Renewable Energy 103 (2017) 501–521

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Application of the GIS-DANP-MABAC multi-criteria model for selecting the location of wind farms: A case study of Vojvodina, Serbia

Ljubomir Gigović [a], Dragan Pamučar [b, *], Darko Božanić [c], Srđan Ljubojević [b]

[a] University of Defence in Belgrade, Department of Mathematics, Pavla Jurisica Sturma 33, 11000 Belgrade, Serbia
[b] University of Defence in Belgrade, Department of Logistics, Pavla Jurisica Sturma 33, 11000 Belgrade, Serbia
[c] University of Defence in Belgrade, Military Academy, Pavla Jurisica Sturma 33, 11000 Belgrade, Serbia

ARTICLE INFO

Article history:
Received 19 November 2015
Received in revised form
20 November 2016
Accepted 28 November 2016
Available online 28 November 2016

Keywords:
Location selection
GIS
DEMATEL
ANP
MABAC
Location
Wind farms

ABSTRACT

The main objective of this study is to develop a reliable model for the identification of locations for the installation of wind farms, which will provide significant support to planners in the strategy for the development and management of wind energy. The proposed model is based on the combined application of Geographic Information Systems (GIS) and Multi-Criteria Decision Analysis (MCDA) using the multi-criteria technique of Decision Making Trial and Evaluation Laboratory (DEMATEL), the Analytic Network Process (ANP) and Multi-Attributive Border Approximation area Comparison (MABAC). Application of the model is presented by means of a case study on the province of Vojvodina, Serbia. The model considers 11 constraints and 11 evaluation criteria which are grouped into economic, social and environmental clusters. The DEMATEL-ANP (DANP) method is used to determine the weight coefficients of the evaluation criteria, and the MABAC method is used to rank the selected viable locations. The final map of benefits is presented using raster cells (alternatives) which are evaluated in the range of 1 (least suitable) to 7 (most suitable). The results show that an area of 321 km^2 in Vojvodina is very suitable for the installation of wind farms. Ranking of viable locations using the MABAC method shows that a location in the vicinity of the village of Laudonovac (L8) is most suitable for the installation of wind farms in the province of Vojvodina. A sensitivity analysis, carried out by changing the input weights of the clusters, indicates that the model is useful for identifying suitable locations for the development of wind farm projects, as well as for assessing the suitability of already licensed projects for the construction of wind farms. The proposed method and the results of this study can be used for spatial development policy at all levels of public administration related to renewable energy resources. The model could also help to successfully identify suitable locations for the installation of wind farms in other areas with similar geographical conditions.

© 2016 Elsevier Ltd. All rights reserved.

1. Introduction

Energy is a key element necessary for the sustainable development and prosperity of a society [1]. Over 80% of the world's energy production is based on fossil fuels - coal, oil and natural gas [2]. However, the global oil reserves are limited and unevenly distributed, which could in the near future lead to serious political and economic conflicts [3]. The increasing demand for energy and the depletion of fossil fuels inevitably causes a rise in their price. This is why most countries have started to develop new energy security policies in order to reduce energy costs and increase energy independence. At the same time, increasing awareness of environmental pollution has also led to an increasing use of renewable energy sources (RES) [4]. Besides renewable energy sources (RES) being inexhaustible and reducing the energy dependence of society on fossil fuels, they are also the most acceptable sources of energy from an environmental point of view and from the aspect of the fight against global climate change [5]. In order to increase energy independence, the European Union (EU) states determined a strategy that by 2020 they would increase the share of renewable sources to 20% of their total energy consumption [6].

The development of RES, together with measures aimed at more efficient use of energy are priorities at a national and European

* Corresponding author.
E-mail addresses: gigoviclj@gmail.com (L. Gigović), dpamucar@gmail.com (D. Pamučar), dbozanic@yahoo.com (D. Božanić), srdjanljubojevic@gmail.com (S. Ljubojević).

http://dx.doi.org/10.1016/j.renene.2016.11.057
0960-1481/© 2016 Elsevier Ltd. All rights reserved.

level, as both the basis of environmental protection and of energy policy. According to Directive 2009/28/EZ [7] and the Decision of the Ministerial Council of the Energy Community [8] a binding target was determined that by 2020, renewable energy would make up 27% of the gross share of energy consumption in the Republic of Serbia. In order to achieve this level and to encourage use of RES, the Republic of Serbia has adopted a number of bylaws in the field of renewable energy which define the conditions for using renewable energy sources [9,10], and it has developed a National action plan for the use of sources of renewable energy [11].

In recent years, wind energy has become one of the most popular sources of renewable energy [12] (Zhao et al., 2012). Use of wind energy has a relatively small impact on the environment (visual effects, the loss of birds colliding with wind turbines, the negative effects of noise on animals, loss or damage to the habitat of certain species, etc. compared to the more serious effects of conventional electricity production, which contribute to climate change and disrupt the natural balance [13,14]. Wind energy is renewable and clean: it does not pollute the air, it does not emit CO_2, and it does not cause acid rain or destroy the ozone layer. For these reasons, many countries have developed projects in recent years and invested in the construction of wind farms (WF); other reasons for wind farm projects are their quick and relatively simple installation [15,16]. Wind energy has proven to be a serious source of renewable energy that is developing globally and that has an installed capacity that significantly increases each year [17].

The choice of suitable locations for wind farms is a complex issue that requires the careful and combined analysis of numerous criteria. On a global level, a large number of wind farms follow mainly economic criteria, ignoring any negative effects on the environment [14–16]. The optimal selection of locations for wind farms requires the resolution of mutually conflicting factors of an economic and technological nature, with ecological and social limitations, while also respecting public opinion [18,19]. In other words, spatial planners are faced with a double challenge, since they must answer for the wind farm projects they work on, which must be able to generate economic benefit on the one hand, while minimizing risks to the environment and the interests of stakeholders on the other [20,21]. In order to achieve this, it is essential to establish certain rules that will evaluate different locations on the basis of a range of environmental, economic and social criteria and constraints [22].

Geoinformation technologies are suitable for this type of study because they can efficiently manage large amounts of spatial and attribute data collected from various sources. Geoinformation systems also have certain shortcomings, seen in their inability to make multi-criteria decisions and to propose optimal locations. In order to facilitate multi-criteria decision making and to present the spatial results using a GIS, it is essential to combine the tools of multi-criteria decision analysis (MCDA) with GIS. The combination of GIS and MCDA is a concept that is widely used in solving problems in many areas, such as the environment, ecology, transportation, urban and regional planning, waste management, hydrology, agriculture, forestry, geology, site selection and bank branches location [23,24].

GIS-MCDA is currently the most frequently applied concept to support decision-makers looking for suitable locations for wind farms. This is confirmed by relevant literature. Miller and Li [17], using the experience gained in a number of studies, defined a set of physical and socio-economic factors, and on the basis of a multi-criteria model in the framework of a GIS they identified areas best suited to the development of wind energy in Nebraska, USA. Aydin et al. [13] used a GIS to define a spatial decision support system (SDSS) for finding locations for wind farms in western Turkey. In their study, the criteria adopted for siting wind farms were wind potential and parameters of environmental suitability. The environmental criteria: noise, bird habitats, safety and aesthetics were represented on a map as fuzzy sets. Their final map of benefits for the location of wind farms was the result of this being combined with a map of wind resources. Similarly, Latinopoulos and Kechagia [25] used a multi-criteria modeling technique in a GIS to find potential locations for wind farms in the Regional Unit of Kozani, in Greece. This procedure was developed with the help of various technological, economic, social and environmental criteria, which were represented as fuzzy sets and used either as factors of constraint or evaluation, and a final check was made using a composite Suitability Index (SI). Using spatial and environmental criteria, Gorsevski et al. [26] modeled a spatial decision support system (SDSS) based on a weighted linear combination and a GIS, in order to find locations for wind farms in northwest Ohio. Haaren and Fthenakis [27] introduced a method for selecting the locations for wind farms in New York State based on a spatial cost-revenue optimization. In the first phase of selection, they dismissed areas in which it was impossible to locate wind farms due to the land use or geological constraints. In the second selection phase, they identified the best feasible sites based on the expected net present value of four major spatially dependent cost and revenue criteria: revenue from the electricity generated, and the cost of access roads, power lines and clearing the land. Finally, in the third phase they evaluated the impact on birds and on their habitat. They compared their results with the actual locations of wind farms. Kim et al. [28] investigated suitable locations for offshore wind farms around the Korean Peninsula, based on benefit to cost ratio. Szurek et al. [29] used a multi-criteria method of spatial analysis based on the Analytic Hierarchy Process (AHP) and Weighted Linear Combination (WLC) within a GIS for assessing the suitability of land for the location of wind farms in a study of the municipality of Prusice, in Lower Silesia, in Poland. The criteria adopted were identified on the basis of available literature. These criteria include the technical, environmental, social and environmental aspects of constructing wind farms. Mekonnen and Gorsevski [30] used a web-based Participatory Geographic Information System (PGIS) to investigate the suitability of an offshore wind farm for Lake Erie in Ohio. When examining suitable sites for wind farms on the island of Lesvos, Tegou LI et al. [14] combined multi-criteria analysis with a GIS. Based on their set of environmental, economic, social and technical constraints which took legal aspects into consideration, they identified potential locations for wind farms. In addition, the study area was evaluated by a variety of criteria, such as wind resources, land cover, electricity demand, visual impact, land value and distance from the power grid. Then the pair-wise comparison method was applied, within the AHP, to calculate the weights of different criteria and to determine the relative importance of the evaluation areas. Using the same methodology in Oman, Al-Yahyai et al. [31] integrated a GIS and multi-criteria analysis to assess the suitability of the land for wind farms. The criteria for analysis were topographic (distance to road, slope), urban, environmental (historical locations and nature) and technical (wind power, energy demand). Similarly, Watson and Hudson [31] used a GIS-MCDM model to assess the suitability of land for wind and solar farms on the south coast of the United Kingdom. They used the AHP method for determining the weights of the criteria. They assessed the reliability of the model by means of a sensitivity analysis. Yeh and Huang [18] used the Goal/Question/Metric (GQM), fuzzy DEMATEL and ANP method to work out the most important factors that determine the choice of locations for wind farms. Their results show that safety and quality criteria and environment and ecology criteria are of paramount importance. As their basic institutional decision making instrument for locating sites for wind farms in Crete, Tsoutsos et al. [33] used a Specific Framework for the Spatial

Planning and Sustainable Development for Renewable Energy Sources (SFSPSD-RES) applied in Geographic Information Systems as well as the parallel integration of a systematic and flexible method of multi-criteria analysis. Bagocius et al. [34] proposed the WASPAS method for selecting the best locations for offshore wind farms and for selecting the best wind turbines in the Baltic Sea. Finally, Azizi et al. [35], for assessing the possibility of establishing wind farms in the Ardabil province of north-western Iran, used the hybrid ANP-DEMATEL method in combination with a GIS. They used DEMATEL for determining the relation between the criteria, and used ANP to determine the relative importance of 13 criteria of a natural, technical or economic character. In addition to the above, there have been many studies about similar problems and those of solar power [36–41].

By analyzing the literature cited here, MCDA in combination with a GIS emerges as an effective tool for identifying areas that are favorable for the utilization of wind energy. This paper presents a hybrid model for identifying the best locations for wind farms. The model considers 11 constraints and 11 evaluation criteria grouped into economic, social and environmental clusters. In the hybrid GIS-MCDA model, the fuzzy DEMATEL method [42] is implemented to determine connections in the network structure based on the criteria. Pair-wise comparisons of the criteria/clusters from the DEMATEL method are the input parameters for the mathematical apparatus of the ANP method. Weight coefficients of the criteria/clusters are obtained as the output values from the ANP method, which are then used in the GIS for obtaining the final map of most suitable locations for wind farms. Examples of DEMATEL and ANP integration can be seen in many studies [43–50]. After determining the most suitable locations, the MABAC method is used to select the most suitable location from them. Application of the model is presented as a case study of the region of Vojvodina in Serbia.

The main contribution of the research in this study is that it develops and tests a complex spatial decision making model for selecting the optimal location for the installation of wind farms. This model can serve as a useful tool in strategic decision-making related to the planning and development of wind energy potential in Serbia. The model is based on a combination of GIS with the DEMATEL, ANP and MABAC methods of multi-criteria analysis. The proposed methodology enables comprehensive and systematic problem solving in the process of decision making when selecting optimal location solutions for the installation of wind farms, in accordance with the adopted criteria, while at the same time securing the timely and effective participation of the interested parties. The scientific contribution of the research is seen in the application of different multi-criteria methods, which are combined in different phases of decision-making with GIS, and used as support in the selection of optimal location solutions for the installation of wind farms in Serbia. The DEMATEL and ANP methods of optimization are used to carry out the evaluation of the used criteria in a scientifically acceptable way, and the MABAC method is used to rank the alternative locations. Finally, the stability of the chosen solution is checked by means of a sensitivity analysis related to the influence of the criteria, and validation of the results using the MABAC method is confirmed by comparing them with the results given by the most commonly used multi-criteria techniques of VIKOR (VIšeKriterijumska Optimizacija I Kompromisno Rešenje in Serbian, means Multicriteria Optimization and Compromise Solution), TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) and COPRAS (COmpressed PRoportional ASsessment). The possibility of applying this model is verified through the analysis of a specific case in the region of Vojvodina, so that with justification it can be said that it can have a significant role in the area of developing spatial plans and construction projects for wind energy. It is expected that this study will lead to a better understanding of the potential of wind energy, which is still in its early stages of development in Serbia.

The paper is organized in four sections. The introductory section presents the importance of renewable sources of energy, as well as an overview of models relevant to the analysis and selection of location for the development of wind farms. The second section of the paper presents and describes the phases of the proposed GIS-DANP-MABAC model. Following this, the third section presents the testing of the GIS-DANP-MABAC model through empirical study in the region of Vojvodina. In addition to testing the GIS-DANP-MABAC model, in the third section a sensitivity analysis is performed, as well as a validation of the results. The validation is performed by comparing the results (locations) of the GIS-DANP-MABAC model with the results given by the most commonly used multi-criteria techniques of VIKOR, TOPSIS and COPRAS. In the fourth and final section are the concluding considerations and suggestions for future research in this area.

2. Methodological background

2.1. Defining the aim/problem and architecture of the model

The model presented in this paper is based on the spatial structure of MCDA. Spatial multi-criteria decision analysis (SMCDA) consists of procedures which include the use of both geographic data and preferences of the decision maker (DM), and the manipulation of data and preferences according to specified decision rules [51,52]. This approach exploits the capabilities of GIS in the management of spatial data, and the flexibility of MCDA to combine real spatial information (e.g. slope, communication, use of the land) with value-based information (e.g. expert opinion, standards, surveys) [53]. The main advantage of integrating GIS and MCDA can be seen in their specific capabilities supplementing each other. GIS has great possibilities for the manipulation, storage, management, analysis and visualization of geospatial data, while MCDA provides a collection of procedures, techniques and algorithms for structuring decision problems, and designing, evaluating and prioritizing decision alternatives [54].

Creating the network structure of the model is an important creative stage in the decision making process, since considering all of the factors and their interactions is a necessary condition for forming a correct model and for the selection of an adequate solution. Because of the complexity of the problem of determining a location, the GIS-MCDA model is proposed as a relevant option for systematic analysis and rational decision making when selecting locations for wind farms. From a methodological point of view, the proposed GIS-DANP-MABAC model for identifying suitable locations for wind farms includes the stages presented in Fig. 1. The following part of the paper presents the stages of the GIS-DANP-MABAC model (see Fig. 2).

Phase 1. Preliminary study. The first step in this phase includes defining the problem, the area of study and the construction of the architectural model. The second step is the complex and significant process of grouping and defining the constraints and the criteria with particular influence on assessing the suitability of land for the installation of wind farms. Experts with a lot of experience in the fields of energy, spatial planning, economics and environmental protection are directly involved in the scientific basis of defining the constraints and the criteria.

Phase 2. Collection of data and their input into the GIS enables the input, acceptance and transformation of spatial and thematic data in digital form. The input data mainly come from cartographic documents, field recordings, different plans and statistical reports. The datasets in a GIS are usually organized in raster format with a defined spatial resolution.

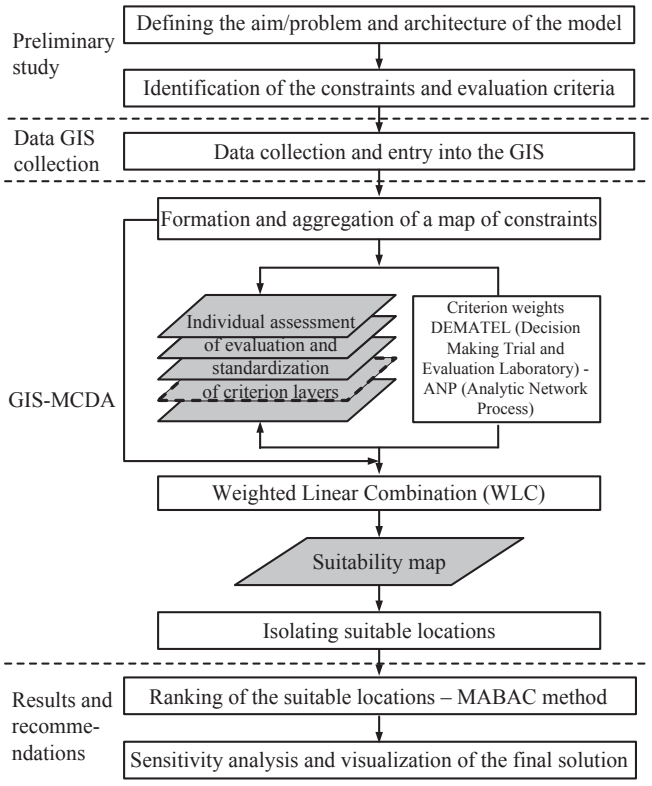


Fig. 1. The GIS-DANP-MABAC model.

Phase 3. The GIS-MCDA phase includes producing a map of constraints, standardization, weighting, a summary analysis of all criteria and clusters to be considered in the evaluation of the land, and defining the most suitable alternative from the standpoint of its suitability for the installation of wind farms.

The first step of this phase is making the map of constraints on the basis of the defined values, which excludes some areas from further analysis. Standardization is the second step of this phase, in which the criteria and constraints, which are presented on the maps in the form of different GIS layers, are transformed (reclassified) into units that can be compared. The standardized values of the constraints are calculated by applying Boolean (logical) algebra and they can have the value of suitable (1) or unsuitable (0). The decision as to which method to apply in the standardization of the evaluation criteria depends on the nature of the attributes and on the decision maker. The most commonly applied method is linear transformation, or calculation on the interval scale, after which

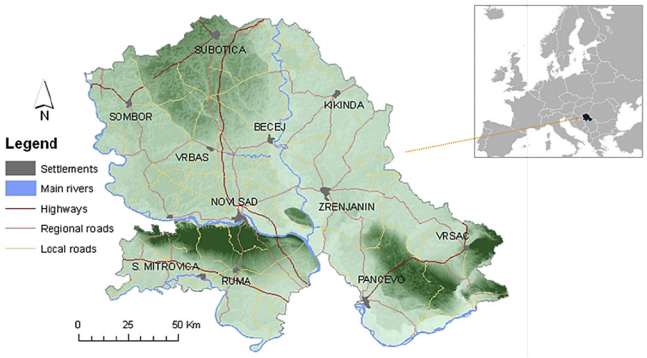


Fig. 2. The geographical position of the study area.

every raster cell (attribute) obtains a dimensionless value x_i on the adopted scale in relation to the objective of the analysis. This makes it possible to continue arithmetic operations with the maps of criteria. In this study, linear standardization was used in the process of standardizing the data sets of the evaluation criteria.

In the next step, weighting is carried out, namely, determining the weight coefficients of the evaluation criteria. When solving real problems, the criteria do not have the same degree of significance, and so it is necessary for the decision maker to define the influence of the individual criteria using appropriate weight coefficients (weights) for the criteria. The DEMATEL and ANP methods are used for calculating the normalized weights of the criteria. Methodologically speaking, DEMATEL and ANP are multi-criteria techniques based on breaking down a complex problem into a hierarchy, and in this model they are used for determining the correlations and the weight coefficients of the clusters/criteria.

As a result of the step applying the weighted linear combination (WLC) method, a suitability map is generated on which the raster cells obtain a dimensionless index value of suitability S_i. Higher S_i values characterize space that is more suitable for the construction of wind farms. The final step of the phase is isolating the cells of the raster with the highest values, representing the most suitable alternatives (locations) for installing wind farms.

Phase 4. This phase of the model includes the steps of ranking the viable locations for the installation of wind farms, checking the results by means of a sensitivity analysis and the final definition of the best location. Ranking of the locations is carried out by means of the Multi-Attributive Border Approximation area Comparison (MABAC) method, according to the same evaluation criteria. The sensitivity analysis is recommended as a means of checking the stability of the results, and as a way of eliminating errors caused by the subjectivity of the decision maker. There are several ways of checking the consistency of the results, and in this study the sensitivity analysis is performed by changing the input parameters of the clusters. Validation of the results obtained using the MABAC method is carried out by comparing them with the results given by the most commonly used multi-criteria techniques of VIKOR, TOPSIS and COPRAS. The final step of the last phase is to define and visualize the most suitable solutions for the location of a wind farm.

The following subsections will include a more detailed description of the phases and the mathematical basis for the GIS-DANP-MABAC model.

2.2. Preliminary study

After defining the problem and establishing the model, the constraints and evaluation criteria are identified. The process of selecting a location is an MCDA problem that requires consideration of a comprehensive set of criteria to establish the suitability of a given area for the defined land use [54]. The identification of criteria involves a systematic analysis of factors that may impact installation of the wind farms [21]. This is achieved through questionnaires [55], workshops organized with stakeholders [56], or based on some expert knowledge or a combination of all of these [57].

Two categories of criteria were used in the decision making process: constraints and evaluation criteria. The constraints are based on criteria which limit (dismiss) possible alternatives and which are based on the Boolean relation (true/false), while the evaluation criteria can be quantified according to their degree of suitability for all feasible alternatives [14,58,59].

By investigating GIS-MCDA studies [13,14,27,29,31–41,60] it can be noted that in the decision making process for the selection of locations for wind farms, the most commonly used clusters are those of an environmental, spatial, social and technical nature,

which are proposed in this model.

2.3. GIS multi-criteria decision analysis

After defining the constraints and clusters/criteria they are entered into the GIS. During this step, it is necessary to form individual maps of the layers that correspond to each of the identified evaluation constraints and criteria. This is achieved using different GIS operations that are used to carry out input acceptance or transformation of spatial and thematic data into a digital form (map overlay, buffering, distance mapping, etc.). The input data originate from digital and analog cartographic documents, field recordings, various plans, statistical reports, etc. The datasets in GIS are usually organized in vector or raster format. In the next steps of the GIS arithmetical operations (reclassification, overlay function, Boolean algebra, etc.), the criteria maps are converted into a raster format, in which each raster cell represents an alternative in relation to the goal. The raster data format is used because of its simplicity compared to the vector data format [61].

2.4. GIS-DANP multicriteria evaluation

GIS-MCDA includes aggregation of the constraints, standardization, weighting, a summary analysis of all the criteria to be considered in the decision-making process and selection of the best alternatives. At the step of forming and aggregating the map of constraints, all of the layers of constraints on the thematic maps are obtained using Boolean (logical) algebra, and the raster cells (alternatives) of the dismissed areas are assigned a value of zero (0), while the alternatives for the remaining areas are given a value of one (1). The final constraints of the area are obtained by the aggregation of all of the layers of constraints. On the final map of constraints, only the locations characterized as suitable (value 1) on all of the layers of constraints are considered as potential locations for constructing wind farms and are the subject of the analysis [20].

After this, individual assessment of the evaluation criteria and standardization of the clusters/criteria takes place. The criteria on the maps are presented in the form of GIS layers in different ways and in different forms. Use of the method of weighted linear combination (WLC) requires that all data sets be standardized [62] or transformed into units that can be compared. There are a variety of approaches that can be used to make the attribute layers of the maps comparable, and a description of some of these can be seen in Malczewski [52]. Selecting a method to be applied depends on the nature of the attributes and the DM. Based on the assessment of the DM and the literature available for scaling the criteria, classification of the attribute values into classes is recommended, since this method gives very good results in real time [29,55]. Data on the raster maps are also divided into i classes of suitability, and then each class is assigned a score of x_i from the adopted scale. In this way, each raster cell (attribute) obtains an integer value of x_i in relation to its membership of class i.

When solving real problems, the criteria do not have the same degree of importance, so it is necessary for the decision maker to define the importance of the individual criteria using appropriate weight coefficients (weights) for the criteria. Use of the WLC method requires normalization of the weights. When determining the weight coefficients of the clusters/criteria, the hybrid DANP model is used for calculating the normalized weight criteria and for the final application of the WLC method.

The DEMATEL method was originally developed by the Science and Human Affairs Program of the Battelle Memorial Institute of Geneva, with the purpose of studying complex and intertwined problematic groups [63]. It has been widely accepted as one of the best tools for solving the cause and effect relationship between the evaluation criteria [63–67]. This method is applied to analyze and form the relationship of cause and effect between the evaluation criteria [68] or to derive interrelationship among the factors [67].

The original DEMATEL method is modified by some researchers so as to make it comply with their problems. The modified fuzzy DEMATEL method used in this paper is adapted from a study by Dalalah et al. [42]. Based on Dalalah et al. [42], the procedure for carrying out the fuzzy DEMATEL method is described in the following section:

Step 1. Gather experts' opinion and calculate the average matrix $\tilde{z}$. A group of m experts and n factors are used in this step. Each expert is asked to view the degree of direct influence between two factors based on pair-wise comparison. The modified fuzzy DEMATEL method is built first, creating the direct-relation fuzzy matrix $\tilde{z}$ where $\tilde{z}$ is the (nxn) matrix, n represents the number of criteria. The direct relation matrices are all obtained by holding a pair-wise comparison among the criteria themselves in which $\tilde{z}_{ij}$ indicates the degree to which criterion C_i affects criterion C_j therefore the relationships between the criteria can be held within a matrix. For each expert, an $[z_{ij}]_{nxn}$ non-negative matrix is constructed (n represents the number of criteria) as $Z^e = [\tilde{z}^e_{ij}]$, where e is the number of experts participating in the evaluation process with $1 \le e \le m$. Thus, $Z^1, Z^2, \ldots, Z^m$ are the matrices from m experts. In this method, the effects of the criteria on each other are expressed in terms of linguistic expressions. Pair-wise comparison of the criteria of the experts is carried out using a fuzzified scale in which linguistic expressions are represented by means of triangular fuzzy numbers $\tilde{z}^e_{ij} = (z^{(l)}_{ij,e}, z^{(m)}_{ij,e}, z^{(r)}_{ij,e}), e = 1, 2, \ldots, m$, where e denotes an expert, and m is the total number of experts. The final matrix $Z = [\tilde{z}_{ij}]$ is obtained by aggregating the expert opinions. The elements of matrix Z are obtained using expressions (1)–(3)

$$z^{(l)}_{ij,e} = \min_M \left\{ z^{(l)}_{ij,e} \right\},\ M = \{1, 2, \ldots, e, \ldots, m\} \tag{1}$$

$$z^{(m)}_{ij,e} = \frac{1}{m} \sum_{k=1}^{m} z^{(m)}_{ij,k} \tag{2}$$

$$z^{(r)}_{ij,e} = \max_M \left\{ z^{(r)}_{ij,e} \right\},\ M = \{1, 2, \ldots, e, \ldots, m\} \tag{3}$$

where $z^{(l)}_{ij,e}$, $z^{(m)}_{ij,e}$ and $z^{(r)}_{ij,e}$ are the preferences of the e-th expert, M is the set of experts involved in the investigation, e denotes an expert, and m is the total number of experts.

Step 2. Calculate the normalized initial direct-relation matrix D. In this step, the elements of the normalized initial direct-relation matrix $D = [d_{ij}]$ are calculated. The elements of matrix D (4) are calculated using equations (5) and (6).

$$D = \begin{bmatrix} d_{11} & d_{12} & \ldots & d_{1n} \\ d_{21} & d_{22} & \ldots & d_{2n} \\ \ldots & \ldots & \ldots & \ldots \\ d_{n1} & d_{n2} & \ldots & d_{nn} \end{bmatrix} \tag{4}$$

The elements of matrix D are obtained by summing the elements of the average matrix Z by rows. Following this, using equation (6), the maximum element R is found among the summed elements. By using simple normalization, equation (5), each element of matrix Z is divided by the value we obtain using expression (6) [69].

$$d_{ij} = \frac{\tilde{z}_{ij}}{R} = \left(\frac{z_{ij}^{(l)}}{r^{(r)}}, \frac{z_{ij}^{(m)}}{r^{(m)}}, \frac{z_{ij}^{(r)}}{r^{(l)}}\right) \tag{5}$$

$$R = \max\left(\sum_{j=1}^{n} \tilde{z}_{ij}\right) = \left(r^{(l)}, r^{(m)}, r^{(r)}\right) \tag{6}$$

where n is the total number of criteria.

Based on Markov chain theory, D^m are powers of matrix D, e.g. $D^1, D^2, \ldots, D^{\infty}$ guarantees the convergent solutions to the matrix inversion as shown below.

$$\lim_{m\to\infty} D^m = [0]_{nxn} \tag{7}$$

Step 3. Derive the total relation matrix T. In this step, the elements of the total relation matrix T are calculated. The total-influence matrix T is obtained by utilizing equation (8), in which, I is an nxn identity matrix. The element of $\tilde{t}_{ij}$ represents the indirect effects that factor i has on factor j, then the matrix T reflects the total relationship between each pair of system factors. The initial normalized direct-relation fuzzy matrix can be separated into separate sub matrices i.e., (D_1, D_2, D_3). It was proven that $\lim_{w\to\infty}(D_s)^w = 0$ and $\lim_{k\to\infty}(I + D_s + \ldots + D_s^2 + \ldots + D_s^k) = (I - D_s)^{-1}$, where 0 is the null matrix and I is the identity matrix [70]. Therefore, the total-relation fuzzy matrix T can be acquired by calculating the following equation [42]:

$$T = \lim_{w\to\infty}\left(D + D^2 + \ldots + D^w\right) = D(I - D)^{-1} \tag{8}$$

On the basis of this, we can present the total relation matrix for criteria (T) as

$$T = \begin{bmatrix} \tilde{t}_{11} & \tilde{t}_{12} & \ldots & \tilde{t}_{1n} \\ \tilde{t}_{21} & \tilde{t}_{22} & \ldots & \tilde{t}_{2n} \\ \ldots & \ldots & \ldots & \ldots \\ \tilde{t}_{n1} & \tilde{t}_{n2} & \ldots & \tilde{t}_{nn} \end{bmatrix} \tag{9}$$

where $\tilde{t}_{11} = (t_{ij}^{(l)}, t_{ij}^{(m)}, t_{ij}^{(r)})$ is the overall influence rating of a decision maker for each criterion i against criterion j.

Step 4. Summing elements ($\tilde{t}_{ij}$) of matrix T by rows and columns. In this step, the DEMATEL method is used to carry out summing of the elements of matrix T by columns and rows. The sum of rows and sum of columns of the sub-matrices T_1, T_2 and T_3 denoted by the fuzzy numbers D_i and R_j, respectively, can be obtained through equations (9) and (10) respectively:

$$D_i = \sum_{j=1}^{n} \tilde{t}_{ij}, \quad i = 1, 2, \ldots, n \tag{10}$$

$$R_i = \sum_{i=1}^{n} \tilde{t}_{ij}, \quad j = 1, 2, \ldots, n \tag{11}$$

where n is the number of criteria.

Let D_i be the sum of the ith row in matrix T. The value of D_i indicates the total of both the direct and indirect effects that factor i has on the other factors.

Let R_j be the sum of the jth column in matrix T. The value of R_j shows the total of both the direct and indirect effects that all other factors have on factor j. If $j = i$, the value of $(D_i + R_j)$ represents the total effects both given and received by factor i. In contrast, the value of $(D_i - R_j)$ shows the net contribution by factor i to the system. Moreover, when $(D_i - R_j)$ is positive, factor i is a net cause. When $(D_i - R_j)$ is negative, factor i is a net receiver [65,66,71,72].

Step 5. Determining the threshold value α. The threshold value α is used to construct a cause and effect relationship diagram. The threshold value α is calculated as the mean value of the elements ($\tilde{t}_{ij}$ of matrix T, according to equation (12). This calculation is aimed at eliminating some minor effects of the elements in matrix T [71].

$$\alpha = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} \tilde{t}_{ij}}{N} \tag{12}$$

where N is the total number of elements in matrix T.

Step 6. Constructing a cause and effect relationship diagram. The cause and effect diagram is constructed by mapping all coordinate sets of $(D_i + R_j, D_i - R_j)$ to visualize the complex interrelationship and provide information to judge which are the most important factors and how they influence the affected factors [68]. The factors for which $\tilde{t}_{ij}$ is greater than α, are selected and shown in a cause and effect diagram [43,71,73]. By applying equation (12) defuzzification is carried out for the fuzzy numbers obtained using equations (4)–(12) [74,75,103].

$$A = \frac{\left(a^{(r)} - a^{(l)}\right) + \left(a^{(m)} - a^{(l)}\right)}{3} + a^{(l)} \tag{13}$$

where $a^{(l)}$ and $a^{(r)}$ respectively are the left and right distribution of the confidence intervals of the triangular fuzzy number, and $a^{(m)}$ is the value in which the triangular function achieves its maximum value.

After constructing the cause and effect relationship diagram, in the next phase the weight coefficients are calculated for the clusters/criteria using the ANP method. In the following section, the implementation of the DEMATEL method is presented in the ANP method.

The ANP method was developed to avoid the hierarchical constraints that exist in the AHP method [76]. ANP is a generalization of the AHP method, in that it replaces the hierarchy with a network by means of feedback. ANP, unlike hierarchically-structured problems, takes into consideration different forms of dependence and feedback. The structure of the feedback is not linear and is much more reminiscent of a network in which there are multiple loops which interconnect groups. When using traditional ANP methods to calculate the relative weights of clusters/criteria, the levels of interdependence of factors are treated as reciprocal values. In contrast to this, when using the DEMATEL method, the levels of interdependence of factors do not have reciprocal values, which is closer to real systems [71].

With the traditional ANP method, a weighted supermatrix is obtained by normalizing the unweighted supermatrix. Each column of the unweighted supermatrix is divided by the number of clusters so that each column will sum to 1. This means that each cluster has the same weight. However, this is not a good assumption because the mutual influence of two clusters may be different. Although it is easy to normalize with this method, it neglects the fact that different groups should have different degrees of influence. Thus, we need to find another way of normalizing the unweighted supermatrix that relaxes this assumption of equal weight among the clusters. Here, we turn to the total-influence matrix T in DEMATEL and a threshold value α for help [68].

In order to overcome the drawbacks mentioned, a total relation matrix (matrix T) is used to calculate the weight coefficients of the criteria/clusters, which is obtained using the DEMATEL method (Step 3, equation (9)). A combination of the DEMATEL and ANP method (DANP) solves the given problem and the results obtained are much closer to real circumstances. We use DEMATEL to find the levels of influence among groups, and use the total relation matrix T

from DEMATEL as the basis for the influence network that forms the supermatrix in ANP. Although DEMATEL gives us the influence relationship, we still need to use ANP to confirm the influence relationship between each group.

The hybrid DANP method, that is, the integration of the DEMATEL and ANP methods, is carried out in five steps, which are implemented after constructing the effect relationship diagram (ERD). The DANP method is described in the following steps [68]:

Step 1. *Determining the unweighted supermatrix*. Before determining the unweighted supermatrix it is necessary to define the network model for the ANP method. The network model is determined on the basis of the total relation matrix and ERD. The first step is based on the network model and the total-influence matrix T to construct the network hierarchical structure of the system to the defined objectives. The total-influence matrix will be obtained from DEMATEL.

Formation of the network model creates the conditions for determining the unweighted supermatrix. Normalize each level with the total degree of influence from the total relation matrix T for criteria by DEMATEL. To carry out normalization of the matrix it is necessary to determine the sum of the matrix elements in columns.

$$T_c = \begin{array}{cc} & \begin{matrix} D_1 & D_1 & D_1 & & \\ c_{11}c_{12}\ldots c_{1m1} & c_{21}c_{22}\ldots c_{2m2} & \ldots & c_{n1}c_{n2}\ldots c_{nmn} \end{matrix} \\ \begin{matrix} & \\ D_1 & \\ & \\ D_2 & \\ & \\ D_3 & \\ & \end{matrix} & \begin{matrix} c_{11} \\ c_{12} \\ \vdots \\ c_{1m1} \\ c_{21} \\ c_{22} \\ \vdots \\ c_{2m2} \\ c_{n1} \\ c_{n2} \\ \vdots \\ c_{nmn} \end{matrix} \begin{bmatrix} T_c^{11} & T_c^{12} & \ldots & T_c^{1n} \\ & & & \\ & & & \\ T_c^{21} & T_c^{22} & \ldots & T_c^{2n} \\ & & & \\ . & . & . & . \\ . & . & . & . \\ . & . & . & . \\ T_c^{n1} & T_c^{n2} & \ldots & T_c^{nn} \end{bmatrix} \end{array} \tag{14}$$

where matrix T_c^{11} contains the factors from group D1 and their influences in relation to the factors from group D1. In matrix T_c^{21} (15) are the factors from group (cluster) D2 and their influences in relation to the factors from group D2 and so on.

$$T_c^{12} = \begin{bmatrix} t_{c^{12}}^{12} & \ldots & t_{c^{1j}}^{12} & \ldots & t_{c^{1m1}}^{12} \\ \vdots & & \vdots & & \vdots \\ t_{c^{i1}}^{12} & \ldots & t_{c^{ij}}^{12} & \ldots & t_{c^{1m1}}^{12} \\ \vdots & & \vdots & & \vdots \\ t_{c^{m12}}^{12} & \ldots & t_{c^{m1j}}^{12} & \ldots & t_{c^{m1m1}}^{12} \end{bmatrix} \tag{15}$$

Each of these columns is a major eigenvector which shows the impact of all of the elements of the i-th component on each element in the jth component. Each criterion t_{ij} of the total-influence matrix T can reveal network information regarding the degree of influence criterion i has on criterion j. The influence matrix T can be divided into T_D based on the perspectives (dimensions, or clusters) and T_c based on the criteria, respectively.

To determine the value of mutual influence it is very important to know the limit values of the stochastic matrix.

Step 2. The normalized total influence matrix for criteria T_c^{α}. After obtaining matrix T_c, it is then normalized. During the process of normalization, the criteria total-influence matrix T_c yields T_c^{α}. Normalized matrix T_c^{α} is shown by equation (16)

$$T_c^{\alpha} = \begin{array}{cc} & \begin{matrix} D_1 & D_1 & D_1 & & \\ c_{11}c_{12}\ldots c_{1m1} & c_{21}c_{22}\ldots c_{2m2} & \ldots & c_{n1}c_{n2}\ldots c_{nmn} \end{matrix} \\ \begin{matrix} & \\ D_1 & \\ & \\ D_2 & \\ & \\ D_3 & \\ & \end{matrix} & \begin{matrix} c_{11} \\ c_{12} \\ \vdots \\ c_{1m1} \\ c_{21} \\ c_{22} \\ \vdots \\ c_{2m2} \\ c_{n1} \\ c_{n2} \\ \vdots \\ c_{nmn} \end{matrix} \begin{bmatrix} T_c^{\alpha 11} & T_c^{\alpha 212} & \ldots & T_c^{\alpha 1n} \\ & & & \\ & & & \\ T_c^{\alpha 21} & T_c^{\alpha 22} & \ldots & T_c^{\alpha 2n} \\ & & & \\ . & . & . & . \\ . & . & . & . \\ . & . & . & . \\ T_c^{\alpha n1} & T_c^{\alpha n2} & \ldots & T_c^{\alpha nn} \end{bmatrix} \end{array} \tag{16}$$

For example, an explanation for the normalization of $T_c^{\alpha 11}$ on dimension D1 is shown by equations (17) and (18). The sum of the factors $c_{11}, \ldots, c_{1m1}$ within group D1 is obtained using equation

$$d_{ci}^{11} = \sum_{j=1}^{m_1} t_{ij}^{11}, i = 1, 2, .., m_1 \tag{17}$$

where t_{cj}^{11} represents the values of the factor influences $c_{11}, \ldots, c_{1m1}$ in relation to factors from group D1, and elements $t_{c11}^{\alpha 11}$ their normalized values.

$$T_c^{\alpha 11} = \begin{bmatrix} t_{c^{11}}^{11}/d_{c1}^{11} & \ldots & t_{c^{1j}}^{11}/d_{c1}^{11} & \ldots & t_{c^{1m1}}^{11}/d_{c1}^{11} \\ \vdots & & \vdots & & \vdots \\ t_{c^{i1}}^{11}/d_{ci}^{11} & \ldots & t_{c^{ij}}^{11}/d_{ci}^{11} & \ldots & t_{c^{1m1}}^{11}/d_{ci}^{11} \\ \vdots & & \vdots & & \vdots \\ t_{c^{m11}}^{11}/d_{cm1}^{11} & \ldots & t_{c^{m1j}}^{11}/d_{cm1}^{11} & \ldots & t_{c^{12}_{m1m1}}^{12}/d_{cm1}^{11} \end{bmatrix} = \begin{bmatrix} t_{c^{11}}^{\alpha 11} & \ldots & t_{c^{1j}}^{\alpha 11} & \ldots & t_{c^{1m1}}^{\alpha 11} \\ \vdots & & \vdots & & \vdots \\ t_{c^{i1}}^{\alpha 11} & \ldots & t_{c^{ij}}^{\alpha 11} & \ldots & t_{c^{1m1}}^{\alpha 11} \\ \vdots & & \vdots & & \vdots \\ t_{c^{m11}}^{\alpha 11} & \ldots & t_{c^{m1j}}^{\alpha 11} & \ldots & t_{c^{m1m1}}^{\alpha 11} \end{bmatrix} \tag{18}$$

The method for calculating the remaining matrices T_c^{ann} within matrix T_c^{α} is identical and we will not therefore explain it in detail here.

Step 3. Calculating the elements of the unweighted supermatrix W. In the traditional approach, the first step in the ANP method is to compare criteria in pairs (pair-wise comparisons). For example, in order to form anun-weighted super matrix, pair-wise comparisons can be carried out based on the following question: How much does the influence of one criterion over another depend on your preferences? However, it is very difficult to obtain consistent data on the basis of an empirical questionnaire. Therefore, this paper presents a hybrid model, based on an original concept that allows parameter values to be matched in the total-influence matrix T_c to complete the relationships between perspectives (clusters) used in the DEMATEL technique. An unweighted supermatrix W (19) can be easily obtained by transposing the normalized influence matrix T_c with respect to the perspectives (clusters).

Because the total influence matrix T_c fills the interdependence among the dimensions and criteria, we can transpose the normalized total influence matrix T_c^{α} by the dimensions based on the basic concept of ANP resulting in the unweighted supermatrix $W = (T_c^{\alpha})\prime$, equation (19)

$$W = (T_c^{\alpha})^T = \begin{array}{c} \\ D_1 \\ \\ \\ D_2 \\ \\ \\ D_3 \\ \\ \end{array} \begin{array}{c} \begin{array}{cccc} D_1 & D_1 & & D_1 \end{array} \\ \begin{array}{cccc} c_{11}c_{12}\ldots c_{1m1} & c_{21}c_{22}\ldots c_{2m2} & \ldots & c_{n1}c_{n2}\ldots c_{nmn} \end{array} \\ \begin{bmatrix} W^{11} & W^{12} & \ldots & W^{1n} \\ & & & \\ W^{21} & W^{22} & \ldots & W^{2n} \\ & & & \\ \vdots & \vdots & \ddots & \vdots \\ & & & \\ W^{n1} & W^{n1} & \ldots & W^{nn} \end{bmatrix} \end{array} \begin{array}{l} c_{11} \\ c_{12} \\ \vdots \\ c_{1m1} \\ c_{21} \\ c_{22} \\ \vdots \\ c_{2m2} \\ c_{n1} \\ c_{n2} \\ \vdots \\ c_{nmn} \end{array} \tag{19}$$

where matrix W^{11} represents the values of the factor influences from group D1 in relation to factors from group D1.

The transpose matrix of matrix T_c type mxn is matrix W type nxm which is obtained from matrix T_c so that the rows of matrix T_c exchange places with the corresponding columns. This interpretation can be represented by equation $(T_c)^T = W$.

Step 4. Calculating the elements of the weighted normalized supermatrix W^{α}.

The elements of the weighted normalized supermatrix W^{α} are obtained by multiplying the elements of the unweighted supermatrix W with corresponding elements from the normalized total influence matrix T_D^{α}. The elements from the normalized total influence matrix T_D^{α} are obtained by normalizing the total influence matrix T_D, using equations (20) and (21).

$$T_c^{\alpha 11} = \begin{bmatrix} t_D^{11} & \ldots & t_D^{1j} & \ldots & t_D^{1n} \\ \vdots & & \vdots & \ldots & \vdots \\ t_D^{i1} & \ldots & t_D^{ij} & \ldots & t_D^{in} \\ \vdots & & \vdots & & \vdots \\ t_D^{n1} & \ldots & t_D^{nj} & \ldots & t_D^{nn} \end{bmatrix} \tag{20}$$

Normalization of the total influence matrix T_D^{α} of the dimensions is carried out, equation (20), resulting in a new normalized total influence matrix T_D^{α}, equation (21).

$$T_D^{\alpha} = \begin{bmatrix} t_D^{11}/d_1 & \ldots & t_D^{1j}/d_1 & \ldots & t_{c^{1m1}}^{11}/d_1 \\ \vdots & & \vdots & \ldots & \vdots \\ t_D^{i1}/d_i & \ldots & t_D^{ij}/d_i & \ldots & t_D^{in}/d_i \\ \vdots & & \vdots & & \vdots \\ t_D^{n1}/d_n & \ldots & t_D^{nj}/d_n & \ldots & t_D^{nn}/d_n \end{bmatrix} = \begin{bmatrix} t_D^{\alpha 11} & \ldots & t_D^{\alpha 1j} & \ldots & t_D^{\alpha 1n} \\ \vdots & & \vdots & \ldots & \vdots \\ t_D^{\alpha i1} & \ldots & t_D^{\alpha ij} & \ldots & t_D^{\alpha in} \\ \vdots & & \vdots & & \vdots \\ t_D^{\alpha n1} & \ldots & t_D^{\alpha nj} & \ldots & t_D^{\alpha nn} \end{bmatrix} \tag{21}$$

where $t_D^{\alpha j} = t_D^{\alpha}/d_i$, and the value of d_i is obtained as $d_i = \sum_{j=1}^{n} t_D^{ij}$.

After determining the elements of T_D^{α} the elements of the new weighted supermatrix W^{α} are calculated. The elements of matrix W^{α} are obtained by multiplying the normalized total influence matrix of the dimensions T_D^{α} with the unweighted supermatrix W, equation (22)

$$W^{\alpha} = T_D^{\alpha} * W = \begin{bmatrix} t_D^{\alpha 11} * W^{11} & \ldots & t_D^{\alpha i1} * W^{i1} & \ldots & t_D^{\alpha n1} * W^{n1} \\ \vdots & & \vdots & \ldots & \vdots \\ t_D^{\alpha 1j} * W^{1j} & \ldots & t_D^{\alpha ij} * W^{ij} & \ldots & t_D^{\alpha nj} * W^{nj} \\ \vdots & & \vdots & & \vdots \\ t_D^{\alpha 1n} * W^{1n} & \ldots & t_D^{\alpha in} * W^{in} & \ldots & t_D^{\alpha nn} * W^{nn} \end{bmatrix} \tag{22}$$

Step 5. Find the limit of the weighted supermatrix W^{α}.

The two stages of this step are to get the limit supermatrix. Multiplying the weighted supermatrix by itself multiple times results in the limit supermatrix; then the weight of each evaluation criterion is obtained. The weighted supermatrix can be raised to the limiting powers until the supermatrix has converged and become a long-term stable supermatrix to obtain the global priority vectors, called DANP influence weights, such as $\lim_{k\to\infty} = W^k$, where W is the limit supermatix, while k is any number.

After determining the weight coefficients of the clusters/criteria, it is necessary to carry out aggregation of the criteria. Weighted Linear Combination (WLC) is used in the process of aggregating the criteria. The weighted linear combination (WLC) aggregation method multiplies each standardized factor map (i.e., each raster cell within each map) by its factor weight and then sums the results. Since the sum of the set of factor weights for an evaluation must be one, the resulting suitability map will have the same range of values as the standardized factor maps that were used. The cells (alternatives) corresponding to the greatest calculated values are the *best* solutions. The following mathematical expression was used to combine the evaluation criteria (factors) according to the weighted linear combination method:

$$S = \sum w_i x_i \tag{23}$$

where S is suitability, w_i is the normalized value of the weight of factor i, and x_i is the criterion score of factor i. In cases where Boolean constraints also apply, the procedure can be modified by multiplying the suitability calculated from the factors by the product of the constraints:

$$S = \sum w_i x_i \cdot \prod c_j \tag{24}$$

where c_j is the criterion score of constraint j.

All GIS software systems provide the basic tools for evaluation of such a model [77]. WLC is relatively easy to understand and can be applied in many different situations. In addition, it is compensatory, meaning that low scores in one criterion can be compensated for by

high scores in another one, which is desired for this particular decision problem. For these reasons, WLC was selected as the method of aggregation. As the final result of applying WLC and the aggregation of criteria maps, a *Suitability map* is obtained.

In the next step it is necessary to separate the suitable locations, by separating the cells with the highest values from the *suitability map,* which represent alternatives for the location of wind farms. The cells are filtered by combining the application of the GIS arithmetic operations and questions, by means of which feasible locations for installing wind farms are defined.

2.5. Results and recommendations

The final decisions or recommendations should be based on the ranking of the feasible locations. Ranking is performed in order to assess each location in relation to the targets set for the analysis. In this model, use of the MABAC method is proposed for selecting the best location. The MABAC method was developed by Pamučar and Ćirović at the Centre for research in the area of logistics defence at the University of Defence in Belgrade [78]. The results of the research by Pamučar and Ćirović [78] demonstrate that the MABAC method gives stable (consistent) results when compared to other methods of multi-criteria decision making (COPRAS, TOPSIS and VIKOR) and is a reliable tool for rational decision making.

The next section outlines the process of implementing the MABAC method, which consists of 6 steps:

Step 1. Forming the initial decision matrix (X). The first step is an evaluation of m alternatives according to n criteria. We present the alternatives with vectors $A_i = (x_{i1}, x_{i2}, ..., x_{in})$, where x_{ij} is the value of the i-th alternative according to the j-th criterion ($i = 1, 2, ..., m;\ j = 1, 2, ..., n$).

$$X = \begin{array}{c} \\ A_1 \\ A_2 \\ \dots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \dots & C_n \end{array} \\ \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & & x_{2n} \\ \dots & \dots & \dots & \dots \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix} \end{array} \tag{25}$$

where A_i $(i = 1, 2, ..., m)$ denotes the alternatives, and C_j $(j = 1, 2, ..., n)$ denotes the criteria according to which the alternatives are selected.

Step 2. Normalization of the elements in the initial matrix (X). The elements of the normalized matrix ($N = [t_i]$) are determined according to the equation:

a) For *Benefit* type criteria (higher criteria values are preferable)

$$t_{ij} = \frac{x_{ij} - x_i^-}{x_i^+ - x_i^-} \tag{26}$$

b) For *Cost* type criteria (lower criteria values are preferable)

Table 1
Constraint criteria description and standardization.

Constraint	Description	Standardization
(C1)	**Wind speed averege**. The average wind speed is a crucial economic factor determining the economic viability of the wind farm project at a particular location. In order for a location to be considered at all, the lowest average wind speed should meet the technical and economic feasibility of the project [37,55].	<3.5 m/s Inside = 0, outside = 1
(C2)	**Land cover/use**. Use of the land cover is important information concerning the constraints of a location for the construction of a wind farm. Information on the use of land is provided by the CORINE project, which provides sufficient comprehensiveness and consistency on the states of the European continent [89].	Artificial cover, wet areas and bodies of water = 0, others = 1.
(C3)	**Urban areas**. The social implications of wind farms, including the impact of noise, the impact of shadows and security, and the impact on people in terms of potential injuries caused by flying fragments of ice or from a damaged propeller, are considered to be very important constraints. The impact of noise should be assessed in accordance with the nature and character of noise sensitive locations, as well as in accordance with the legislation in this area [82].	500 m buffer zone is set. Inside = 0, outside = 1
(C4)	**Protected areas.** Protected areas are characterized by high geological, biological and ecosystem diversity. The protected areas in the Republic of Serbia are defined by seven different categories: national park, nature park, landscape of exceptional characteristics, strict nature reserve, special nature reserve, natural monument and protected habitat [83].	2000 m buffer zone is set. Inside = 0, outside = 1
(C5)	**Electricity network**. Due to the risk of potential damage to power lines, there should be adequate space between the columns and cable lines as stipulated by the relevant electrical power company. The electromagnetic field generated by the transmission line facilities also has a detrimental effect on human health. Therefore, a minimum distance of 16.5 m from the power grid is recommended [14,84].	200 m buffer zone is set. Inside = 0, outside = 1
(C6)	**Slope.** Due to the extra costs of construction and maintenance, topography with steep slopes and inclines is generally considered unsuitable for the development of wind farms [14,57].	>7% Inside = 0, outside = 1.
(C7)	**Roads**. Although wind farms are being built in accordance with building standards and are stable constructions, examples from actual practice suggest that it is advisable to achieve a safe distance from roads [14].	200 m buffer zone is set. Inside = 0, outside = 1
(C8)	**Telecommunications network.** A wind farm produces electromagnetic radiation, which can interfere with the broadcasting of radio communications. This also applies to mobile phone operators [29]. Wind farms must not cause electromagnetic interference to the operation of telecommunications networks and they need to comply with measures for the prevention of electromagnetic interference in the operation of telecommunications networks and the reception of their signals [84].	250 m buffer zone is set. Inside = 0, outside = 1
(C9)	**Airports.** Locating wind turbines may have implications for the operation of systems for communication, navigation and surveillance which are used in air traffic control and are related to the safety of air transport [13]. In Serbia the Civil Aviation Directorate prescribes the criteria used to determine whether an object is an obstacle that affects the air traffic and gives consent for the construction of wind farms with regard to the safety of air traffic.	3000 m buffer zone is set. Inside = 0, outside = 1
(C10)	**Tourist sites**. The visual impact of wind farms can be extremely negative if the areas are considered suitable for the development of tourism. Wind farms can reduce the attractiveness of tourist arrangements based on a preserved natural area [25].	1000 m buffer zone is set. Inside = 0, outside = 1
(C11)	**Military facilities**. Military facilities have a special security status, for which the Ministry of Defence is responsible. Following the examples of European countries, and at the same time respecting the local circumstances the army must be consulted with regard to installing wind turbines at a safe distance from military facilities and zones of special military interest [55].	5000 m buffer zone is set. Inside = 0, outside = 1

Table 2
Evolution criteria description.

Cluster	Criterion	Description
Environmental (En)	(En_1)	**Wind speed averege**. The most important economic factor to be considered when building a wind power plant is the speed of the wind at the given location [87]. Locations with an average wind speed greater than 3.5 m/s are considered to have continuity, with the recommendation that locations with the highest wind speed values be selected [20].
	(En_2)	**Land cover/use.** Land is one of the most important factors for energy investment [88]. Land use is considered as a factor in environmental protection. Data on land use were taken on the basis of the Corine Land Cover 2006 (CLC2006) database, collected in the framework of the European Commission's CORINE (Coordination of Information on the Environment) programme [89]. Criterion evaluation included a second level of classification of land use: arable land (211–213), permanent crops (221–223), pastures 231, diverse agricultural areas 241–244, forest (311–313), bushes and grassy vegetation cover (321–335) and areas with negligible or without plant cover (331–332). Wind farms should be installed in areas which would least interfere with existing land use.
	(En_3)	**Distance from urban areas**. Setting up wind farms near urban areas can cause negative impacts on local residents. In order to minimize their negative impact, it is recommended that wind farms are built at the greatest distance possible from urban areas [13,14,55].
	(En_4)	**Distance from protected areas**. In order to avoid or reduce the negative environmental impact, it is desirable to locate wind farms as far away as possible from protected areas [13,14].
Economic (Ec)	(Ec1)	**Distance from power lines**. One of the most important issues when it comes to reducing the cost of building wind farms is reducing the cost of building the infrastructure for transmitting the energy. When choosing the location it is necessary to consider the availability of and access to the existing electricity network [14].
	(Ec2)	**Slope**. In the physical sense, wind farms should be situated in suitable locations. Areas with steep slopes are generally considered less suitable, because of the extra costs of construction and maintenance [14,90].
	(Ec_3)	**Distance from main road network**. The specificity of the transport of equipment for the installation and subsequent maintenance of wind turbines can be seen in the need for securing the road network to the location of the wind farm, with maximum use of the existing road network. In order to reduce transport costs it is preferable that the distance from the road, outside the buffer zones, should be as small as possible [81,82].
	(Ec_4)	**Aspect**. The orientation of slopes relative to the direction of the wind is an important criterion from the perspective of being able to use the full wind potential. It is preferable that the orientation of slopes for the location of wind farms is towards the direction in which the dominant wind blows [81].
Social (Soc)	(Soc_1)	**Distance from telecommunications**. This distance is important due to the creation of electromagnetic radiation during operation of wind farms and the possible impact on the broadcasting of communication signals [90].
	(Soc_2)	**Distance from tourist facilities**. Considering that the proximity of wind farms adversely affects public opinion and the development of tourism, it is desirable to locate wind farms as far as possible from tourist facilities and areas [25].
	(Soc_3)	**Population density**. Due to the adverse effects of wind farms on local residents (shadow, noise, security aspect, visual disturbance of the landscape, etc.), the installation of wind farms is subject to public opposition and the concerns of local residents [18]. Consequently, it is recommended that wind farms be installed in areas with lower population density [57].

$$t_{ij} = \frac{x_{ij} - x_i^+}{x_i^- - x_i^+} \tag{27}$$

where x_{ij}, x_i^+ and x_i^- are the elements of initial decision matrix (X), for which x_i^+ and x_i^- are defined as:

$x_i^+ = \max(x_1, x_2, \ldots, x_m)$ and represents the maximum values of the observed criterion for each alternative.

$x_i^- = \min(x_1, x_2, \ldots, x_m)$ and represents the minimum values of the observed criterion for each alternative.

Step 3. Calculation of the elements of weighted matrix (V). The elements of weighted matrix (V) are calculated on the basis of equation (28)

$$v_{ij} = w_i \cdot t_{ij} + w_i \tag{28}$$

where t_{ij} represent the elements of the normalized matrix (N), w_i

Table 3
Data sources for input layers in land suitability assessment for the province of Vojvodina.

Layers		Data source
Constraints	Protected areas	Map of protected areas of Vojvodina [91].
	Urban areas	CORINE Land Cover 2006 (100 × 100) [89].
	Land cover/use	
	Wind speed average	Wind Atlas of the Autonomous Province of Vojvodina [80].
	Slope	Digital Terrain model (DMT 25) [92].
	Roads	
	Electricity network	Digital topographic map (DTKP 300), 1:300.000 [93].
	Telecommunications network	
	Airports	
	Tourist sites	
	Military facilities	
Evaluation Criteria	Distance from protected areas	Map of protected areas of Vojvodina [91].
	Distance from urban areas	CORINE Land Cover 2006 (100 × 100) [89].
	Land cover/use	
	Wind speed averege	Wind Atlas of the Autonomous Province of Vojvodina [80].
	Distance from roads	Digital topographic map (DTKP 300), 1:300,000 [93].
	Distance from transmission lines	
	Slope	Digital Terrain model (DMT 25) [92].
	Aspect	
	Distance from telecommunications	Digital topographic map (DTKP 300), 1:300,000 [93].
	Population density	Digital statistical base of the Republic Geodetic Authority [94].
	Distance from tourist sites	Digital topographic map (DTKP 300), 1:300,000 [93].

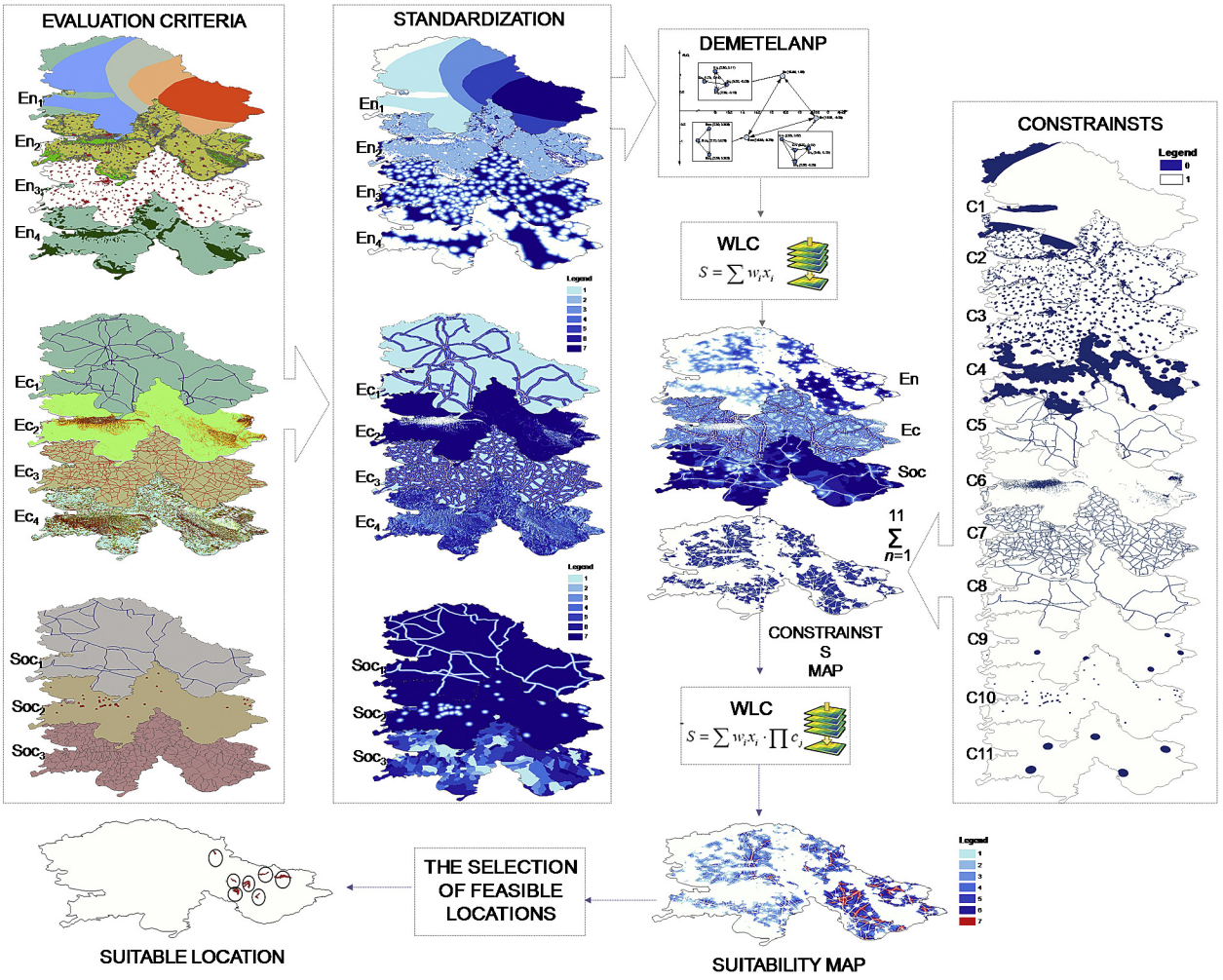


Fig. 3. GIS-DANP multi-criteria evaluation of locations for wind farms in Vojvodina.

represents the weight coefficients of the criteria. By using equation (28) we obtain weighted matrix V

$$V = \begin{bmatrix} v_{11} & v_{12} & \dots & v_{1n} \\ v_{21} & v_{22} & & v_{2n} \\ \dots & \dots & \dots & \dots \\ v_{m1} & v_{m2} & \dots & v_{mn} \end{bmatrix} = \begin{bmatrix} w_1 \cdot t_{11} + w_1 & w_2 \cdot t_{12} + w_2 & \dots & w_n \cdot t_{1n} + w_n \\ w_1 \cdot t_{21} + w_1 & w_2 \cdot t_{22} + w_2 & \dots & w_n \cdot t_{2n} + w_n \\ \dots & \dots & \dots & \dots \\ w_1 \cdot t_{m1} + w_1 & w_2 \cdot t_{m2} + w_2 & \dots & w_n \cdot t_{mn} + w_n \end{bmatrix} \quad (29)$$

where n is the total number of criteria, m is the total number of alternatives.

Step 4. Determining the matrix of border approximation areas (G). The border approximate area for each criterion is determined by equation (30)

$$g_i = \left(\prod_{j=1}^{m} v_{ij} \right)^{1/m} \quad (30)$$

where v_{ij} represent the elements of weighted matrix (V), m is the total number of alternatives. After calculating the value of g_i for the criteria, a matrix of border approximation values G (30) is formed with the format $nx1$ (n is the total number of criteria according to which the selection is made from the alternatives offered).

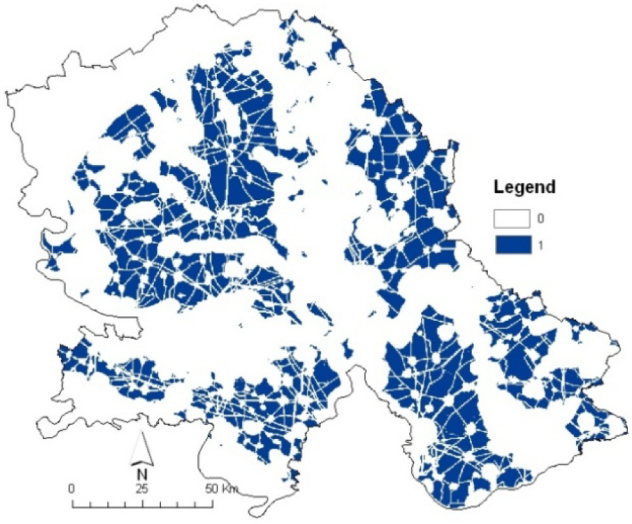


Fig. 4. Map of constraints.

Table 4
Evaluation criteria description and standardization.

Klaster		Criteria	Intensity of importance						
			1	2	3	4	5	6	7
			very low suitability	low suitability	moderately low suitability	moderate suitability	moderately high suitability	high suitability	very high suitability
En	Environmental	En_1	2000–2500 m	2501–3000 m	3001–3500 m	3501–4000 m	4001–4500 m	4501–5000 m	>5000 m
		En_2	500–1000 m	1001–1500 m	1501–2000 m	2001–2500 m	2501-3000 m	3001–3500 m	>3500 m
		En_3[a]	(221,222)	(211)	(242)	(243)	(324)	(321,331)	(231)
		En_4	3.5–4 m/s	–	4.1–4.5 m/s	–	4.6–5 m/s	–	>5.0 m/s
Ec	Economic	Ec_1	>2000 m	1701–2000 m	1401–1700 m	1101–1400 m	801–1100 m	501–800 m	200–500 m
		Ec_2	>2000 m	1701–2000 m	1401–1700 m	1101–1400 m	801–1100 m	501–800 m	200–500 m
		Ec_3	6°–7°	5°–5.9°	4°–4.9°	3°–3.9°	2°–2.9°	1°–1.9°	<1°
		Ec_4	W	NW	SW	N,S	NE	SE, FLAT	E
Soc	Social	Soc_1	250–500 m	501–750 m	751–1000 m	1001–1250 m	1251–1500 m	1501–2000 m	>2000 m
		Soc_2	>110 p/km^2	90–110 p/km^2	70–90 p/km^2	50–70 p/km^2	30–50 p/km^2	10–30 p/km^2	<10 p/km^2
		Soc_3	1001–1500 m	1501–2000 m	2001–2500 m	2501–3000 m	3001–3500 m	3501–4000 m	>4000 m

[a] Third level of the CORINE nomenclature.

$$G = \begin{matrix} C_1 & C_2 & \dots & C_n \\ [g_1 & g_2 & \dots & g_n] \end{matrix} \tag{31}$$

where $C_j (j = 1, 2, \dots, n)$ represents the criteria according to which the alternatives are selected.

Step 5. Calculation of the distance of the alternatives from the border approximation area (Q)

$$Q = \begin{bmatrix} q_{11} & q_{12} & \cdots & q_{1n} \\ q_{21} & q_{22} & & q_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ q_{m1} & q_{m2} & \cdots & q_{mn} \end{bmatrix} \tag{32}$$

The distance of the alternatives from the border approximation area (q_{ij}) is determined as the difference between the elements in the weighted matrix (V) and the values of the border approximation areas (G)

$$Q = V - G = \begin{bmatrix} v_{11} & v_{12} & \cdots & v_{1n} \\ v_{21} & v_{22} & & v_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ v_{m1} & v_{m2} & \cdots & v_{mn} \end{bmatrix} - [g_1 \quad g_2 \quad \dots \quad g_n] \tag{33}$$

$$Q = \begin{bmatrix} v_{11} - g_1 & v_{12} - g_2 & \cdots & v_{1n} - g_n \\ v_{21} - g_1 & v_{22} - g_2 & \cdots & v_{2n} - g_n \\ \cdots & \cdots & \cdots & \cdots \\ v_{m1} - g_1 & v_{m2} - g_2 & \cdots & v_{mn} - g_n \end{bmatrix} = \begin{bmatrix} q_{11} & q_{12} & \cdots & q_{1n} \\ q_{21} & q_{22} & & q_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ q_{m1} & q_{m2} & \cdots & q_{mn} \end{bmatrix} \tag{34}$$

where g_i is the border approximation area for criterion C_i, v_{ij} is the elements of weighted matrix (V), n is the number of criteria, m is the number of alternatives.

Alternative A_i could belong to the border approximation area (G), upper approximation area (G^+) or lower approximation area (G^-), that is $A_i \in \{G \vee G^+ \vee G^-\}$. The upper approximation area (G^+) is the area which contains the ideal alternative (A^+), while the lower approximation area (G^-) is the area which contains the anti-ideal alternative (A^-).

Step 6. Ranking the alternatives. A calculation of the values of the criterion functions for the alternatives (35) is obtained as the sum of the distance of the alternatives from the border approximation areas (q_i). By summing the elements of matrix Q by rows we obtain the final values of the criterion functions of the alternatives

$$S_i = \sum_{j=1}^{n} q_{ij},\ j = 1, 2, \dots, n,\ i = 1, 2, \dots, m \tag{35}$$

where n is the number of criteria, m is the number of alternatives.

2.6. Sensitivity analysis and visualization of the final solution

The final step of the proposed GIS-DANP-MABAC model involves a sensitivity analysis and visualization of the final results. A sensitivity analysis is a study of the stability of the solution (the alternative selected and the rank of the alternatives) to changes in the input data. The aim of such an analysis is to identify the effects of changes in the input data (geographic data and preferences of the DM) on the output values (rank of the alternatives). An unavoidable process in a sensitivity analysis is an analysis of the stability of the solution to changes in the relative weight of the clusters and criteria, as a representative of subjectivism in multi-criteria decision analysis. Visualization of the choice of location is carried out in the form of a GIS cartographic representation, charts, tables and others [52].

3. Results and discussions. A case study of Vojvodina, Serbia

On the basis of research into wind and solar energy resources carried out by the Institute for multidisciplinary research, who published an Atlas of Solar and Wind Energy Potentials in Serbia [79], it is well-known that in Serbia there are potentially suitable locations for wind energy. At these locations, it would be possible to install about a 1300 MW production capacity and produce about 2300 GWh of electricity annually. This would result in wind energy being a new branch of energy. The most promising locations for the construction of wind power plants are located in Vojvodina, concluded in the project Wind Atlas of the Autonomous Province of Vojvodina (Wind Atlas) [80]. The results of the study *Wind Atlas of Serbia* showed that the territory of Vojvodina has the highest wind

Table 5
Fuzzy scale for evaluating the clusters/criteria.

N.o.	Linguistic terms	Triangular fuzzy numbers
1.	Very high influence (VH)	(4.50,5.00,5.00)
2.	High influence (H)	(2.50,3.50,4.50)
3.	Low influence (L)	(1.50,2.50,3.50)
4.	Very low influence (VL)	(0.00,1.50,2.50)
5.	No influence (No)	(0.00,0.00,1.50)

Table 6
Initial direct-relation matrix – criteria (D_{ck}).

Criteria	En1	En2	En3	En4	Soc1	Soc2	Soc3	Ec1	Ec2	Ec3	Ec4
En1	0.115	0.176	0.176	0.115	0.142	0.115	0.159	0.229	0.133	0.140	0.097
En2	0.173	0.081	0.125	0.092	0.076	0.093	0.109	0.166	0.107	0.112	0.077
En3	0.182	0.131	0.086	0.075	0.081	0.130	0.126	0.164	0.102	0.107	0.070
En4	0.216	0.161	0.159	0.077	0.104	0.099	0.120	0.210	0.128	0.144	0.105
Soc1	0.193	0.125	0.167	0.097	0.081	0.088	0.131	0.209	0.126	0.145	0.081
Soc2	0.175	0.124	0.157	0.098	0.126	0.067	0.118	0.168	0.125	0.119	0.072
Soc3	0.202	0.139	0.118	0.092	0.132	0.103	0.089	0.186	0.130	0.124	0.075
Ec1	0.241	0.160	0.159	0.140	0.134	0.106	0.163	0.116	0.149	0.146	0.122
Ec2	0.122	0.111	0.098	0.068	0.094	0.090	0.104	0.140	0.071	0.110	0.098
Ec3	0.183	0.136	0.126	0.089	0.127	0.109	0.142	0.220	0.128	0.100	0.094
Ec4	0.094	0.100	0.076	0.063	0.043	0.041	0.051	0.108	0.083	0.097	0.039

energy potential in Serbia, with average annual speeds greater than 6 m/s, which from the economic aspect is considered favorable for implementing wind farm projects.

There are four main winds that blow in Vojvodina (the “kosava”, northern, southern and western winds). An additional advantage is the developed network of roads, railways, waterways and a cargo port, which favours the installation and maintenance of wind farms.

To utilize the full potential energy of these winds, the selection of locations for wind generators is of vital importance. As a step towards identifying the constraints and clusters/evaluation criteria of potential locations, and on the basis of valid legal regulations and the opinions of DM, a group of 11 constraints and 11 evaluation criteria was selected (Tables 1 and 2). For this purpose, the current status of the territory was studied (cities, roads, rivers, protected areas, etc.), together with the applicable legal framework (European, national, regional and local laws, etc.). After that, according to the recommendations given by Aydin et al. [13], the value limits were defined that exclude some areas from further analysis. The limits of the constraint values were defined taking into account the opinions of authors who have dealt with the problem of selecting the location of wind farms and DM, while respecting the applicable legal framework in the Republic of Serbia. 11 constraints were highlighted that define areas to be excluded from further analysis (Table 1).

Unlike the constraints, according to which the alternatives are expressed on a binary scale as suitable or unsuitable, the evaluation criteria area assessed on a continuous scale, and their goal is to express the degree of suitability of particular alternatives (cells) [86]. Taking into account the recommendations of the authors of similar works and the opinions of DM, 11 evaluation criteria were adopted, which were grouped into environmental, economic and social clusters (Table 2).

The defined constraints and clusters/criteria, when entered into the GIS, are represented in the form of spatially defined vector or raster maps, whose cells represent different alternatives. All of the GIS processes (digitalization, conversion, 3D Analyst etc.) during entry and construction of the spatial base of criteria and constraints are carried out using the integrated tool ArcGIS 10.2 from the ESRI software firm. The sources of the GIS data sets are provided in Table 3.

For the purposes of the GIS-DANP multicriteria evaluation, first of all suitable locations for wind farms in Vojvodina were identified, Fig. 3.

By aggregating the constraints given in Table 1, areas were obtained that are suitable for the installation of wind farms in Vojvodina. The constraints in the form of thematic layers were generated using Boolean (logical) algebra, using the integrated tools ArcGIS 10.2 application. Each map was converted into a raster format, after which a reclassification was carried out according to which raster cells containing areas that had been dismissed were given a value of zero (0), while the cells for the remaining areas gained a value of one (1). The summary map of constraints was established by aggregating all of the layers of constraints. On the final map of constraints, only the locations that were evaluated as suitable (value 1) for all of the layers of constraints could be considered as potential locations (alternatives) for the construction of wind farms, Fig. 4 [20].

By analyzing the thematic layer in Fig. 4 it can be seen that for the whole territory of Vojvodina (21 506 km^2), 29.7% of the area has no constraints for the installation of wind farms. This corresponds to a total area of 6397 km^2 of the territory. This area consists of 10 234 593 cells (resolution 25 × 25 m) which are potential locations for wind farms.

In the process of individual assessment of the evaluation criteria and standardization, each map of criteria was converted into a raster, and then reclassified according to the adopted standardized values of the classes. In accordance with applied practice, the experience of experts and available literature, the suitability of the criteria in this study were reclassified on a scale of 1–7, where 7 is the most suitable, and 1 is the least suitable value of the attribute in relation to the target. The reclassified criteria, with defined limits between the classes, are shown in Table 4. In this way, each raster cell was assigned a value on a scale from 1 do 7, where 1 has very low suitability as a location, and 7 has very high suitability as a location for constructing a wind farm. In this way, the reclassified maps were converted into an operational raster background for applying the WLC method. The suitability of the alternatives on the criteria maps is usually symbolized by different shades of colour, so that lighter shades of a colour represent less suitable, and darker shades represent more suitable alternatives for the location of wind farms (Fig. 4).

In the study, when determining the weight coefficients of the clusters/criteria, eleven experts with rich experience in the design of renewable energy sources and capital projects were involved. Experts were identified who had a minimum of five years’ consulting experience in the design of renewable energy sources. After surveying the experts, the data collected were processed and their opinions were aggregated. Collecting data by surveying the experts was carried out during the period from May 2014 to December 2014.

In the first step of applying the DEMATEL method, the experts

Table 7
Total relation matrix – clusters (T_c).

Clusters	Ec	En	Soc
Ec	1,12	3,52	3,59
En	3,17	2,28	2,69
Soc	2,92	2,57	1,13

Table 8
The sums of given and received impact among the clusters/criteria.

Clusters/criteria	D_i	R_i	$D+R$	D-R
En	**8.14**	**8.37**	**16.51**	**−0.23**
En1	0.959	1.766	2.725	−0.807
En2	0.842	1.996	2.838	−1.154
En3	1.040	1.913	2.953	−0.873
En4	0.923	1.764	2.687	−0.842
Soc	**6.62**	**7.41**	**14.03**	**−0.79**
Soc1	1.472	0.896	2.368	0.576
Soc2	1.927	0.457	2.384	1.469
Soc3	1.793	0.323	2.116	1.470
Ec	**8.23**	**7.21**	**15.44**	**1.02**
Ec1	1.291	0.662	1.953	0.628
Ec2	2.308	0.719	3.027	1.589
Ec3	0.930	1.719	2.648	−0.789
Ec4	0.544	1.813	2.358	−1.269

used a fuzzy scale to evaluate the clusters/criteria [78,95], Table 5.

This scale was used for obtaining the average matrix $\tilde{Z}$ for each of the experts. After collecting the survey questions, a total of eleven average matrices $\tilde{Z}$ were obtained for the clusters/criteria. Aggregation of the expert opinions was carried out using equations (1)–(3). After aggregating the expert opinions, a unique average matrix $\tilde{Z}$ was obtained. By normalization and defuzzification of the elements of the average matrix $\tilde{Z}$, equations (5) and (13), the elements of the initial direct-relation matrix D were formed for the clusters (D_c) and criteria (D_{ck}) (Table 6).

Normalization of the elements of the initial direct-relation matrix was performed by dividing each element of the average matrix with the value of R which was obtained using equation (6). Using equation (8), the elements of the total relation matrix cluster (T_c) (Table 7) and criterion (T_{ck}) were identified.

The values of matrix T were summed by rows (D_i) and columns (R_i) using equations (10) and (11). The summed values of matrices T_c and T_{ck} by rows and columns are shown in Table 8.

Based on the results shown in Tables 6–8 and equation (12) a cause and effect relationship diagram - CERD (Fig. 5) was formed, which shows the interdependence of clusters and the impact of the criteria within the observed cluster on one other. As a result of data processing in the first stage using the DEMATEL method CERD was obtained, which served as the basis for implementing the ANP method and better understanding the relationship between the clusters/criteria.

Based on the calculations obtained in matrices T_c and T_{ck}, the threshold values α and the cause and effect relationship diagram, a map of network relationships was obtained, Fig. 6. The map of network relationships makes it easier to understand the model of the ANP method which is used to calculate the relative weights of the clusters/criteria.

In the first step of the ANP method a total-influence matrix T was included in the ANP model and using equations (14)–(19) an unweighted supermatrix was obtained (Table 9).

After this, and using equations (20) and (21) the elements of the weighted supermatrix were calculated (22). The elements of the weighted supermatrix can be seen in Table 10.

In the final stage of the ANP method, the elements of the limited supermatrix were determined (Table 11), whose vectors represent the weight coefficients of the model (Table 12).

After determining the weight coefficients of the clusters/criteria, the standardized values of the criteria were summed using the WLC method (Table 12), resulting in a final suitability map (Fig. 7a). Cells with higher values characterize space which is more suitable for the construction of wind farms.

The final step of the GIS-DANP multi-criteria evaluation was identifying the alternatives with the highest values from the final suitability map. These are cells that have pixels with a value of 7 (red in Fig. 7a). From Table 13, it can be seen that the total area of most suitable space (cell value of 7) for the installation of wind farms is 320 km^2, which is about 1.5% of the total territory of Vojvodina. The final result of the GIS-DANP model is that in the area of Vojvodina, a total of 2085 suitable locations were identified for the installation of wind farms. The locations were different sizes, from 400 m^2 to 13.7 km^2, predominantly situated in the southeast of

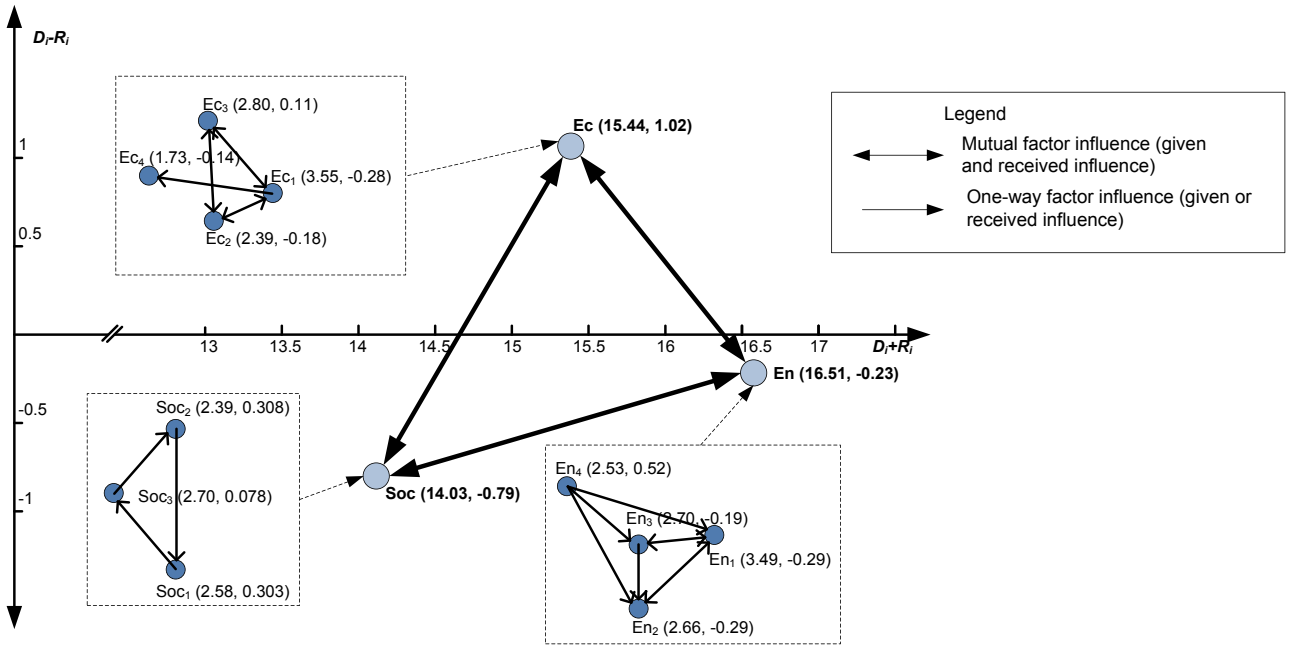


Fig. 5. Cause and effect relationship diagram.

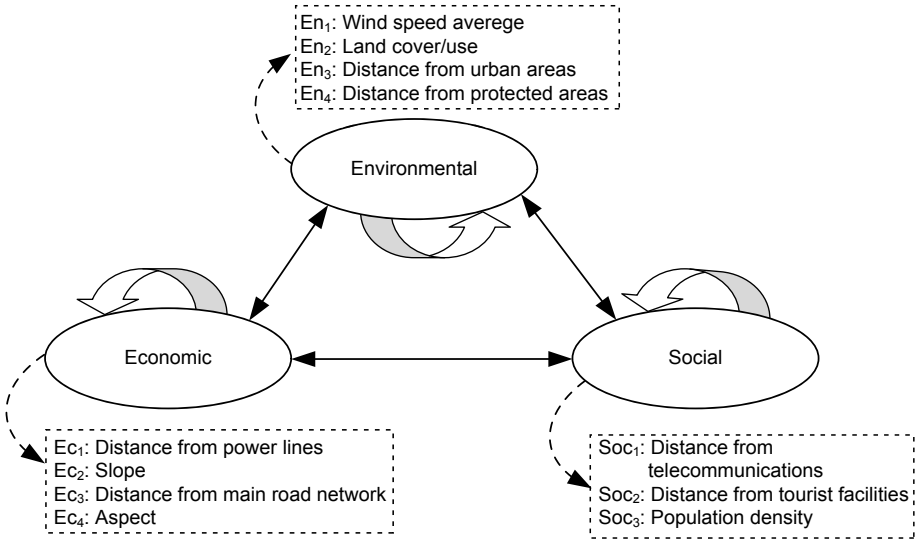


Fig. 6. Map of network relationships of the ANP model.

Vojvodina. The area tested is shown in Table 13 based on cells of suitability.

Considering that, according to expert opinion, a sustainable area for the construction of a wind farm of 75–150 MW needs to be a minimum of 5 km^2 criteria [96], areas of over 5 km^2 were selected on the suitability map. In Vojvodinaa total of 11 viable locations were identified that meet this requirement: Debeljača (L 1), Crepaja (L 2), Putnikovo (L 3), Samos (L 4), Novi Kozjak (L 5), Dolovo (L 6), Velika Greda (L 7), Laudonovac (L 8), Veliki Ritovi (L 9), Vršac (L 10) and Novi Itebej (L 11). These locations are situated in the region of Banat, mainly in the southeastern part (Fig. 7b).

After identification of the viable locations, they were ranked and the most suitable location was selected using the MABAC method [104]. Firstly, the initial decision matrix was formed (Table 14), after which, using equations (26) and (27) normalization of the criteria was carried out. The data presented in Table 14 represent the average values of suitability obtained for the locations using GIS Zonal statistical operations from the standardized (reclassified) map of evaluation criteria.

Since all of the values for criterion Soc1 for all of the alternatives are equal and amount to 7.000, we can eliminate criterion Soc1, because it does not affect the ranking of the locations. We distributed the weight coefficient for Soc1 evenly across the other criteria ($\Delta w_{Soc1} = w_{Soc1}/10 = 0.090/10 = 0.009$), that is, we added the

Table 9
Unweighted supermatrix.

Clusters/criteria	En1	En2	En3	En4	Soc1	Soc2	Soc3	Ec1	Ec2	Ec3	Ec4
En1	0.160	0.272	0.266	0.245	0.328	0.263	0.223	0.230	0.267	0.228	0.247
En2	0.200	0.129	0.198	0.187	0.164	0.170	0.148	0.169	0.189	0.189	0.176
En3	0.201	0.201	0.128	0.186	0.162	0.183	0.201	0.216	0.160	0.170	0.174
En4	0.129	0.147	0.111	0.086	0.122	0.166	0.114	0.133	0.123	0.117	0.137
Soc1	0.193	0.151	0.136	0.172	0.201	0.148	0.125	0.240	0.225	0.175	0.182
Soc2	0.155	0.187	0.221	0.164	0.103	0.160	0.136	0.124	0.175	0.163	0.171
Soc3	0.218	0.220	0.213	0.200	0.163	0.236	0.207	0.225	0.151	0.259	0.208
Ec1	0.208	0.192	0.184	0.188	0.148	0.207	0.196	0.178	0.191	0.185	0.192
Ec2	0.118	0.121	0.113	0.112	0.137	0.111	0.116	0.131	0.131	0.120	0.113
Ec3	0.124	0.127	0.118	0.127	0.146	0.103	0.134	0.124	0.125	0.158	0.144
Ec4	0.084	0.086	0.075	0.091	0.078	0.088	0.073	0.073	0.074	0.079	0.082

Table 10
Weighted supermatrix.

Clusters/criteria	En1	En2	En3	En4	Soc1	Soc2	Soc3	Ec1	Ec2	Ec3	Ec4
En1	0.057	0.093	0.091	0.084	0.076	0.078	0.090	0.082	0.078	0.079	0.070
En2	0.066	0.044	0.066	0.062	0.049	0.056	0.062	0.054	0.071	0.059	0.075
En3	0.067	0.067	0.043	0.062	0.066	0.071	0.053	0.054	0.063	0.054	0.057
En4	0.043	0.049	0.038	0.030	0.038	0.044	0.041	0.047	0.043	0.038	0.047
Soc1	0.062	0.049	0.044	0.056	0.039	0.074	0.069	0.057	0.058	0.058	0.055
Soc2	0.050	0.060	0.071	0.053	0.043	0.039	0.054	0.045	0.056	0.050	0.054
Soc3	0.070	0.071	0.068	0.064	0.064	0.069	0.047	0.069	0.064	0.065	0.066
Ec1	0.078	0.072	0.070	0.071	0.077	0.070	0.075	0.054	0.061	0.078	0.064
Ec2	0.045	0.047	0.043	0.043	0.047	0.052	0.052	0.051	0.031	0.046	0.049
Ec3	0.048	0.049	0.045	0.049	0.053	0.050	0.050	0.049	0.048	0.036	0.057
Ec4	0.033	0.034	0.030	0.035	0.030	0.030	0.030	0.041	0.043	0.033	0.023

Table 11
Limited supermatrix.

Clusters/criteria	En1	En2	En3	En4	Soc1	Soc2	Soc3	Ec1	Ec2	Ec3	Ec4
En1	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080
En2	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060
En3	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059
En4	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044
Soc1	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056
Soc2	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052
Soc3	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066
Ec1	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071
Ec2	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047
Ec3	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
Ec4	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035

value Δw_{Soc1} to each weight coefficient of a criterion.

Then, using equations (28) and (29) the elements of the weighted matrix and elements of the matrix of border approximation areas, respectively, were calculated. By subtracting the elements of the weighted matrix from the elements of the matrix of border approximation areas (equations (33) and (34)), a matrix of the distance of the alternatives from the border approximation areas was obtained (34), Table 15. Finally, using expression (35), the total distance of each alternative from the border approximation areas was determined, Table 15.

The results presented in Table 15 show that location Laudonovac (L 8), as the first ranked, is the most suitable location for wind farms in Vojvodina. The results of the MCDM method to a great extent depend on the relative importance assigned to individual criteria. Sometimes the ranks of alternatives vary with very small changes in the weight coefficients of the criteria, because of which the results of the MCDM method are followed as a rule by an analysis of their sensitivity to these changes [78].

In most multi-criteria decision processes, a sensitivity analysis is recommended as a means of checking the stability of the results against the subjectivity of the decision-makers [46,97]. The sensitivity analysis of the results in this study was carried out using the initial weight coefficients of the clusters, according to the scenarios in Table 16.

On the basis of the changed weight coefficients of the clusters in the process of generating the map of benefits, maps of each scenario were obtained, Fig. 8.

Fig. 8 presents the results of the sensitivity analysis for four scenarios (Table 16). From Fig. 5, it can be seen that there is a high level of spatial overlapping of the best locations for installing wind farms from the final suitability map (Fig. 7a), with the most suitable locations on the maps of scenarios A, B, C and D. Spatial overlapping (expressed in %) of the most suitable alternative (cell 7) from the final map of benefits with suitable alternatives (cells 5, 6 and 7) from the maps of scenarios, was confirmed by applying the GIS Spatial analyst functions, and is shown in Table 17.

From Table 17 the complete stability of scenarios A and B can be seen. The lowest stability, at 88.4% overlap, can be seen in scenario D, in which social criteria are favoured. The results of the sensitivity analysis indicate a high stability of the model.

Since MABAC is a new method of multi-criteria decision making, within the framework of its validation and sensitivity analysis there needs to be a comparison of the ranks obtained using the MABAC method with the ranks suggested by models of multi-criteria decision making that have already been developed. There are different studies associated with location selection decisions, many of which have been carried out using multi-criteria decision-making (MCDM) techniques. These include location problems with the COPRAS method [98,99], selection of distribution centers for a firm and the choice of location for distribution centers using VIKOR [87], location selection for a logistics centre based on Fuzzy AHP and TOPSIS [101], the selection of a logistics centre location using fuzzy TOPSIS based on entropy weight [102]. Analysis of the above literature singles out the use of the VIKOR, TOPSIS and COPRAS methods in the majority of studies for ranking locations. Along with application in location problems, VIKOR, TOPSIS and COPRAS have been applied in many other areas, such as multi-objective design of control chart [106], risk ranking [107], supplier selection [108], target market prioritization [109] etc. In the following section these methods are used to compare the ranks of the locations obtained by means of the MABAC method.

In order to be able to adequately compare the ranks of alternatives obtained by the different methods, it is necessary to apply the same method of normalizing the input data. For this reason, for all of the methods, a linear method of normalizing the input data

Table 12
Weight coefficients of the clusters/criteria.

Clusters/Criteria	Weight coefficient	Rank
Environmental	**0.392**	**1**
En1 – Wind speed	0.129	1
En2 – Land use	0.097	4
En3 – Distance from urban areas	0.095	5
En4 – Distance from protected areas	0.071	10
Economic	**0.327**	**2**
Ec1 – Distance from power lines	0.115	2
Ec2 – Slope of the land	0.076	9
Ec3 – Distance from roads	0.081	8
Ec4 – Aspect	0.056	11
Social	**0.281**	**3**
Soc1 – Distance from telecommunication infrastructure	0.090	6
Soc2 – Distance from tourist facilities	0.084	7
Soc3 – Population density	0.106	3

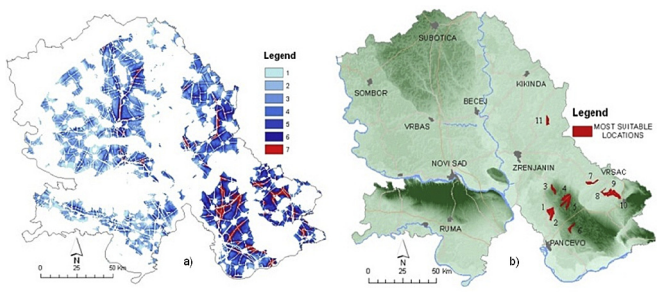


Fig. 7. Suitability maps and Suitability locations in DANP for Vojvodina.

Table 13
The areas of classes from the final land suitability map.

Rating	Classes	Area (km^2)	Area of Vojvodina (%)	Number of cells (25 × 25)
1	Very low suitability	447	2.1	716 311
2	Low suitability	1072	5.0	1 716 426
3	Moderately low suitability	1299	6.0	2 079 178
4	Moderate suitability	1276	5.9	2 042 974
5	Moderately high suitability	1161	5.4	1 859 020
6	High suitability	817	3.8	1 307 400
7	Very high suitability	320	1.5	513 284

was used. The original mathematical apparatus of the VIKOR [110], TOPSIS [105,111] and COPRAS [112] methods was not changed. In the TOPSIS method, instead of vector normalization, equation (36), linear normalization was used, equations (26) and (27)

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \tag{36}$$

(r_{ij} represents the normalized elements of the matrix, x_{ij} elements of the initial decision matrix which are normalized, and m the total number of alternatives).

In the COPRAS method, instead of its original method of normalizing data using equations (37) and (38), the process was also carried out using linear normalization:

- for benefit type criteria (higher values are better)

$$r_{ij} = \frac{x_{ij}}{x_{ij}^{+}} \tag{37}$$

- for cost type criteria (lower values are better)

$$r_{ij} = \frac{x_{ij}}{x_{ij}^{-}} \tag{38}$$

where x_{ij} represents elements from the initial decision matrix which are normalized, and x_{ij}^{-} and x_{ij}^{+} represent the minimum/maximum criteria values.

The same input data (parameters of the locations) are used in VIKOR, TOPSIS and COPRAS applications as in application of the MABAC method (they are shown in Tables 14 and 15). Since the aforementioned values for criterion Soc1 for all of the alternatives are equal (value 7.000, in Table 14), criterion Soc1 is eliminated, because it does not affect the locations ranking. Weight coefficient

Table 14
Initial matrix for evaluating the alternatives.

Location	Criteria										
	En1	En2	En3	En4	Ec1	Ec2	Ec3	Ec4	Soc1	Soc2	Soc3
	$w_1 = 0.129$	$w_2 = 0.097$	$w_3 = 0.095$	$w_4 = 0.071$	$w_5 = 0.115$	$w_6 = 0.076$	$w_7 = 0.081$	$w_8 = 0.056$	$w_9 = 0.090$	$w_{10} = 0.084$	$w_{11} = 0.106$
L 1	7.000	2.000	6.342	7.000	5.857	7.000	4.252	3.526	7.000	7.000	3.029
L 2	7.000	2.000	6.223	7.000	5.115	6.976	5.309	4.130	7.000	7.000	3.722
L 3	7.000	2.000	5.135	6.813	4.095	6.798	5.277	3.115	7.000	7.000	6.000
L 4	7.000	2.000	6.673	5.722	5.332	6.615	4.846	4.815	7.000	7.000	5.595
L 5	7.000	2.000	6.772	6.488	3.404	6.649	6.094	4.484	7.000	7.000	4.877
L 6	7.000	2.000	6.863	6.922	5.314	6.659	3.452	3.812	7.000	7.000	4.000
L 7	7.000	2.000	4.309	6.942	5.825	7.000	3.546	5.371	7.000	6.262	5.491
L 8	7.000	2.291	6.668	5.877	1.951	7.000	5.863	4.170	7.000	7.000	6.461
L 9	7.000	2.000	6.986	6.213	3.809	7.000	4.299	3.538	7.000	7.000	6.629
L 10	7.000	2.208	5.893	3.719	5.637	7.000	5.702	2.964	7.000	7.000	7.000
L 11	5.000	2.105	6.637	6.484	5.752	7.000	4.990	4.037	7.000	7.000	5.656

Table 15
Rank of the alternatives.

Location	Criteria										ΣS_i	Rank
	En1	En2	En3	En4	Ec1	Ec2	Ec3	Ec4	Soc2	Soc3		
	$w_1 = 0.138$	$w_2 = 0.106$	$w_3 = 0.104$	$w_4 = 0.080$	$w_5 = 0.124$	$w_6 = 0.085$	$w_7 = 0.090$	$w_8 = 0.065$	$w_9 = 0.093$	$w_{10} = 0.115$		
L 1	0.0169	−0.0159	0.0077	0.0196	0.0397	0.0311	−0.0179	−0.0109	0.0114	−0.0596	0.0219	7
L 2	0.0169	−0.0159	0.0030	0.0196	0.0161	0.0258	0.0181	0.0054	0.0114	−0.0396	0.0608	4
L 3	0.0169	−0.0159	−0.0392	0.0150	−0.0163	−0.0135	0.0170	−0.0220	0.0114	0.0264	−0.0203	9
L 4	0.0169	−0.0159	0.0205	−0.0116	0.0230	−0.0539	0.0023	0.0239	0.0114	0.0147	0.0312	6
L 5	0.0169	−0.0159	0.0244	0.0071	−0.0382	−0.0464	0.0448	0.0150	0.0114	−0.0061	0.0128	8
L 6	0.0169	−0.0159	0.0279	0.0177	0.0224	−0.0442	−0.0452	−0.0032	0.0114	−0.0315	−0.0437	10
L 7	0.0169	−0.0159	−0.0713	0.0182	0.0387	0.0311	−0.0420	0.0389	−0.0816	0.0117	−0.0555	11
L 8	0.0169	0.0901	0.0203	−0.0078	−0.0843	0.0311	0.0369	0.0065	0.0114	0.0397	0.1608	1
L 9	0.0169	−0.0159	0.0327	0.0004	−0.0253	0.0311	−0.0163	−0.0106	0.0114	0.0446	0.0689	3
L 10	0.0169	0.0598	−0.0098	−0.0604	0.0327	0.0311	0.0315	−0.0261	0.0114	0.0554	0.1424	2
L 11	−0.1211	0.0223	0.0191	0.0070	0.0363	0.0311	0.0072	0.0029	0.0114	0.0164	0.0327	5

Table 16
Combination of weights for the sensitivity analysis.

Scenarios	Clusters weights		
	Environmental	Economic	Social
A – uniform weights	0.330	0.330	0.330
B - priority En	0.550	0.225	0.225
C - priority Ec	0.225	0.550	0.225
D - priority Soc	0.225	0.225	0.550

of the criteria Soc 1 is equally distributed to the other criteria. The value Δw_{Soc1} ($\Delta w_{Soc1} = w_{Soc1}/10 = 0.090/10 = 0.009$) is added to each weight coefficient. As a result, modified values of the weight coefficients are obtained and used in further calculations: $w_1 = 0.138$, $w_2 = 0.106$, $w_3 = 0.104$, $w_4 = 0.080$, $w_5 = 0.124$, $w_6 = 0.085$, $w_7 = 0.090$, $w_8 = 0.065$, $w_9 = 0.093$ and $w_{10} = 0.115$.

Table 18 shows the results of ranking the alternatives according to criteria from Table 15 using the VIKOR, TOPSIS and COPRAS methods.

The final result obtained by application of the GIS-DANP-MABAC model is rank of alternatives: L8>L10 > L9>L2>L11 > L4>L1>L5> L6>L7 (Table 15). The same rank is obtained by VIKOR and COPRAS applications (Table 18), but not by TOPSIS application. Difference between TOPSIS and GIS-DANP-MABAC results are in the first two ranked alternatives. According to TOPSIS alternative L10 dominates alternative L8, but according to GIS-DANP-MABAC model alternative L8 dominates alternative L10. Ranking positions of the rest alternatives (L1, L2, L3, L4, L5, L6, L7, L9 and L11) are identical in all ranks obtained by applied methods and GIS-DANP-MABAC model. Obviously, result of the GIS-DANP-MABAC model is exactly the same, or very similar to results obtained by common MCDM methods.

4. Conclusion

A combination of the DEMATEL-ANP (DANP) hybrid model and MABAC method with a GIS was implemented here for the first time for selecting the optimal locations for wind farms, using the example of the province of Vojvodina in the Republic of Serbia, and it is a model that can be applied to other locations with similar natural characteristics. The DANP technique was used in the section for determining the weights, that is, the significance of each

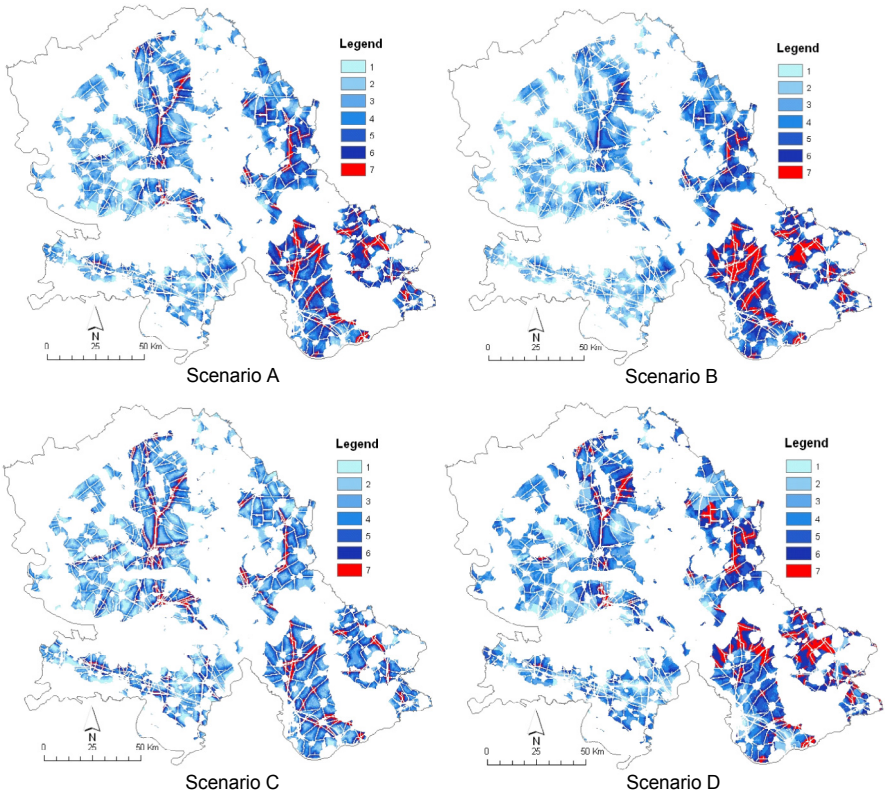


Fig. 8. Sensitivity analysis.

Table 17
Overlapping of the cells from the final map of benefits with cells from the maps of scenarios.

Scenarios	Classes							
	5		6		7		6 + 7	
	Number of cells	%	Number of cells	%	Number of cells	%	Number of cells	%
A - uniform weights	–	–	61 403	12.0	451 881	88.0	513 284	100.0
B - priority En	–	–	81 554	15.9	431 730	84.1	513 284	100.0
C - priority Ec	34 187	6.7	191 624	37.3	287 408	56.0	479 032	93.3
D - priority Soc	46 097	9.0	122 437	23.9	331 479	64.6	453 916	88.4

Table 18
Alternative ranking according to the VIKOR, TOPSIS, COPRAS methods and GIS-DANP-MABAC model.

Alternative	VIKOR		TOPSIS		COPRAS		GIS-DANP-MABAC rank
	F	Rank	*F*	Rank	*F*	Rank	
L 1	0.6229	7	0.5868	7	82.19	7	7
L 2	0.4554	4	0.6177	4	87.18	4	4
L 3	0.6427	9	0.5804	9	76.80	9	9
L 4	0.5236	6	0.5875	6	83.40	6	6
L 5	0.5662	8	0.5817	8	81.04	8	8
L 6	0.6970	10	0.5607	10	73.79	10	10
L 7	0.7241	11	0.5435	11	72.28	11	11
L 8	0.3793	1	0.6734	2	100.00	1	1
L 9	0.4367	3	0.6312	3	88.22	3	3
L 10	0.0425	2	0.7047	1	97.64	2	2
L 11	0.7962	5	0.6154	5	83.58	5	5

criterion, and the WLC technique was used for summing the weights and for the final identification of the suitable locations for building wind farms. The connection of the tools was possible in the ArcGis software environment using the ArcGIS Advanced 10.2 software firm ESRI. Finally, after defining the suitable locations, the most suitable alternative (L 8 - Laudonovac) was selected using the MABAC technique. In the final phase of applying the modela sensitivity analysis of the solution proposed by the GIS-DANP-MABAC model was carried out, as well as its validation by comparing its results with those obtained by the multi-criteria techniques of VIKOR, TOPSIS and COPRAS.

Application of the DAN GIS MABAC multi-criteria spatial model involved the construction of a hierarchical spatial model which consisted of 11 constraints and 11 evaluation criteria. The evaluation criteria were grouped into natural, economic and social clusters. A final map of benefits was obtained as a result of the research. The size of the areas of the suitable locations for constructing wind farms, in this study, varied from 0.0004 to 13.7 km^2, and came to a total of 321 km^2. On the basis of the size of the area required, 11 suitable locations were identified as the final result of the model. Ranking of the suitable alternatives was carried out using the MABAC method. The sensitivity analysis, in which the weight coefficients of the clusters were changed, showed a high degree of stability in terms of overlapping of the most suitable locations according to the scenarios, both at the level of the total map of benefits and at the level of the selected locations. Validation of the results for the ranks of the locations using the MABAC method was carried out by comparing the results with those of theVIKOR, TOPSIS and COPRAS multi-criteria techniques and it demonstrates its credibility in its selection of Laudonovac (L 8) as the most suitable for installing a wind farm in the area of Vojvodina.

This model broadens the theoretical framework of knowledge in the field of location problems. The existing problem is considered using new methodology, which creates the basis for further theoretical and practical improvement. In addition, this model highlights new and modified criteria and constraints which until now other models have not considered, and which are of significance to this issue. It is important to note that the criteria applied for the selection of sites for the development of wind farms vary in different regions and depend on the governing socio-economic and natural resources. Therefore, this procedure allows the inclusion of other criteria that were not included in this study. This is primarily related to the requirements of investors, municipal and non-governmental agencies and environmentalists, as well as limitations in terms of their visibility in relation to settlements and facilities for sport and recreation [37,57]. All these criteria can have an additional role in selecting the best solution. The practical significance of this model is the possibility of its application in solving location problems in various fields, including the environment, transport, risk and others.

The main recommendations for the further use of this model are its accessible mathematical apparatus and the stability (consistency) of its solution, as well as the possibility of combining it with other methods, especially in the section related to determining the weight criteria. Directions for future improvement of the GIS-DANP-MABAC model should be based on the application of classical fuzzy sets and the intervals of fuzzy numbers in the process of determining the parameters of the criteria/clusters. Fuzzification makes it possible to exploit the uncertainty that arises when defining the parameters of the criteria/clusters. Besides the fuzzy approach, suitable tool for application in conditions of uncertainty and ambiguity is the gray theory [113,74], proposing the gray theory for future research guidelines and extension of the proposed model. In addition, another possible future application can be seen in the implementation of individual phases of the MABAC method in phases of the VIKOR, TOPSIS or COPRAS methods, which would exploit the strengths of these methods.

References

[1] M. Amer, T.U. Daim, Selection of renewable energy technologies for a developing county: a case of Pakistan, Energy Sustain. Dev. 15 (2011) 420–435.
[2] International Energy Agency (IEA), Key World Energy Statistics, 2014, 2015. http://www.iea.org/publications/freepublications/publication/keyworld2014.pdf (Accessed 25 August 15).
[3] P. Kaiser, R.B. Unde, C. Kern, A. Jess, Production of liquid hydrocarbons with CO_2 as carbon source based on reversewater-gas shift and fischer-tropsch synthesis, Chem. Ing. Tech. 85 (2013) 489–499.
[4] A.H.I. Lee, C.Y. Lin, H.Y. Kang, W.H. Lee, An integrated performance evaluation model for the photovoltaics industry, Energies 5 (2012) 1271–1291.
[5] N.L. Panwar, S.C. Kaushik, S. Kothari, Role of renewable energy sources in environmental protection: a review, Renew. Sustain Energy Rev. 15 (2011) 1513–1524.
[6] European Commission (EC), Renewable energy road map. Renewable energies in the 21st century: building a more sustainable future, in: Commun Comm Counc Eur Parliam 2007, 2012. http://ec.europa.eu/transparency/regdoc/rep/1/2006/EN/1-2006-848-EN-F1-1.Pdf (Accessed 17 August 12).
[7] European Union, Directive 2009/28/EC of the European parliament and of the council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC 2009. http://iet.jrc.ec.europa.eu/remea/directive-200928ec-european-parliament-and-council-23-april-2009-promotion-use-energy-renewable, 2014 (Accessed 18 June 14).
[8] Energy Community (EC), Decision of the Ministerial Council of the Energy Community, Energy Community, 2015. Annex 18, Ref.: 10th MC/18/10/2012/-Annex18.09.07.2012, 2012, http://www.energy-community.org/pls/portal/docs/1766219.PDF (Accessed 10 June 15).
[9] Official Gazette of the Republic of Serbia 99/09, Regulation on Incentives for the Production of Electricity Using Renewable Energy Sources and Combined Production of Electrical and Heating Energy, Belgrade, 2009.
[10] Official Gazette of the Republic of Serbia 72/09, Regulation on the Conditions for Obtaining the Status of Privileged Power Producer and Criteria for Assessing the Fulfillment of These Conditions, Belgrade, 2009.
[11] Ministry of Energy, Development and Environmental Protection Republic of Serbia. National renewable energy action plan of the Republic of Serbia (In

accordance with the template foreseen in the Directive 2008/29/EC- Decision 2009/548/EC), 2013 (Accessed 19 March 15), https://www.energy-community.org/portal/page/portal/ENC_HOME/DOCS/2144185/NREAP_OF_REPUBLIC_OF_SERBIA_28_June_2013.pdf, 2015.
[12] P. Zhao, J. Wang, J. Xia, Y. Dai, Y. Sheng, J. Yue, Performance evaluation and accuracy enhancement of a day-ahead wind power forecasting system in China, Renew. Energy 43 (2012) 234–241.
[13] N.Y. Aydin, E. Kentel, S. Duzgun, GIS-based environmental assessment of wind energy systems for spatial planning: a case study from Western Turkey, Renew. Sustain Energy Rev. 14 (2010) 364–373.
[14] L.I. Tegou, H. Polatidis, D.A. Haralambopoulos, Environmental management framework for wind farm siting: methodology and case study, J. Environ. Manag. 91 (2010) 2134–2147.
[15] A. Nadai, Planning 'Siting' and the local acceptance of wind power: some lessons from the French case, Energy Policy 35 (2007) 2715–2726.
[16] M. Wolsink, Near-shore wind powerdprotected seascapes, environmentalists' attitudes, and the technocratic planning perspective, Land Use Policy 27 (2010) 195–203.
[17] A. Miller, L. Ruopu, A geospatial approach for prioritizing wind farm development in Northeast Nebraska, USA, ISPRS Int. J. Geo-Inf 3 (2014) 968–979.
[18] T.M. Yeh, Y.L. Huang, Factors in determining wind farm location: integrating GQM, fuzzy DEMATEL, and ANP, Renew. Energy 66 (2014) 159–169.
[19] N.G. Douglas, G.S. Saluja, Wing energy development under the UK non-fossil fuel and renewables obligations, Renew. Energy 6 (1995) 701–711.
[20] H. Hansen, GIS-based Multi-criteria Analysis of Wind Farm Development. 10th Scandinavian Research Conference on Geographical Information Science (ScanGIS), 2005, pp. 75–85.
[21] F. Joerin, M. Thériault, A. Musy, Using GIS and outranking multicriteria analysis for land-use suitability assessment, Int. J. Geogr. Inf. Sci. 15 (2001) 153–174.
[22] A. Gourgiotis, E. Kyriazopoulos, Electrical energy production from wind turbine Parks: the Finistere wind turbine Chart (France) and the greek spatial planning experience (in greek), in: Interdisciplinary Congress on Education, Research, Technology. From Yesterday till Tomorrow, 2007, pp. 27–30.
[23] J. Malczewski, Review article GIS-based multicriteria decision analysis: a survey of the literature, Int. J. Geograp. Inf. Sci. 20 (2006) 703–726.
[24] S. Allahi, M. Mobin, A. Vafadarnikjoo, C. Salmon, An integrated AHP-GIS-MCLP method to locate bank branches, in: Proceedings of the 2015 Industrial and Systems Engineering Research Conference (ISERC2015), Tennessee, USA, 2015.
[25] D. Latinopoulos, K. Kechagia, A GIS-based multi-criteria evaluation for wind farm site selection. A regional scale application cin Greece, Renew. Energy 78 (2015) 550–560.
[26] P.V. Gorsevski, S.C. Cathcart, G. Mirzaei, M.M. Jamali, X. Ye, E. Gomezdelcampo, A group-based spatial decision support system for wind farm site selection in northwest Ohio, Energy Policy 55 (2013) 374–385.
[27] R. Haaren, V. Fthenakis, GIS-based wind farm site selection using spatial multicriteria analysis (SMCA): evaluating the case for New York State, Renew. Sustain Energy Rev. 15 (2011) 3332–3340.
[28] J.Y. Kim, K.Y. Oh, K.S. Kang, J.S. Lee, Site selection of offshore wind farms around the Korean Peninsula through economic evaluation, Renew. Energy 54 (2013) 189–195.
[29] M. Szurek, J.A. Blachowski, Gis-based method for wind farm location multicriteria analysis Received, Min. Sci. 21 (2014) 65–81.
[30] A.D. Mekonnen, P.V. Gorsevski, A web-based participatory GIS (PGIS) for offshore wind farm suitability within Lake Erie, Ohio, Renew. Sustain. Energy Rev. 41 (2015) 162–177.
[31] S. Al-Yahyai, Y. Charabi, A. Gastli, A. Al-Badi, Wind farm land suitability indexing using multi-criteria analysis, Renew. Energy 44 (2012) 80–87.
[32] J.J.W. Watson, M.D. Hudson, Regional Scale wind farm and solar farm suitability assessment using GIS-assisted multi-criteria evaluation, Landsc. Urban Plan. 138 (2015) 20–31.
[33] T. Tsoutsos, I. Tsitoura, D. Kokologos, K. Kalaitzakis, Sustainable siting process in large wind farms case study in Crete, Renew. Energy 75 (2015) 474–480.
[34] V. Bagocius, E.K. Zavadskas, Z. Turskis, Multi-person selection of the best wind turbine based on the multi-criteria integrated additive-multiplicative utility function, J. Civ. Eng. Manag. 20 (2014) 590–599.
[35] A. Azizi, H.R. Malekmohammadi, H. Jafari, V.A. Nasiri, Land suitability assessment for wind power plant site selection using ANP-DEMATEL in a GIS environment: case study of Ardabil province, Iran. Environ. Monit. Assess. 186 (2014) 6695–6709.
[36] U. Mevlut, GIS-based solar farms site selection using analytic hierarchy process (AHP) in Karapinar region, Konya/Turkey, Renew. Sustain. Energy Rev. 28 (2013) 11–17.
[37] J.R. Janke, Multicriteria GIS modeling of wind and solar farms in Colorado, Renew. Energy 35 (2010) 2228–2234.
[38] H. Dagdougui, A. Ouammi, R. Sacile, A regional decision support system for onsite renewable hydrogen production from solar and wind energy sources, Int. J. Hydrogen Energy 36 (2011) 14324–14334.
[39] Y. Charabi, A. Gastli, PV site suitability analysis using GIS-based spatial fuzzy multi-criteria evaluation, Renew. Energy 36 (2011) 2554–2561.
[40] H.T. Nguyen, J.M. Pearce, Estimating potential photovoltaic yield with r.sun and the open source geographical resources analysis support system, Sol. Energy 84 (2010) 831–843.
[41] J.M. Sánchez-Lozano, J. Teruel-Solano, P.L. Soto-Elvira, M. Socorro García-Cascales, Geographical information systems (GIS) and multi-criteria decision making (MCDM) methods for the evaluation of solar farms locations: case study in south-eastern Spain, Renew. Sustain Energy Rev. 24 (2013) 544–556.
[42] D. Dalalah, M. Hayajneh, F. Batieha, A fuzzy multi-criteria decision making model for supplier selection, Expert Syst. Appl. 38 (2011) 8384–8391.
[43] C.H. Hsu, F.K. Wang, G.H. Tzeng, The best vendor selection for conducting the recycled material based on a hybrid MCDM model combining DANP with VIKOR. Resources, Conserv. Recycl. 66 (2012) 95–111.
[44] C.C. Hsu, J.J. Liou, Y.C. Chuang, Integrating DANP and modified grey relation theory for the selection of an outsourcing provider, Expert Syst. Appl. 40 (6) (2013) 2297–2304.
[45] W.Y. Chiu, G.H. Tzeng, H.L. Li, A new hybrid MCDM model combining DANP with VIKOR to improve e-store business, Knowledge-Based Syst. 37 (2013) 48–61.
[46] L.J. Gigović, D. Pamučar, D. Lukić, S. Marković, Application of the GIS - fuzzy DEMATEL MCDA model for ecotourism development site evaluation: a case study of "Dunavski ključ", Serbia, Land Use Policy 58 (2016) 348–365.
[47] L.J. Gigović, D. Pamučar, Z. Bajić, M. Milićević, The combination of expert judgment and GIS-MAIRCA analysis for the selection of sites for ammunition depots, Sustainability 8 (2016) 372.
[48] G. Büyüközkan, S. Güleryü, An integrated DEMATEL-ANP approach for renewable energy resources selection in Turkey, Int. J. Prod. Econ. 182 (2016) 435–448.
[49] I. Gölcük, A. Baykasoğlu, An analysis of DEMATEL approaches for criteria interaction handling within ANP, Expert Syst. Appl. 46 (2016) 346–366.
[50] C.C. Hsu, J.J.H. Liou, Y.C. Chuang, Integrating DANP and modified grey relation theory for the selection of an outsourcing provider, Expert Syst. Appl. 40 (6) (2013) 2297–2304.
[51] M.A. Sharifi, V. Retsios, Site selection for waste disposal through spatial multiple criteria decision analysis, J. Telecommun. Inf. Technol. 3 (2004) 28–38.
[52] J. Malczewski, GIS and Multicriteria Decision Analysis, John Wiley and Sons, New York, 1999, p. 392.
[53] D. Geneletti, E. Beinat, C.J. Chung, A.G. Fabbri, H.J. Scholten, Accounting for uncertainty factors in biodiversity impact assessment: lessons from a case study, Environ. Impact Assess. Rev. 23 (2003) 471–487.
[54] G. Gamboa, G. Munda, The problem of wind farm location: a social multicriteria evaluation framework, Energy Policy 35 (2007) 1564–1583.
[55] S. Baban, T. Parry, Developing and applying a GIS-based approach to locating wind farms in the UK, Renew. Energy 24 (2001) 59–71.
[56] S. Stagl, Multicriteria evaluation and public participation: the case of UK energy policy, Land Use Policy 23 (2006) 53–62.
[57] L.C. Rodman, R.K. Meentemeyer, A geographic analysis of wind turbine placement in Northern California, Energy Policy 34 (2006) 2137–2149.
[58] R.J. Eastman, P.A.K. Kyen, J. Toledno, A procedure for multiple- objective decision making in GIS under conditions of conflicting objectives, in: J. Hents, H.F.L. Ottens, H.J. Scholten (Eds.), Fourth European Conference on GIS (ESIG 93) Proceedings, Genova (IT), vol. 1, 1993, pp. 438–447.
[59] N.B. Chang, G. Parvathinathan, J.B. Breeden, Combining GIS with fuzzy multicriteria decision-making for landfill siting in a fast-growing urban region, J. Environ. Manag. 87 (2008) 139–153.
[60] J. Van Hoesen, S. Letendre, Evaluating potential renewable energy resources in Poultney, Vermont: a GIS-based approach to supporting rural community energy planning, Renew. Energy 35 (2010) 2114–2122.
[61] K.T. Chang, Introduction to Geographic Information System, Tata McGraw Hill, New Delhi, 2006.
[62] J.R. Eastman, Guide to GIS and Image Processing, Clark Labs, Clark University, Worcester, MA, USA, 1999.
[63] W.W. Wu, Y.T. Lee, Developing global managers competencies using the fuzzy DEMATEL method, Expert Syst. Appl. 32 (2) (2007) 499–507.
[64] Y.J. Chiu, H.C. Chen, G.H. Tzeng, J.Z. Shyu, Marketing strategy based on customer behavior for the LCD-TV, Int. J. Manag. Decis. Mak. 7 (2006) 143–165.
[65] G.H. Tzeng, C.H. Chiang, C.W. Li, Evaluating intertwined effects in Elearning programs: a novel hybrid MCDM model based on factor analysis and DEMATEL, Expert Syst. Appl. 32 (2007) 1028–1044.
[66] J.J.H. Liou, G.H. Tzeng, H.C. Chang, Airline safety measurement using a hybrid model, Air Transp. Manag. 13 (2007) 243–249.
[67] C.L. Lin, G.H. Tzeng, A value-created system of science (technology) park by using DEMATEL, Expert Syst. Appl. 36 (6) (2009) 9683–9697.
[68] Y.P. Ou Yang, H.M. Shieh, J.D. Leu, G.H. Tzeng, A novel hybrid MCDM model combined with DEMATEL and ANP with applications, Int. J. Op. Res. 5 (2008) 160–168.
[69] A. Vafadarnikjoo, Corrigendum to "Using fuzzy DEMATEL to evaluate the green supply chain management practices, J. Clean. Prod. 40 (2013) 32–39. Journal of Cleaner Production 2014;82:232.
[70] R. Goodman, Introduction to Stochastic Models, Cummings Pub, Benjamin, 1988.
[71] J.L. Yang, G.H. Tzeng, An integrated MCDM technique combined with DEMATEL for a novel cluster-weighted with ANP method, Expert Syst. Appl. 38 (2011) 1417–1424.
[72] W.S. Lee, G.H. Tzeng, J.L. Guan, K.T. Chien, J.M. Huang, Combined MCDM techniques for exploring stock selection based on Gordon model, Expert Syst. Appl. 36 (2009) 6421–6430.

[73] A. Vafadarnikjoo, M. Mobin, S. Allahi, A. Rastegari, A hybrid approach of intuitionistic fuzzy set theory and DEMATEL method to prioritize selection criteria of bank branches locations, in: Proceedings of the 2015 American Society of Engineering Management Conference (ASEM2015), Indiana, USA, 2015.
[74] A. Vafadarnikjoo, M. Mobin, C. Salmon, N. Javadian, An integrated gray-fuzzy cause and effect approach to determine the most significant categories of project risks, in: Proceedings of the 2015 Industrial and Systems Engineering Research Conference (ISERC2015), Tennessee, USA, 2015.
[75] S. Opricovic, G.H. Tzeng, De-fuzzification within a multi-criteria decision model. International journal of uncertainty, Fuzziness Knowledge-Based Syst. 11 (2003) 635–652.
[76] T.L. Saaty, Decision Making with Dependence and Feedback: the Analytic Network Process, RWS Publications, Pittsburgh, PA, USA, 1996.
[77] J.R. Eastman, Idrisi Andes – Tutorial, Clark Labs., Clark University, Worcester, MA, 2006.
[78] D. Pamučar, G. Ćirović, The selection of transport and handling resources in logistics centers using Multi-Attributive Border Approximation area Comparison, Expert Syst. Appl. 42 (2015) 3016–3028.
[79] Institute for Multidisciplinary Research, Atlas of Solar and Wind Energy Potentials in Serbia, 2007, 2010.
[80] Provincial Secretariat for Energy and Mineral Resources, Wind Atlas of the Autonomous Province of Vojvodina, Novi Sad, 2008.
[81] A. Taghilo, Calculation of Wind Potential for Wind Power Construction Plant (Case Study in Zanjan Province), Tarbiat Modarres University, Tehran, Iran, 2011.
[82] B. Moiloa, Geographical Information Systems for Strategic Wind Energy Site Selection, Vrije Universiteit, Amsterdam Netherlands, 2009.
[83] Official Gazette of the Republic of Serbia 31/12, Regulation on Regimes of Protection, Belgrade, 2012.
[84] P. Nosović, M. Bakalović, Electromagnetic fields and safety distances from overhead lines, Infoteh-Jahorina 10 (2011) 1043–1047.
[86] J.R. Eastman, W. Jin, P.A.K. Kyem, J. Toledano, Raster procedures for multi-criteria/multi-objective decisions, Photogramm. Eng. Remote Sens. 61 (1995) 539–547.
[87] K.H. Lee, S.O. Jun, K.H. Pak, D.H. Lee, K.W. Lee, J.P. Park, Numerical optimization of site selection for offshore wind turbine installation using genetic algorithm, Curr. Appl. Phys. 10 (2010) S302–S306.
[88] C. Kahraman, I. Kaya, S. Cebi, A comparative analysis for multiattribute selection among renewable energy alternatives using fuzzy axiomatic design and fuzzy analytic hierarchy process, Energy 34 (2009) 1603–1616.
[89] Corine Land Cover 2006 raster data, European Environment Agency (EEA), 2015. http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2006-raster-3 (Accessed 18 August 15).
[90] H. Farajisabokbar, H. Nasiri, M. Hamzeh, S. Talebi, Y. Rafee, Analysis of land suitability to locate rural service centres using PROMETHEE II and AHP methods in GIS environment (Case study in Soltanieh-Abhar city), J. Rural Dev. 2 (2010) 95–118.
[91] Provincial Institute for the Protection of Nature, Map of Protected Areas of Vojvodina, Novi Sad, 2011.
[92] Military Geographical Institute, Digital Terrain Model (DMT 25), Belgrade, 2006.
[93] Military Geographical Institute, Digital Topographic Map (DTKP 300), Belgrade, 2003.
[94] Statistical Office of the Republic of Serbia, Census of Population Households and Dwellings in the Republic of Serbia. Book 1: Ethnicity, Data by Municipalities and cities., Belgrade, 2011.
[95] Q. Li, A novel Likert scale based on fuzzy sets theory, Expert Syst. Appl. 40 (2013) 1609–1618.
[96] P. Denholm, M. Hand, M. Jackson, S. Ong, Land-use Requirements of Modern Wind Power Plants in the United States, National Renewable Energy Laboratory, USA, 2009.
[97] C.S. Meszaros, T. Rapcsak, On sensitivity analysis for a class of decision systems, Decis. Support Syst. 16 (1996) 231–240.
[98] J. Barysiene, A multi-criteria evaluation of container terminal technologies applying the COPRAS-G method, Transport 27 (4) (2012) 364–372.
[99] N. Rezaeiniya, S.H. Zolfani, E.K. Zavadskas, Greenhouse locating based on ANP-COPRAS-G methods - an empirical study based on Iran, Int. J. Strategic Prop. Manag. 16 (2) (2012) 188–200.
[101] S. Wang, P. Liu, The evaluation study on location selection of logistics centre based on fuzzy AHP and TOPSIS, in: International Conference on Wireless Communications, Networking and Mobile Computing, 21–25.09.2007, 2007, pp. 3779–3782.
[102] S. Chen, X. Liu, Factors and a method of selecting a site for a logistical centre, J. Weinan Teach. Coll. 3 (2006) 2356–2368.
[103] X. Xu, R. Law, W. Chen, L. Tang, Forecasting tourism demand by extracting fuzzy Takagi-Sugeno rules from trained SVMs, CAAI Trans. Intell. Technol. 1 (2016) 30–42.
[104] D. Božanić, D. Pamučar, S. Karović, Use of the fuzzy AHP - MABAC hybrid model in ranking potential locations for preparing laying-up positions, Vojnoteh. glasnik/Military Tech. Cour. 64 (3) (2016) 705–729.
[105] D. Pamučar, D. Božanić, D. Kurtov, Fuzzification of the Saaty's scale and a presentation of the hybrid fuzzy AHP-TOPSIS model: an example of the selection of a brigade artillery group firing position in a defensive operation, Vojnoteh. glasnik/Military Tech. Cour. 64 (4) (2016) 966–986.
[106] M. Tavana, Z. Li, M. Mobin, M. Komaki, E. Teymurian, Multi-objective design of control chart optimization using NSGA-III and MOPSO enhanced with DEA and TOPSIS, Expert Syst. Appl. 50 (2016) 17–39, 2016.
[107] C. Salmon, M. Mobin, A. Roshani, TOPSIS as a Method to Populate Risk Matrix Axes, Proceedings of the 2015 Industrial and Systems Engineering Research Conference (ISERC2015), Tennessee, USA, 2015.
[108] M. Mobin, A. Roshani, M. Saeedpoor, M. Mozaffari, Integrating FAHP with COPRAS-g method for supplier selection (case study: an iranian manufacturing company), in: Proceedings of the 2015 American Society of Engineering Management Conference (ASEM2015), Indiana, USA, 2015.
[109] M. Mobin, M. Dehghani, C. Salmon, Food product target market prioritization using fuzzy MCDM approaches, in: Proceedings of the 2014 Industrial and Systems Engineering Research Conference (ISERC2014), Montreal, Canada, 2014.
[110] Mobin M, Dehghani M, Salmon C. Food product target market prioritization using fuzzy MCDM approaches. Proceedings of the 2014 Industrial and Systems Engineering Research Conference (ISERC2014), Montreal, Canada, 2014.
[111] C. Salmon, M. Mobin, A. Roshani, TOPSIS as a method to populate risk matrix axes, in: Proceedings of the 2015 Industrial and Systems Engineering Research Conference (ISERC2015), Tennessee, USA, 2015.
[112] M. Mobin, A. Roshani, M. Saeedpoor, M. Mozaffari, Integrating FAHP with COPRAS-g method for supplier selection (case study: an iranian manufacturing company), in: Proceedings of the 2015 American Society of Engineering Management Conference (ASEM2015), Indiana, USA, 2015.
[113] K. Govindan, R. Khodaverdi, A. Vafadarnikjoo, A grey DEMATEL approach to develop third-party logistics provider selection criteria, Ind. Manag. Data Syst. 116 (4) (2016) 690–722.