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Spatial Decision Support System for Site Permitting of Distributed Generation Facilities

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Abstract: Distributed Generation (DG) facilities require, like other energy projects, a sitting review process to acquire the permits and approval needs for construction and operation. In this process different groups and individuals with different roles, interests and priorities are involved. This paper presents a Spatial Decision Support System (SDSS) that helps to identify permissible areas to install DG facilities. Wind energy facilities are used in this paper to exemplify the use of the SDSS.

Keywords – Geographic Information Systems, Spatial Decision Support System, Distributed Generation, Permitting Facilities.

I. INTRODUCTION

As other energy facilities, the DG facilities require a sitting process geographically constrained by laws or conditioned by the acceptability or unacceptability from the several entities involved in the process. The permitting processes are today more difficult due to the decision-making being more sensitive to the project impacts and due to the interest and effectiveness of various environmental and social interest groups.

The DG technologies are particularly affected, by this permitting process, due to its spatial distribution characteristic. One of the steps of the permitting process consists in the mapping and ranking of potential areas to install and operate the DG technologies. Mapping and ranking site solutions require the use of a Spatial Decision Support System (SDSS).

The permitting process is a multi-criteria decision problem requiring the evaluation of several spatial criteria like: economical (electricity production cost), technical constraints (installation and operation), political (cohesion with local policies) and environmental (air quality, noise, land use, etc.). Other aspect of the problem is the involvement of several actors on the decision process, and the objectives and interests of these actors that could be in conflict. Examples of actors that should be involved on the process are: the DG technology developers and investors, local and national government and agencies, community groups and environmental organizations.

In the perspective of the multi-criteria decision aid, the permitting problem has several actors involved on the decision making (e.g. technology developers, environmental organizations). For each actor there is a set of criteria represented by geographic thematic maps (e.g. maps of electricity production cost, environment protected areas). Each thematic map is classified by attributes that could consist on quantitative ranges or qualitative classes (e.g. several ranges of electric production costs, several ranges of distance to habited areas, several classes of land use). And finally the alternative solutions, to be evaluated on the decision process, are the thousands of possible locations.

The evaluation of a large number of possible site solutions requires the use of a Spatial Decision Support System (SDSS). The SDSS is a decision aid tool adequate to aid the decision process that involves decision through a large set of spatial alternatives. The SDSS should be composed by the decision aid tools, geographical interface and support for spatial data and support for spatial analysis. This paper presents the general methodology used on the SDSS, implemented on ArcView GIS, as a part of a main research project 2FD97-1514 (sponsored by the Spanish authorities and European Union funds). It has been applied to the site permitting of wind energy facilities in the region of La Rioja (Spain). The selected example illustrates the spatial decision process in its several phases. Namely: 1) the definition of the criteria and attributes; 2) evaluation of tolerability index maps for specific interest-groups; 3) outranking site solution based on different interest perspectives.

II. METHODOLOGY ADOPTED

A detailed description of the methodology is presented in this paper, including one application for the permitting of wind energy facilities.

The methodology developed was designed as flexible as possible in order to be applicable for the several DG technologies, and applicable by different decision actors in different decision environments.

The methodology admits that there are several groups with conflicting interests. Each group is represented by a decision actor that uses the SDSS to translate the preferences and tolerability indexes of its group into one unique index of relative tolerability. In the methodology it is admitted that individuals or sub-groups composing each interest group should have non-conflict interests. They only have different grades of tolerability or preference.

A. *Defining the Criteria.*

The interest-actor should define the set of criteria that are relevant for the interest-groups. The criteria consist on thematic maps selected and preprocessed by the actor. The thematic maps represent issues directly valuable by the interest-groups (e.g. land use, noise, biological resources, terrain slope, wind resource, distance to electric network, distance to existing road infrastructures).

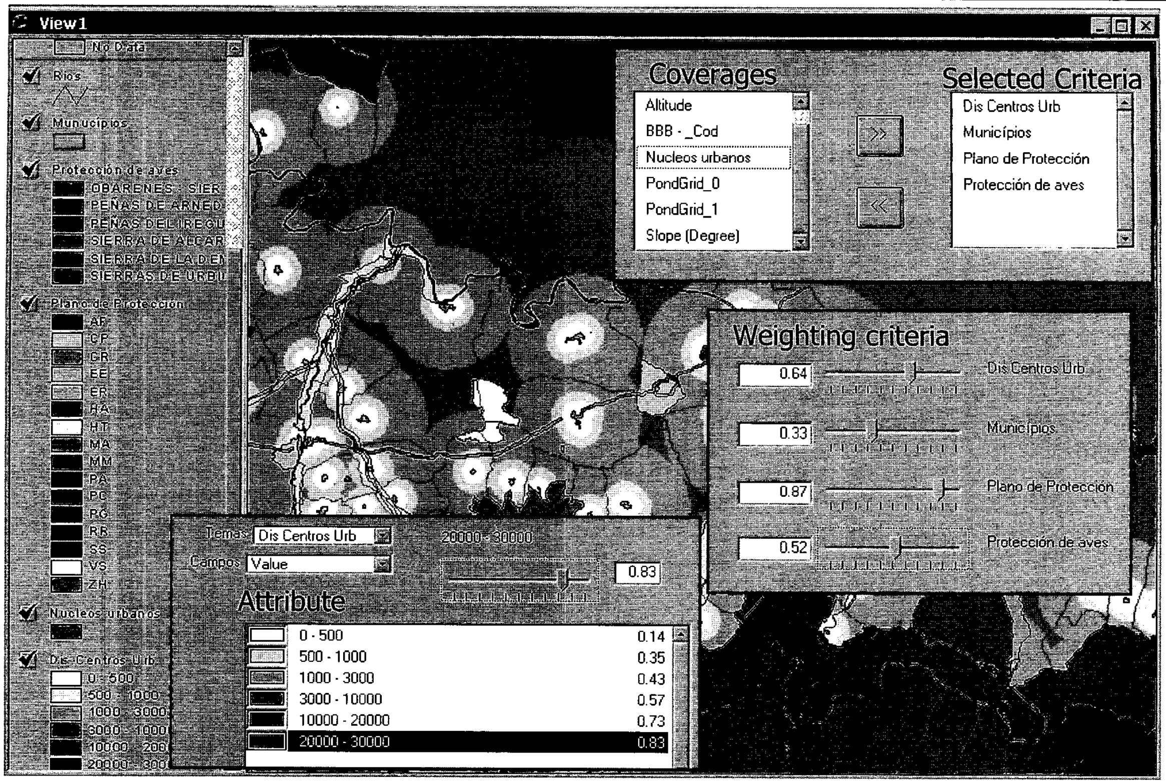

Figure 1 – Example of the GIS interface for the selection of geographical criteria, weighting each criteria and setting the attributes to the classes of the criteria.

We could identify three types of criteria, all represented by a geographic coverage. The first one is a quantitative criteria, where the attributes are a set of ranges of measurable values. For instance the distance to the electric network could be classified in three ranges of values ([<1km]; [1km,5km]; [>5km]). The second type of criteria is the qualitative criteria, for which the attributes are qualitative classes. For instance, the different types of land-use. The third type is the zonal criteria, representing multiple geographical zones, each one influenced by specific local interest-group. An example of these criteria is the representation of local policies of the municipalities.

B. *Moderating the attributes for each criteria.*

As explained, the interest-actor selects a relevant set of geographical coverage representing the correspondent set of criteria, each coverage is classified by class attributes. The next step consists in the assignment of a tolerability/preference index to each attribute class. This value is assigned by the interest-actor but it should represent the relative preference or tolerability of the represented interest-groups. The tolerability assignment is done in a pre-defined scale [0, 1], where values lower than 0.5 are a degree of disagreement and values higher than 0.5 represent a degree of agreement. In this predefined scale there are the veto threshold and the preference threshold. The veto threshold is a value between 0 and 0.5 for which lower values represent the veto to the DG installation. The preference threshold is a value between 0.5 and 1 for which higher values represent total agreement with the DG installation.

The attributes are assigned for a class set predefined in each criteria (coverage). The classes of attributes correspond to the legend of the coverage predefined by the user. These attribute classes (legend classes) could be quantitative, qualitative or zone-specific.

C. *Weighting the criteria.*

The ponderation of attributes is done for each criterion independently of the other criteria. In order to evaluate the relative importance of criteria it is necessary to assign a relative weight to each one. The method used is based on the definition of the shape for a sigmoid curve. This sigmoid is a value function, transforming the ponderation p in [0,1] specified by the user in another value $S(p)$ in [0,1], where higher weights correspond to more accentuated impacts of the ponderation values. The weight is a value between 0 and 1, resulting in sigmoid functions exemplified in the figure 2. In fact, a higher value for the weight corresponds to a larger differentiation between agreement (>0.5) and disagreement (<0.5) ponderations. In the weighting phase, the scales used for ponderation are defined, as well as the veto and preference threshold. The weight must be defined before the ponderation of attributes in order to predefine the ponderation scale for each criterion.

Weighting the criteria is the definition of relative values for the importance of each criterion. Low values of the weight correspond to a geographical soft differentiation between good and bad sites to install the DG technology. On the other hand, the high values of the weight correspond to a strong differentiation between good or bad sites. The high values of the weight define the veto and preference threshold and the scale for which the user defines the ponderation values.

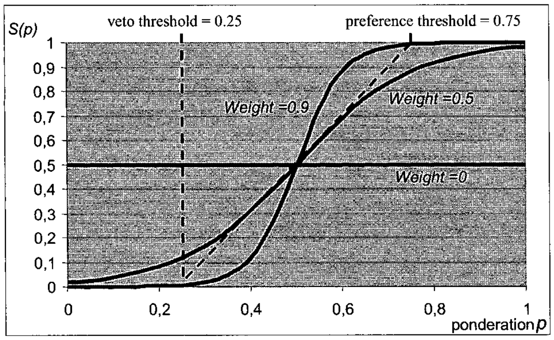

Figure 2 – The figure represents the sigmoid value functions for three different weights (0.9, 0.5 and 0). The specification of the weight automatically defines the threshold values, obtained from the derivative of the *S(p)* for p=0.5. The figure exemplifies the threshold values for weight=0.5.

The objective of the weighting process is to obtain for each interest-group a unique tolerability index, aggregating the non-conflict preferences of all the individuals of the interest-group. In fact this map of tolerability should represent the relative ranking of preference sites for the DG permitting.

In order to weight the several criteria, for obtaining the tolerance maps $[T_i]$ for interest-group *i*, the SDSS performs several spatial operations where the ponderated maps $[S_c(p)]$ for each criteria *c* are weighted by the geometric mean:

$$[T_i] = \sqrt[c]{\prod_c [S_c(p)]} \quad (1)$$

For exemplifying the process, we formulated the following problem for permitting wind farms in the region of La Rioja (Spain). It was assumed the existence of two interest groups, the environmental group (EG) and the wind farm developer group (WFDG). The EG represent environmental agencies, organizations, activists and community groups, all worried about the negative impacts of the wind farm installation. The WFDG represents the wind project developers, the financial institutions and economical development agencies, all with interest in developing wind farms on sites with high economical potential.

The environmental interest-group specified, for this example, the following set of criteria: environmental protected areas from the regional environment protection plan (2 different coverages); birds protected areas; vegetation coverage; proximity to habited areas.

The wind farm development group specified, for this example, the following set of criteria: electricity production cost (including energy resources, costs of road and electric network interconnection, land property values); terrain slope; altitude.

The results of the tolerance index maps are shown in the figure 3 for the environment interest-group and in figure 4 for the wind farm development interest-group.

We can observe better interest areas in some locations with high potential resources and technically acceptable sites.

D. *Outranking the site solution.*

The second part of the SDSS is a module that ranks the site solution using the several maps of tolerance index proposed by each interest-group. This ranking of solutions is not trivial because the several groups could have conflict interests. Thus, in the map of solutions there are locations where all interest-groups are favorable to the installation and there are other sites where some groups are favorable and the other ones are against the installation of DG.

This conflict of preferences should be solved by negotiation. There are two issues that could be negotiated. The first one is to negotiate the permitted sites. In this negotiation, each interest-group negotiates to permit sites with high preference or to veto sites with low tolerance. The second issue is the negotiation of the global permitting area. Obviously, the interest-groups favorable to the DG installation negotiate to maximize the permitted area, contrarily to the groups worried about the DG impact, that negotiate to minimize the area.

In some usual situations the area to be permitted is fixed by the global energy planning as a regional target for the DG development (e.g. the wind farm development for the next 10 year should be 100MW). This kind of targets fixes the area to be permitted, stating the basis for the negotiation.

In both types of negotiation the interest-actor needs the SDSS to rank the site solution from the perspective of the individual groups and from the perspective of combinations of several interest-groups.

The process used by the SDSS to outrank the solutions is based on the count of better solutions, as illustrated in the figure 5. For example: for each site s_{ij}, the SDSS counts the number of better sites from the perspective of EG (e.g. in the perspective of group EG exist X_1 better sites than site s_{ij}), from the perspective of WFDG (e.g. in the perspective of group WFDG exist X_2 better sites than site s_{ij}), and from the perspective of both interest-groups (the two groups agree that exist X_{12} better sites than site s_{ij}). The sum of the counts X_1, X_2 and X_{12} give a global count. The list of this global count, for each possible site on the region could be used as global outranking. Lower values for the global count usually correspond to better sites. However, it is possible the appearance in a good ranking position of sites that are excellent from the perspective of one group but unacceptable from the perspective of the other group. These situations should be negotiated between the interest groups.

The global outranking is the basis for the negotiation. The progressive selection of sites following the outrank enlarges the selected area (permitted area) and the individual rank from the perspective of each group also decreases until the lowest limit tolerable by each interest group is reached. This aspect could be observable on table I and on figure 5.

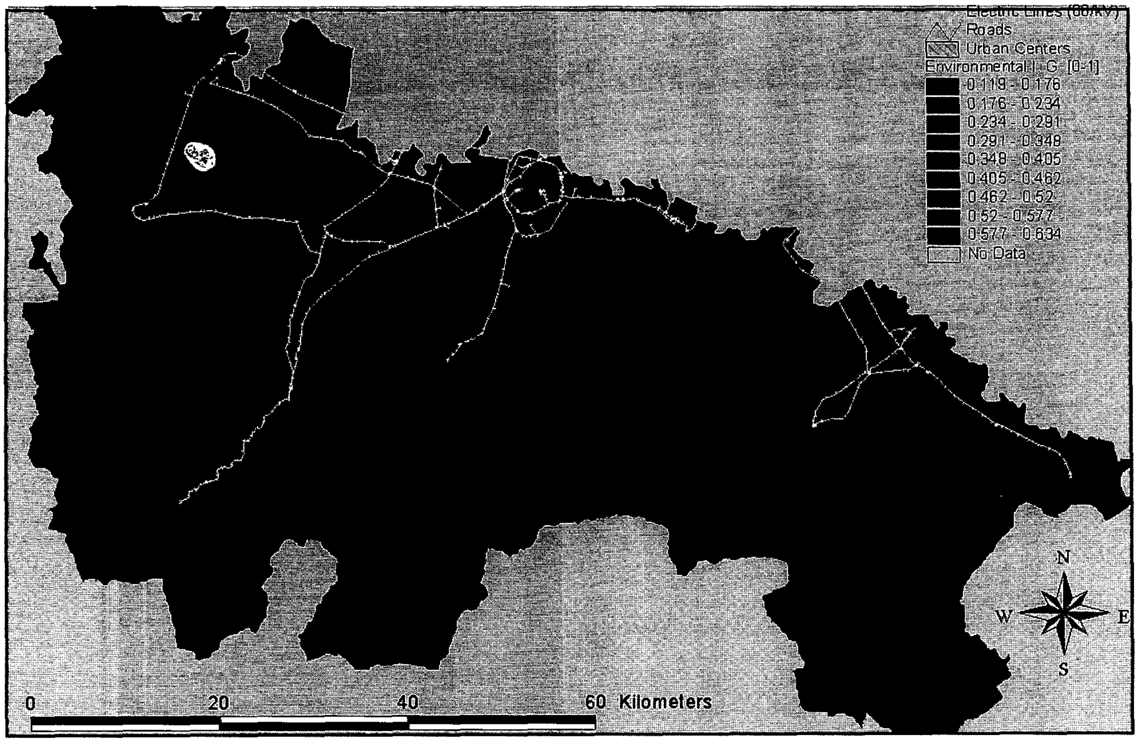

Figure 3 – Tolerance index maps for the environment interest-group. The red zones represent sites with lower tolerance. We can observe less tolerable zones near urban centers and in the environmental protected areas.

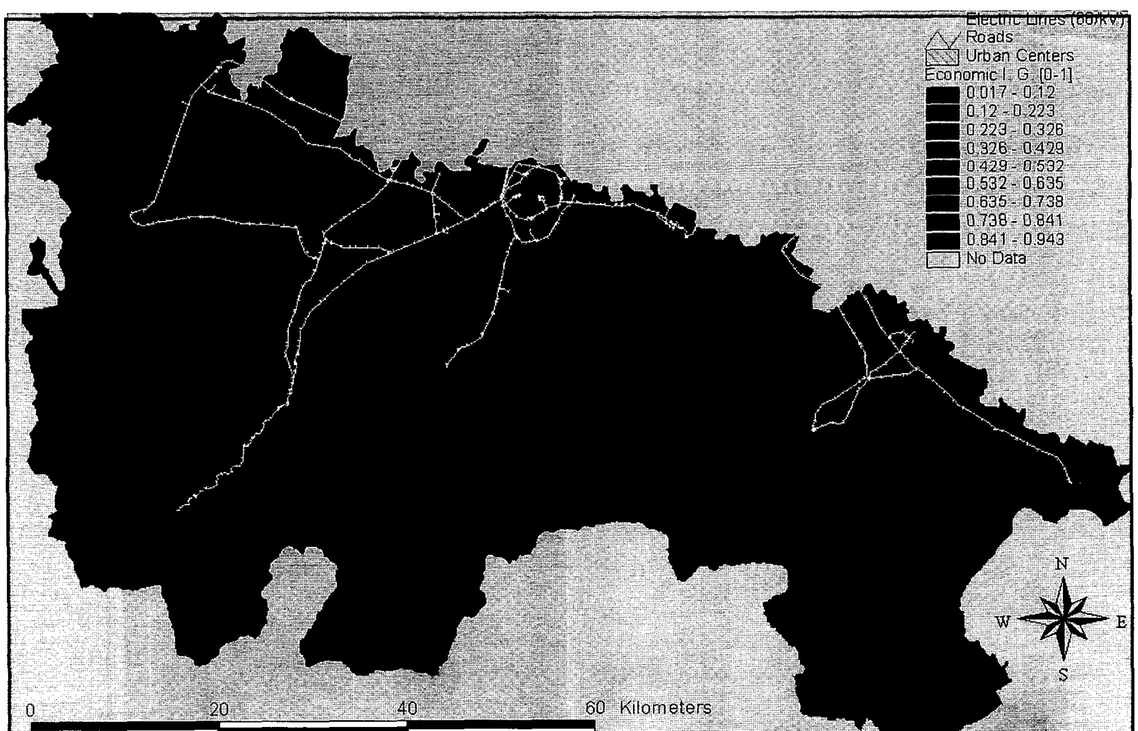

Figure 4 – Tolerance index maps for the economic interest group. The red zones represent sites with lower tolerance. The mountain zones have low preference due to the high uncertainty on wind resources. On the valley zones, a wide range of preference values exists that depends on the costs and the wind resources for each site.

Table I – Ranking classes (0 is the index for the best sites) corresponding to the images A, B, C and D on figure 5 related with fours different scenarios for wind farm development. The Outranking is the ranking evaluation as a conjunction of both interest groups. The other two ranking columns correspond to the absolute ranking for each interest group.

Area selection	Outranking	Ranking for Environment	Ranking for Economic	Wind development target
A	1	0	0	30 MW
	2	1	0	
	3	0	2	
	4	2	0	
B	5	1	2	160 MW
	6	2	1	
	7	2	2	
C	8	0	3	220 MW
	9	1	3	
	10	2	3	
D	11	0	4	550 MW
	12	1	4	
	13	2	4	

The SDSS allows a simple interface for managing the area selection. The area is progressively selected by relaxing the global outrank lowest limit and the interest groups observe the progressive decreasing of the several ranks. Each group could state, by accordance with the other groups, their own lowest limit. A table of site records are observable allowing the individual evaluation of each site including the ranking in the several perspectives and attribute characteristics of the specific site. In order to reach a target level of DG integration, the several groups must relax its tolerability limit. The consequences of the tolerability relaxation of each group are instantaneously observed in the map interface.

For the example presented in this paper we observed that is quite easy to find 30 MW of good location without conflictive solutions. However when the pressure of wind farm development increases to 220 MW, the economic potential of the sites decrease and some critical areas appear for environmental group. With the increasing of the development pressure the quality of the sites become worst form all the perspectives and the negotiation problem becomes more conflictive.

III. CONCLUSIONS

The paper presents a Spatial Decision Support System to support the permitting process of Distributed Generation technologies. The presented SDSS uses an innovative multi-criteria methodology by separating the problem in two phases: in the first phase, non-conflicting interest-groups create a map of a relative tolerability index, using criteria represented by geographical coverages; in the second phase, the site solutions are outranked from the perspective of the several conflicting interests producing a support information for the negotiation.

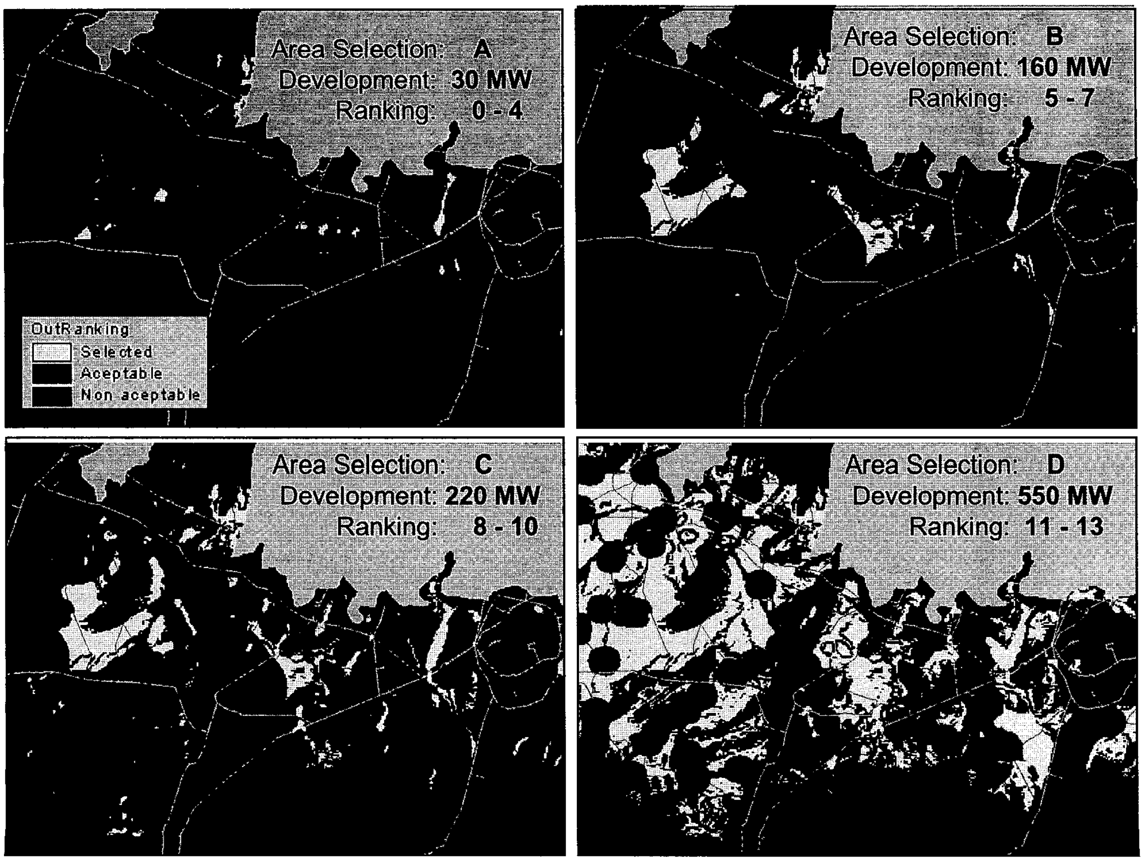

Figure 5 – Outranking grid and selection areas for a zoom area . The red zones represent sites with lower outranking values for both groups, the environmental and economic interest groups. The four selection scenarios represent different pressure of wind farm development, forcing the selection of sites with a lower preference from the perspectives of both groups.

The paper has presented an application of the methodology for the permitting of wind energy facilities in La Rioja, a region in Spain.

IV. ACKNOWLEDGEMENTS

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V. REFERENCES

[1] "Permitting of Wind Energy Facilities – A Handbook", Report prepared by NWCC Siting Subcommittee, March 1998

[2] Carver, S.J.. "Integrating Multi-Criteria Evaluation With Geographical Information Systems" International Journal of Geographical Information Systems. 5(3):331-339, 1991

[3] Densham, P.J.. "Spatial Decision Support Systems". In D.J. Maguire, M.F. Goodchild, and D.W. Rhind, ed., Geographical Information Systems: Principles and Applications, 403-412, New York: John Wiley, 1991

[4] Olson, D.L.. "Decision Aids for Selection Problems". New York: Springer-Verlag., 1996

[5] Jankowski, P. 1995. "Integrating Geographical Information Systems And Multiple Criteria Decision-Making Methods". International Journal of Geographical Information Systems. 9(3):251-273, 1995

[6] Jankowski, P. Nyerges T., Smith A., Moore T., Horvath E. "Spatial group choice: a SDSS tool for collaborative spatial decision-making". International Journal of Geographical Information Science. 11(6):577-602, 1997

[7] Malczewski J.,. " A GIS-based approach to multiple criteria group decision-making". International Journal of Geographical Information Science. 10(8):955-971, 1996