Planning for Urban Growth and Sustainable Industrial Development

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Abstract This chapter describes a planning application designed in EMDS to evaluate land areas for their suitability to industrial park siting. The search for sustainable development approaches to park siting and for improving future viability of existing parks necessitated a structured decision-making process, which took into account all the phases of development, and anticipated uses of the neighboring land and resources. This chapter analyzes key factors in siting, and proposes a multi-criteria decision tool that is useful to considering the viability of present and future industrial areas, and their integration with their surroundings. The inherently spatial characteristics of our planning problem necessitated the use of an application development tool like EMDS to assist us in planning. EMDS was an appropriate platform for developing this application and for assessing the relative suitability of different land areas to siting. Our application was developed for a 646.2 km^2 district in the Cantabria region of northern Spain. We specified and integrated the sustainability criteria and the resulting maps clearly identified suitable zones for industrial park siting. The tool we developed is also extensible to evaluating existing industrial parks and opportunities for retrofitting.

Keywords Urban planning · Sustainable development · Spatial decision support · EMDS · Industrial park

1 Historical Background

Territorial and urban planning greatly influences the social, economic and environmental conditions of many regions of Spain. The siting (location) of industrial parks is a critical part of this process. Industrial parks are defined as "land which is

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K. M. Reynolds et al. (eds.), *Making Transparent Environmental Management Decisions*, Environmental Science and Engineering,
DOI: 10.1007/978-3-642-32000-2_11, © Springer-Verlag Berlin Heidelberg 2014

divided and developed for the simultaneous use of various economic activities with shared infrastructures and proximity between the enterprises" (Trinder et al. 1993). Industrial park planning and promotion have been a fundamental part of urban land use plans. Furthermore, industrial park development is an important component of economic development strategies employed worldwide since 1970, particularly among developed nations (Smith 1971). Nevertheless, industrial parks present a significant environmental risk because they spatially concentrate the environmental problems of each of the component enterprises, and the park's infrastructure and services greatly modify native ecosystem structure and processes. Moreover, the lack of a comprehensive environmental management approach often leads to impacts resulting from waste generation, air and water pollution, and unsafe working or environmental conditions (UNEP 1997), which can interfere with and create conflicts with adjacent or concurrent urban, tourism, and recreation zones.

In urban planning, industrial areas are usually located far from residential areas to minimize environmental impact and land use conflicts. However, with time, urban growth can bring residential and industrial areas into greater proximity, making it increasingly difficult to separate land uses. The integration of industry with the environment rather than the transformation of environments by industry is a necessary strategy for minimizing conflicts associated with disparate land uses in close proximity, especially as available land area for such uses declines.

According to the guidelines of European Directive 2001/42/EC (2001), integration of environmental concerns during early industrial planning and project design phases greatly reduces impacts and the overall footprint of industrial parks on the natural environment. Likewise, pollution may be reduced where industrial operations are designed to mimic ecosystem structure and process, a principle of industrial ecology.

Industrial ecology proposes the search for common ground between industrial operations and urban or exurban surroundings, wherein industrial production and ecological processes are considered interdependent elements. The main objective is to promote symbiosis and synergy between various human and ecological activities in a given area through the carefully planned use or exchange of materials and energy, knowledge use, and development of shared facilities or initiatives (Graedel and Allenby 2003). Urban planning, production system design, and environmental management have always been considered separately in the planning and design of industrial areas. Industrial ecology seeks integrated solutions using an approach combining economic and environmental advantages.

The first publication to explicitly address industrial ecology was by Frosh and Gallopoulos (1989), although scientific publications on the basic ideas of industrial ecology date back to the mid-1950s (Erkman 1997). There are many examples of the use of industrial ecological principles in production systems at the corporate level through material, energy and water exchange, and recycling cycles (Lowe and Evans 1995; Frosh 1995; UNEP 1995). These principles also emerge at the international level for the planning and design of all the lifecycle phases of industrial parks (Kirschner 1995; Rosenfeld 1997; UNEP 1997; Roberts 2004; Tudor et al. 2007).

The conditions and evolution of these industrial ecosystems have been presented in various scientific works published in the last decade (Côté and Cohen-Rosenthal 1998; Lambert 2002; Gibbs 2005; Korhonena and Snäkin 2005; Gibbs 2007). Initiatives are found mainly in Western Europe (United Kingdom, Netherlands, and France), North America, and East Asia (China, Japan, Philippines), in developed countries and those with current high economic growth. Nevertheless, the true level of implementation is limited when compared with the number of planned projects. Furthermore, a great number of the studied cases involve transforming already functioning industrial areas into eco-industrial parks.[1]

The analysis of industrial siting factors in developed nations shows that the proximity to transportation infrastructures, workforce availability, and market or raw material proximity are still the principal driving variables (Leitham et al. 2000; Figueiredo et al. 2002; Somlev and Hoshino 2005). In contrast to the goal of reducing establishment and working costs found in classic location (siting) theories (Hoover 1948; Isard 1954; Lösch 1954), the current challenge is to find new competition factors. Environmental responsibility and proximity of businesses to infrastructure and R&D centers are recent examples.

According to Aalborg (1994), agreements on balanced development, the relationship between an urban environment with optimal social services, and the search for a quality physical environment to be conserved, have taken on a key role in the combining of industrial activity and the environment. Thus, it is essential to carry out integrated planning that includes the different policies of various sectors (e.g., transportation, energy, land use) when combining socio-economic development and environmental protection. Under the opinion of the author, a lack of foresight in the planning of spaces for urban development and economic activity leads to frequent changes in spatial organization and frequently re-building alignment and typology. Rational planning should consider and forecast, to a practical extent, industrial siting factors that make socio-economic and environmental interests compatible.

It is therefore crucial to consider new criteria in classical industrial location theory that help achieve integrated planning of the use of resources and minimize negative impacts to the environment created by establishment of new land uses. With the current state of development, there is no doubt that industrial parks should be sited to simultaneously maximize production capacity and minimize adverse effects on the environment. Reaching this level of integration is complex and requires the development of models and tools that allow for interrelating and ranking the numerous variables in a coherent and structured manner, to aid in the

[1] An eco-industrial park (EIP) is an industrial park in which businesses cooperate with each other and with the local community in an attempt to reduce waste and pollution, efficiently share resources (such as information, materials, water, energy, infrastructure, and natural resources), and help achieve sustainable development, with the intention of increasing economic gains and improving environmental quality. An EIP may also be planned, designed, and built in such a way that it makes it easier for businesses to co-operate, and that results in a more financially sound, environmentally friendly project for the developer (Lowe 2001).

decision making process for the agents who are directly involved in sustainable regional and urban design.

The combination of spatial analysis with multi-criteria decision analysis techniques (MCDA) has allowed for the creation of Multi-Criteria Spatial Decision Support Systems (MC-SDSS) with the objective to formulate and resolve spatial decision problems. MC-SDSS differ from conventional multi-criteria analysis techniques by including a spatially explicit geographic component (Malczewski 1999). In contrast with MCDA, spatial MCDA requires information on the values of the evaluation criteria, the geographic locations of the alternatives, and the preferences of the decision-makers regarding the values of the criteria and their locations.

The geographical information system (GIS) component of MC-SDSS may include statistical and mathematical modeling to explore existing data sources and spatially extrapolate the results. These tools can be also be used to explore alternative decisions and evaluate uncertainties associated with the available data, and the sensitivity of decisions to errors associated with the data or their extrapolation.

A well-designed user interface component can aid decision makers by helping them to visualize the key components of decisions and the supporting data, the chief differences among alternatives, and how these are displayed geographically and by criteria.

MC-SDSS applications have been developed in a wide variety of field applications. For example, in environmental planning and management, there are applications aimed at waste management (Maniezzo et al. 1998; Chang et al. 2008); natural resource management (Kallali et al. 2007), and territorial and urban planning (Dai et al. 2001; Herbst and Herbst 2006; Hernández et al. 2004). Depending on the specifications of applications and their system requirements, each project presents its own unique integration of a GIS and an MCDA model.

One application in particular, designed for land suitability evaluation, employs an expert system (ES) (Kalogirou 2002; Tabeada et al. 2006). ESs are rule, fact, and/or procedural knowledge-bases that have been employed to solve specialized problems, where significant expert-based information may exist. They provide several advantages: (1) they can easily handle qualitative and quantitative knowledge in the same utility; (2) can readily organize the implicit knowledge of experts; (3) are structurally flexible, and (4) are adaptable for different applications. As such, ESs may be highly useful to adaptive management, especially in capturing a snapshot of the relevant knowledge that is applied to a management concern, and the specific ways in which it was used to formulate alternative management approaches (e.g., see Humphries et al. 2008).

Here, we present a new application of an MC-DSS; an industrial area siting (location) model that incorporates the core principles of industrial ecology and sustainable development (Fernández and Ruiz 2009). Our model includes location and environmental sustainability factors, and evaluates prospective land areas at two levels: the first identifies the best regional, district, or district group siting

areas for industrial development; the second evaluates specific aspects of localized land areas identified in the first level.

Due to the variety of criteria applied in evaluation, spatial analysis and presentation of the variables is necessary to aid in decision making by the local or regional agents involved. To accomplish this, a fuzzy rule-based expert system was constructed with NetWeaver software using the Ecosystem Management Decision Support (EMDS) system (Reynolds 2002, 2005). The result was a spatial urban planning MC-SDSS that employs MCDA. In our application, we created digital summary maps that show the suitability of different zones for locating potential industrial areas. Additionally, the tool is extensible to evaluating existing industrial areas.

2 Methods

2.1 Study Area

The study area is located in the Cantabria region of northern Spain, in one of the region's principal river corridors. The Cantabria region covers 18 municipalities with a total land surface area of 646.2 km^2, and a population of 121,629 inhabitants (Fig. 1).

2.2 Structure of the Model

Our model applies theory and methods appropriate to industrial area location developed by Fernández and Ruiz (2009). The model includes traditional as well as new value-added factors representing contributions to the global economy. Given the wide variety in potentially available productive spaces, this model focuses on mixed industrial parks, which are typified by small and mid-sized enterprises from secondary and tertiary economic sectors of local and regional importance. In these types of parks, there is little interdependence between enterprises, which are highly varied; there is often much turnover in tenancy, leading to a dynamic rather than fixed cross-section of business enterprises. The conceptual framework of the model is shown in Fig. 2, and described as follows:

- *Structuring the logic model.* This first stage establishes the geographic application scale of the siting model. Each of the levels in the model represents a sorting and ranking of the objectives by the application scale. Once established, the variables and their respective evaluation criteria are defined, categorized, and subcategorized within levels. The place they occupy within the model structure represents the order in which variables are analyzed.

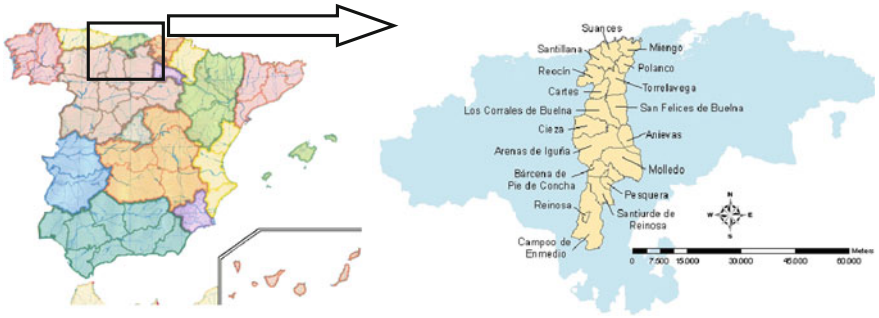


Fig. 1 Location of the study area in the region of Cantabria, Spain

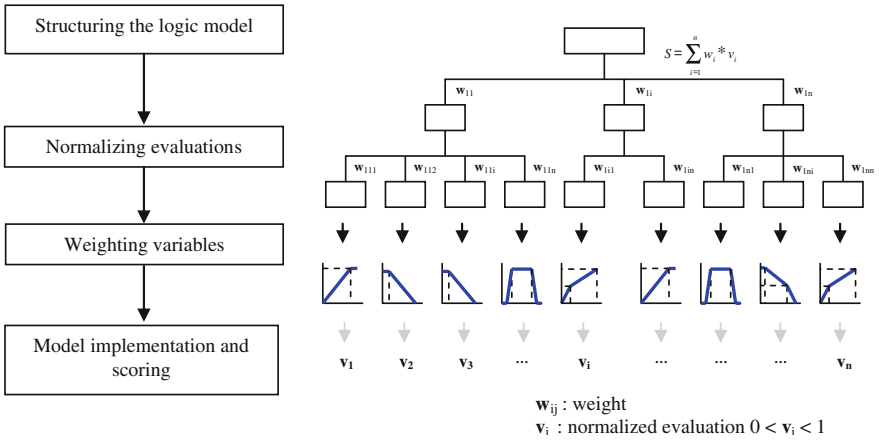


Fig. 2 Overall flow of the logic modeling effort

- *Normalizing evaluations.* Each of the defined variables in the structure is evaluated according to criteria and subcriteria, and reference ranges of values for each criterion and sub-criterion via functions that normalize the results to values that fall between 0 and 1. The evaluation functions are represented using fuzzy logic (Mukaidono 2004) and are implemented in the NetWeaver component of EMDS.
- *Weighting variables.* This is the third stage of the evaluation method and consists of assigning the degree of importance using weights for each level, category, subcategory and indicator. Weights are derived using the Analytical Hierarchy Process (Saaty 1980, 2005). Each of the parties involved in the project acts as decision maker and individually obtains weighting factors. Each decision maker builds comparison matrices using pairs of variables that are present in each node of the hierarchy in descending order. From the comparison matrices, the weight vector is obtained by means of the geometric sum method

and it is checked that the consistency ratio for each trial is less than 10 % so that therefore the obtained weights are consistent. The final weights are calculated using the geometric average of the weighting factors obtained individually and through the consensus of the group. In order to carry out this weighting process the software Expert Choice® was used.

- *Model implementation and scoring*. The scoring of sites is accomplished using a simple weighted scoring algorithm that considers each level, criterion, sub-criterion, and variable, and its weighted contribution, in ascending order in the data structure. The final score represents the estimated degree of compliance of any given site with the established criteria, considering their relative influence. Partial results are obtained for all criteria and sub-criteria, and the final map result is the evaluated area divided into zones and colorized according to the final score, which ranges between 0 and 1.

Figure 3 shows the structure and flow of the siting model and the evaluation sequence. Model structure is presented in two phases: Phase 1) Evaluation and selection of appropriate regional and district zones, and Phase 2) Evaluation of specific lots within regions or districts. The first phase applies to regions or districts covering one or more municipalities, and considers socio-economic, physical-environmental, and infrastructure and urban development criteria. Legal and technical restrictions (sub-criteria) are considered later for areas selected in Phase 1.

Legal restrictions protect zones with outstanding natural beauty, environmental sensitivity, or cultural interest. Technical restrictions are applied to avoid construction or development in zones of high quality soils for agricultural uses, or to avoid physical or substrate hindrances to construction, such as zones with a steep grade or occurring over solid bedrock.

After legal and technical restrictions are considered, potential and probable risks are evaluated, including risks of flooding, landslides, subsidence, and the like. Final lot selection is done in Phase 2 at a local level, using the detailed analysis resulting from Phase 1. In Phase 2, we evaluate available resources and infrastructure linked to water, energy, waste management facilities and ICTs and the specific costs associated with acquiring each lot. The economic feasibility of developing the land is determined as well, along with cost estimates of construction and development of each new industrial park. These factors vary considerably and employ detailed technical reports that are unique to each lot.

2.3 Design of the Spatial Decision Support System

Five methodological steps were followed in developing the logic model:

- *Obtaining the information*. Collect necessary data to parameterize and validate the model.
- *Data entry*. ArcGIS was chosen as the GIS platform (ArcGIS 1997), and all map layers were projected in vector format. In this step, all map layers were set to a

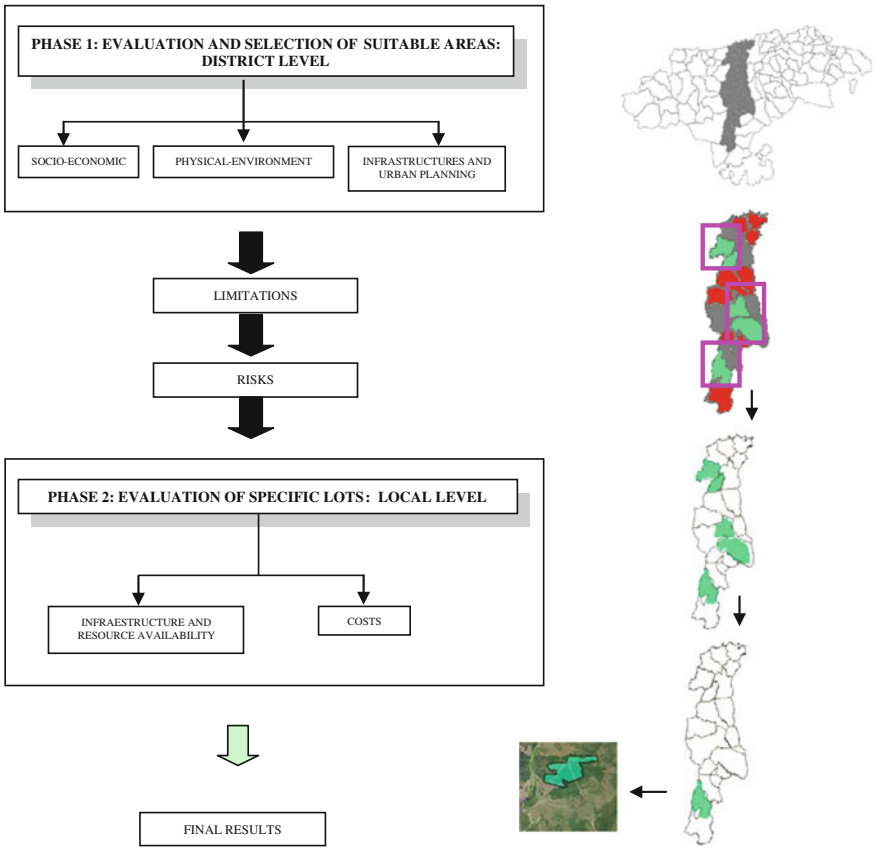


Fig. 3 Structure and flow of the logic model

common map projection (Universal Transverse Mercator System), edited, and edge matched.

- *Data preparation for NetWeaver modeling.* All map layers were grouped into a common file geodatabase and readied for access as a structured flat file that was readable by the NetWeaver model.
- *Multi-criteria evaluation*. Fuzzy evaluation functions and weights were applied to evaluation variables to calculate partial scores.
- *Output.* Results were graphically presented in maps and a dynamically linked data table, which allowed decision makers and users to visualize contributions of variables, subcategories, and categories to the overarching goal.

Linear and trapezoidal fuzzy functions were developed for each variable included in the MC-SDSS (Figs. 3 and 4). The function type (see examples in Fig. 3), parameters of each variable and weighting factor for the socio-economics, physical-environmental, infrastructure, and urban development primary criteria and sub-criteria are shown in Tables 1, 2 and 3 respectively.

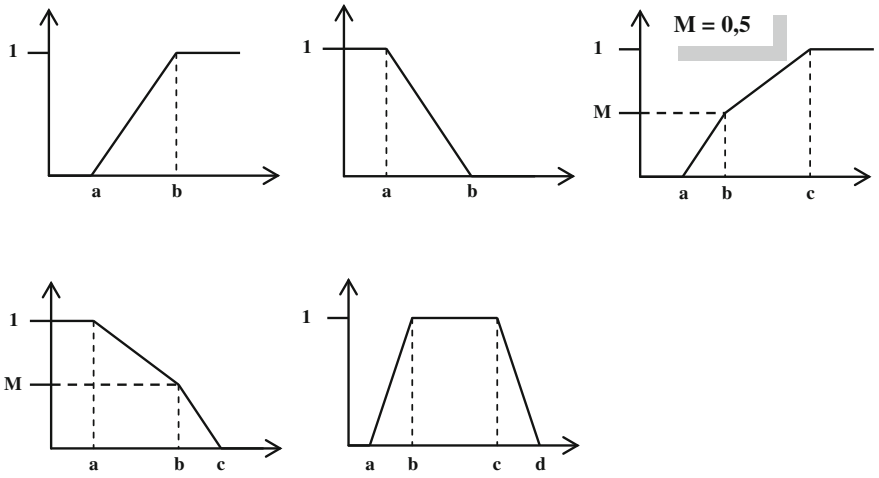


Fig. 4 Evaluation functions used were: *L1* positive linear function; *L2* negative linear function; *L3* positive linear function with changes in slope; *L4* negative linear function with changes in slope; *T1* trapeziodal function

The socio-economic criterion evaluated the potential viability of developing new industrial areas in the context of other economic sector alternatives (Table 1). For example, analysis was completed to determine the contributions of local economies, populations (e.g., demographics, occupations), existing workforces (e.g., age, education level) and locally implemented economic strategies to new industrial activities (Amiti and Pissarides 2005; Kilkenny and Thies 1999).

The physical-environmental primary criterion evaluated the capacity of the natural environment to absorb the impacts resulting from new industrial activities (Table 2). To this end, issues such as water and land availability and quality were analyzed as natural resources. A natural environment can be severely damaged by population density or industrial activity, or by poor management (Ferrarini et al. 2001). Avoiding damage requires knowing the impact absorption capacity and carrying out a thorough planning of the use of resources (Fabbri 1998).

The infrastructure and urban development criterion evaluated the infrastructures and facilities needed for viable operation of a new industrial area using analyses of existing transportation infrastructure, water and electrical supply, among other factors (Table 3). Presence of adequate infrastructure and services of emergency or information and communication is essential for the development of new production activities, and increases the likelihood that a good standard of living is associated with project implementation (Martin 1999; Ferrarini et al. 2001).

Model Builder, a standard utility in ArcGIS, was used to manipulate data and compute values for criteria, sub-criteria, and variables (Fig. 5). NetWeaver software was used to reflect the logic of the ES in a logic dependency network (NetWeaver Developer 1987; EMDS 2004).

Table 1 Evaluation functions and weights of the socio-economic factors

Indicator	Normalized evaluation		Weights
Socio-economical	Type	Parameters	0.143
Social			0.269
Population change (%)	L1	**a** = 0; **b** = 30	0.134
Unemployment rate (%)	L1	**a** = 5; **b** = 10	0.433
Rate of aging (%)	L2	**a** = 1; **b** = 1.25	0.117
Population age structure			0.171
Ages between 16–44 (%)	L1	**a** = 25; **b** = 50	0.667
Ages between 45–49 (%)	L1	**a** = 10; **b** = 20	0.333
Educational level			0.145
Population with no education (%)	L2	**a** = 0; **b** = 11	0.088
Population with primary education (%)	L2	**a** = 25; **b** = 100	0.199
Population with secondary education (%)	T1	**a** = 0; **b** = 23; **c** = 60; **d** = 100	0.478
Population with university education (%)	T1	**a** = 0; **b** = 21; **c** = 30; **d** = 100	0.235
Economic			0.731
Economic sector efficiency			0.120
Efficiency of primary sector (% *population*/ % *GVA*)	L1	**a** = 0.7; **b** = 1.3	0.157
Efficiency of secondary sector (% *population*/ % *GVA*)	L2	**a** = 0.7; **b** = 1.3	0.572
Efficiency of tertiary sector (% *population*/ % *GVA*)	L2	**a** = 0.7; **b** = 1.3	0.271
Occupancy levels in industrial areas (%)	L1	**a** = 0; **b** = 80	0.354
Costs			0.526
Land prices (*normalized cost estimate*)	L1	**a** = 1; **b** = 0	0.651
Workforce costs (€/*worker*/*month*)	L2	**a** = 1297; **b** = 1297.1	0.198
Housing costs (%)	L2	**a** = 0; **b** = 15.75	0.151

3 Results and Discussion

This section presents and discusses the results obtained from applying the MC-SDSS to the Cantabria region. Model results are presented by the primary criteria–socio-economic factors, physical-environmental factors, and infrastructures and urban development factors. Combining partial scores leads to an overall result that provides diagnostically important information about the most appropriate zones for the development of a new industrial area using sustainability criteria. Legal and technical restrictions that could limit the resulting available land areas are applied to the final results.

Table 2 Evaluation functions and weights of the physical-environmental factors

Indicator	Normalized evaluation		Weights
Physical-environmental	Type	Parameters	0.327
Atmosphere			0.193
Air			0.500
Zones of atmospheric safety (m)	L1	**a** = 500; **b** = 2000	0.276
Environmental pollutant concentration (n° times)	L4	**a** = 30; **b** = 60; **c** = 100	0.473
Stationary pollution sources (m)	L1	**a** = 1000; **b** = 2000	0.252
Noise (dBA)	L4	**a** = 35; **b** = 50; **c** = 65	0.250
Environmental electromagnetic pollution ($\mu W/cm^2$)	L2	**a** = 0; **b** = 450	0.125
Light pollution (*type of luminosity in the sky*)	L1	**a** = 0; **b** = 1	0.125
Land			0.623
Construction specifications			0.443
Land use capacity (*soil type*)	L1	**a** = 0; **b** = 1	0.360
Grade (*grade*)	L2	**a** = 5; **b** = 10	0.640
Soil quality			0.557
Soil agricultural capacity (*scale used in Cantabria*)	L1	**a** = 0; **b** = 1	0.290
Prior industrial use (*yes/no*)	L1	**a** = 0; **b** = 1	0.710
Water			0.184
Presence of surface water			0.255
Presence of rivers (m)	T1	**a** = 250; **b** = 500; **c** = 1000; **d** = 2000	0.682
Presence of lakes, reservoirs (m)	T1	**a** = 250; **b** = 500; **c** = 1000; **d** = 2000	0.318
Surface water quantity			0.454
River quantity (m^2)	L1	**a** = 25000; **b** = 2576100	0.619
Lake, reservoir quantity (m^2)	L1	**a** = 25000; **b** = 2576100	0.381
Surface water quality			0.290
River quality (*water type*)	L1	**a** = 0; **b** = 1	0.619
Lake, reservoir quality (*water type*)	L1	**a** = 0; **b** = 1	0.381

3.1 Socio-Economic Factors

Results from evaluating sub-criteria under the socio-economic factors primary criterion (Fig. 6c) were derived from a weighted scoring of social (26.9 %, Fig. 6a) and economic sub-criteria (73.1 %, Fig. 6b). The presence of zones with moderate suitability was due to lower than average land prices, distance from protected spaces and from important economic activity centers, the presence of more efficient economic sectors, and a higher unemployment rate. Inversely, zones with lowest suitability were characterized by higher than average land prices, poor efficiency of economic sectors, and a low unemployment rate.

Table 3 Evaluation functions and weights of the infrastructures and urban development factors

Indicator	Normalized evaluation		Weights
Infrastructures and urban development	Type	Parameters	0.53
Infrastructures and facilities			0.550
Transportation			0.400
Land transport			0.422
Presence of land transport infrastructures			0.518
Turnpikes and motorways (m)	L4	**a** = 2000; **b** = 5000; **c** = 10000	0.685
Main roads (m)	L4	**a** = 500; **b** = 1500; **c** = 4000	0.224
Secondary roads (m)	L4	**a** = 100; **b** = 1000; **c** = 2000	0.091
Fluidity of land transport infrastructures			0.482
Turnpikes and motorways (*intensity/capacity*)	L2	**a** = 0.5; **b** = 0.9	0.685
Main roads (*intensity/capacity*)	L2	**a** = 0.5; **b** = 0.8	0.231
Secondary roads (*intensity/capacity*)	L2	**a** = 0.5; **b** = 0.7	0.084
Railway transport			0.156
Presence of railway transport infrastructures			0.518
Presence of transfer stations (m)	L4	**a** = 5000; **b** = 10000; **c** = 20000	0.543
Presence of railway (m)	L4	**a** = 3000; **b** = 10000; **c** = 15000	0.457
Railway transport infrastructures quality			0.482
Transfer station category (*station category*)	L1	**a** = 0; **b** = 1	0.568
Railway category (*railway type*)	L1	**a** = 0; **b** = 1	0.432
Sea transport			0.074
Presence of a port (m)	L2	**a** = 20000; **b** = 50000	0.623
Port category (*port category*)	L1	**a** = 0; **b** = 1	0.377
Air transport			0.052
Presence of an airport (m)	L4	**a** = 10000; **b** = 18000; **c** = 30000	0.623
Airport category (*airport category*)	L1	**a** = 0; **b** = 1	0.377
Access to personal transport			0.112
Public transport			0.819
Road transport (m)	L4	**a** = 400; **b** = 1000; **c** = 1200	0.500
Railway transport (m)	L4	**a** = 400; **b** = 1000; **c** = 1200	0.500
Possibility of travelling on foot or by bicycle (m)	L2	**a** = 500; **b** = 2000	0.181
Junctions (m)	L2	**a** = 10000; **b** = 25000	0.184
Energy			0.123
Electricity			0.688
High tension lines (m)	L4	**a** = 100; **b** = 500; **c** = 1000	0.435
Low tension lines (m)	L4	**a** = 50; **b** = 200; **c** = 300	0.122
Power stations and substations (m)	L2	**a** = 500; **b** = 1500	0.444
Natural gas (m)	L2	**a** = 1000; **b** = 5000	0.202
Combustible liquids (m)	L2	**a** = 5000; **b** = 30000	0.110

(continued)

Table 3 (continued)

Indicator	Normalized evaluation		Weights
Water			0.216
Water supply			0.755
Water supply network (m)	L4	**a** = 500; **b** = 1500; **c** = 2000	0.400
Other large infrastructures (water highway) (m)	L2	**a** = 1000; **b** = 10000	0.600
Wastewater treatment			0.245
Wastewater network (m)	L4	**a** = 500; **b** = 1500; **c** = 2000	0.800
Wastewater treatment stations (m)	L4	**a** = 1000; **b** = 7000; **c** = 10000	0.200
Dumping sites (m)	L4	**a** = 10000; **b** = 20000; **c** = 50000	0.050
Waste treatment management and facilities			0.050
Urban solid waste management (m)	L4	**a** = 10000; **b** = 20000; **c** = 50000	0.233
Non-hazardous waste management (m)	L4	**a** = 10000; **b** = 20000; **c** = 50000	0.403
Hazardous waste management (m)	L4	**a** = 10000; **b** = 20000; **c** = 50000	0.364
Landfills			0.060
Presence of landfills			0.400
Urban waste landfills (m)	L4	**a** = 10000; **b** = 20000; **c** = 50000	0.179
Inert waste landfills (m)	L4	**a** = 10000; **b** = 20000; **c** = 50000	0.165
Non-hazardous waste landfills (m)	L4	**a** = 10000; **b** = 20000; **c** = 50000	0.377
Hazardous waste landfills (m)	L4	**a** = 10000; **b** = 20000; **c** = 50000	0.279
Infrastructure capacity			0.600
Urban waste landfills (*years*)	L3	**a** = 10; **b** = 25; **c** = 50	0.254
Inert waste landfills (*years*)	L3	**a** = 10; **b** = 25; **c** = 50	0.152
Non-hazardous waste landfills (*years*)	L3	**a** = 10; **b** = 25; **c** = 50	0.312
Hazardous waste landfills (*years*)	L3	**a** = 10; **b** = 25; **c** = 50	0.282
Information and communication technologies (m)	L4	**a** = 500; **b** = 750; **c** = 2000	0.030
Emergency services (min)	L2	**a** = 10; **b** = 60	0.030
Urban development			0.450
Land use classification and zoning (*zoning*)	L1	**a** = 0; **b** = 1	0.500
Industrial land use (%)	L3	**a** = 65; **b** = 75; **c** = 100	0.100
Territorial land policy			0.400
Coastal law (POL) (*land use policies*)	L1	**a** = 0; **b** = 1	0.568
Special plans (*yes*)	L1	**a** = 0.5; **b** = 1	0.432

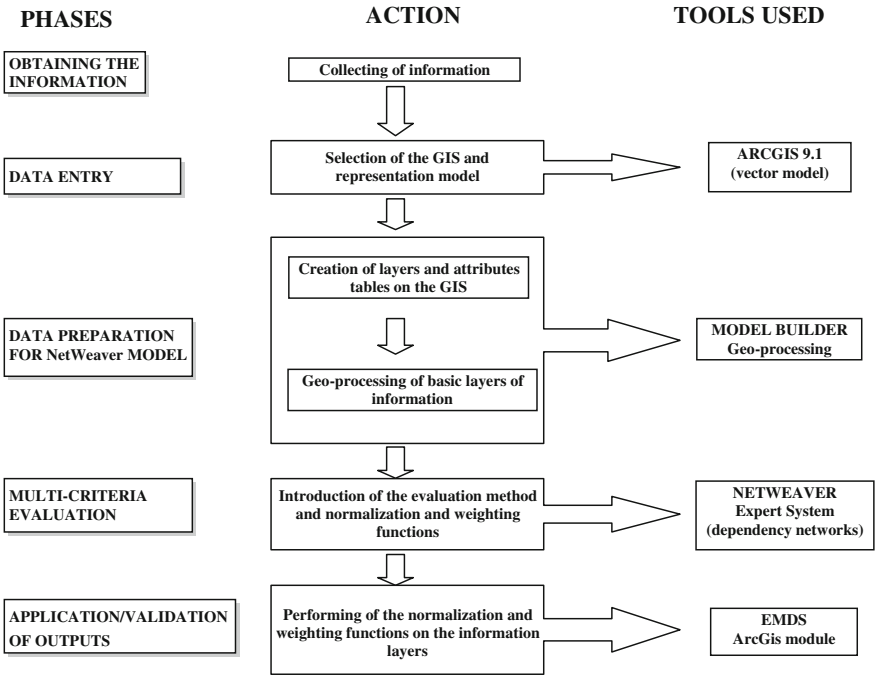


Fig. 5 Implementation methodology for the assessment model

3.2 Physical-Environmental Factors

Results from evaluating subcriteria under the physical-environmental factors primary criterion (Fig. 7d) were derived from a weighted scoring of atmosphere (19.3 %, Fig. 7a), land (62.3 %, Fig. 7b), and water (18.4 %, Fig. 7c) sub-criteria. Model results in Fig. 7d show that none of the eighteen municipalities had homogeneous suitability; rather that suitability diminished as one moved down the Besaya River corridor from south to north, varying from a moderately positive to a very low suitability result.

Regions with low overall physical and environmental suitability displayed low suitability scores in the land and water sub-criteria. For the majority of the municipalities studied, low land suitability was driven by inherently steep grades and a lack of land area already degraded by prior industrial use. Even though the *quantity* of available water (calculated as 50 % of the difference between the annual average volume and the ecological volume) indicated overall suitability throughout the Besaya River basin, the poor *quality* of the water in the tributaries of the lower and central basin led to a negative score for the water sub-criterion.

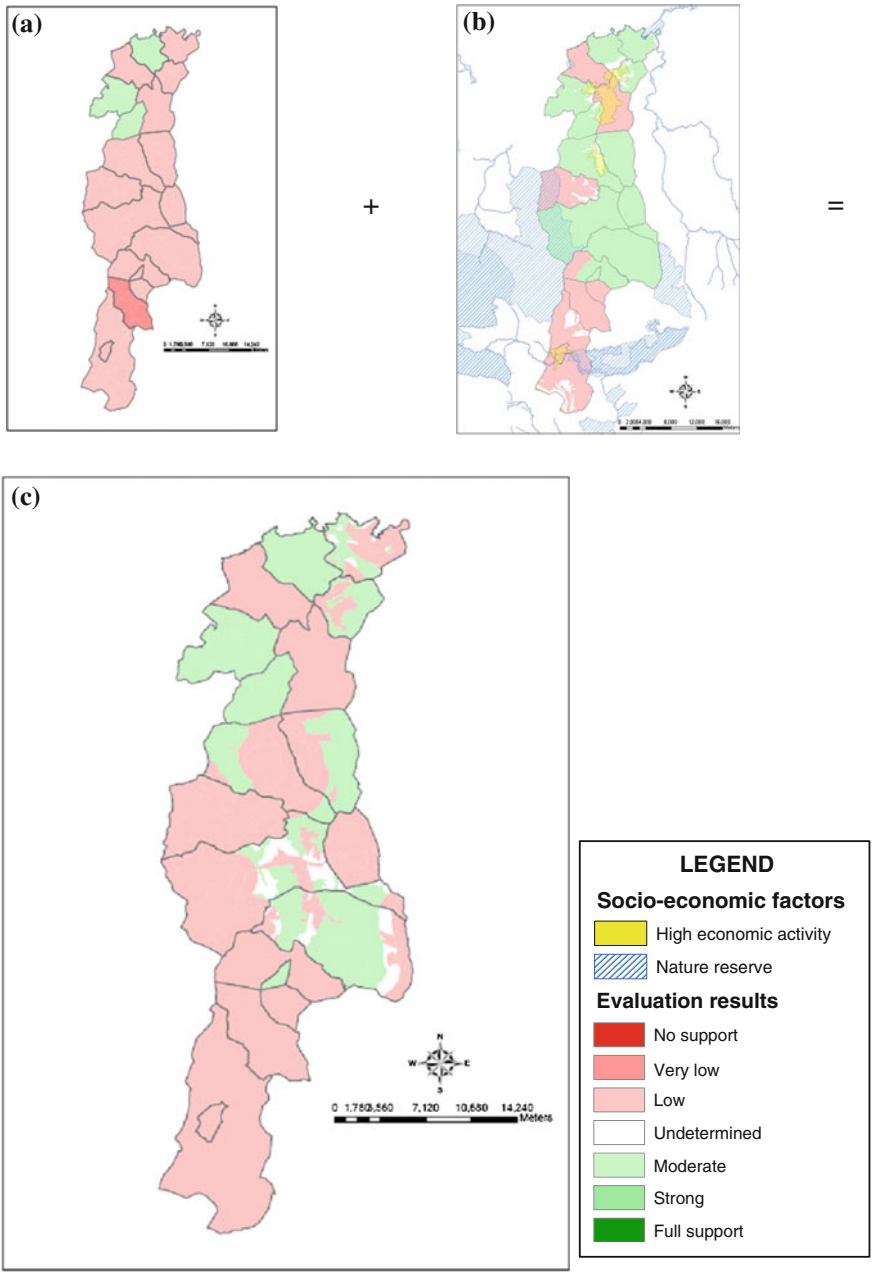


Fig. 6 Results from the evaluation of socio-economic factors: **a** social factors; **b** economic factors; **c** overall result of socio-economic factors

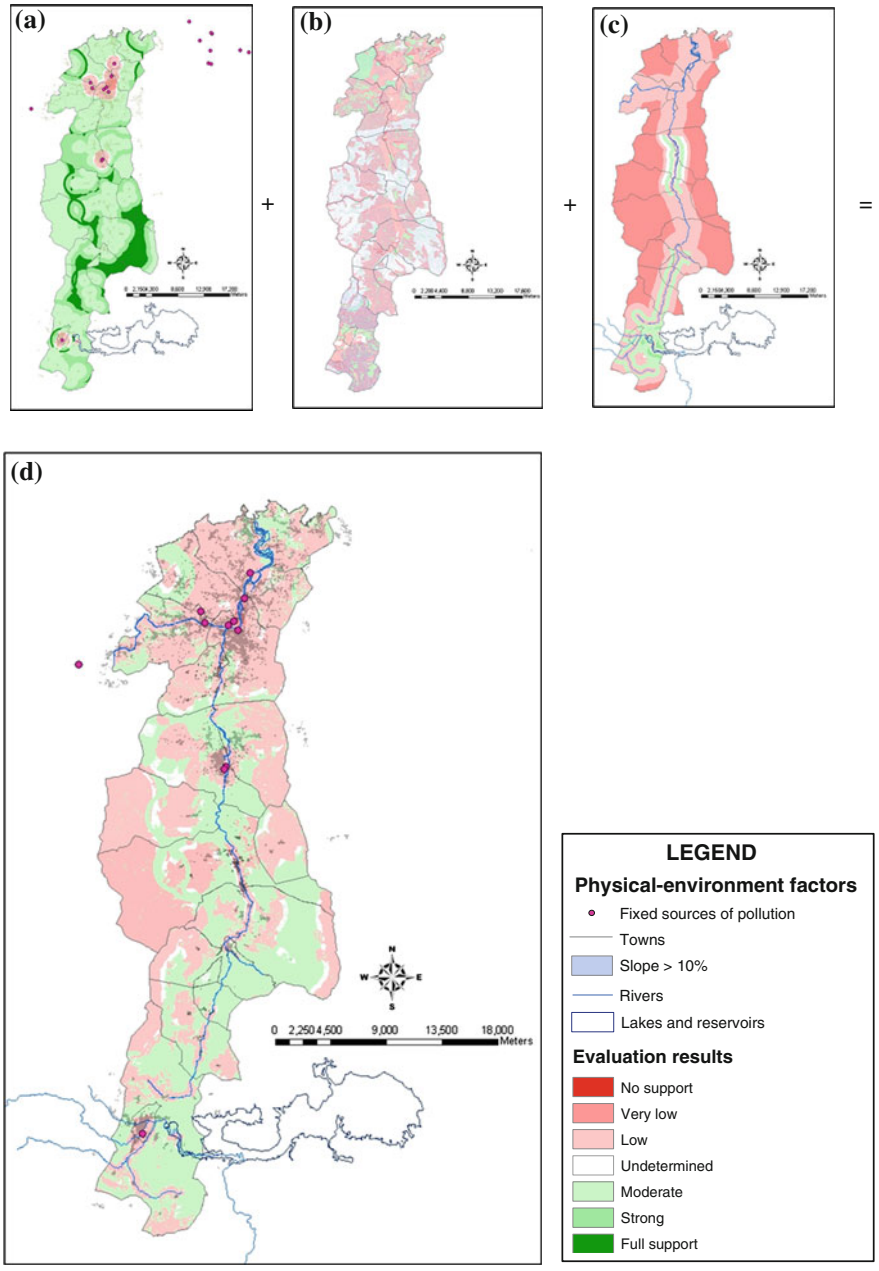


Fig. 7 Results from the evaluation of physical-environmental factors: **a** atmosphere; **b** land; **c** water; **d** overall results of the physical-environmental factors

In contrast, regions that were scored as moderate suitability displayed relatively high air quality, due to distance from point pollution sources, low concentration of pollutants in the environment, good land characteristics for development due to low grades and high carrying capacity, and readily available water resources from nearby rivers and lakes. The moderate suitability displayed in municipalities of zone S-E were exceptional; difficult terrain for development of this zone was compensated for by overall suitability offered by adequate air quality.

3.3 Infrastructures and Urban Development Factors

The map resulting from the evaluation of the infrastructure and urban development criterion is shown in Fig. 8c. Results were derived from a weighted scoring of the infrastructures and facilities (45.7 %, Fig. 8a) and urban development (54.3 %, Fig. 8b) sub-criteria. The central and upper portions of the Besaya River basin exhibited low or very low suitability for development of industrial areas. The zones displaying positive suitability were located in the central and lower basin near road, railway, water and energy infrastructures. Low and very low suitability were primarily driven by low partial scores among urban development factors (45 % of the overall weight), which hinders stimulus and development of new areas of economic activity.

3.4 Full Model and Limitations

The weighted sum of the socio-economic (weight of 14.3 %), physical-environmental (weight of 32.7 %) and infrastructures and urban development (weight of 53 %) criteria shown above provided the total evaluation and final results of the model (Fig. 9).

The resulting land surface area displaying moderate suitability (not considering legal and technical restrictions) was 62,824,157 m^2, 12.77 % of the regional area analyzed. Of the 18 municipalities evaluated, only one exhibited suitability in each of the three primary criteria, five showed low suitability for establishment of an industrial area, and the remaining municipalities produced a mixed distribution of zones with moderate and poor suitability.

The legal and technical restrictions applied to the model in Phase 2 are reflected in the overall map shown in Fig. 10. The majority of the zones were affected by restrictions from Coastal laws, urban zoning, protected spaces and steep grades. The land surface area suitable for industrial development after legal and technical

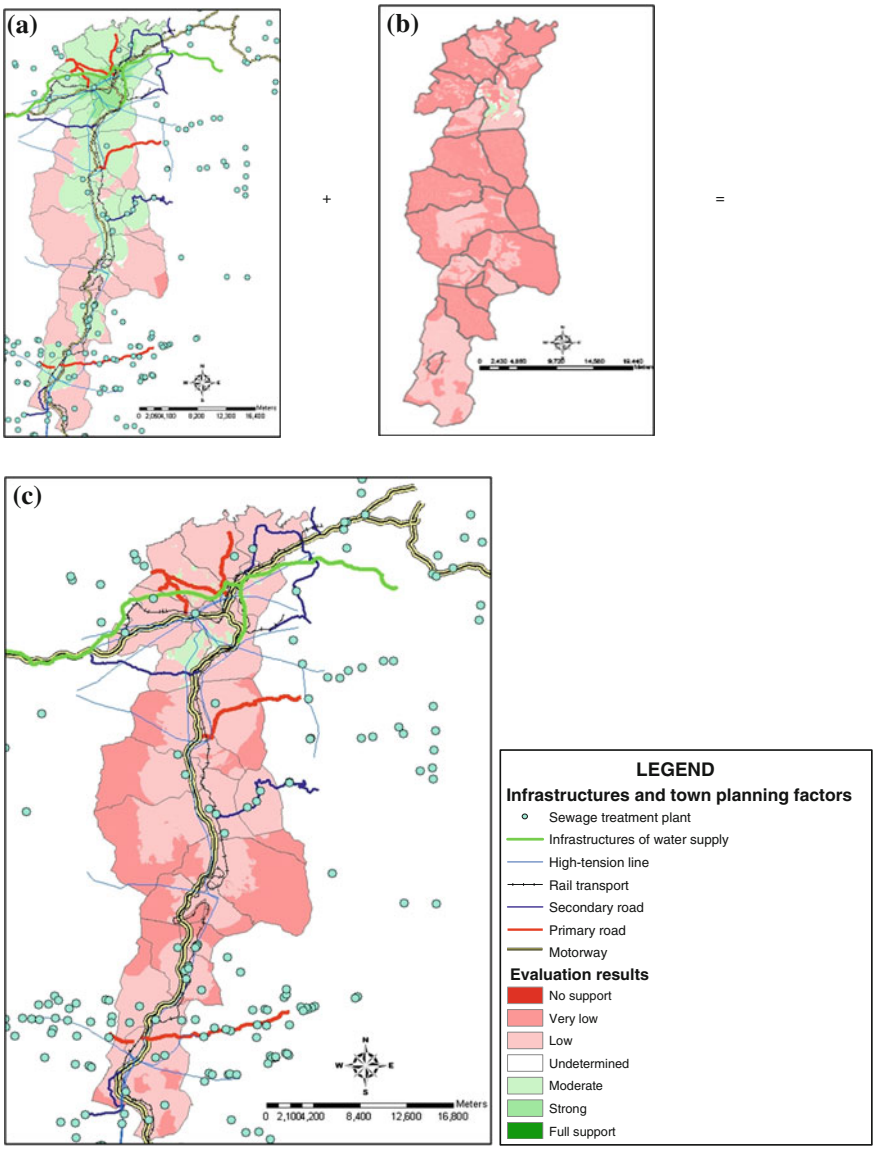


Fig. 8 Results from the evaluation of the infrastructures and urban development factors: **a** infrastructures and facilities; **b** urban development; **c** overall results for infrastructures and urban development factors

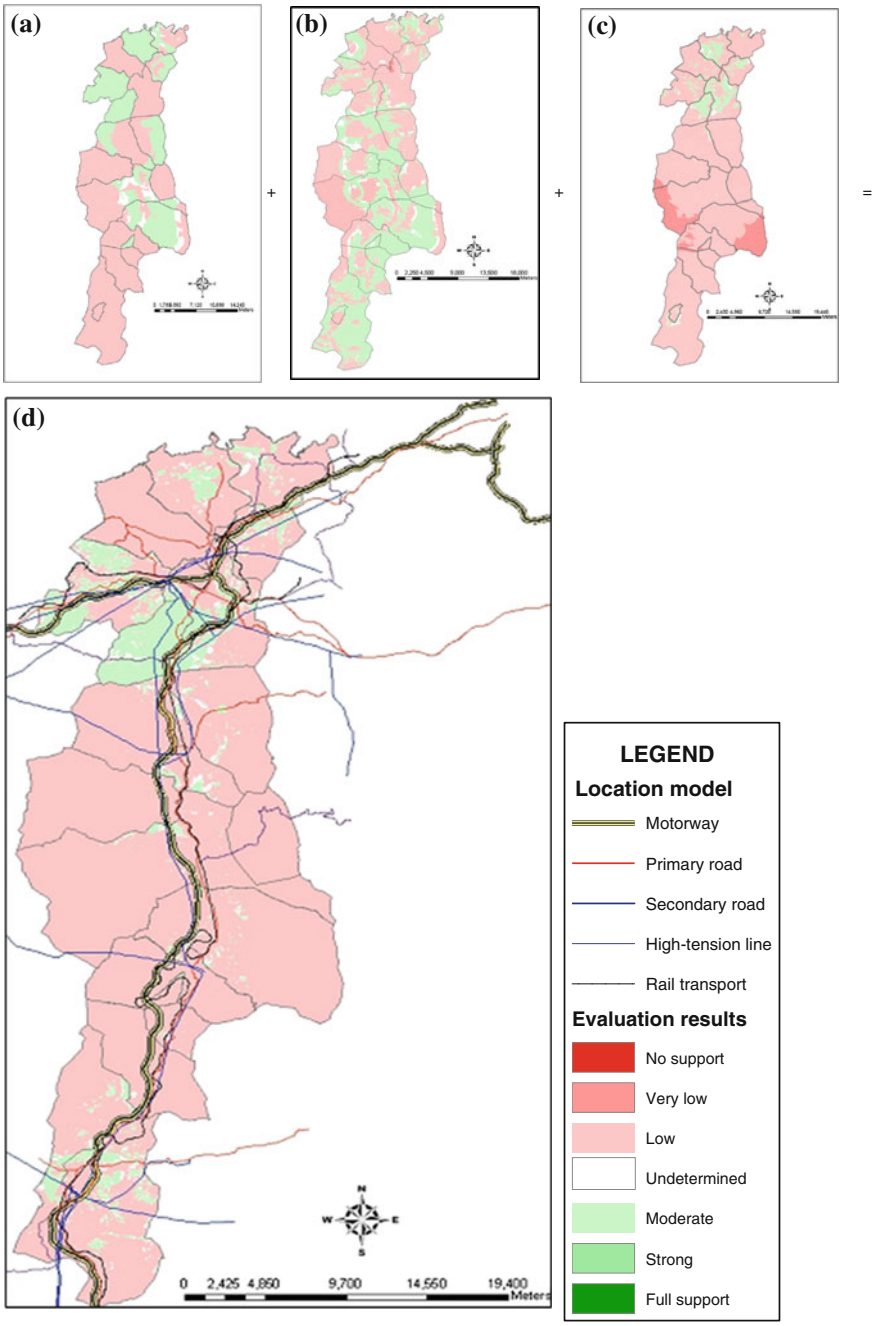


Fig. 9 Complete model: **a** socio-economic factors; **b** physical-environmental factors; **c** infrastructures and urban development factors; **d** overall evaluation

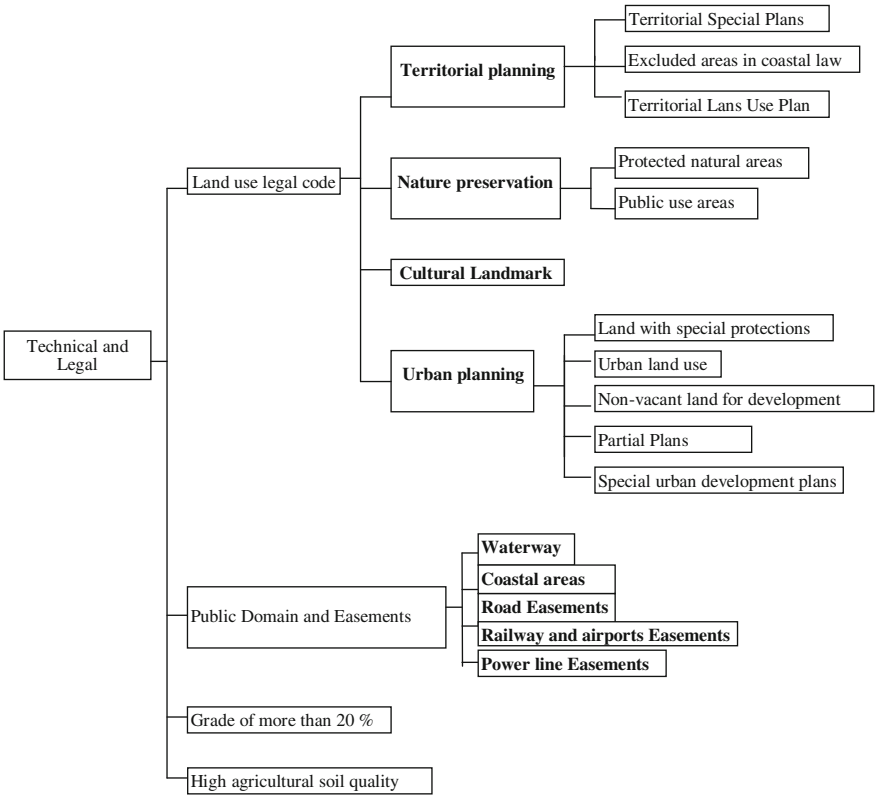


Fig. 10 Overview of land-use restrictions implemented in the model

restrictions were applied was reduced to 33,877,132 m^2, or 5.24 % of the area analyzed. The results for municipalities with moderate suitability before and after applying the restrictions are shown in Table 4. Using these results, one can establish a preference for municipalities where land development for industrial production is socially and environmentally sound, technically feasible, and legally responsible. With few exceptions, we were able to complete evaluations of all municipalities using the same model evaluation sequence before and after applying the legal and technical restrictions.

Table 4 Data on the surface areas of municipalities with moderate suitability

Municipality	Municipal surface area (m^2)	Moderate suitability surface area (m^2)		
		Total	Restricted	Free of restrictions
Cartes	19,000,000	18,049,397.79	10,782,012.10	7,267,385.73
Reocín	32,100,000	13,611,702.49	3,805,280.80	9,806,421.69
Campoo de Enmedio	91,100,000	8,425,884.87	4,683,060.48	3,742,824.39
Torrelavega	35,500,000	8,018,268.10	3,535,653.02	4,482,615.08
Suances	24,600,000	3,588,650.88	665,911.45	2,922,739.43
Polanco	12,700,000	2,888,330.47	502,827.43	2,385,503.04
Miengo	24,500,000	2,159,872.72	1,212,092.60	947,780.12
Los Corrales de Buelna	45,400,000	1,930,014.93	1,788,373.91	141,641.02
Molledo	71,100,000	1,263,473.09	496,964.85	766,508.24
Arenas de Iguña	86,800,000	1,095,616.39	965,045.72	130,570.67
Reinosa	4,100,000	961,770.86	61,731.82	900,039.04
San Felices de Buelna	36,200,000	717,451.11	416,990.55	300,460.56
Pesquera	8,900,000	113,723.34	31,080.45	82,642.89

4 Conclusions

Planning and location of industrial areas is a strategic decision with powerful implications for existing and future activities and human communities within a given area. Typically, industrial location or siting models have only considered the presence of basic infrastructures and proximity to raw materials or the market place. However, past failures to design the built environment to be in greater harmony with the natural environmental have generated a new awareness of the need to create a more sustainable industrial development model. Such a model requires attention to a wider range of environmental criteria, legal and technical restrictions, which can add complexity to any decision making. The MC-SDSS set forth in this chapter demonstrates a clear application of this new awareness.

Integration of socio-economic and environmental information, as in the present model, is a valuable and practical approach to decision making and the elaboration of strategic policies. The present model shows how one can integrate the principles of industrial ecology with an operational siting of industrial areas.

Of the available options for the design and construction of an MC-SDSS, the combined NetWeaver and EMDS-ArcGIS platform met the needed requirements. The NetWeaver tool allowed us to propose in the design stages, a variety of different criteria and structures for grouping variables and evaluating data, which facilitated the planning process for decision makers and provided considerable flexibility in model design and implementation. Furthermore, the use of an expert

system approach implemented with fuzzy logic allowed for the relatively simple application of a theoretic model with 75 variables.

The MC-SDSS is an open and changeable system. The logic structure, data considered, and evaluation criteria may all be readily adapted to unique territorial needs and the scientific and technical advances at the time. But to be clear, a new user of the MC-SDSS system would need to spend several days with the model and data to become adequately familiar with its structure and data requirements, such that they could adapt it to their own uses. However, this is generally true when a user is gaining familiarity with any new modeling system—there is start-up time.

One final aspect when considering transfer and application of an MC-SDSS, such as this one, to another environment is the critical nature of the data collection stage. In general, at least 75–90 % of the overall effort is collecting and organizing the needed data structure for access by the MC-SDSS. In our application, the SDSS was applied to a region of Spain located in the corridor of one of its principal rivers. The surface area analyzed was 646.2 km^2, or roughly 12.38 % of the entire region. To facilitate a rapid data capture and development process, we created an integrated work environment in ArcGIS, which reduced the time and effort needed to generate useful information. We also spent considerable time evaluating available data sources for the highest quality data because the reliability and quality of the information used has a critical influence on the accuracy of the results. Low quality data lead to low quality modeling and industrial area planning results.

In conclusion, we constructed a decision-support system for regional and urban planning using the functionality of EMDS. This application of EMDS led to the creation of digital maps that were highly useful to distinguishing different zones and their appropriateness for sustainable industrial area siting.

References

Aalborg Chart (1994) First conference or sustainable cities and Towns, Aalborg

Amiti M, Pissarides CA (2005) Trade and industrial location with heterogeneous labour. J Int Econ 67:392–412

ArcGis v9.1 (1997) Environmental Systems Research Institute ESRI, Inc., Redlands. http://www.esri-es.com

Chang N, Parvathinathan G, Breeden JB (2008) Combining GIS with fuzzy multicriteria decision-making for landfill sitting in a fast-growing urban region. J Environ Manage 87:139–153

Côté RP, Cohen-Rosenthal E (1998) Designing eco-industrial parks: a synthesis of some experiences. J Clean Prod 6:181–188

Dai FC, Lee CF, Zhang XH (2001) GIS-based geo-environmental evaluation for urban land-use planning: a case study. Eng Geol 61:257–271

Directive 2001/42/EC (2001) Directive of the European Parliament and of the Council on the assessment of the effects of certain plans and programmes on the environment, Luxembourg

EMDS v3.1 (2004) Ecosystem Management Decision Support. Redlands Institute, Redlands. http://www.institute.redlands.edu/emds/index.htm

Erkman S (1997) Industrial ecology: an historical view. J Clean Prod 5(1–2):1–10
Fabbri KP (1998) A methodology for supporting decision making in integrated coastal zone management. Ocean Coast Manage 39:51–62
Fernández I, Ruiz MC (2009) Descriptive model and evaluation system to locate sustainable industrial areas. J Clean Prod 17:87–100
Ferrarini A, Bodini A, Becchi M (2001) Environmental quality and sustainability in the province of Reggio Emilia (Italy): using multi-criteria analysis to assess and compare municipal performance. J Environ Manage 63:117–131
Figueiredo O, Guimaraes P, Woodward D (2002) Home-field advantage: location decisions of Portuguese entrepreneurs. J Urban Econ 52:341–361
Frosh R (1995) The industrial ecology of the 21st century. Sci Am 273(8):178–181
Frosch RA, Gallopoulos NE (1989) Strategies for manufacturing in managing planet earth. Sci Am 261(3):144–153
Gibbs D, Deutz P (2005) Implementing industrial ecology? Planning for eco-industrial parks in the USA. Geoforum 36:452–464
Gibbs D, Deutz P (2007) Reflections on implementing industrial ecology through eco-industrial park development. J Clean Prod 15:1683–1695
Graedel TE, Allenby BR (2003) Industrial ecology. Prentice Hall, New Jersey
Herbst H, Herbst V (2006) The development of an evaluation method using a geographic information system to determine the importance of wasteland sites as urban wildlife areas. Landsc Urb Plan 77:178–195
Hernández J, García L, Ayuga F (2004) Assessment of the visual impact made on the landscape by new buildings: a methodology for site selection. Landsc Urb Plan 68:15–28
Hoover M (1948) The location of economic activity. McGraw-Hill, New York. http://www.archive.org/details/locationofeconom 02987 4mbp. Accessed 20 Oct 2008
Humphries HC, Bourgeron PS, Reynolds KM (2008) Suitability for conservation as a criterion in regional conservation network selection. Biodivers Conserv 17:467–492
Isard W (1954) Location and space-economy. The M.I.T Press, Cambridge
Kallali H, Anane M, Jellali S, Tarhouni J (2007) GIS-based multi-criteria analysis for potential wastewater aquifer recharge sites. Desalination 215:111–119
Kalogirou S (2002) Expert systems and GIS: an application of land suitability evaluation. Comput Environ Urban Syst 26:89–112
Kilkenny M, Thies JF (1999) Economics of location: a selective survey. Comput Oper Res 26:1369–1394
Kirschner E (1995) Eco-industrial parks find growing acceptance. Chem Eng News 73:15
Korhonena J, Snäkin J (2005) Analysing the evolution of industrial ecosystems: concepts and application. Ecol Econ 52:169–186
Lambert AJD, Boons FA (2002) Eco-industrial parks: stimulating sustainable development in mixed industrial parks. Technovation 22:471–484
Leitham S, McQuaid RW, Nelson JD (2000) The influence of transport on industrial location choice: a stated preference experiment. Transp Res 34:515–535
Lösch A (1954) The economics of location. Yale University Press, New Haven
Lowe EA, Evans LK (1995) Industrial ecology and industrial ecosystems. J Clean Prod 3(1–2):47–53
Lowe EA (2001) Eco-industrial park handbook for Asian developing countries. A Report to Asian Development Bank, Environment Department, Indigo Development, Oakland
Malczewski J (1999) GIS and multicriteria decision analysis. Wiley, New York
Maniezzo V, Mendes I, Paruccini M (1998) Decision support for sitting problems. Decis Support Syst 23:273–284
Martin P (1999) Public policies, regional inequalities and growth. J Public Econ 73:85–105
Mukaidono M (2004) Fuzzy logic for beginners. World Scientific, New Jersey
NetWeaver Developer (1987) Rules of Thumb, Inc., Pennsylvania. http://rules-of-thumb.com

Reynolds KM (2002) Landscape evaluation and planning with EMDS 3.0. 2002 ESRI user conference, San Diego, CA, 9–12 July 2002. Environmental Systems Research Institute, Redlands

Reynolds KM (2005) Integrated decision support for sustainable forest management in the United States: fact or fiction? Comput Electron Agric 49:6–23

Roberts BH (2004) The application of industrial ecology principles and planning guidelines for the development of eco-industrial parks: an Australian case study. J Clean Prod 12:997–1010

Rosenfeld SA (1997) Bringing business clusters into the mainstream of economic development. Eur Plan Stud 5:3–23

Saaty TL (1980) The analytic hierarchy process: planning, priority setting, resource allocation. McGraw-Hill, New York

Saaty TL (2005) Theory and applications of the analytic network process: decision making with benefits, opportunities, costs and risks. RWS Publications, Pittsburgh

Smith D (1971) Industrial location: an economic geographical analysis. Wiley, New York

Somlev IP, Hoshino Y (2005) Influence of location factors on establishment and ownership of foreign investments of foreign investments: the case of the Japanese manufacturing firms in Europe. Int Bus Rev 14:577–598

Tabeada J, Matías JM, Araújo M, Ordóñez C (2006) Assessing the viability of underground slate mining by combining an expert system with a GIS. Eng Geol 87:75–84

Trinder B, Fohl A, Shayt DH et al (1993) The blackwell encyclopedia of industrial archaeology. Blackwell Publishers, Oxford

Tudor T, Adam E, Bates M (2007) Drivers and limitations for the successful development and functioning of EIPs (Eco-Industrial Parks): a literature review. Ecol Econ 61:199–207

UNEP, United Nations Environment Programme (1995) Cleaner production: a guide to sources of information. UNEP, Paris

UNEP, United Nations Environment Programme (1997) The environmental management of industrial estates. UNEP, Paris