A MULTICRITERIA DECISION SUPPORT FRAMEWORK FOR ASSESSING ALTERNATIVE WIND PARK LOCATIONS: THE CASE OF TANAGRA - BOIOTIA

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Abstract
The focus of the present paper is on the development of a decision support framework for assessing alternative wind park locations using MCA tools. In the first part, it elaborates on the development of such a framework, with emphasis placed on the evaluation stage. More specifically, two multicriteria evaluation techniques are used (ELECTRE I and REGIME) as tools that can relief 'method uncertainty' and deal with conflicts and different perspectives in the decision making process. In the second part, this decision support framework is applied in a real world decision problem, namely the selection of wind park location in a Greek region (Tanagra-Boiotia) for the installation of a wind park that will partly serve the energy demand of a newly planned industrial area. Finally, some conclusions are drawn as to the empirical results obtained by the two multicriteria methods as well as their capacity to deal with multiobjective evaluation problems.

Keywords: *decision making, multicriteria evaluation, quantitative and qualitative data, conflicting objectives, wind park location*

1. Introduction

Planning deals with problems exhibiting many different dimensions e.g. social, cultural, environmental etc. in seeking for sustainable development solutions in support of policy makers. In such a context, clear cut solutions to planning problems do not exist. Instead, various alternative options are available, which need to be further evaluated as to their performance in respect to certain evaluation criteria that largely reflect the values and priorities of the study system at hand. Evaluation thus consists of an integral part of the planning process (Khakee, 1998), aiming at the assessment and appraisal of alternative policy options in order to reach optimal, transparent and resource-preserving policy decisions. It is considered as a process, within which conflicts and different perspectives and interests of various stakeholders balance for a compromise in a coherent and transparent way, ending up with an optimal decision, which reflects as much as possible different stakeholders' interests. Moreover, evaluation is considered as part of a decision support system that supports both the development and the selection stage of the decision making process (Janssen, 1994).

Complex and unstructured decision problems, involving a number of conflicting objectives and a variety of stakeholders need to be dealt with in planning exercises. These call for proper evaluation tools. Multicriteria Decision Analysis (MCA), in this respect, is a useful tool in support of decision-makers in planning problems, as it can incorporate both conflicting objectives and different views involved. As Nikamp and Torrieri (2000) point out, it is a tool combining both assessment techniques and judgment methods, offering thus a solid analytical basis for modern decision analysis.

Key advantages of multicriteria analysis mainly relate to its potential to (Finco and Nijkamp, 1997):

- take into account a diverse set of different criteria that are important for the evaluation problem at hand;
- take into account both quantitative and qualitative aspects, even of a fuzzy nature (see Munda 1995);

- establish a structured communication with decision-makers and policy-making bodies through the use of a range of policy weights for respective evaluation criteria; and
- address future uncertainties by including also scenario experiments in the analysis.

Evaluation methods - in particular, multicriteria methods - aim to identify the best possible alternative or the most plausible ranking of alternatives out of a set of distinct choice possibilities (Janssen, 1992). A variety of MCA methods have been developed during the last decade, rendering the choice of an MCA method for a specific evaluation problem a very tricky task. These are differentiating as to: the nature of the data handled (quantitative, qualitative or mixed data); the formal relationship between policy objectives and choice attributes; the nature of weights attached to the evaluation criteria (quantitative or qualitative); the treatment of outcomes of alternatives in an impact matrix (e.g. pairwise comparison); the specification of decision rules; the type of standardization used for the criteria outcomes; etc.

Use of different methods can sometimes lead to divergent results, in particular when a complete ranking of alternatives is needed (Finco and Nijkamp, 1997). This implies the need for a careful selection of the MCA method to be used in each single evaluation problem, based on the specific characteristics of the method and the problem at hand. To deal with the method uncertainty, many authors suggest the use of two or more MCA methods in a certain evaluation problem in order to validate results obtained. Such a multi-method approach can enrich policy making by reviewing preferences and judgments derived from more than one MCA method (Voogd, 1983; Mysiak, 2006).

The scope of the present paper is to present a decision support framework supporting both the development and the selection phase of wind park location. In the first part, it elaborates on the development of such a framework, with emphasis placed on the evaluation stage. More specifically, two multicriteria evaluation techniques are used (ELECTRE I and REGIME) as tools that can relief ‘method uncertainty’ and deal with conflicts and different perspectives in the decision making process. In the second part, this framework is applied in a real world decision problem, namely the selection of wind park location in a Greek region (Tanagra-Boiotia) for the installation of a wind park that will partly serve the energy demand of a new industrial area. Finally, some conclusions are drawn as to the empirical results obtained by the two multicriteria methods as well as their capacity to deal with multi-objective evaluation problems.

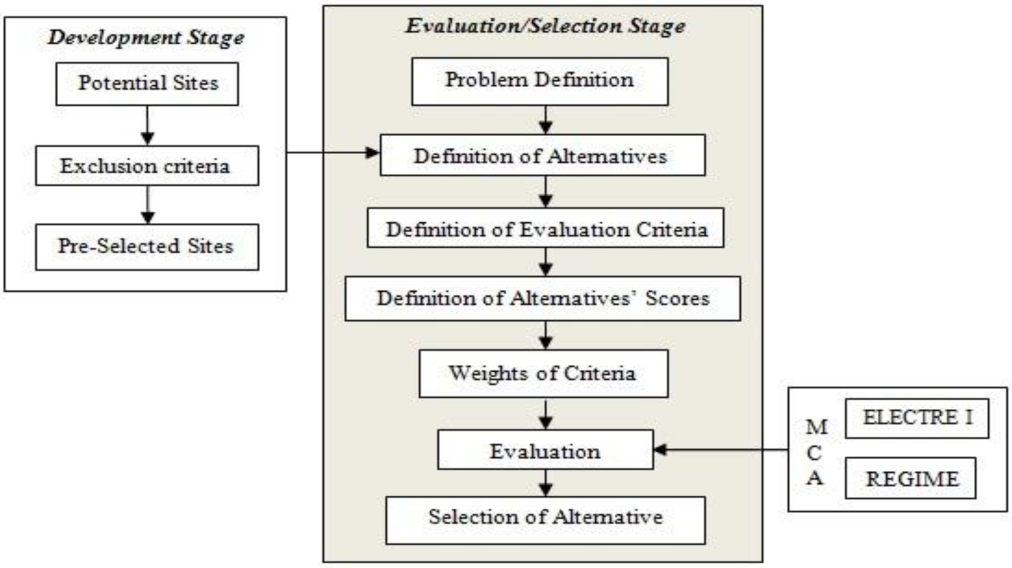
2. The Methodological Framework

The methodological framework presented in the following aims at elaborating on the *development* and *selection* of wind park location for policy purposes. It consists of two distinct stages, where (see Fig. 1 below):

- The first stage - *development stage* - focuses on the development of alternative solutions, implying a process of collection and evaluation of various types of data on potential sites for wind park location and a process of partial elimination of certain sites on the basis of certain exclusion criteria. The output of this stage is a limited number of pre-selected sites, best fitting wind part location in the region at hand; and
- The second stage – *evaluation/selection stage* - proceeds to the evaluation of the pre-selected sites by means of MCA methods, on the basis of certain evaluation criteria, relevant to the problem at hand. The core of the evaluation / selection stage is based on the multicriteria evaluation, as an approach that best fits to planning exercises (Voogd, 1983). Towards this end, two MCA techniques are used, namely ELECTRE I and REGIME, in order to deal with ‘method uncertainty’ and support a more confident decision in the problem at hand.

In the following are discussed the two stages of the above presented methodological framework.

Fig. 1: The decision support framework



2.1 The Development Stage

The development stage aims at defining a set of pre-selected alternative solutions, to be further evaluated at the second stage (evaluation / selection stage). It includes the following steps (see Fig. 1 above):

- *Delineation of potential sites*: involves the collection and analysis of data as to the whole set of options available for wind park location in the study region. Such information may refer to: characteristics of potential locations e.g. topography, wind potential, land use patterns; social characteristics e.g. adjacent settlements; environmental characteristics e.g. valuable ecosystems, landscape; and existing legislative framework, defining policy priorities for wind parks' location.
- *Definition of exclusion criteria*: the emerging set of potential options is roughly evaluated, in a first round, on the basis of certain exclusion criteria. Depending on the problem at hand, as exclusion criteria can be considered the: wind potential in each specific site; number (density) of potential wind mills; spatial characteristics of potential sites, e.g. morphology, accessibility; environmental, social and cultural attributes of potential sites; closeness of potential sites to settlements; distance from energy distribution networks; legislative constraints as to wind park location patterns; etc.
- *Choice of pre-selected sites*: The output of this stage is a limited number of dominant potential sites, candidate for a more in depth evaluation at the evaluation/selection stage.

2.2 The Evaluation / Selection Stage

This stage aims at evaluating the pre-selected alternative solutions in order to support decision making in the problem at hand. It makes use of multicriteria evaluation techniques, capable of dealing with such kind of decision problems.

The steps followed (see Fig. 1) have as follows:

- Problem definition: referring to the description of the evaluation problem at hand;
- Definition of alternatives: set of pre-selected sites, as defined at the development stage;
- Definition of evaluation criteria: set of criteria, according to which the pre-selected set of alternatives is evaluated;
- Definition of scores of alternatives: structuring of the evaluation matrix for the problem at hand, by defining the impact of each alternative in respect to each evaluation criterion;
- Definition of weights of criteria: attaching relative importance to each evaluation criterion;

- Evaluation: use of multicriteria techniques for carrying out the evaluation of the set of the pre-selected sites; and
- Choice of the alternative option best performing as to the evaluation criteria considered.

Based on the nature of data used in a specific evaluation problem, measuring the impact of alternatives as to the evaluation criteria (i.e. quantitative or qualitative), the following multicriteria methods are disposable:

- Quantitative data, where the impacts are measured on a cardinal scale. The multicriteria methods that can be used in this respect are weighted summation, multi-attribute utility approach, ideal point method, concordance (or ELECTRE) method (see Janssen, 1992; Nijkamp et al, 1995) etc.
- Qualitative data, where the impacts are measured on an ordinal or binary scale. Methods that can be applied are: permutation method, extreme expected and random value method (Kmietowicz and Pearman, 1981; Rietveld, 1980), etc.
- Mixed data, where the impacts are measured on both quantitative and qualitative scales. The REGIME MCA method is relevant in such a context (Hinloopen et al., 1983; Hinloopen and Nijkamp, 1986).

In the present study, were chosen two of the above MCA methods, namely the ELECTRE I and the REGIME method, which are shortly described in the following.

2.2.1. The ELECTRE I multicriteria evaluation method

The ELECTRE I method, also known as concordance analysis, is based on a pairwise comparison of all alternatives, using only the interval character of the scores presented in the effects table. It is principally designed for selection problems (Buchanan et al, 1999) and aims at solving a decision problem consisting of:

m alternatives M_i, i = 1, . . . , m;
n evaluation criteria g_j , j = 1, . . . , n; and
n weighting factors ω_j , j = 1, . . . , n
with $\sum_{j=1}^{n} \omega_j = 1$

On the basis of the above elements, an *m x n decision (impact) matrix* is built (Table 1 below). The goal of the method is to select the best alternative on the basis of its performance with respect to all evaluation criteria concerned.

The core of the method is the *outranking relationship* or *dominance relationship* between two alternatives M_i and M_k, examining whether M_i is preferred to M_k ($M_i \rightarrow M_k$ or $M_i S M_k$). M_i is considered as being preferred to M_k in case that M_i is at least as good as M_k on the majority of the evaluation criteria and M_i is not significantly bad than M_k on the rest of the criteria. To identify this relationship, a pair wise comparison of each and every pair of alternatives is carried out for the whole set of the evaluation criteria. Such identification requires two sets of comparisons: one among the criteria in which $g_j(M_i)$ is superior to $g_j(M_k)$ and one among the criteria in which $g_j(M_i)$ is not superior to $g_j(M_k)$. This implies that the ELECTRE I method examines separately the criteria for which M_i is preferred to M_k and those for which M_i is not preferred to M_k. Taking also into account the priorities of the evaluation criteria, the method aims at estimating the level to which scores and their associated weights confirm or contradict the dominant pair wise relationships among alternatives (Jansen, 1994).

Table 1**: The impact matrix**

Alternatives / Criteria	Alternative 1	Alternative 2	….	Alternative I
Criterion 1	$Score_{11}$	$Score_{21}$		$Score_{I1}$
Criterion 2	$Score_{12}$	$Score_{22}$		$Score_{I2}$
...	...	...		...
Criterion J	$Score_{1J}$	$Score_{2J}$		$Score_{IJ}$*

** $Score_{IJ}$: performance of the alternative I in respect to the criterion J*

The two sets of comparisons are performed by means of *concordance* and *discordance* tests.

The *concordance test* allows the decision maker to verify whether M_i is at least as good as M_k, with the difference between the two within a predefined threshold. This test is carried out for those evaluation criteria for which M_i performs better than M_k. In ELECTRE I and II the concordance test is binary in nature, with the index taking the value of 1 in case that M_iSM_k is true and 0 in the opposite case. In ELECTRE III and IV the concordance test uses a *fuzzy* outranking relation, with the index taking values which range from 0 to 1, depending on how far $g_j(M_i)$ is better than $g_j(M_k)$.

For the rest of the criteria, namely those for which M_i performs worse than M_k, a *discordance test* is performed, testing whether there is a high opposition to the outranking relationship M_iSM_k. Failure of discordance test implies that outranking relationship M_iSM_k does not hold.

Generally, in order to verify an outranking relationship M_iSM_k (dominance relationship of alternative M_i on M_k), *both* the concordance and discordance tests should be passed.

The application of ELECTRE I, used in the present study, implies the definition of a concordance and a discordance set for each and every pair of alternatives M_i and M_k i,k=1,2,…m, i≠k, of the following form (Milani et al, 2006):

Concordance set = $J_{ik}^{+} = \{j \mid r_{ij} \geq r_{kj}\}$,

Discordance set = $J_{ik}^{-} = \{j \mid r_{ij} < r_{kj}\}$, (2.1)

where r_{ij}, r_{kj} refer to scores of the impact matrix (Table 1), i.e. impact of the i,k alternatives in respect to the evaluation criterion j.

On the basis of the concordance and discordance indexes for each pair of alternatives, the concordance and discordance tables are constructed.

For each pair of alternatives i and k, the weights set by the decision maker for the corresponding concordance set are summed to arrive at a *global concordance index* C_{ik} ($0 \leq C_{ik} \leq 1$),

$$C_{ik} = \frac{\sum j \in J_{ik}^{+} \omega_j}{\sum_{j=1}^{n} \omega_j} \quad (2.2)$$

Similarly, the *global discordance* D_{ik} index for each pair of alternatives is defined ($0 \leq D_{ik} \leq 1$) by the following analytical relationship:

$$D_{ik} = \frac{\max_{j \in J_{ik}^{-}} \left| \omega_j (r_{ij} - r_{kj}) \right|}{\max_{j \in J\{1,\ldots,n\}} \left| \omega_j (r_{ij} - r_{kj}) \right|} \quad (2.3)$$

A *global concordance threshold c* and a *global discordance threshold d* are chosen to perform the global concordance and discordance tests. These are exogenously determined values. The more severe the global threshold values the more difficult is to pass the tests (Milani et al, 2006). As Collette and Siarry (2003) claim, thresholds of $c = 0.7$ and $d = 0.3$ are often sufficient for performing such kind of tests.

For an outranking relation M_iSM_k to be judged as true, both global concordance C_{ik} and discordance D_{ik} indices should not violate the corresponding threshold that is:

$$\begin{cases} C_{ik} \geq c \\ D_{ik} \leq d \end{cases} \quad (2.4)$$

Once the two tests are completed for all pairs of alternatives, the preferred alternatives are those that outrank more than being outranked.

Given the threshold values, a *final appraisal score* s_i for each *alternative i* can be calculated by the following formula (Voogd, 1983):

$$s_i = \sum_{\substack{k=1 \\ k \neq i}} z_{ik} - \sum_{\substack{i=1 \\ i \neq k}} z_{ik} \tag{2.5}$$

where z_{ik} is defined as follows:

$$z_{ik} = \begin{cases} = 0 \text{ if } c_{ik} < c \text{ and } d_{ik} > d \\ = 1 \text{ if } c_{ik} \geq c \text{ and } d_{ik} \leq d \end{cases} \tag{2.6}$$

The choice option with the highest score can then be considered as the *most attractive (preferred) choice option*.

2.2.2. The REGIME multicriteria evaluation method

The REGIME analysis is a discrete multicriteria method, used to evaluate both projects and policies (Nijkamp et al., 1990; Vreeker et al, 2001). The advantage of the method lies on its capacity to deal with mixed (quantitative and qualitative) data as to the effects and criteria priorities considered in the evaluation problem at hand.

The application of the method is based upon two kinds of input data: the *evaluation (impact) matrix* and a *set of political weights*. The evaluation matrix is composed of elements that measure the effect of each alternative i, i=1,2,…,I in respect to each judgement criterion j, j=1,2,…,J (see Table 1 above). The set of political weights provides information on the relative importance of criteria to be considered in the evaluation context (Nijkamp and Torrieri, 2000).

Each value e_{ij} with i= 1,2,..I (set of alternatives) and j= 1,2, ..., J (set of evaluation criteria) (see Table 1 above), represents the score of alternative i as to the criterion j, but also a short of rank order of alternative i in respect to the criterion j. It could then be assumed that if $e_{ij} > e_{i'j}$, the choice option i is more preferred than i' for the evaluation criterion j (Nijkamp, 1987).

The REGIME method is based on a pairwise comparison of all alternatives, where the comparison of each specific set of alternatives is not influenced by the presence and effects of other alternatives, while the potential rank order of a certain alternative is conditioned by the remaining alternatives (Hinloopen and Nijkamp, 1986).

The development of the REGIME method is based on the concept of the 'regime'. As such is defined the $s_{ii'j} = e_{ij} - e_{i'j}$. In case of ordinal information, the magnitude of the 'regime' is not relevant but only its sign, where $\sigma_{ii'j}$ = sign $s_{ii'j}$ = + implies that alternative i is better than i' as to the criterion j, while $\sigma_{ii'j}$ = sign $s_{ii'j}$ = - implies that alternative i is worse than i' as to the criterion j. By carrying out comparisons between alternatives i and i' for all j=1,2, ..., J judgement criteria, a Jx1 regime vector $r_{ii'}$ can be constructed, taking the following form (Nijkamp, 1987):

$$r_{ii'} = (\sigma_{ii'1}, \sigma_{ii'2}, \ldots, \sigma_{ii'J})^T, \quad \forall\, i, i', i' \neq i \tag{2.7}$$

This vector contains only + and – signs and reflects a certain degree of dominance of option i over i' for the unweighted effects of all J criteria (Nijkamp, 1987). For all I(I-1) pairwise comparisons, I(I-1) regime vectors can be created, which can be combined into the JxI(I-1) regime matrix R of the following form (Hinloopen and Nijkamp, 1986):

$$R = \left[\, \underbrace{r12\ r13\ \ldots\ r1I}\ \ ,,,,\ \ \underbrace{rI1\ rI2\ \ldots\ rI(I-1)}\, \right] \tag{2.8}$$

As there is usually not a single dominating alternative, additional information is needed on the relative importance of the set of evaluation criteria. Such information is usually provided by means of preference weights, attached to the judgement criteria.

In case of ordinal information, the weights are represented by means of rank orders w_j (j=1,2, .., J) in a weight vector of the following form (Hinloopen and Nijkamp, 1986):

$$w = (w_1, w_2, ..., w_j)^T \quad (2.9)$$

where if $w_j > w_{j'}$, criterion j is regarded as more important than j' (Nijkamp, 1987).

These are considered as a rank order representation of the cardinal weights:

$$\underline{w}^* = (\underline{w_1}^*, \underline{w_2}^*, ..., \underline{w_j}^*)^T \text{ with } \max \underline{w_j}^* = 1, w_j^* > 0, \text{ for every } j=1,2,\dots,J \quad (2.10)$$

The ordinal ranking of weights is supposed to be consistent with the quantitative information incorporated in the unknown cardinal vector w^*, that is (Hinloopen and Nijkamp, 1986):

$$\text{if } w_j > w_{j'} \rightarrow w_j^* > w_{j'}^* \quad (2.11)$$

Then the weighted dominance of alternative i with regard to i' can be represented by the following stochastic expression (Hinloopen and Nijkamp, 1986):

$$v_{ii'} = \sum_{j=1}^{J} \sigma_{ii'j} \underline{w_j}^* \quad (2.12)$$

If $v_{ii'} > 0$, alternative i is dominant with respect to i'. But $\underline{w_j}^*$ is not known. What is known is only the ordinal value w_j, which is assumed to be consistent with $\underline{w_j}^*$. Therefore, a certain probability can be introduced for the dominance of alternative i with regard to i':

$$P_{ii'} = \text{prob}\,(v_{ii'} > 0) \quad (2.13)$$

Then the probability of alternative i to rank higher than the rest of the alternatives can be calculated by the following formula (Hinloopen and Nijkamp, 1986):

$$P_i = \frac{1}{I-1} \sum_{i \neq i'} P_{ii'} \quad (2.14)$$

i.e. P_i is the average probability that alternative i is higher valued than any other alternative (Hinloopen and Nijkamp, 1986). Rank order of P_i's is then defining the ranking of respective alternative choice options.

3. Application of the Decision Support Framework in the Area of Tanagra -Boiotia

The focus of this chapter is on the application of the above presented decision support framework. It provides a short description of the study region, the evaluation problem at hand and the empirical results obtained.

3.1 The Study Region

The study region refers to the nomos[1] of Boiotia, which is part of the Region of Sterea Ellada. Boiotia is an area endowed by nature in terms of land morphology, water, mineral, landscape and renewable energy resources.

The industrial sector - heavy industry and manufacturing - prevails in the local economic structure due to its *proximity* to the Athens metropolitan region; its *good accessibility*; and a strong *policy incentives framework*, rendering the region a quite attractive location for industrial development.

The region is considered as an important *energy distribution node,* based on the energy distribution networks crossing its territory and its proximity to the largest refineries of the Greek state. Moreover, there is a growing interest in energy investments in the region, based on the abundance of renewable (wind, water) and non-renewable (lignite deposits) energy resources.

The *energy consumption pattern* of the region is largely reflecting its industrial development pattern. The industrial sector is the most energy-consuming sector, with a share which exceeds 85% for the years 1998, 1999 and 2000, while the rest of the sectors are exhibiting a considerably lower share of energy demand.

At the national level, the region occupies the third position in terms of energy demand, while in terms of industrial energy consumption it occupies the first position, where more than $1/5^{th}$ of the national energy consumption in the industrial sector is consumed in the study region.

[1] Administrative unit corresponding to NUTS3 level.

3.2 The Evaluation Problem

The planned location of a new industrial area in Tanagra-Boiotia region is placed along the efforts of supporting the rational organization and spatial development of the industrial sector in the study region. The new industrial region is expected to act as a local/regional development pole, attracting investments and further contributing to the employment opportunities and development of the region.

The location of the new industrial infrastructure is expected to increase the energy demand in the region. Since it is already a highly industrialized area, this may further deteriorate environmental quality and assets. Along these lines, the *goal* of the present study is to support decision making as to the location of a wind park installation, which will provide part of the energy consumed in the new industrial area by exploiting renewable energy (wind), serving thus sustainability aspects in the region.

The evaluation problem at hand is the selection of the most proper location for the wind park installation. This is accomplished by the application of the above presented methodological framework, described in the following.

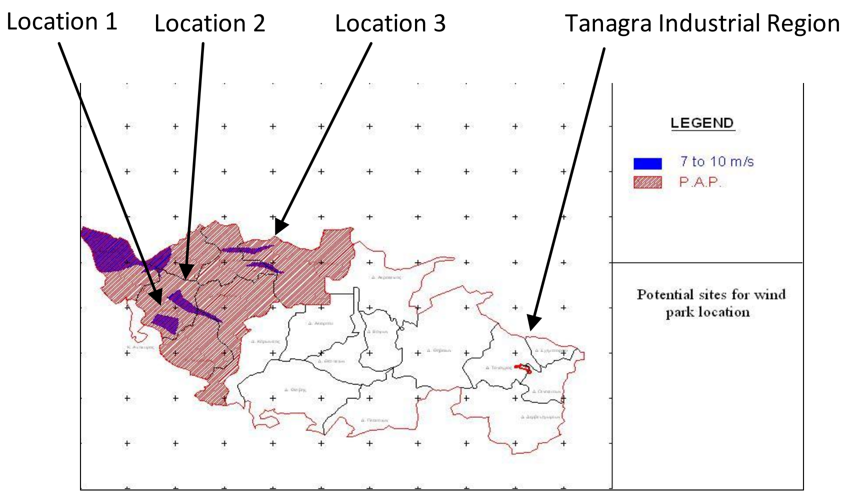
3.2.1. The development stage

At this stage, a set of potential sites (five sites) for wind park location were examined. A first round evaluation was carried out, concluding to a limited number of alternative solutions – the pre-selected sites. The evaluation was based on the following *exclusion criteria*:

- *wind velocity*, where sites disposing wind velocity less than 7 m/s were excluded.
- *proximity* to the *energy distribution network*, where sites far away from the network were discarded; and
- *proximity* to *vulnerable sites or urban constellations*, conditioning the density of windmills' installation according to the Greek legislative framework (Ecotechnica, 2007), where sites with low density windmills' installation potential (e.g. tourist sites in the area) were excluded.

On the basis of the above exclusion criteria, three potential sites were pre-selected for further evaluation (see Fig. 2 below). All of them lie on the mountainous part of the region, which ensures both high wind speed (7-10 m/s) as well as lower competition in terms of land use. Two sites lie on the southern part of the region of Boiotia, while the third on the northern part. The latter is comprised of two smaller sub-regions, at a distance of 3 km.

Fig. 2: Pre-selected sites for wind park location



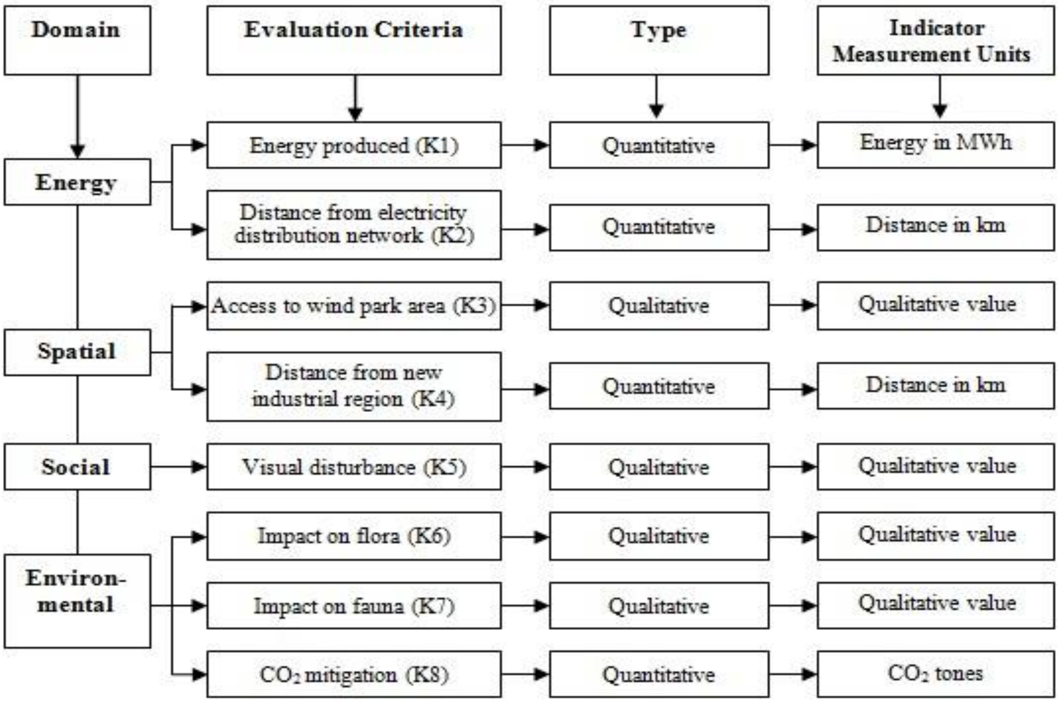
3.2.2. The evaluation / selection stage

In the following are presented the evaluation criteria, considered in the present study, their priorities as well as the impact matrix of the decision problem at hand.

⇒ *The evaluation criteria*

For the evaluation problem at hand, a set of qualitative and quantitative evaluation criteria were considered (Fig. 3 below) falling into the energy, spatial, social and environmental domains.

Fig. 3: Evaluation criteria (evaluation / selection stage)



These were used for the evaluation of the pre-selected sites by means of two multicriteria evaluation methods, namely the ELECTRE I and the REGIME method.

⇒ *Criteria priorities*

Defining weights in an evaluation problem, i.e. attaching priorities between different criteria, is fundamentally a political problem (Nijkamp and Torrieri, 2000).

The criteria priorities set in the present study (Table 2 below) reflect the preferences of local administrative bodies, in alignment with the goal of the study. These are based on the following rationale:

- Of first priority is considered the *energy domain*. The area at hand is a highly industrialized region, which has resulted to a certain deterioration of its environmental quality. At the same time, the region is very attractive for the location of new productive activities, due to its proximity to the Athens metropolitan region. Moreover, current industrial policy is expected to further stimulate the location of industry in the region. In order to keep or even improve the environmental assets of the area at hand, energy consumption patterns of the industrial sector are crucial. In this respect, there is a need to ensure that each new productive infrastructure will assure the production of at least a certain part of its energy demand by RES exploitation, serving thus local environmental objectives. Along these lines, energy domain criteria are considered as of highest priority, where the more the energy (K1) produced by the wind park installation the better for the region's environmental objectives; while the least the distance (K2) from the electricity distribution network the less the losses of electricity from the production site (wind park) to the network.

- Second highest priority is attached to *environmental criteria* and more specifically the CO_2 mitigation potential (K8) as well as flora (K6) and fauna (K7) protection due to the functioning of the wind park installation. Environmental benefits are strongly depended on the amount of energy produced by the wind park. The more the energy produced the larger the CO_2 mitigation potential, compared to the use of fossil fuels by the industrial firms located in the industrial region; and the lower the impact on the flora and fauna of the region.
- *Social criteria* are considered as third priority in respect to energy and environmental criteria, since the proposed wind park location areas entail a low visual disturbance (K5) for the surrounding local communities; while *spatial criteria*, relating to the accessibility (K3) of wind park areas as well as the distance (K4) from the industrial region are considered of equal priority to social criteria in the evaluation problem at hand.

Table 2: Criteria priorities

Criteria Priorities	Groups of criteria of equal priority
a. Energy	K1, K2
b. Environmental	K6, K7, K8
c. Social - spatial	K3, K4, K5

⇒ *Impact matrix*

On the basis of the evaluation criteria and the scores of the alternative sites i.e. the performance of each alternative site in respect to each single evaluation criterion, the following *impact matrix* is constructed, presenting the evaluation problem at hand (see Table 3 below).

Table 3: Impact matrix **-** Input to the evaluation / selection stage

Alternative / **Criterion**	**Alternative 1**	**Alternative 2**	**Alternative 3**
K1[2]	41.004 MWh	51.187 MWh	39.807 MWh
K2	3.7 Km	0 Km	2.9 Km
K3	- - -	+ + +	-
K4	77 Km	73 Km	60 Km
K5	5	3	1
K6	- - -	- - -	-
K7	- - -	- - -	-
K8	34853 ton.	43509 ton.	33836 ton.

3.3 Evaluation of Potential Sites – Empirical Results

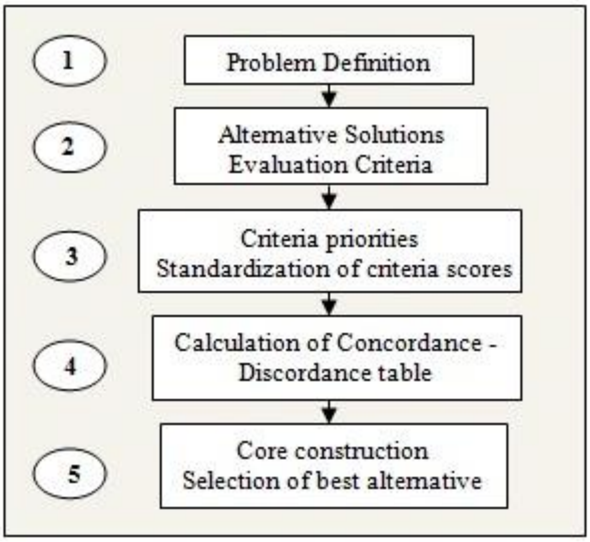
In this section, are presented the results obtained from the application of the ELECTRE I and REGIME multicriteria methods in the evaluation problem at hand.

3.3.1. Empirical results by use of ELECTRE I method

The steps undertaken in the ELECTRE I MCA method are presented in Fig. 4 below. Steps 1 and 2 of this process are already presented in previous sections. In Step 3, two very important issues of the ELECTRE I evaluation process are defined, namely the criteria priorities as well as the standardized scores of criteria.

[2] Calculated by the RETScreen Wind Energy model, RETScreen (2004).

Fig. 4: Steps in the ELECTRE I evaluation process



Criteria priorities are presented in Table 4 below and are following the previously described rationale.

Table 4: Criteria priorities and respective weights in the application of ELECTRE I

Criteria priorities	Groups of criteria	Weight (%)
Energy	K1, K2	45
Environment	K6, K7, K8	35
Social - Spatial	K3, K4, K5	20

Next step concerns the *standardization* of criteria scores. As scores presented in the impact matrix (Table 3 above) are mutually incomparable due to the different nature of criteria (quantitative and qualitative) and respective measurement units, a certain transformation of scores has to be carried out in order to standardize score values.

By considering a range of scores from 0 to 20, the following formula was used for the standardization *of quantitative* scores:

*Standardized raw score i = [‘raw’ score i / maximum ‘raw’ score]*20* [3] (3.1)

Table 5: Concessions for the transformation of quantitative scores into 0-20 scale

α/α	Criterion	Minimum – maximum range
K1	Energy produced	Minimum is 0 MWh – maximum value is considered the 60.000 MWh, corresponding to the value of 20.
K3	Distance from electricity network (400 kv dc)	Least distance is considered as the best (value of 20) while maximum distance of 15km is grading to 0.
K4	Distance from industrial region	Least distance is considered as the maximum (best - value of 20), while maximum distance of 200 km is grading to 0.
K8	Decrease of CO_2 emissions	Maximum value is considered a decrease of CO_2 emissions of 50.000 tones (best value corresponding to 20).

Ratio-scale properties of quantitative scores still hold in the transformation of formula 3.1. For arithmetic reasons, instead of the maximum raw score, a hypothetical maximum score was used. As Voogd (1983) notices, such a score can be considered as a kind of *achievement level* e.g.

[3] Multiplication by 20 transforms range of scores from ‘0 to 1’ to ‘0 to 20’.

maximum energy production of 60.000 KWh or *constraint* e.g. maximum distance from electricity network 15 km (see Table 5 above).

With regard to the transformation of the *qualitative scores*, standardization is accomplished by defining the *step* for each ordinal scale in respect to the range of 0 to 20. In such a context, in the first ordinal scale[4] (--- to +++, 6 classes, 5 steps), --- corresponds to 0, -- to 4, - to 8, + to 12, ++ to 16 and +++ to 20; while in the second ordinal scale[5] (1 to 5, 5 classes, 4 steps), 1 corresponds to 20, 2 to 15, 3 to 10, 4 to 5 and 5 to 0.

Table 6: Impact matrix with standardized criteria scores

Criterion \ Alternative		Alternative E1	Alternative E2	Alternative E3	Criterion weight
K1	Energy produced	13.67~14.00	17.06~17.00	13.27~13.00	45/2 = 22.5
K2	Distance from the electricity network (400kv dc)	15.07~15.00	20.00	16.13~16.00	45/2 = 22.5
K3	Access to wind park area	0.00	20.00	8.00	20/3 = 6.67
K4	Distance from industrial region	12.30~12.00	12.70~13.00	14.00	20/3 = 6.67
K5	Visual disturbance	0.00	10.00	20.00	20/3 = 6.67
K6	Impact on flora	0.00	0.00	8.00	35/3 = 11.67
K7	Impact on fauna	0.00	0.00	8.00	35/3 = 11.67
K8	Decrease of CO_2 emissions	13.94~14.00	17.40~17.00	13.53~13.50	35/3 = 11.67

Moreover, within each criteria domain, criteria are considered to get the same weight. In such a context, in the 'energy' domain, criteria K1 and K2 are getting an equal weight of 22.5 (45/2); in the 'environment' domain, criteria K6, K7 and K8 are getting a weight of 11.67 (35/3); while in the 'social-spatial' domain, criteria K3, K4 and K5 are getting a weight of 6.67 (20/3).

Based on the above described transformations, the impact matrix takes the form presented in Table 6 above.

It follows Step 4, where the concordance and discordance tables are constructed (see Fig. 4 above).

The elements of the *concordance table* are calculated by use of the following analytical formulas (Psarras, 2008):

$$C(a,b) = \frac{1}{w} \sum_{gj(a) \geq gj(b)} w_j \qquad (3.2)$$

$$0 \leq C(a,b) \leq 1 \qquad (3.3)$$

where w_j, j=1, 2,…,n, is the weight of those criteria for which $g_j(\alpha)Sg_j(b)$ with $g_j(\alpha)$ and $g_j(b)$ the scores of alternatives a and b in respect to the criterion j.

Table 7: Concordance table

	NaN	0.23	0.34
c =	1.00	NaN	0.63
	0.66	0.37	NaN

The output is an *mxm concordance table*, with m the number of choice options. The concordance table of the evaluation problem at hand has as follows (Table 7 above):

The *discordance table* is calculated by use of the following analytical formula (Psarras, 2008) (Table 8):

[4] - - - very high negative effect, - - high negative effect, - low negative effect, + low positive effect, ++ high positive effect, +++ very high positive effect,

[5] 1:very good, 2:good, 3:neutral (no impact), 4:bad 5:very bad

$$D(a,b) = \frac{1}{\delta} \max_j (g_j(b) - g_j(a)) \tag{3.4}$$

$$0 \leq D(a,b) \leq 1 \tag{3.5}$$

where $$\delta = \max_{a,b,j} (g_j(a) - g_j(b)) \tag{3.6}$$

Table 8: Discordance table

	NaN	1.00	1.00
c =	0	NaN	0.50
	0.05	0.60	NaN

In Step 5 (see Fig. 4 above), the core is identified as the set of alternatives that pass both concordance and discordance tests. For that purpose, every pair of *alternatives a and b* is tested on the basis of concordance $\hat{c}$ and veto $\hat{d}$ thresholds, verifying whether the outranking relation aSb is true (Psarras, 2008):

$$aSb \Leftrightarrow \begin{cases} C(a,b) \geq \hat{c} & (3.7) \\ D(a,b) \leq \hat{d} & (3.8) \end{cases}$$

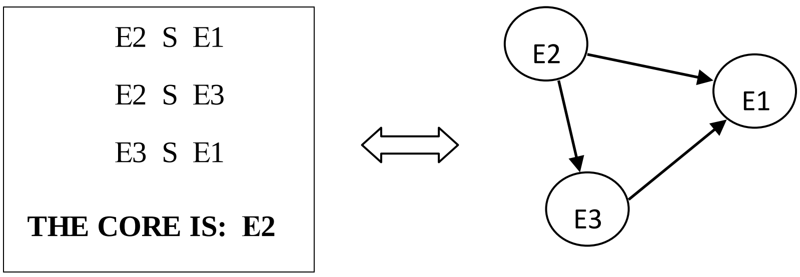
where $\hat{c}$ the concordance and $\hat{d}$ the discordance (veto) thresholds.

The identification of the core consists of an iterative process, starting with values of $\hat{c}$ close to 1 and $\hat{d}$ close to 0. The whole process is repeated by use of different threshold values, where concordance threshold decreases, while veto threshold increases gradually.

The following tests were carried out in the present evaluation study:

- *Concordance threshold $\hat{c}$ = 0.9 and veto threshold $\hat{d}$ = 0.1.* Alternative E2 prevails over E1, while the relationship between E1 and E3 is not known. Core is Π = {E2, E3}.
- *Concordance threshold $\hat{c}$ = 0.6 and veto threshold $\hat{d}$ = 0.3.* Alternative E2 prevails over E1 and E3 prevails over E1. Core is Π = {E2, E3}.
- *Concordance threshold $\hat{c}$ = 0.6 and veto threshold $\hat{d}$ = 0.5.* Alternative E2 prevails over E1 and E3. Core is Π = {E2} (see Fig. 5 below).

Fig. 5: Concordance – discordance tests for $\hat{c}$ = 0.6 and $\hat{d}$ = 0.5.

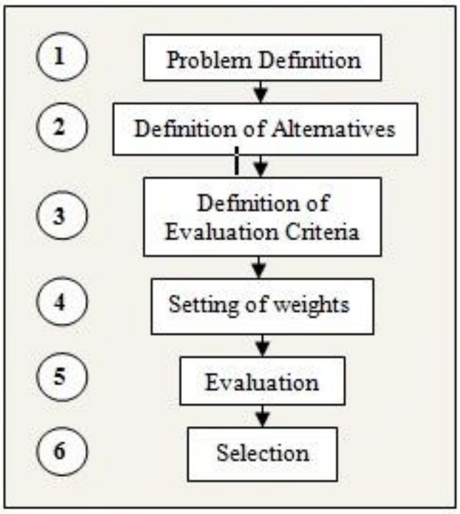


The above analysis supports the selection of alternative 2 (E2) as the prevailing one in the evaluation problem at hand.

3.3.2. Empirical results by use of REGIME method

The steps followed in the REGIME method are shown in Fig. 6 below. The impact matrix is the main input to the REGIME[6] MCA method (see Table 3), together with information on the nature, scale and direction of the evaluation criteria (see Fig. 3) and their priorities (Table 2).

Fig. 6: Steps of the evaluation process in the REGIME method



The probability table (Table 9) calculated by the REGIME method shows the relative success indices of each alternative. Each element of the probability table presents the probability a certain alternative (row alternative) to prevail over another alternative (column alternative).

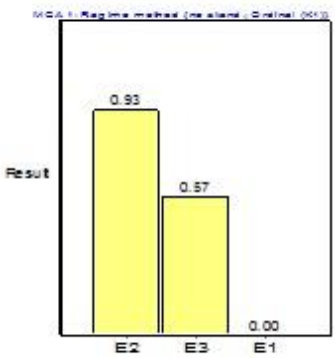
Table 9: Probability table

	E1	**E2**	**E3**
E1	-	0.00	0.00
E2	1.00	-	0.86
E3	1.00	0.14	-

Figure 7: Results obtained by the REGIME method

Criteria priorities	
1st	K1: energy produced K2: distance from electricity network
2nd	K6: impact on flora K7: impact on fauna K8: decrease of CO_2 emissions
3rd	K3: access to wind park area K4: distance from industrial region K5: visual disturbance

Alterna-tive	Total score
E1	0.00
E2	0.93
E3	0.57



The overall score of each alternative is then calculated as the *row average* of the relative success indices. As shown in Fig. 7, the highest score is attained by alternative E2, getting a row

[6] Use of DEFINITE Software (DEcisions on a FINITE Set of Alternatives), Janssen et al (2001).

average of 0.93, followed by E3 with a row average of 0.54, while E1 ranks at the bottom, getting a raw average of 0.00.

The above analysis results to the selection of alternative 2 (E2) as the prevailing option, which further reinforces the results obtained by the ELECTRE I multicriteria analysis.

4. Conclusions

The focus of the present paper is on the development of a methodological framework for the assessment of alternative wind park locations. Such a framework needs to take into account technical, economic, environmental, cultural and other aspects involved in the development of renewable energy installations, which imply the need to deal effectively with both qualitative and quantitative data. Moreover, it needs to take into consideration the different views/priorities set by the variety of stakeholders involved.

Towards this end, multicriteria evaluation has proved to be a useful tool, as it may offer a flexible and multidisciplinary assessment framework that is capable of: capturing the plurality of dimensions involved in such planning problems; prioritizing alternative solutions and supporting decision making in a coherent and transparent way; increasing participatory potential by involving priorities of a range of stakeholders, associated with the particular decision problem at hand; offering a platform for a structured debate with stakeholders; and making better use of available data resources, both quantitative and qualitative.

The empirical study, presented in this paper, has applied the proposed methodology in a real world example, namely the assessment of alternative wind park locations, using MCA tools. Two MCA techniques were used in this respect, namely the ELECTRE I method and the REGIME method, in order to deal with method uncertainty and validate evaluation results obtained. The two methods exhibit certain differences as to the: *data handled*, where ELECTRE I deals only with quantitative data on both criteria scores and priorities, while REGIME deals with both quantitative and qualitative (mixed) data on criteria scores and priorities; and the *output*, where ELECTRE I provides the prevailing choice option, but not a clear picture on the prioritization of the rest of the alternatives, while REGIME provides a more clear cut picture, by prioritizing all choice options. This consists of the main advantage of the REGIME method over the ELECTRE I, which, unlike the REGIME method, does not always lead to an unambiguous solution. Finally, the convergence of empirical results, obtained by both techniques, on the prevailing choice option supports a more confident decision in the evaluation problem at hand.

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