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Promotion of new wind farms based on a decision support system

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Abstract

The integration in electric power networks of new renewable energy facilities is the final result of a complex planning process. One of the important objectives of this process is the selection of suitable geographical locations where such facilities can be built. This selection procedure can be a difficult task because of the initially opposing positions of the different agents involved in this procedure, such as, for example, investors, utilities, governmental agencies or social groups. The conflicting interest of the agents can delay or block the construction of new facilities.

This paper presents a new decision support system, based on Geographic Information Systems, designed to overcome the problems posed by the agents and thus achieve a consensual selection of locations and overcome the problems deriving from their preliminary differing preferences. This paper presents the description of the decision support system, as well as the results obtained for two groups of agents useful for the selection of locations for the construction of new wind farms in La Rioja (Spain).

Keywords: Decision support system; Decision making; Spatial analysis; GIS; Power generation planning

1. Introduction

Power plants based on renewable resources are increasing their integration in power system networks. National efforts to achieve energy supply non-dependent on foreign resources, the challenge of climate change, rising energy prices and better prospects for conservation of the environment have fuelled the planning, construction and operation of this kind of power plants.

In recent years, wind power has been the most promising renewable resource with a total global capacity of 47.3 GW at the end of 2004 [1]. Wind farms with tens of installed Megawatts are the most representative wind power facilities, and their integration in electric power networks is growing day by day. But their planning and building frequently poses problems. One such problem, and often one of the most difficult to resolve, is the selection of locations where these wind farms can be built when several decision groups have different, or even opposite, interests in these wind farm locations.

The selection of final location for the construction of wind farms must often be negotiated among the groups involved in the planning process, where the different groups may have conflicting interest: for example, investors and power utilities will look for economically more attractive locations, while other agents, such as environmentalist groups, might consider some of these places as unacceptable from an environmental impact standpoint and will always look for locations with the minimum environmental impact. This conflict of interests can delay, and even block, the construction of new wind farms.

Wind farm planning is subject to multi-agent decision-making processes under uncertainty with conflicting technological, economic, environmental and social aspects. The best solution offered by the first power system planning models was based on minimum economic cost, although later models included uncertainty and conflicting objectives in search of the proposed solution [2]. Some authors have developed planning models with the inclusion

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of the preferences of social groups as a part of the process to select the best planning strategy under uncertainty [3] or have studied the effect of different methods to quantify values and use them to rank alternatives when they are presented to such groups [4]. Most of these models integrate a multiple-criteria model in an attempt to consider jointly most of the economic, technical, environmental and social implications of the planning problem, where the selection of the weights attributed to each criterion is one of the most contentious tasks in the planning process [5].

The selection of locations for new wind farms is a multi-agent decision-making process with significant geographical characteristics [6]. The development of decision support computer tools can help in the selection of consensual locations for new wind farms from initially conflicting positions and can make these processes faster and more effective, obtaining acceptable solutions for all the groups. Geographic Information Systems or GIS (software technology developed for spatial data analysis) offer the proper platform for developing these tools. GIS have been applied to other decision support systems, such as in the evaluation of regional renewable energy potential [7], exploitation of local renewable resources [8] or the selection of power technology in rural electrification [9], thanks to their capacity to handle geographical data, their calculation capabilities and the visual representation of results. They have also been used to select potential locations for new wind farms [10], using criteria obtained by means of questionnaires remitted to public and private agents.

This paper presents a decision support system implemented on a GIS platform to assist in the selection of consensual locations for the construction of new wind farms with previously defined characteristics (rated installed power, type of wind turbine (WT), etc.), although it can be used for other types of power plants.

The decision support system helps to build criteria maps containing the criteria values of each group (for example, economic profit value associated to wind farm installation in each geographical location, or GIS cell, of the studied zone for the economic group); and later, it helps to identify the preference/tolerance of each group (tolerance maps) for the best preferred locations to build wind farms in a geographic zone (for example, locations with higher economic profit are preferred by the economic group).

Thus, the decision support system can select the geographical positions that are simultaneously the best preferred locations for all the groups to build a new wind farm. Furthermore, the system can be applied to support a new methodology for negotiation among the groups to identify other consensual locations for wind farms which will be presented in a new paper in the future.

The decision support system has been applied to selected zones in the region of La Rioja, Spain, including two interest groups: the economic group, formed by investors, financial institutions, power utilities and economic development agencies; and the environmentalist group, comprising environmental agencies, social activists and community groups interested in smoothing the environmental effects of new power plants.

In summary, the decision support system presented here is comprised of an advanced and powerful GIS-based computer-aided tool to assist in the selection of the preferred consensual locations between groups for the construction of new wind farms.

2. Methodology for the creation of tolerance maps

This section presents a summary of the complex methodology for creating the tolerance index maps of the groups. The two main stages of the process for determining tolerance maps are:

(i) the creation of criteria maps for each group (the economic group and the environmentalist group); and
(ii) the creation of tolerance maps of the groups.

In the first stage, each group defines their criteria maps and attribute sets. Then, in the second stage, the tolerance maps of the groups that describe their preference order are obtained, essentially through the definition of criteria weights and the aggregation of criteria.

2.1. Stage one

Criteria maps: The preferences of each group for geographical locations use a set of specified criteria. For example, the environmentalist group can select maps of the visual impact of wind farms, or maps of the distances of wind farms from inhabited zones, or maps of ecologically sensitive areas due to bird collisions, etc. The economic group can use maps of economic profit from wind farms, that can be calculated from the ''levelized electricity cost'' (LEC) [11] (€/kWh), economic risk of wind farm investments, terrain slopes, etc. Sections 3 and 4 of this paper include descriptions of some maps of criteria in detail. Depending on the resolution used (size of the elementary GIS-square cell), several thousands of km^2 are included in the studied geographical area of the maps.

Attribute sets: An attribute B is a measure of the degree to which the location of a wind farm satisfies a given criterion. Thus, for a given criterion, a map of the preference/tolerance of a group for each wind farm location (in terms of values between 0 and 1) is considered an attribute map. For example, the LEC maps allow us to obtain the economic profit values in each GIS cell that can be transformed into values between 0 (0 for the null or negative economic profit) and 1 (1 for the best economic profit). Thus, the GIS cells of the former attribute map with the highest values (between 0 and 1) correspond to the most favourable economic locations to install wind farms.

Therefore, for a given criterion, attribute values of 0 are associated with very bad locations and values of 1 with excellent locations. Then, the decision support system uses attributes to reclassify criteria maps (moreover, possible effects of the altruistic or malevolent behaviour of the groups can also be avoided by special automatic standardization procedures on attributes).

2.2. Stage two

Step one: Pair-wise weights and relative weights for the global set of criteria.

Setting weights for a set of criteria can be a difficult task. For example, when considering the economic profits and the risk of investments in wind farms, weights representing the relevance of the risk versus the economic profits are not obvious. Thus, a first step consists in determining pair-wise weights (weights between pairs of criteria) based on the experience and the professional points of view of the group, also using spatial maps of the criteria on GIS. In a second step, these weights between pairs of criteria give the global relative weights W (between 0 and 1) for all the criteria, correcting possible inconsistencies. The classical Saaty matrix [12] (applied to pair-wise weights) together with Chu's method [13] have been used with the decision support system to determine these global relative weights automatically.

Step two: Aggregation of criteria.

An index T aggregated from the attributes is calculated as a linear combination of these attributes. Then,

$$T = \sum_{c} W_c B_c, \quad (1)$$

where the weights W_c and the attributes B_c are referred to the criteria c.

Therefore, this allows us to obtain the map of tolerances (or preferences) for each group representing the aggregated index T, where their map GIS cells have an associated value between 0 and 1. Suitable tables of records are created where each record represents an elementary wind farm location (map GIS cell). Thus, for a given group, the ordering of the corresponding table of records with respect to the function T provides the individual ranking of that group. This ranking is performed automatically by the decision support system.

From the tolerance maps of the groups, the decision support system can help to select the GIS cells containing a value 1 (or very close to 1) simultaneously on such maps. These are the best locations to build new wind farms since all the groups agree that such cells (locations) are the most suitable ones. All the cells that contain a value 0 (or very close to 0) simultaneously on all the tolerance maps are locations where no construction of wind farms is allowed by the system since the groups consider that these cells are the worst ones. For the remaining cells, a set of sophisticated procedures can be applied by the decision support system to lead a negotiation process between the groups in order to determine other consensual locations to build new wind farms which will be described in further detail in a new paper in the future.

Sections 3 and 4 of this paper present examples of tolerance index maps for the economic group and the environmentalist group.

3. Tolerance maps for the economic group

The economic group tolerance map is obtained by creating attribute maps for different criteria of this group, such as the economic profit criterion, the investment risks criterion, the terrain slopes criterion, etc. In the following paragraphs (Section 3.1), the process for creating the attribute map for economic profit criterion will be explained. Later (Section 3.2), an example of tolerance maps for the economic group will be presented.

3.1. An economic criterion: economic evaluation for the selection of new wind farm locations

The attribute map creation process for the economic profit criterion is divided into three steps: the evaluation of wind resources; the spatial filtering of the studied region to identify feasible locations for consideration; the evaluation of the economic profit from the LEC (€/kWh) in all the feasible locations for the installation of a new wind farm; and the corresponding final result, i.e. an attribute map containing the preference/tolerance of the economic group, in each location, for installation of the new wind farm with the characteristics (installed power, types of WTs, etc.) defined by this economic group.

3.1.1. Wind energy resources

A detailed examination of wind resources is a time-consuming task that depends on the orography, terrain roughness, obstacles and historical wind speed and direction values measured at weather stations. Several software tools have been specially developed to perform this task. One such tool is the Wind Atlas Analysis and Application Program (WA^{S}P) developed at RISØ National Laboratory, Denmark. This software uses complex models for the vertical and horizontal extrapolation of wind data. WA^{S}P software is based on a dynamical model for wind and its accuracy has been tested even in the worst conditions [14].

WA^{S}P software manipulates wind data using its probability density distribution. The probability density distribution, with the best description of the wind speed time series, is the Weibull distribution, which is expressed by two parameters: the shape factor, k; and the scale factor, A. These parameters vary from place to place according to the local climate, orography and roughness of the studied terrain. This roughness explains the influence of vegetation or any obstacle that may reduce wind speed in the proximity and modify the vertical wind speed profile. Both parameters in the Weibull wind speed distribution are used to evaluate the average energy production of a WT.

The data supplied to the WA^{S}P software are:

- orography, with level lines (isolines) or a digital model of the terrain;
- maps of ruggedness, built previously with the GIS platform, based on vegetation and land-use maps;
- wind speed and wind direction time series measured at weather stations;
- definition and location of obstacles around weather stations.

The results obtained are the two GIS grids with the values of the Weibull parameters, A and k, evaluated at a given, assumed height of the rotor position of the WT. Fig. 1 shows the final results for the scale factor of the wind speed Weibull distribution for the whole region.

3.1.2. *Spatial filtering of prohibited areas for the installation of wind farms*

After calculating the final wind resources results, the decision support system filters these data in order to exclude every location where the installation of a wind farm is not feasible. The following areas were excluded areas in this case:

- Natural parks and environmentally protected areas (areas completely protected from a legal standpoint).
- Areas around any inhabited zones (urban areas, villages, towns, etc.).
- Areas with possibility of electromagnetic interferences, such as areas near radio or television repeaters.
- Any other restricted areas such as airports, military zones, etc.

Thus, the filtered results generally include only the wind resources for those locations where the installation of WTs can be legally permitted by authorities. Of course, if needed other aspects can be considered in spatial filtering depending on the geographical region studied.

3.1.3. *LEC and attribute maps*

The most favourable economic locations for installing wind farms are selected by applying economic calculations over the filtered locations obtained in the previous process. In order to apply these economic calculations, we define the load factor, the annual energy supplied (AES) and the LEC [11].

The load factor, LF, depends on the characteristics of the location where the wind farm is installed and represents the quotient between the mean power generated in that location and the rated installed power of the wind farm, $P_{\max}$, as given below (2). It is computed by integrating the product of the power curve of the WT used, $PC(v)$, and the speed of the wind in that specific location, expressed as its Weibull distribution, $f_{A,k}(v)$. The power curve of the WT represents the power generated depending on the wind speed.

$$\mathrm{LF} = \frac{\int PC(v) f_{A,k}(v)\,\mathrm{d}v}{P_{\max}}. \qquad (2)$$

The AES, or annual electric energy generated, is calculated as the product of the rated installed power, the load factor and the number of hours per year:

$$\mathrm{AES} = P_{\max}\,\mathrm{LF} \times 8760. \qquad (3)$$

The LEC, in €/kWh, represents the ratio between the annualized cost and the annual electric energy generated:

$$\mathrm{LEC} = \frac{C_{\mathrm{fix}} + C_{\mathrm{con}} + C_{\mathrm{road}} + C_{\mathrm{land}} + C_{\mathrm{om}} - P_{\mathrm{s}}\,\mathrm{AES}}{\mathrm{AES}}. \qquad (4)$$

The parameter C_{fix} involves the economic cost of all the equipment for the wind farm including engineering works.

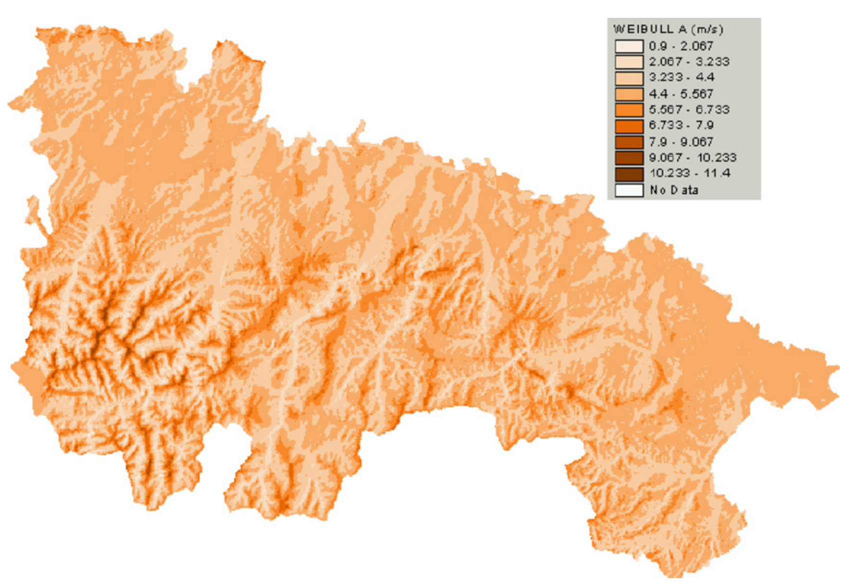

Fig. 1. Scale factor of the wind speed Weibull distribution for the region of La Rioja, Spain.

It depends on equipment economic cost and financing conditions (subsidies from authorities can decrease this cost component); it does not depend on geographical characteristics.

The parameter C_{con} is computed directly by an optimization GIS model available in the GIS platform [15] and it corresponds to the economic cost of an electric power line to connect the wind farm to the electric power network. The optimization model finds out a minimal cost path for this line. This cost has a high geography influence: C_{con} depends on geographic factors as the terrain slope, the presence of some obstacles as water zones or buildings, the accessibility or distance from the nearest electric power line or nearest road, etc.

The parameter C_{road} involves the cost of a new road, if needed, to access the selected possible location for the wind farm. It is computed in a similar manner as the parameter C_{con}. The optimization GIS model finds out the minimal cost path, taking into account the different types of each piece of land crossed by the new road (rocky, muddy, etc.).

The parameter C_{land} corresponds, as its name indicates, to the cost of the necessary land for the installation of the wind farm and their auxiliary equipment. It depends on the usage of each piece of terrain and the conditioning works needed for its use.

These first four cost components, C_{fix}, C_{con}, C_{road} and C_{land}, must be annualized according to the lifetime of the wind farm.

The parameter C_{om} includes the annual operation and maintenance cost for the wind farm. It depends on geographic characteristics as the local climate or the distance to the maintenance centre.

The parameter P_{S} is the mean value of the incomes per unit of generated energy, taking into account the possible subsidies from authorities or the mean value of electric energy selling in a power market.

Fig. 2 shows the LEC map obtained after the application of (4) to all the GIS cells of the studied region considering a 10 MW wind farm. In this map the cells present LEC values ranging from −0.043 to 0.12 (€/kWh). The economic profit can be calculated directly from the LEC. A negative value for LEC means an economic profit, while a positive LEC value represents an actual economic cost. Furthermore, the zones with lower values of LEC correspond to locations where the profits obtained with the wind farms will be larger than that obtained in any other zone of the studied region, and, therefore more preferred by the economic group.

The corresponding attribute map (Section 2) for this criterion (economic profit that is derived from LEC) can be easily obtained since, the LEC value in each GIS cell of the map of LEC can be transformed into a value between 0 (0 for all the cells with a positive LEC value or null LEC value) and 1 (1 for the cells with the lowest value of the map of LEC). Then, the GIS cells of the former attribute map with higher values (between 0 and 1) correspond to economically more favourable locations to install wind farms.

Thus, the attribute map of the economic profit criterion is one of the attribute maps that will be used (together with other suitable attribute maps) by the economic group for the creation of the tolerance index map of such group.

3.2. Tolerance index maps for the economic group

The criteria that can be used by the economic group include the following: the above-mentioned economic profit; the investment risk for the installations of wind farms basically due to the potential risk associated with uncertainties stemming from unknown derivations from the wind resources evaluation predicted in different orographic locations; unwanted terrain slope above a given

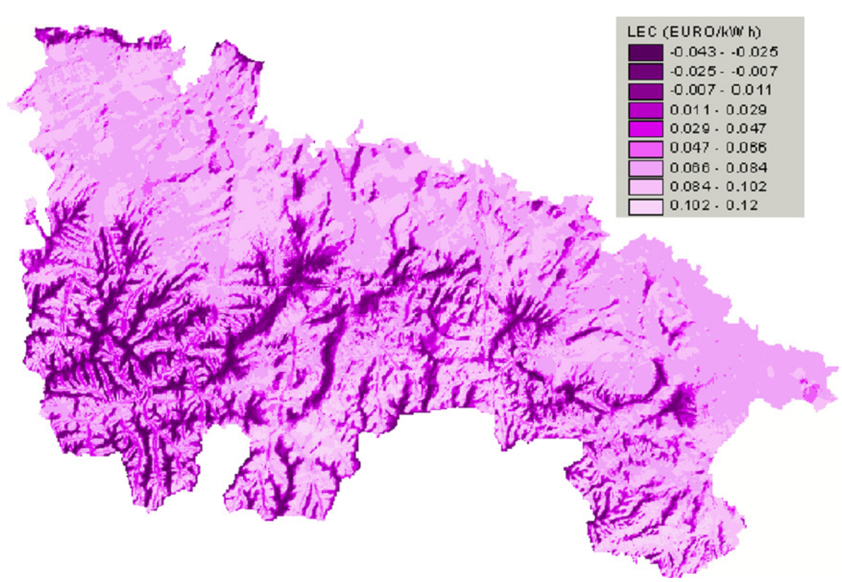

Fig. 2. Result map showing the levelized electricity cost (LEC) in the studied region.

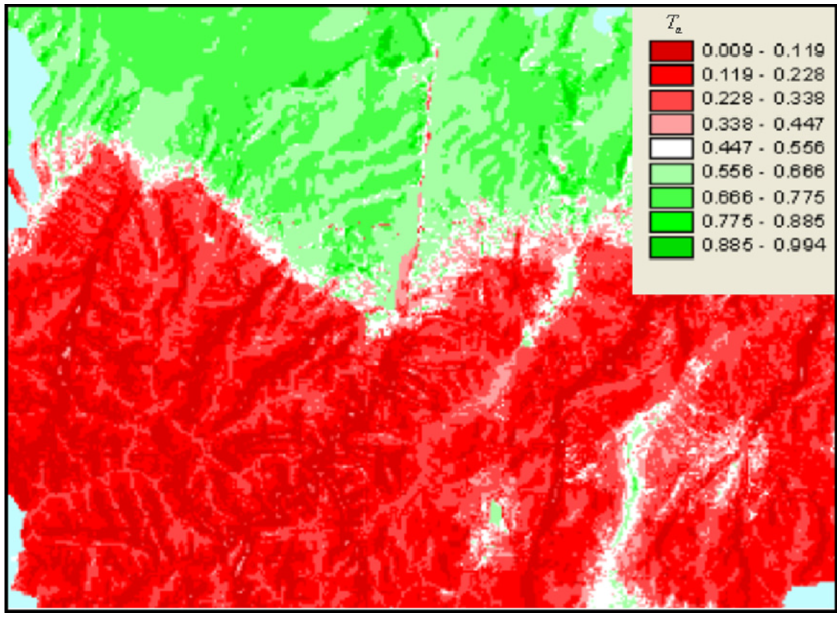

Fig. 3. Tolerance index maps for the economic group.

level of slope, with a preference for lower slopes of terrain; the altitude of wind farms, with a preference for lower altitude values; etc.

According to Section 2, various maps of attributes can be obtained for the economic group. Then, in the second stage, tolerance maps are determined by aggregating maps of attributes for this group, accordingly. An example of a tolerance map (corresponding to a selected area in La Rioja) for the economic group is shown in Fig. 3, where the maps of attributes used correspond to the criteria of economic profit, risk of investment associated with the building of wind farms, terrain slope and altitude of locations for the installation of wind farms.

T_a values in Fig. 3 are the values of the resulting aggregated index T (Section 2) for the economic group using the above mentioned attributes maps. In Fig. 3, with a representation range 0–1, the areas with higher values represent locations with a higher preference: the most interesting areas are usually locations with high potential wind resources, that are also economically and technically acceptable sites.

4. Tolerance maps for the environmentalist group

For regions with high wind energy resources, with large areas covered by wind farms, it is natural for certain environmental sensitivities to arise against this type of distributed generation. Some of these sensitivities and intolerances highlighted by environmental actors include the visual impact of wind farms and WTs, sound impact, birds colliding with WTs, the impact of other infrastructures associated with wind farms such as roads and overhead electric power lines, the impact on vegetation (impact on environmentally sensitive areas), etc.

Section 4.1 presents the original procedures for modelling the criterion of the visual impact of wind farms for the environmentalist group, in order to obtain the corresponding criterion map; and an example of the visual impact criteria map is included. Other criteria can also be considered by the environmentalist group in order to determine the attribute maps and then the tolerance index maps (Section 4.2) representing the preferences/tolerances of this group to enable construction of new wind farms in a given area. Section 4.2 also includes an example of a tolerance map for the environmentalist group corresponding to several environmental criteria.

4.1. An environmental impact criterion: visual impact maps and attribute maps

Areas of significant interest for the economic group, with relatively high wind resources and high economical profit potential for the installation of wind farms, are frequently located in exposed areas. New wind farms to be installed in these areas would be visible from a distance of several kilometres, with important visual impacts on scenic value. However these scenic impacts are very subjective. Many people see them as a welcome symbol of clean energy, while others consider that they are negative scenic additions to the landscape. There are several factors involved, including the number of WTs, their height and the distance from the observer to the wind farm.

The decision support system can be used to evaluate quantitative impact indices, according to the distance to the wind farm and the number of WTs visible from each geographical location.

In our approach, we are interested in maps with quantitative indicators of the visual impact of wind farms. The objective is to obtain maps representing the visual impact of all potential wind farm locations. The wind farm is generalized as a set of WTs with a predefined size. Wind farm location is the geographical variable for which aggregated impact, caused in a set of fixed observation points, is evaluated.

One geographical input of the decision support system is the map of reference observation points, representing locations of inhabited centres or locations of representative scenic points. Each observer point is characterised by the number of observers, the frequency of the observations and the relative importance of the observation. Inhabited centres with larger numbers of observers are the most important observation points. Observation points where people observe the wind farm more frequently are more important and exceptional observations from a scenic standpoint are more important than routine observations from inhabited places.

The decision support system computes the impact of the generic wind farm at each observer point and aggregates the impacts caused in all the observer points. For each reference observation point, the system uses GIS functions to compute the distance to the wind farm locations and the visibility of a pattern of wind farm turbines. A visual impact function is applied using, as inputs, the number of WTs that can be visualized and the function of the distance to the wind farm. The visual impact function I_{ij} is obtained from the sigmoid function calculated for all the geographical locations where the wind farm is visible as follows

$$I_{ij} = \left(1 + \mathrm{e}^{(8(D_{ij}(70/h)-s))/r}\right)^{-1}, \tag{5}$$

where, D_{ij} is the distance from the observer location i to the wind farm location j; r the function parameter given by $r = 11.167 + 2.2599n$; s the function parameter given by $s = 3.98635 + 1.0206n$; h the WT height in meters and n the number of WTs in the wind farm.

The visual impact is zero in locations where the wind farm is not visible. The values of parameters r and s were obtained based on statistics of inquiries among more than 100 people about their perception of the impact they felt when observing a set of photomontages covering a range of distances from 0 to 30 km and a range of WTs. These inquiries consisted of showing 4 sequences (different number of WTs) with 8 photographs of a wind farm, from the nearest to the farthest WT.

Fig. 4 shows the decrease in visual impact with the distance between the observer and the wind farm and it provides the aspect of the sigmoid function of (5) depending on the number of WTs (1, 3, 6 or 9 WTs). Wind farms with more WTs have higher impacts, and the same impact is perceived farther. Notice that WT height directly affects the scale of the distance between observer and wind farm, as expressed in (5).

A global value for the visual impact is computed as the sum of impacts on all the observers in the region. The observers are geographically represented by a observation point (in location i) containing the following characteristics: number of observers N_i that can be the number of people living in this point; F_{ij}, which is the estimated number of times people look at the wind farm (in the location j) per year and G_{ij}, which is the relative weight representing the importance of the observation from location i to the wind farm location j (a value between 0 and 1). A scenic location which people visit exceptionally has a high value $G_{ij} = 0.9$; and in places where people observe the wind farm routinely the observation has a low weight $G_{ij} = 0.1$. The corresponding observer index O_{ij} is given as:

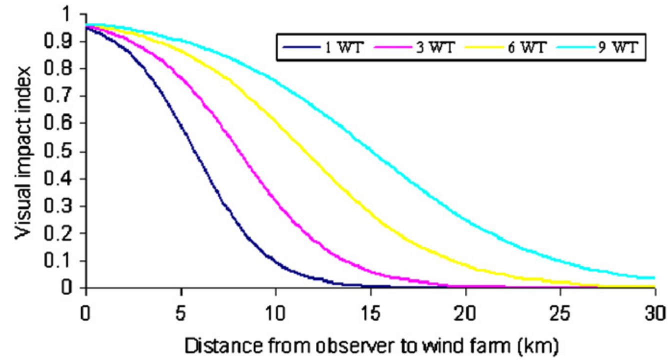

Fig. 4. Sigmoid function.

$$O_{ij} = N_i F_{ij} G_{ij}. \tag{6}$$

The weighted aggregation of the impact for all the observers is the index $I_{\mathrm{agree}\,j}$ of the global visual impact for the wind farm in the location j. This index aggregation is given as:

$$I_{\mathrm{agree}\,j} = \frac{\sum_i O_{ij} I_{ij}}{\sum_i O_{ij}}. \tag{7}$$

This quantification index $I_{\mathrm{agree}\,j}$ is stored in a geographical grid for the wind farm location j. On repeating the process for all wind farm locations j, a map of visual impacts J is obtained together with the map of observers I.

Fig. 5 shows the resulting background grid map of visual impact J for a wind farm (with technical characteristics defined by the economic group), corresponding to an area in La Rioja, Spain. The bullets indicate the reference observer points located in all the inhabited areas of the studied zone. The number of observers N_i associated with each observer point is proportional to the population number; the frequency of observation F_{ij} and the weights G_{ij} are assumed to be equal for all the points because all represent the same type of residential observation points.

This kind of visual impact maps can be used as one of the criteria to evaluate the overall environmental impact of wind farms. Thus, visual impact map J can be converted into a new map (attribute map) containing values of $(1-I_{\mathrm{agree}\,j})$ for each location j, which represents preferred/tolerated locations for the installation of wind farms due to their lower visual impacts. Then GIS cells with values close to 1 are the most preferred/tolerated locations. Thus, this final attribute map can be used together other

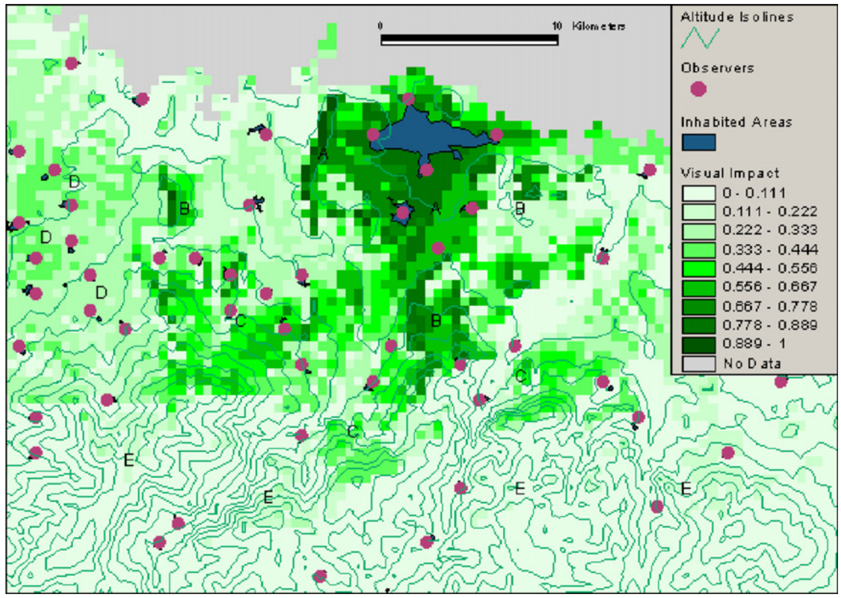

Fig. 5. Map of visual impact.

environmental impact attribute maps of the environmentalist group to obtain the tolerance index map for this group.

4.2. Tolerance index maps for the environmentalist group

The following criteria can be used by the environmentalist group: the above-mentioned visual impact; the distance to inhabited areas with a given length limit around these areas (safety for humans and the noise of WTs at distances lower than 500 m), with a preference for distances above the limit; environmentally protected areas with different levels of protection (from prohibited areas to less restrictive areas for the construction of wind farms under specific protection conditions) according to environment protection legislation, including protected areas due to the risk of bird collisions and protected areas depending on the types of vegetation; other environmentally sensitive areas (especially ecologically sensitive areas); etc.

In the first stage of the selection of new wind farm locations (Section 2), the environmentalist group defines several criteria maps. Then, in the second stage, tolerance maps are obtained by aggregating the attribute maps corresponding to these criteria maps for this group. Fig. 6 shows an example (of an area in La Rioja) of a tolerance index map for the environmentalist group corresponding to suitable aggregation of attribute maps of several criteria, namely environmentally protected areas according to the official regional environmental protection plan in La Rioja, Spain (two different GIS coverages that are vegetation areas GIS coverage and bird protected areas GIS coverage), distance to inhabited areas, and visual impact.

T_b values in Fig. 6 corresponds to the values of the resulting aggregated index T (Section 2) for the environmentalist group using the above-mentioned criteria. In Fig. 6, the areas with lower values (between 0 and 1) represent locations with a lower tolerance: for this area, mainly less tolerable areas are near urban centres and in some environmentally protected areas.

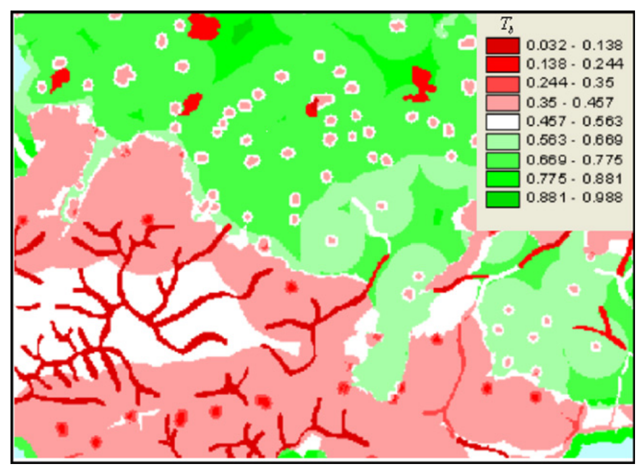

Fig. 6. Tolerance index maps for the environmentalist group.

5. Conclusions

The decision support system presented in this paper has been developed to assist in the selection of consensual geographical locations for the construction of new renewable energy facilities when the participating agents, organized as decision groups, have initially opposing positions. The system has been developed on a GIS platform, taking advantage of its spatial calculation and visualization capabilities.

The decision support system is based on an original methodology with a main objective: the creation of tolerance maps. These tolerance maps, which are different for each group, contain their preference/tolerance for the best preferred locations for construction of new renewable energy facilities. They are produced in accordance with several GIS procedures specially designed for the creation of specific criteria and attribute maps, the pair-wise comparison of criteria, the selection of global relative weights for each criterion and criteria aggregation, with all the procedures made with the GIS platform.

Thus, the decision support system helps to identify on all the tolerance maps the geographical locations containing the value 1 (or a value close to 1) that are the consensual locations to build a new wind farm. Furthermore, the tolerance maps obtained and a set of sophisticated procedures from the decision support system can provide an adequate framework to conduct a complex negotiation process aimed at obtaining other consensual locations among the groups which will be described in a new paper in the future.

The potential users of the decision support system are groups formed by one or more agents, e.g. governmental agencies, investors, project developers, financial institutions, public organizations, environmental agencies, activists and community actors. Frequently, the original differing preferences are the interest of some of these agents in the development of new power facilities (under economic or technical criteria), whereas, in contrast, other agents are interested in limiting the impacts of new power facilities on the environment or society.

This paper presents a set of testing results of tolerance maps useful for the selection of consensual locations for the construction of new wind farms in the region of La Rioja (Spain), with the participation of two groups (an economic group and an environmentalist group).

The proposed decision support system can be easily adapted to any other region, to any other type of renewable energy facility and to any number of groups, and constitutes a helpful tool for the integration in electric power systems of new distributed generation power plants based on renewable sources.

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