between the different components, and where the consideration of the spatial distribution of the key elements of the environmental system under analysis plays a vital role.

References

Aerts, J.C., Esinger, E., Heuvelink, G.B. and Stewart, T.J. (2003), "Using integer linear programming for multi-site land-use allocation", *Geographical Analysis*, Vol. 35, pp. 148-169.

Andrienko, G., Andrienko, N. and Jankowski, P. (2003), "Building spatial decision support tools for individuals and groups", *Journal of Decision Systems*, Vol. 12, pp. 193-208.

Armstrong, M.P. (1993), "Perspectives on the development of group decision support systems for locational problem solving", *Geographical Systems*, Vol. 1, pp. 69-81.

Armstrong, M.P., Densham, P.J. and Rushton, G. (1986), "Architecture for a microcomputer-based decision support system", *Proceedings of the 2nd International Symposium on Spatial Data Handling, International Geographical Union*, Williamsville, NY, July 6-10, pp. 120-131.

Arnott, D. and Pervan, G. (2005), “A critical analysis of decision support systems research”, *Journal of Information Technology*, Vol. 20, pp. 67-87.

Bedord, Y., Merrett, T. and Han, J. (2001), “Fundamentals of spatial data warehousing for geographic knowledge discovery”, in Miller, H. and Han, J. (Eds), *Geographic Data Mining and Knowledge Discovery*, Taylor and Francis, London, pp. 45-68.

Beinat, E. (1997), *Value Functions for Environmental Management*, Kluwer Academic Publishers, Dordrecht.

Boerboom, L. and Ferretti, V. (2014), “Actor-Network-Ttheory perspective on a forestry decision support system design”, *Scandinavian Journal of Forest Research*, doi:10.1080/02827581.2014.946960.

Brandon, P.S. and Lombardi, P. (2011), *Evaluating Sustainable Development in the Built Environment*, 2nd ed., Wiley-Blackwell (GBR).

Buenrostro Delgado, O., Mendoza, M., Lopez Granados, E. and Geneletti, D. (2008), “Analysis of land suitability for the siting of inter-municipal landfills in the Cuitzeo Lake Basin, Mexico”, *Waste Management*, Vol. 28 pp. 1137-1146.

Carver, S. (1991), “Integrating multi-criteria evaluation with geographical information systems”, *International Journal of Geographical Information Systems*, Vol. 5, pp. 321-339.

Charlton, M. and Ellis, S. (1991), “GIS in planning”, *Journal of Environmental Planning and Management*, Vol. 34 No. 1, pp. 20-26.

Church, R.L., Scaparra, M.P. and Middleton, R.S. (2004), “Identifying critical infrastructure: the median and covering facility interdiction problems”, *Annals of the Association of American Geographers*, Vol. 94, pp. 491-502.

De Roo, G., Visser, J. and Zuidema, C. (2004), *Smart Methods for Environmental Externalities: Urban Planning, Environmental*, Ashgate Publishing Ltd.

Densham, P.J. (1991), “Spatial decision support systems”, in Maguire, D.J., Goodchild, M.F. and Rhind, D.W. (Eds), *Geographical Information Systems: Principles and Applications*, John Wiley and Sons, New York, NY, pp. 403-412.

Densham, P.J. and Armstrong, M.P. (1987), “A spatial decision support system for locational planning: design, implementation and operation”, *Proceedings of the Eighth International Symposium on Computer-Assisted Cartography (AutoCarto 8)*, Baltimore, MD, March 29-April 3, pp. 112-121.

Densham, P.J. and Goodchild, M.F. (1989), “Spatial decision support systems: a research agenda”, *Proceedings GIS/LIS’89*, Orlando, FL, pp. 707-716.

Eastman, J.R. (2006), *IDRISI Andes. Guide to GIS and Image Processing*, Clark University, Worcester, MA.

Eastman, R.J., Kyen, P.A.K. and Toledano, J. (1993), “A procedure for multiple-objective decision making in GIS under conditions of conflicting objectives”, *Proceedings of the Fourth European Conference on GIS (ESIG’93), Genova*, Vol. 1 No. 2, pp. 438-447.

European Commission (2014), “European innovation partnership on Smart Cities and Communities Operational Implementation Plan: first public draft”, available at: http://ec.europa.eu/eip/smartcities/files/operational-implementation-plan-oip-v2_en.pdf (accessed July 19, 2014).

Feick, R.D. and Hall, B.G. (2004), “A method for examining spatial dimension of multi-criteria weight sensitivity”, *International Journal of Geographical Information Science*, Vol. 18, pp. 815-840.

Ferretti, V. (2011), “A multicriteria-spatial decision support system (MC-SDSS) development for siting a landfill in the Province of Torino (Italy)”, *Journal of Multi-Criteria Decision Analysis*, Vol. 18, pp. 231-252.

Ferretti, V. (2013), "Le Analisi Multicriteri spaziali a supporto delle procedure di pianificazione e valutazione: Analisi e classificazione della letteratura scientifica", *Geoingegneria Ambientale e Mineraria*, Vol. 139 No. 2, pp. 53-66.

Ferretti, V. and Pomarico, S. (2012), "Integrated sustainability assessments: a spatial multicriteria evaluation for siting a waste incinerator plant in the Province of Torino (Italy)", *Environment, Development and Sustainability*, Vol. 14 No. 5, pp. 843-867.

Ferretti, V. and Pomarico, S. (2013), "An integrated approach for studying the land suitability for ecological corridors through spatial multicriteria evaluations", *Environment*, *Development Sustainability*, Vol. 15 No. 3, pp. 859-885.

Ferretti, V., Bottero, M. and Mondini, G. (2014), "An integrated approach for exploring opportunities and vulnerabilities of complex territorial systems", in Murgante, B. et al. (Eds), *ICCSA 2014*, Part III, LNCS 8581, pp. 667-681.

Finco, A. and Nijkamp, P. (1999), "Planning for sustainable spatial development: principles and application", Serie research memoranda, Vrije Universiteit, Amsterdam.

Franco, A. and Montibeller, G. (2010), "Facilitated modelling in operational research", *European Journal of Operational Research*, Vol. 205, pp. 489-500.

Geneletti, D. (2010), "Combining stakeholder analysis and spatial multicriteria evaluation to select and rank inert landfill sites", *Waste Management*, Vol. 30 No. 2, pp. 328-337.

Geneletti, D. and Ferretti, V. (2014), "Multicriteria analysis for sustainability assessment: concepts and case studies", *Handbook of Sustainability Assessment*, Edward Elgar Publishers, (in press).

Geneletti, D., Bagli, S., Napolitano, P. and Pistocchi, A. (2007), "Spatial decision support for strategic environmental assessment of land use plans. A case study in southern Italy", *Environmental Impact Assessment Review*, Vol. 27, pp. 408-423.

Goodchild, M.F. (1993), "The state of GIS for environmental problem solving", in Goodchild, M.F., Parks, B.O. and Steyaert, L.T. (Eds), *Environmental Modeling with GIS*, Oxford University Press, New York, NY pp. 8-15.

Janssen, R. and Rietveld, P. (1990), "Multicriteria analysis and GIS; an application to agricultural landuse in the Netherlands", in Scholten, H.J. and Stillwell, J.C.H. (Eds), *Geographical Information Systems and Urban and Regional Planning*, Kluwer Academic Publishers, Dordrecht, pp. 129-139.

Jongman, R.H.G. and Pungetti, G. (2004), *Ecological Networks and Greenways. Concept, Design, Implementation*, Cambridge University Press, Cambridge.

Keeney, R.L. (1992), *Value-Focused Thinking: A Path to Creative Decision Making*, Harvard University Press, Cambridge.

Kontos, T.D., Komilis, D.P. and Halvadakis, C.P. (2003), "Siting MSW landfills on Lesvos island with a GIS-based methodology", *Waste Management & Research*, Vol. 21, pp. 262-277.

Lami, I. and Ferretti, V. (2014), "Spatial decisional processes: evaluation tools and new challenges", in Melis, G. and Masala, E. (Eds), *InViTo – A European Experience for Brownfield Redevelopment*, Celid, Turin, pp. 57-71.

Leung, Y. (1997), *Intelligent Spatial Decision Support Systems*, Springer-Verlag, Berlin.

Li, Y., Shen, Q. and Li, H. (2004), "Design of spatial decision support systems for property professionals using MapObjects and Excel", *Automation in Construction*, Vol. 13, pp. 565-573.

Lombardi, P. and Cooper, I. (2009), "The challenge of the eagora metrics: the social construction of meaningful measurements", *International Journal of Sustainable Development*, Vol. 12 Nos 2/3/3, pp. 210-222.

McHarg, I. (1969), *Design with Nature*, Garden City: Natural History Press, New York, NY.

Malczewski, J. (1999), *GIS and Multicriteria Decision Analysis*, John Wiley and Sons, New York, NY.

Malczewski, J. (2006), "GIS-based multicriteria decision analysis: a survey of the literature", *International Journal of Geographical Information Science*, Vol. 20 No. 7, pp. 703-726.

Pereira, J.M.C. and Duckstein, L. (1993), "A multiple criteria decision making approach to GIS-based land suitability evaluation", *International Journal of Geographical Information Systems*, Vol. 7 No. 5, pp. 407-424.

Provincia di Torino (2006), "Programma Provinciale di Gestione dei Rifiuti (PPGR)", available at: www.provincia.torino.it/ambiente/rifiuti/programmazione/ppgr2006 (accessed July 16, 2014).

Rotmans, J., van Asselt, M. and Vellinga, P. (2000), "An integrated planning tool for sustainable cities", *Environmental Impact Assessment Review*, Vol. 20 No. 3, pp. 265-276.

Runhaar, H., Driessen, P.P.J. and Soer, L. (2009), "Sustainable urban development and the challenge of policy integration: an assessment of planning tools for integrating spatial and environmental planning in the Netherlands", *Environment and Planning B*, Vol. 36 No. 3, pp. 417-431.

Saaty, T.L. (1980), *The Analytic Hierarchy Process*, McGraw-Hill, New York, NY.

Saaty, T.L. (2005), *Theory and Applications of the Analytic Network Process: Decision Making with Benefits, Opportunities, Costs and Risks*, RWS Publications, Pittsburgh, PA.

Saaty, T.L. (2013), "The modern science of multicriteria decision making and its practical applications: the AHP/ANP approach", *Operations Research*, Vol. 61 No. 5, pp. 1101-1118.

Spatial Decision Support Knowledge Portal (2013), available at: www.spatial.redlands.edu/sds/ (accessed June 20, 2014).

Sumathi, V.R., Natesan, U. and Sarkar, C. (2008), "GIS based approach for optimized siting of municipal solid waste landfill", *Waste Management*, Vol. 28, pp. 2146-2160.

Thill, J.C. (Ed.) (1999), *GIS and Multiple Criteria Decision Making: A Geographic Information Science Perspective*, Ashgate, London.

Vreeker, R., Deakin, M. and Curwell, S. (Eds) (2008), *Sustainable Urban Development: The Toolkit for Assessment (Vol. 3)*, Routledge, Oxon.

Vuilleumier, S. and Prélaz-Droux, R. (2002), "Map of ecological network for landscape planning", *Landscape and Urban Planning*, Vol. 58, pp. 157-170.

Wang, G., Qin, L., Li, G. and Chen, L. (2009), "Landfill site selection using spatial information technologies and AHP: a case study in Beijing, China", *Journal of Environmental Management*, Vol. 90 No. 8, pp. 2414-2421.

Wang, H., Shen, Q. and Tang, B. (2014), "GIS-based framework for supporting land use planning in urban renewal: case study in Hong Kong", *Journal of Urban Planning and Development*, doi:10.1061/(ASCE)UP.1943-5444.0000216.

Wang, H., Shen, Q., Tang, B. and Skitmore, M. (2013), "An integrated approach to supporting land-use decisions in site redevelopment for urban renewal in Hong Kong", *Habitat International*, Vol. 38, pp. 70-80.

Wu, F. (1998), "SimLand: a prototype to simulate land conversion through the integrated GIS and CA with AHP-derived transition rules", *International Journal of Geographical Information Science*, Vol. 12, pp. 63-82.

Further reading

Lombardi, P. (2009), "Evaluation of sustainable urban redevelopment scenarios", *Proceedings of the Institution of Civil Engineers. Urban Design and Planning, Vol. 162*, pp. 179-186.

Lombardi P., Huovila, P. and Sunikka-Blank, M. (2010), "The potential of e-participation in sustainable development evaluation – evidence from case studies", in Reddick, C.G. (Ed.), *Politics, Democracy and E-Government: Participation and Service Delivery*, IGI global, Hershey, PA pp. 1-16.

Sharifi, M.A. and Retsios, V. (2004), "Site selection for waste disposal through spatial multiple criteria decision analysis", *Journal of Telecommunications and Information Technology*, Vol. 3, pp. 28-38.