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A Decision Support System methodology for selecting wind farm installation locations using AHP and TOPSIS: Case study in Eastern Macedonia and Thrace region, Greece

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ABSTRACT

The optimization of spatial planning in order to identify the most suitable places for the installation of wind farms is one of the most difficult problems mainly due to the need of identification and calculation of a variety of qualitative and quantitative parameters as well as their effect on the final solution. Multi Criteria Decision Making Methods (MCDM) are commonly used in order to solve this problem and are combined with Geographic Information Systems (GIS) to spatially represent the results from the application of the MCDM methodology. This paper presents a methodology which is based on the combination of a MCDM methodology called Analytical Hierarchy Process (AHP) and GIS in order to determine the most suitable locations for wind farms installation. The calculated locations are then ranked using the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) in order to rank the locations based on installation suitability. The application of this methodology can help decision makers to easily overcome conflicting parameters and propose optimal solutions which are acceptable from citizens and stake holders while at the same time are economical and environmental friendly.

1. Introduction

Electricity and energy production play a key role in modern life, and they are considered very important for modern societies. Each country according to its level of development, which is a key indicator of energy consumption, uses imported or domestic sources of energy, in the form of coal, petroleum, natural gas and nuclear fuels (Rahman and Miah, 2017).

During the last two decades we witness an evolution in the energy sector. Many countries throughout the world are shifting their energy production methods from fossil fuel usage to more environmental friendly methods. These methods are described under the term Renewable Energy Methods and propose the usage of sustainable sources based on Wind, Water, Biomass, Solar Energy and Geothermal Energy for the production of energy (Doukas et al., 2009). This shift was mainly caused due to the increase of public awareness on environmental problems and climate change which are both related to the increase of Green House Gas (GHG) emissions (Rahman and Miah, 2017; Kaldellis et al., 2012; Giacomarra and Bono, 2015). Under this scope the European Union (EU) has created a legislative framework which is enhanced by a series of actions in order to further develop and encourage the usage of Renewable Energy Sources (RES) in all member states (Giacomarra and Bono, 2015).

The most well-known action is the 20-20-20 target. All EU states are committed to achieve at least 20% reduction of GHGs emissions by the year 2020. The baseline for this reduction is the year 1990. Also the member states should reduce energy consumption by 20% and increase energy efficiency by 20% (Giacomarra and Bono, 2015). The recently legislated EU directive 2009/28/EC entitles member states to implement cooperation mechanisms in order to promote the usage of RES and enables them to more easily achieve the goal of 2020 (Giacomarra and Bono, 2015; Papapostolou et al., 2017a; Tampakis et al., 2017).

European Union's progress in the increase on the use of renewable energy and the enhancement of energy efficiency is showing slowing down signs which puts the achievement of 2020 and 2030 targets in jeopardy, according to the report of the European Environment Agency (European Environment Agency, 2017). Regarding the 2030 action, energy efficiency in the European Union must be improved by 32.5%, while the share of renewable energy sources in gross final consumption must reach at least the rate of 32%. Both targets are going to be reconsidered by 2030, but the pursued rates can only be increased rather than decreased (Energy Union, 2018). The increasing energy

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consumption, especially in the transport sector, is mainly responsible for this slowdown, as the EEA notes in its annual report on the targets set for renewable energy sources and energy efficiency. According to the Agency's data, power generated from renewable energy sources, such as wind and solar energy, is estimated at 17.4% of the gross final energy consumption in European Union for the year 2017, which exceeds the corresponding rate of 17% in 2016. Of course, these rates only stress that the European Union is still on track towards the achievement of the 20% renewable energy usage target by 2020, however signs of deceleration are evident. In fact, the progress made in achieving the 10% renewable energy target for the transport sector by 2020 is considered inadequate. For the first time, member states are bound to take specific energy efficiency measures which will benefit those who have difficulty in meeting their heating or electricity needs. In addition, by 31 December 2019 and every ten years each member state must develop ten-year integrated national energy and climate plans, which will involve national targets, contribution percentages, policies and measures.

The evolution which has taken place in the field of wind turbines, with the manufacture of more energy efficient and less noisy turbines has allowed wind energy to be transformed in a major RES, which is expected to evolve in near feature (Tampakis et al., 2013), furthermore the application of wind energy presents minimal environmental implications (Wolsink, 2007). Important role in the installation of RES is the attitude of citizens. (see Tables 4 and 5)

Therefore, it is essential prior to the investment in a wind farm to understand and analyze local community's attitudes towards the selected locations in order to issue and use the proper strategies which can lead to the mitigation of their reactions. Additionally, we must also take under consideration the relevant national legislation as well as the selection of locations which provide maximum energy production.

In this paper we aim at designing a Decision Support System which can encapsulate all the parameters affecting the installation of a wind farm in order to minimize setbacks and maximize the produced energy.

In detail we aim at presenting a methodology framework which will combine all the criteria affecting the location of a wind farm, with the national legislation and at the end, provide a ranking of the optimal locations. The initial selection of areas suitable for wind farm installation will be provided by the application of the legislation. These areas will be further refined by the application of the AHP methodology. Afterwards the remaining locations will be evaluated based on a series of criteria using TOPSIS. The end result will be the creation of a ranking which will include the optimal installation locations. Additionally, we will apply the proposed methodology in a prefecture in northern Greece, were we will determine the optimal locations for wind farms installation.

2. Literature review

2.1. RES in Greece

In Greece the current share of RES usage is steadily increasing during the last decade as it can be easily noted in Fig. 1 (Eurostat, 2017). Furthermore, the line trend of energy produced from RES is following the general increasing trend of the other EU countries although it presents a bend mainly due to the economic crisis that is affecting the country from 2010 and onwards (Arabatzis et al., 2017; Mondol and Koumpetsos, 2013) (see Fig. 2).

Greece, due to its geographic position, geo-morphologic profile and climate, presents a lot of opportunities regarding the usage of wind and solar energy (Koundouri et al., 2009), biomass energy (Manolis et al., 2016), hydropower (Kaldellis et al., 2005; Arabatzis and Myronidis, 2011) and geothermal energy (Economou, 2012). According to the most recent data from the Hellenic Transmission System Operator (HTSO, 2011a), in 2011 the total produced energy from wind farms was 2.596 MW, Hydropower Stations 560.628, Photovoltaic's 441.553 MW and 199.102 MW from Biomass.

By Law 2244/1994 Greece proceeded faster and earlier in institutional and legal recognition of the role of RES and the adoption of the guaranteed price target in order to attract financial investments in comparison to other European countries (Diakoulaki, 2014). Additionally, according to Directive 2009/28/EC and the Greek law 3851/2010 Greece set a targeted participation of 20% RES in total final energy consumption by 2020 (Ministry of Environment, 2010). However, the enactment of Greek law 3851/2010 was followed by the economic recession with consequent impacts in financing schemes that could foster the wider penetration of RES in the existing energy mixture (Ministry of Environment, 2014). Greek law 4254/2014 established new lower prices for energy produced by RES and further decreased the interest for investments in the field (Ministry of Environment, 2014b).

2.2. Criteria affecting wind farm installation

The proposal of the spatial allocation for feature wind farms is based on the evaluation of a series of different criteria. These criteria range can be divided in two categories, quantitative criteria and qualitative criteria. The first category includes criteria like wind speed and its effect on energy production (Feijóo and Villanueva, 2016; Jena and Rajendran, 2015; Goh et al., 2016; Wang et al., 2016), the regions topography, the slope and elevation of a location etc. The latter category includes more abstract criteria like land uses and their value prior and after the installation of a wind farm (Villacreses et al., 2017; Al-Yahyai et al., 2012; Atici et al., 2015), people's attitudes towards the installation of wind turbines (Tampakis et al., 2017), the effect of wind farms on locale fauna (Peste et al., 2015; Santos et al., 2013; Schläppy et al., 2014) etc. All of the aforementioned criteria must be combined with national and EU legislation in order to determine the optimal locations (Sánchez-Lozano et al., 2014).

2.3. Energy produced by wind farms

A wind farm can be defined as a cluster of wind turbines that acts and is connected to the power system as a single electricity producing power station (Petersen and Madsen, 2015). This type of RES power plants is very common. In the year 2016, more than 35 GW of new capacity was installed globally and by the year's end the total installed wind power capacity reached 411.214 GW. The global market forecast for the years 2017–2021 estimates an average capacity growth rate of 11.5% reaching a total of 741.7 GW of energy produced by wind power by the year 2021 (GWEC, 2016).

In China, the global leader in the field of wind power development, energy production from wind farms has reached 13.5 TWh, making wind power the third largest type of power supply in the country, topped only by thermal power and hydropower (Angelopoulos et al., 2017). In USA energy produced by wind has reached 82,184 MW in 2016 ranking the country second in wind energy production followed by Germany (50,018 MW), India (28,700 MW) and Spain (23,074 MW) (GWEC, 2016). The cumulative market forecast for the years 2017–2021 places European Region at the second place after Asia and depicts the potential of energy production by wind in the following years (GWEC, 2016). Currently in Greece wind farms produce 2.596 MW (Diakoulaki, 2014), and is anticipated to further increase in order for the country to reach the target of 20% share of renewable energy in the total final energy production share by 2020, which is estimated to be 7.200 MW (Angelopoulos et al., 2017). Under this context the study of the country's wind energy potential is attracting increasing interest in recent years (Fan et al., 2015; Bagiorgas et al., 2008; Fyrippis et al., 2010; Kotroni et al., 2014).

2.4. Spatial analysis

In order to optimize the location of an installation we must perform

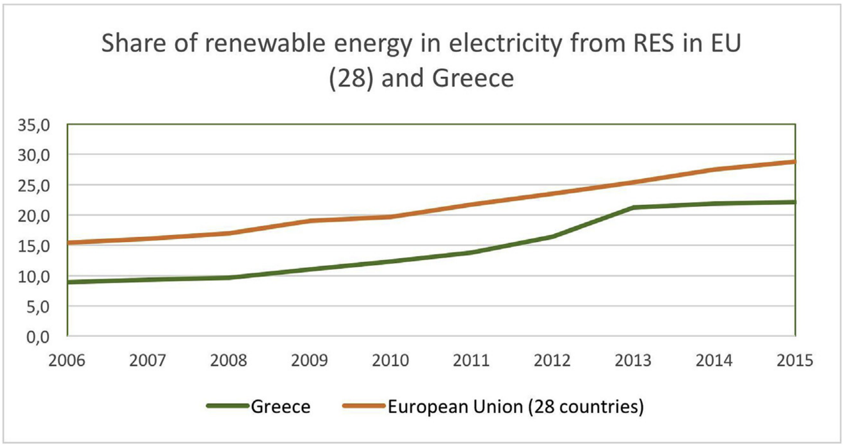

Fig. 1. Share of RES in electricity in EU and Greece.

a spatial analysis of the area. This analysis must take under consideration a series of criteria and parameters affecting the selection of the location. The effect of each criterion to the spatial analysis goal, which is the selection of the optimal location, differs. In order to establish the weight coefficient of each criterion, we must apply a Multi Criteria Decision Analysis Method (MCDM) which allows the determination of the effect of each criterion to the overall goal.

There are many MCDM methods, such as Analytical Hierarchy Process (AHP) (Saaty, 1980), Case Based Reasoning (Petersen and Madsen, 2015), ELECTRE (Daengdej et al., 1999), PROMETHEE (Roy, 1968).

AHP determines the weight coefficients of the criteria by performing pair wise comparisons between them (Brans et al., 1984). The main advantages of this methodology are: the ease of use because it uses pair wise comparisons to weight criteria or coefficients and compare alternatives, the scalability provided which allows the insertion or removal of criteria (Ioannou et al., 2011), the ability to easily create scenarios by recalculating the weight coefficients (Velasquez and Hester, 2013), and the ability to combine the results provided by AHP with Geographical Information Systems (GIS) in order to visualize the results from the analysis in the form of maps (raster or vector) (Myronidis et al., 2016).

AHP was used for a big scale hydroelectric power plant in Turkey. Nine criteria were evaluated and weighted. After the calculations and consistency check the alternative with the biggest score was selected. The alternative was considered to be consisted from the optimum combination of criteria (Özcan et al., 2017). A new methodology was developed in order to perform simulation. In this case the weights associated with all the criteria used for suitability modeling were varied one-at-a-time (OAT) in order to investigate their relative impacts on the final evaluation results (Chen et al., 2010), this methodology was enhanced and extended in order to analyze weight sensitivity caused by both direct and indirect weight changes using the OAT technique (Chen et al., 2013).

Combination of GIS and AHP was used in the determination of the most suitable locations for solar farm installation. The result was grouped into four categories regarding their suitability as: low suitable, moderate, suitable and best suitable with an equal interval method (Uyan, 2013), for selecting the optimal placement of photovoltaic solar power plants in Spain (Sánchez-Lozano et al., 2013), in the evaluation of existing terrain conditions of a large management area in order to determine zones for harvesting operations, assess which portions of the terrain can be harvested by the different equipment types and locate landing sites for ground-based skidding operations (Ezzati et al., 2016), in determining the wind energy potential zones and divided them into

	2016	2017	2018	2019	2020	2021
Cumulative [GW]	486.8	546.1	607.0	671.7	741.7	817.0
Cumulative capacity growth rate [%]	12.5%	12.2%	11.2%	10.7%	10.7%	10.4%
Annual installed capacity [GW]	54.6	59.4	60.9	64.7	70.0	75.3
Annual installed capacity growth rate [%]	-14.2%	8.8%	2.5%	6.2%	8.2%	7.6%

Source: GWEC

Fig. 2. RES market forecast for 2017–2021 (Source GWEC).

four categories ranging from high suitable to not suitable (Jangid et al., 2016) and for assessing the photovoltaic landscapes (Scognamiglio, 2016).

In Greece similar studies have been applied. A GIS and multi criteria decision analysis was proposed for the selection of sites for hybrid offshore wind and wave energy systems (Vasileiou et al., 2017), for the optimization of complementarity between small hydropower plants and solar photo voltaic systems (Kougias et al., 2016), for exploring the possibility that RES exploitation can satisfy the increasing power demands at a regional level (Mourmouris and Potolias, 2013) and for selecting the optimal sitting location of small hydroelectric plants (Tsoutsos et al., 2007).

2.5. TOPSIS methodology

The results provided by the Multi Criteria Decision Analysis can be further enhanced by applying the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). This methodology was used in order to determine the critical levels of electric equipment faults in hydroelectric power plants in order to plan the optimal maintenance strategies (Özcan et al., 2017). In India, researchers have used a combination of AHP and fuzzy TOPSIS in order to determine the best location for solar farms. The application of TOPSIS followed that of AHP and allowed ranking of the locations provided by the MCDA (Sindhu et al., 2017). A similar combination of AHP and TOPSIS was used in Turkey to prioritize renewable energy alternatives. In this case an interval type-2 fuzzy AHP method was applied to determine the weights of decision criteria, and hesitant fuzzy TOPSIS was applied to prioritize renewable energy alternatives (Çolak and Kaya, 2017). The same methodology was used in order to prioritize the assessments of AHP according to their degree of adequacy regarding the evaluation of solar farms locations in south-eastern Spain (Sanchez-Lozano, 2014). TOPSIS is used to show how energy policy objectives towards sustainable development and renewable energy sources options are related and assessed using linguistic variables. In this study the numerical multi criteria method is extended for processing linguistic variables, thus eliminating the loss of information caused by the approximation procedures and the ambiguity of the fuzzy ranking method's selection (Doukas et al., 2010). TOPSIS is also used for group decision support in order to evaluate alternative policy scenarios for achieving the 2020 renewable energy target. In this context different effort-sharing arrangements among Member States are evaluated to determine the optimal burden sharing of the common renewable energy target among countries (Papapostolou et al., 2017b). Other authors propose the usage of a fuzzy multicriteria method for the evaluation of renewable energy alternatives, in which the priority weights of the criteria are determined by interval type-2 fuzzy AHP, and the alternatives are ranked using hesitant fuzzy TOPSIS (Öztayşi and Kahraman, 2016). In Iran researchers used a combination of TOPSIS and VIKOR to outrank candidate sites for wind farms installation. The initial locations were determined by using a combined fuzzy decision making approach (Hejazi et al., 2016). Finally, TOPSIS Is also used in combination with Analytical Network Process (ANP) to determine a renewable energy perspective for Turkey (Kuleli Pak et al., 2015).

2.6. Public attitudes towards the installation of wind farms

Most of the time, when a wind farm project is under consideration for an area it meets the protests of both residents as well as stake holders involved in the installation area. These protests must be overcome and transformed into a positive attitude towards the installation (Tampakis et al., 2013). The citizen's attitude towards the installation of wind farms and the subsequent delay due to social reactions has increased the scientific interest regarding the causes that enhance this negative reaction (Wolsink, 2007).

Therefore, numerous studies have been applied for the selection of areas presenting the maximum energy potential, but at the same time to study the attitudes of citizens in an effort to reduce negative reactions (Haggett, 2011). Thus, design developments in the field of wind energy appear to be a complex issue in most countries. Designers can easily support renewable energy sources; information campaigns can be created to highlight environmental benefits. Designers that take “common knowledge” for granted may have negative consequences in the rates of implementation of renewable energy sources. Negative reactions emerge due to the large number of wind turbines required to produce significant amounts of energy, mainly because even the most modern types of wind turbines present small efficiency (Waldo, 2012).

The effects caused by the installation are mainly related to landscape deformation, noise production and the effects on avifauna (Tsoutsos et al., 2009). These effects make difficult the spatial allocation of areas which are acceptable to citizens and at the same time can produce significant amounts of energy (Tsoutsos et al., 2009). Regarding the preference between off shore and land wind farms, researchers has shown that citizens prefer those located on land (Ladenburg, 2008), despite the fact that off shore wind farms present significant advantages including the minimization of noise annoyance and landscape deformation (Waldo, 2012; Henderson et al., 2002). The main reason for this preference is that they present problems to beach users, especially when wind farms are installed along the shoreline affecting tourists visiting the beach (Soerensen et al., 2003; Dalton et al., 2008).

However, land installed farms present significant advantages in installation and maintenance (Ladenburg, 2008).

According to some studies, in Europe and USA citizens show moderate to strong support in the implementation of RES and in particular for the production of energy from wind farms (Ek, 2005; Kaldellis, 2005; Firestone et al., 2009; Swofford and Slattery, 2010). On the other hand, there are also studies that express the negative attitude of citizens towards RES (Ladenburg, 2008; Tsoutsos et al., 2007). In order to overcome installation problems, it is possible that one part of the investment to be transferred to the local society. In Scotland this solution has proven to alleviate citizens' concerns and made the local society more receptive to the installation of the wind farm compared to another area were a similar approach did not take place. This reinforces the view that changing the development model and the involvement of the local communities can have positive impact on public attitudes (Warren and McFadyen, 2010).

3. Materials and methods

3.1. Study area

Drama prefecture is located in Northern Greece, it is part of the Region of East Macedonia and Thrace. The regional unit is the northern most within the geographical region of Macedonia and the westernmost in the administrative region of East Macedonia and Thrace. The north part of the prefecture which borders Bulgaria is very mountainous with two mountain ranges dominating the area (Orvilos and Falakro). In the northeast area of the prefecture the virgin forest of Karantere is located, which is considered as one of the last virgin forests in Europe. The region is also crossed by the Nestos River where three dams are located for producing energy and regulating the river's water for agriculture.

Inside the prefecture there are numerous Natura 2000 sites located mainly in the northeast and west regions. The economy is mainly based on agriculture, forestry and mountainous tourism. Overall, Drama presents a lot of opportunities in the field of Renewable Energy Sources as it presents a lot of tributaries suitable for the installation of Small Hydro Power Plants, a significant wind potential and geothermal fields located in the northeast part of the prefecture (CRES, 2009) (see Fig. 3).

Fig. 3. Drama prefecture (magenta) within the East Macedonia and Thrace region and Greece.

3.2. AHP

AHP proposes the creation of a hierarchy of criteria and the parameters affecting a decision. On the top of the hierarchy the goal must be placed (Fig. 4). The construction of the hierarchy is followed by pair wise comparisons which allow the user to determine the weight coefficients of each parameter and criteria and therefore their impact to the goal (Saaty, 1980).

If we want to summarize the application of the methodology, we can do so by creating 6 steps: (Uyan, 2013; Tahri et al., 2015).

In the first step, we set the goal which is followed by the selection of alternatives. Practical judgment is mandatory for selecting criteria which is a measurable facet assisting in illustration and enumeration of alternatives (Khan and Rathi, 2014). In step two we perform the pair wise comparisons among Criteria and among the parameters of each criterion.

The matrixes of pair wise comparisons are created from experts (professors, researchers) in the fields of economy, renewable energy and social sciences using the fundamental scale from 1 to 9. The comparison matrix is obtained as (n × n) where n denotes the number of criteria. In step 3 we calculate the weight coefficients based on the values given in the previous step. If X_{ij} is the order of preference of ith factor when compared to jth factor, then $X_{ji} = 1/X_{ij}$

In Step 4 we create the pair-wise comparison matrix.

The next step (step 5) includes the calculation of the Eigen vector, maximum Eigen value and Consistency Index (CI) using equation (1).

$$\mathrm{CI} = \frac{\lambda_{max} - n}{n - 1} \tag{1}$$

Where λ_{max} is the Eigen value of the paired comparison matrix and n is the number of criteria.

Finally, in step 6 the Consistency Ratio (CR) is calculated using equation (2).

$$\mathrm{CR} = \frac{CI}{RI} \tag{2}$$

Where, RI is the random index. The values of RI are shown in the following table (Table 1).

The acceptable range of CR value is dependent on matrix order e.g. CR value for a 3 × 3 matrix is 0.05, for a 4 × 4 matrix it is 0.08 and 0.1 for all the matrices having order ≥5 (Saaty and Sodenkamp, 2008; Saaty, 2000).

The following criteria were used for the application of the AHP methodology in order to determine the initial installation locations. The selection of these criteria was partially based on the Special Framework for Spatial Planning and Sustainable Development for RES as it was approved by the Greek Government, via its decision 49828/2008 (Government Gazette B 2464) which aimed to formulate sitting policies of RES power generation projects and partially to other restrictions:

3.2.1. Distance from existing road network

The distance from the existing road network plays a very important role in the selection procedure. In general, investors select locations that are already accessible or near to the existing road network regardless of each state. This is mainly due to the fact that it is more economical for the reduction of installation cost to exploit the current road network than to create new (Cristiano and Gonella, 2019). In this study we subdivided this criterion into 5 parameters for the distance from the current road network 0-100 m, 100-200 m, 200-500 m, 500-1000 m and finally 1000-15000 m.

3.2.2. Wind Speed

Wind speed plays the most important role for the installation of wind farms. In this study we used wind speed data for Greece provided in shape file format. The data were downloaded from opendata. gov.gr and are available for free (Geodata, 2017). The provided data were divided into 5 categories for wind speeds 0–2,5 m/sec, 2,5-5 m/s, 5–7,5 m/sec, 7,5-10 m/s and 10–12,5 m/sec.

3.2.3. Slope

Slope is considered as a very important factor mainly because it affects the accessibility of an area from trucks. Trucks can easily access

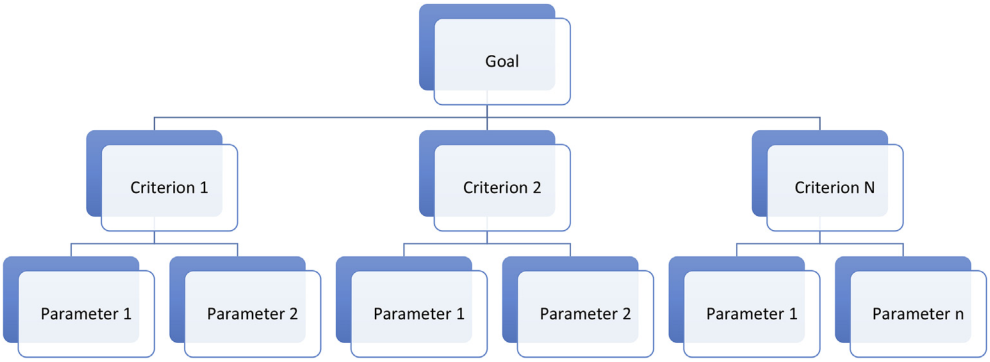

Fig. 4. A graphical representation of an AHP methodology.

Table 1
Criteria used to previous studies.

Quantitative criteria			Relation to Study
	Wind Speed	Feijoo and Villanueva (2016) Jena and Rajendran (2015), Goh et al. (2016), Wang et al. (2016)	Wind Speed maps where created in order to estimate energy potential
	Slope	Feijoo and Villanueva (2016) Jena and Rajendran (2015) Goh et al. (2016), Wang et al. (2016), Sunak et al. (2015), Baban and Parry (2001), Ministry of Environment, 2001	Slope maps where created in order to exclude areas with steep slopes
	Elevation/Height	Atici et al. (2015)	High elevation areas where excluded due to difficulties in installation
	Distance from cities	Baban and Parry (2001), Effat (2014), Noorollahi et al. (2016)	Buffer zones where created in order to avoid areas near cities, villages and other infrastructure (airport, motorways etc)
	Distance from coastline	Effat (2014), Noorollahi et al. (2016)	Buffer zones where created in order to avoid coastlines
	Distance from road network	Cristiano and Gonella (2019)	Distances from rural road network where determined in order to select sites near existing network
	Distance from electrical network	Sunak et al. (2015), Effat (2014), Noorollahi et al. (2016), Ayodele et al. (2018)	Buffer zones where created in order to determine locations near power transfer network
Qualititative Criteria			
	Natural and National Parks, Ramsar Sites,	Al-Yahyai et al. (2012), Atici et al. (2015)	Parks and Ramsar sites where excluded
	Birds and Bats Habitats	Sliz-Szkliniarz and Vogt (2011), Gorsevski et al. (2013), Peste et al. (2015) Santos et al. (2013) Schläppy et al. (2014)	Habitats of birds and bats where excluded
	EU Legislation	Sánchez-Lozano et al. (2014)	Compatibility of areas under investigation with current legislation
	Cultural Heritage	Baban and Parry (2001), Effat (2014)	Cultural heritage sites where excluded

areas with slopes ranging between 0 and 20%. Inclinations exceeding 20% are inaccessible to vehicles and therefore these are not suitable for installation of wind farms using conventional methods (Ministry of Environment Planning and Public works, 2001). For this reason, we have incorporated a category for slope ranging from 0 to 10%, one for 10-20% and one for 20 to maximum.

3.2.4. Land Uses

Current land usage status is also considered an important factor for the installation of wind farms. The general idea is that we prefer the farms to be installed in remote barren lands with low land use value. Therefore, for example we prefer the installation to mineral extraction sites and not to agricultural land, because the latter area's value is higher. For this reason, we used data provided by the CORINE 2000 land use mapping program (CORINE, 1994). We recognized the following parameters in the specified criterion: Mineral extraction sites, Non irrigated arable land, Irrigated land, Vineyards, Trees and Plantations, Pastures, Agricultural land (in general), Broad leaved forest, Coniferous forest, Mixed forest, Grasslands, Bare rocks, Transitional woodland, Sclerophyllous vegetation, Sparsely vegetated areas and Marshes.

3.2.5. Distance from substations

The purpose of this criterion is the determination of the distance between the wind farm installation and the public energy transfer network. In general areas closer to the transfer grid are preferred (Sunak et al., 2015; Hala 2014; Noorollahi et al. (2016); Ayodele et al., 2018). This criterion was divided into 3 parameters, one for distances up to 5000, from the energy transfer grid, one for 5000–10000 m and one for distances from 10000 m and beyond.

3.3. Technique for Order Preference by similarity to ideal solution (TOPSIS)

The technique of order of preference by similarity to ideal solutions (TOPSIS) is a multi-criteria decision analysis methodology introduced in 1981 (Hwang and Yoon, 1981). TOPSIS suggests that the optimal alternative from a series of alternatives should present the shortest geometric distance from the positive ideal solution (Sindhu et al., 2017). Under the same principal the optimal solution should also present the longest geometric distance from the negative ideal solution. Similar to AHP, TOPSIS can be encoded in 7 distinct steps.

The first step includes the creation of an evaluation matrix which consists of m alternatives and n criteria. The intersection of each alternative with each criteria is given as x_{ij} and therefore the matrix can be described as $(x_{ij})_{mxn}$.

The second step includes the normalization of the matrix.

$$R = (r_{ij})mxn \text{ where } r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}, i = 1,2,....,m \ , j = 1,2,...,n$$

The third step includes the calculation of the weighted normalized decision matrix

$$t_{ij} = r_{ij} * w_j, i = 1,2, \ldots, m, \ j = 1,2, \ldots, n$$

Where $w_j = W_j / \sum_{j=1}^{n} W_j$, j = 1,2, …,n so that $\sum_{j=1}^{n} W_j = 1$ and W_j is the original weight given to the indicator v_j, j = 1,2, …,n.

On step 4 we calculate the worst alternative (A_w) and the best alternative (A_b).

$$A_w =$$
$$A_b =$$

Where $J_+ = \{j = 1,2, \ldots, n$ and $J_- = \{j = 1,2, \ldots, n$

On step 5 we calculate the L2 distance between the target alternative *i* and the worst condition A_w

$$d_{iw} = \sqrt{\sum_{j=1}^{n} (t_{ij} - t_{wj})^2} \ , i = 1, 2, \ldots, m$$

and the distance between the alternative i and the best condition A_b

$$d_{ib} = \sqrt{\sum_{j=1}^{n} (t_{ij} - t_{wj})^2}$$

where d_{iw} and d_{ib} are the L2 normalized distances from the target alternative i to the worst and best conditions.

On step 6 we calculate the similarity to the worst condition

$$s_{iw} = \frac{d_{iw}}{(d_{iw} + d_{ib})}, \ 0 \le s_{iw} \le 1, \ i = 1,2, \ldots, m$$

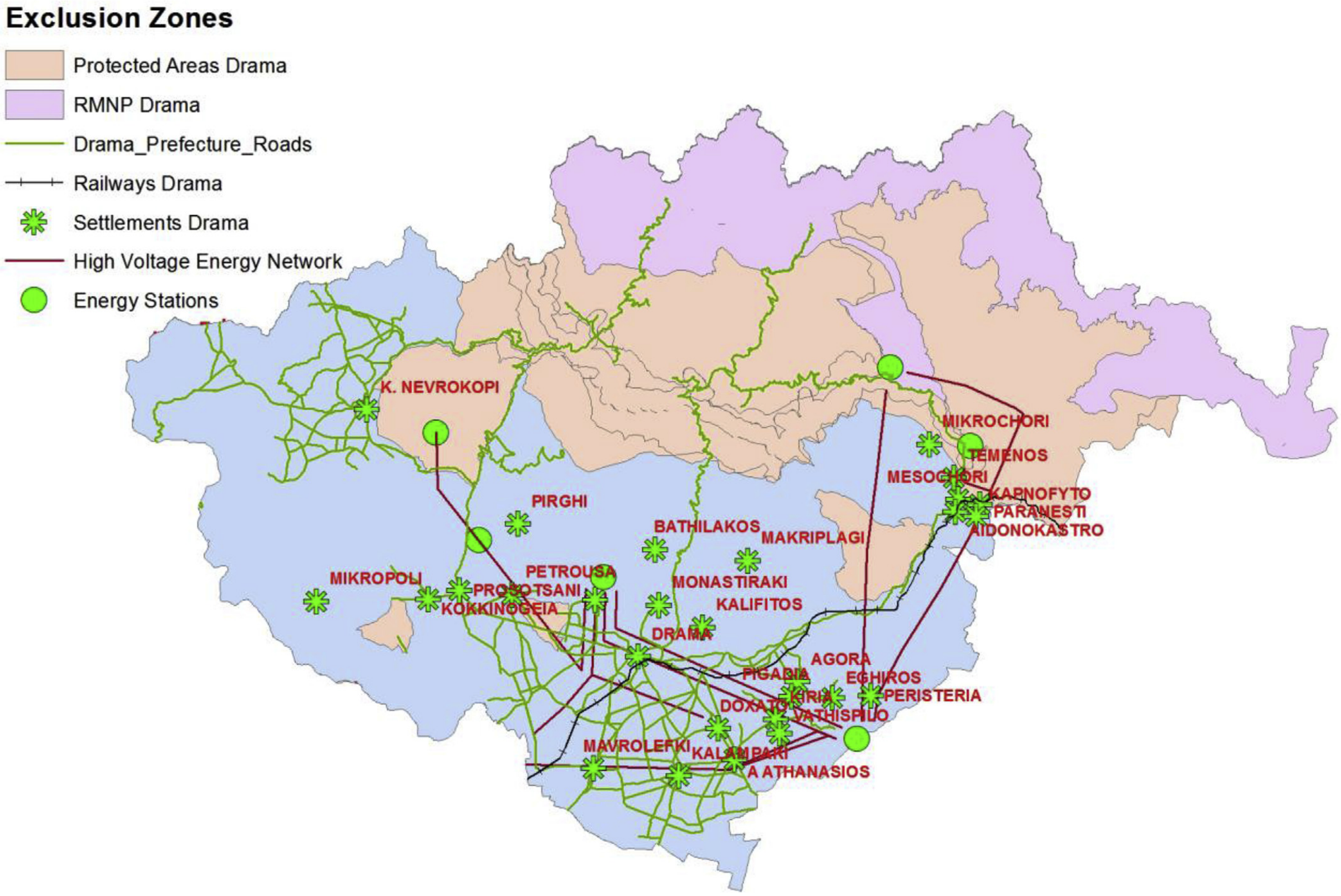

Fig. 5. Drama prefecture Exclusion zones.

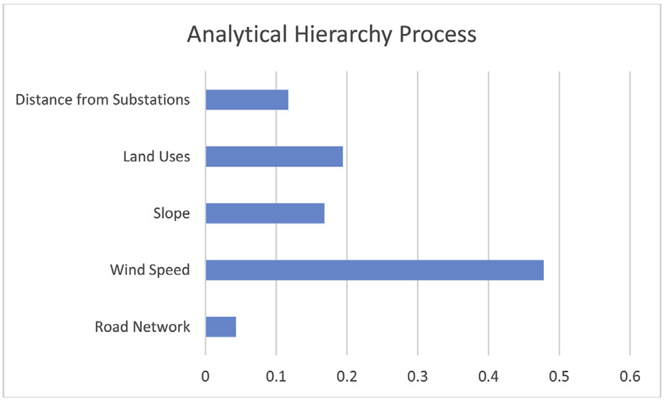

Fig. 6. Parameters AHP results.

$s_{iw} = 1$ if and only if the alternative solution represents the best condition.

$s_{iw} = 0$ if and only if the alternative solution represents the worst condition.

Finally, on step 7 we rank the alternatives according to $s_{iw}(i = 1,2,\ldots,m)$(Yoon, 1987).

In the case of wind farms selection, the criteria used for the TOPSIS application where the following:

3.3.1. *Distance from villages*

According to this criterion we prefer wind farms locations that are at least 5–10 km or more from the center of nearby villages and settlements. Locations that are closer are rated lower compared to other locations.

3.3.2. *Noise from wind turbines*

According to the Presidential decree 1180/1981 the maximum permissible noise limits to a residence is 45 dB (Presidential Decree, 1981/81). The noise level which is referred to the legislation and concerns the receiver, is inversely proportional to the square of the distance, which is reduced by 6 dB for each doubling of the distance (Theofiloyiannakos and Voutsinas, 1999). Thus a typical wind turbine which produces 101 dB(A) at base level will produce 43 dB(A) at 200 m and 38 dB(A) at 400 m. These two distance limits where used for the application of the TOPSIS method.

3.3.3. *Optical annoyance*

For the determination of optical annoyance, we performed a visibility analysis of each wind turbine using Arc Map, prior to the application of the TOPSIS method.

3.4. *Geographical Information Systems*

The calculations provided by the AHP as well as the expression of the legislation and the TOPSIS methodology were incorporated in Arc Map using the various spatial analysis tools as well as the Map Algebra tool, which enables the user to calculate the characteristics of each raster cell and perform basic mathematical calculations between maps. Each parameter and criterion calculated was incorporated on the respective map using the reclassify tool.

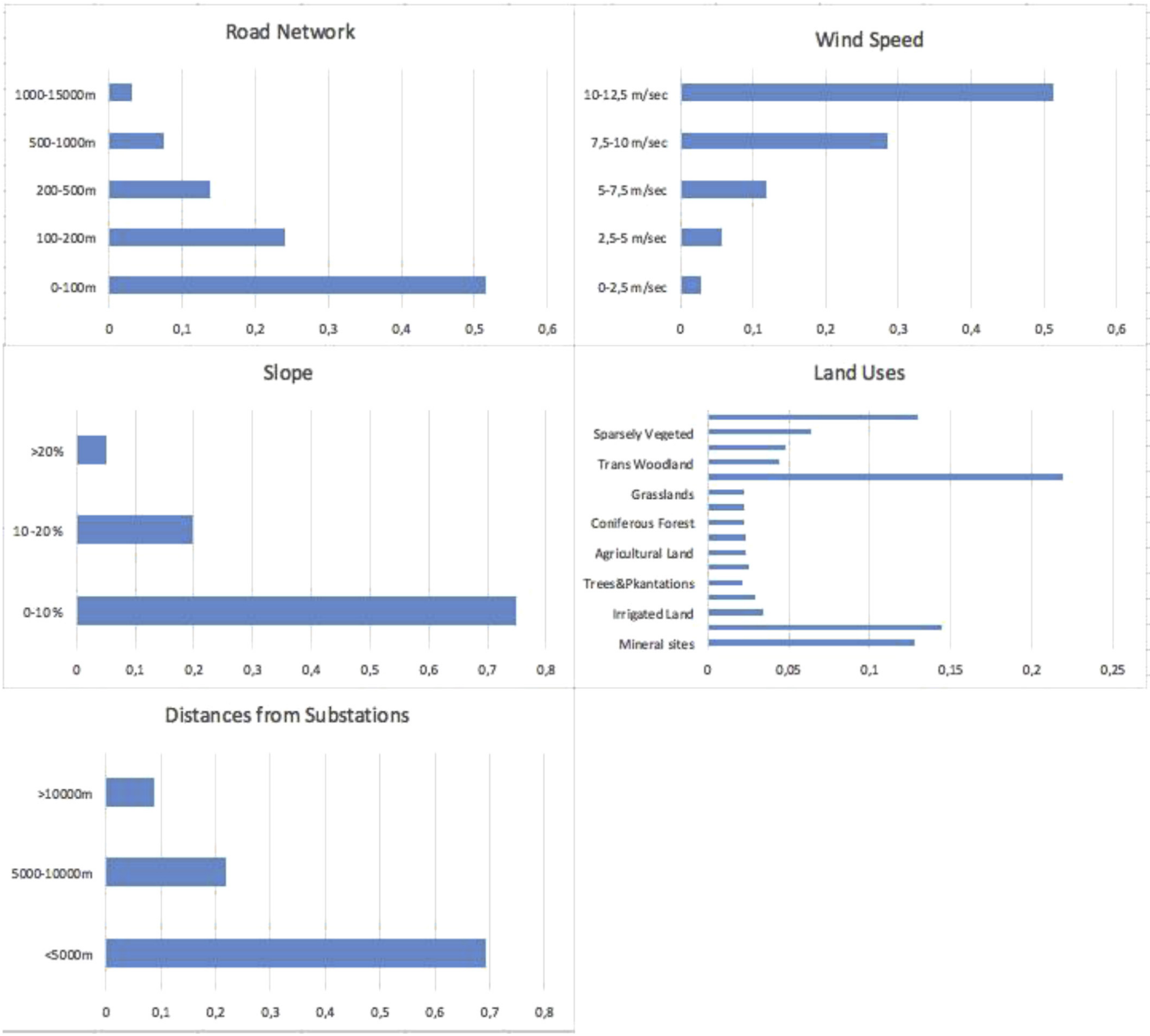

Fig. 7. Criteria AHP results.

4. Results

4.1. Exclusion zones creation

The first step in the application of the proposed methodology is the exclusion of areas were wind farms cannot be installed due to local legislation restrictions (statute 49828/2008 as issued in the Government Gazette B 2464).

These restrictions are divided in six major categories.

The first category includes the maximum distances from road network, energy transfer network and minimum distance between wind turbines. The maximum distance from any type of road network is considered to be 15000 m whereas the maximum distance from the energy transfer network is set by the independent Greek power transmission operator (ADMIE). In the case of the study area the entire road network and transfer energy network were used in order to create the proper exclusion zones.

The second category includes distances from areas of environmental concern. In this areas there cannot be any type of installation without special permission. Under this category are included Natura 2000 and Ramsar sites, Areas of absolute protection, coastal regions, fowl areas etc. In the case of the study area regions which fall under these restrictions were removed.

The third category includes exclusion zones from archeological sites, historical landmarks, cultural sites etc. In general, there should be a distance of at least 3000 m between the proposed wind farms and these types of areas. In the case of the study area there were no exclusion zones of this type.

The fourth category includes the determination of the distance between the location of the wind farm and towns, villages, settlements, traditional settlements and monastery's. In general, the distance between the proposed wind farm and towns must be at least 1000 m, from traditional settlements at least 1500 m, and from monastery's and other settlements at least 500 m. In the case of the study area we created buffer zones around these types of structures in order to create the appropriate exclusion zones.

The fifth category defines the minimum distances from public infrastructure (road network, energy grid, airports, radars etc.). In

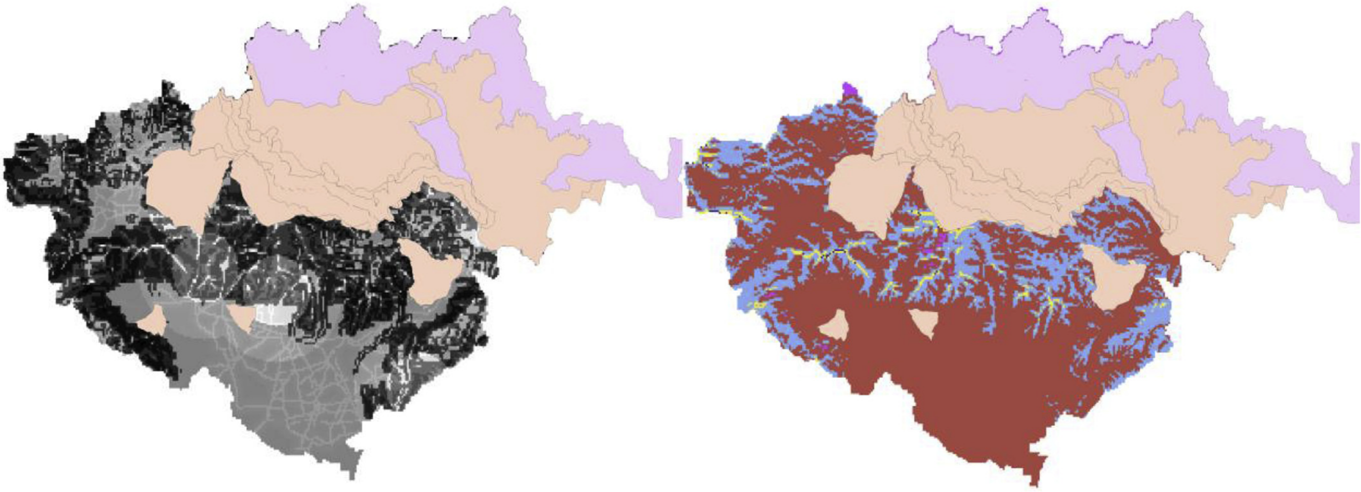

Fig. 8. Initial wind map and reclassified wind map.

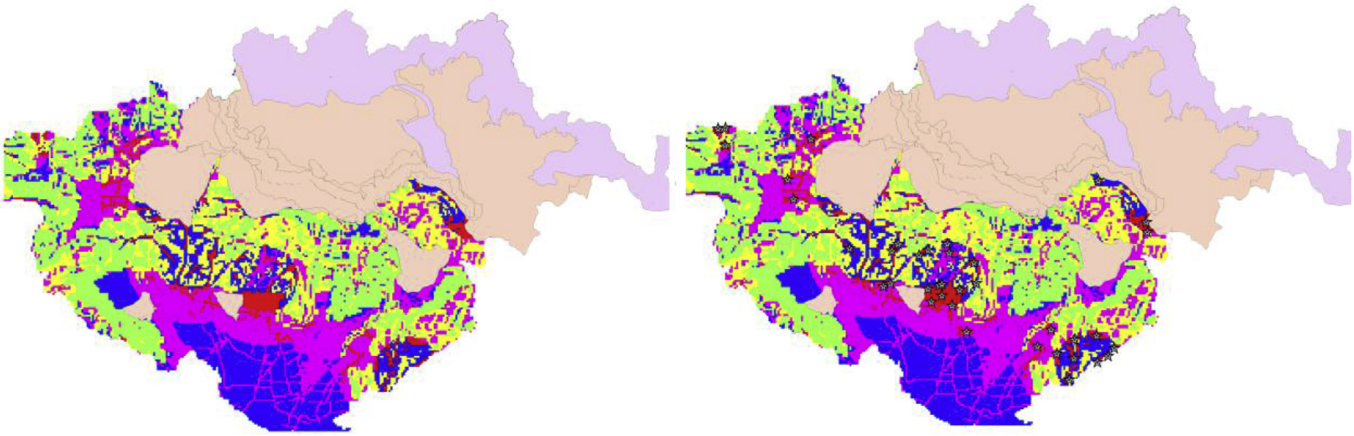

Fig. 9. Results from the calculation and Wind Farm Locations.

Table 2
Possible values of RI.

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Table 3
Initial wind farm locations.

FID	POINT_X	POINT_Y	FID	POINT_X	POINT_Y
1	532085,044645	4552517,1042	18	506817,2858	4565349,422
2	528780,7319	4551936,7515	19	509727,7083	4566275,465
3	528705,4127	4549093,322	20	509992,2921	4564952,546
4	526151,0721	4549801,8172	21	513696,4662	4563497,335
5	527983,994776	4545902,50764	22	514079,3255	4560402,058
6	532217,336576	4548548,34627	23	539542,3055	4569546,084
7	533804,839751	4549474,38979	24	539692,2152	4568044,243
8	534730,88327	4550665,01717	25	532349,6285	4575800,484
9	506839,7611	4559531,2467	26	476468,952	4583665,342
10	511579,795301	4559396,28463	27	475359,4828	4583541,509
11	510456,773	4557025,3599	28	476413,2772	4581075,964
12	508914,0552	4558500,83	29	485774,3216	4575931,628
13	507316,7562	4557609,718	30	489268,3592	4582029,066
14	495043,303895	4565614,0054	31	512630,4539	4553117,618
15	501393,316595	4565217,1296	32	486664,9586	4572985,675
16	500130,5174	4559940,456	33	525304,9041	4553460,17
17	505494,366463	4564555,66995	34	523249,5879	4550925,28

Table 4
TOPSIS criteria.

Criteria	Units	Importance	Goal
Distance from villages	Meters	6	Maximize
Noise from turbines	dB/m	5	Minimize
Optical annoyance	Yes/No	8	Minimize

general, these distances are related to the diameter of the wind turbine and are set as a minimum of 1,5 d where d is the diameter of the turbine. In this case we created buffer zones around public infrastructures in order to define the minimum allowed distance having in mind the diameter of the typical wind turbine. The typical wind turbine diameter is set by statute 49828/2008 as 85 m.

The sixth category defines the minimum distances from areas of productive activities (high productivity agricultural land, embattled livestock, quarry zones, fish farms, tourist sites etc.). Again the minimum distance is set to be 1.5 d expect areas quarry zones where the distance is set as 500 m and tourist sites where the distance is set as 1000 m. In this case we created also buffer zones to be used as exclusion zones around these types of activities.

After the application of the restrictions described in the legislation and the resulting spatial analysis the initial map of the prefecture is modified as shown in Fig. 5. The region in light blue is the area where Wind Farm installation is allowed whereas areas in magenta and orange are protected areas. The buffer zones around villages, road network etc.

Table 5
TOPSIS results.

LocationNr	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Criterion 1	890	508	2420	2138	4315	3115	2638	2599	1839	2560	2755	1366	2601	5138	1348	1490	3909
Criterion 2	20	38	0	0	0	0	0	0	20	12	0	18	16	0	20	14	0
Criterion 3	1	0	0	1	1	1	1	1	1	0	1	1	1	0	1	1	1
Score	0,23	0,11	0,44	0,42	0,48	0,45	0,43	0,43	0,25	0,36	0,44	0,26	0,31	0,52	0,24	0,30	0,47
LocationNr	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**
Criterion 1	4884	4597	3914	727	981	789	552	5808	15600	13620	3357	5852	1917	4029	939	708	1602
Criterion 2	0	0	0	20	20	20	0	0	0	0	0	0	10	6	20	20	16
Criterion 3	0	0	0	1	0	0	0	0	0	0	0	0	1	1	1	1	1
Score	**0,51**	**0,50**	**0,48**	**0,23**	**0,25**	**0,25**	**0,40**	**0,54**	**1,00**	**0,89**	**0,46**	**0,54**	**0,34**	**0,43**	**0,23**	**0,23**	**0,28**

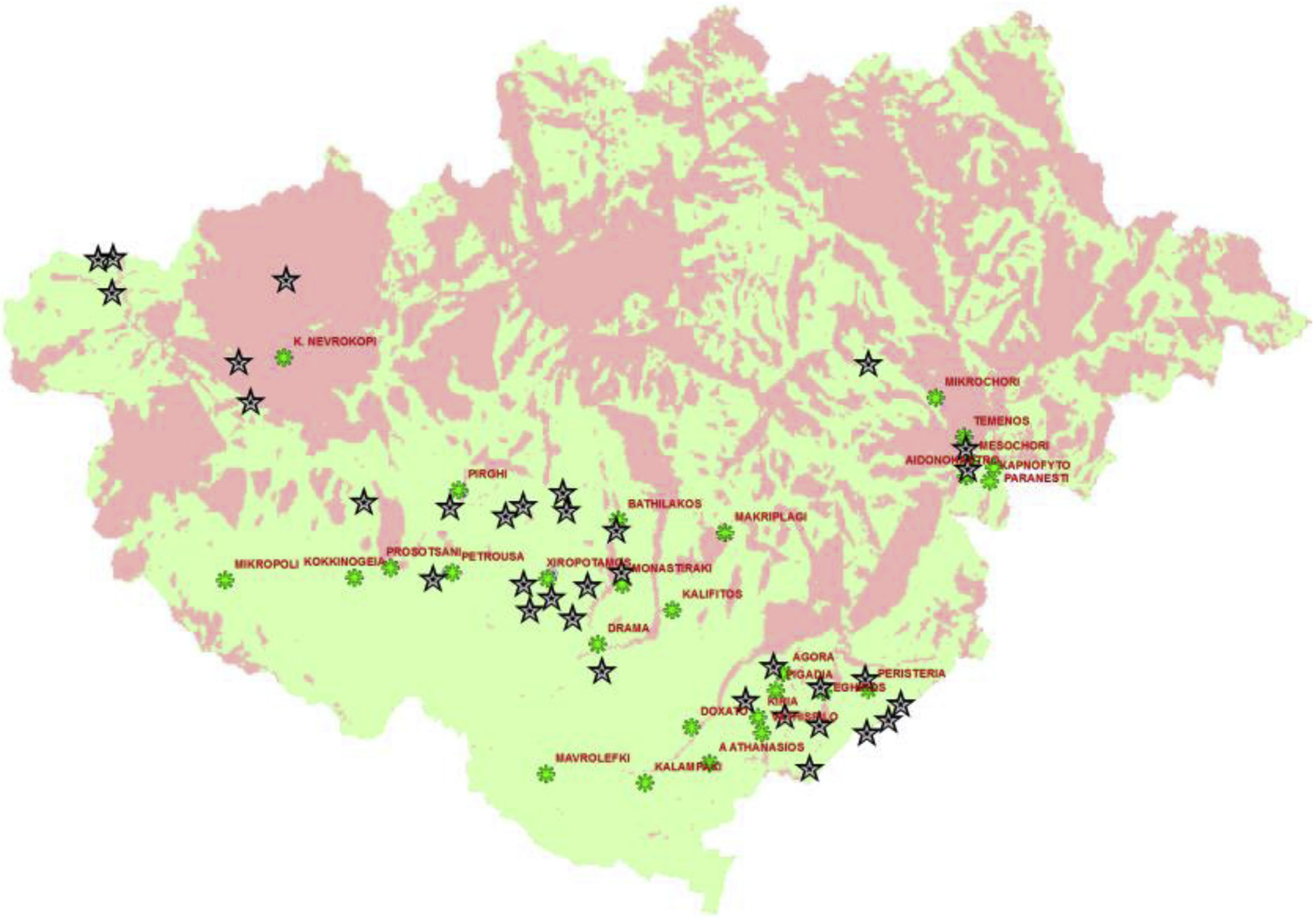

Fig. 10. Results from the visibility analysis.

Is not visible due to the map scale.

4.2. Results from the AHP

The application of Analytical Hierarchy Process in the criteria set has created the following results with a Consistency Ratio of 0.08:

It is evident from the previous figure that the most important criterion for the selection of the most suitable location for wind farm installation is Wind Speed with a weight coefficient of0,478, followed by Land Uses with weight coefficient 0,194, Slope with weight coefficient 0,168, Distance from sub stations with weight coefficient of 0,117 and finally Road Network with weight coefficient of 0,043.

The results of the parameters weight coefficient for each criterion are shown in Fig. 7.

The results shown in the previous figures (6 and 7) will be incorporated to the corresponding maps using the reclassify tool. The maps will be converted to raster with cell size equal to 250 m. The reclassify tool will create classes equal to the presented criteria and each cell will be assigned with the appropriate weight coefficient based on the AHP calculations. Thus the produced raster maps will include a value for each cell.

The maps presented in Fig. 8 present the initial wind map (left) without the reclassification. On the right the same map was reclassified using 5 manual classes and each class was assigned to the corresponding weight coefficient as calculated by the application of AHP. The same methodology was applied to the other 4 maps.

Subsequently the 5 maps were used in order to create the final map which presents the location were the installation of wind farms is more suitable based on the parameters set and the legislation. For the creation of the final map we used the following equation which is based on

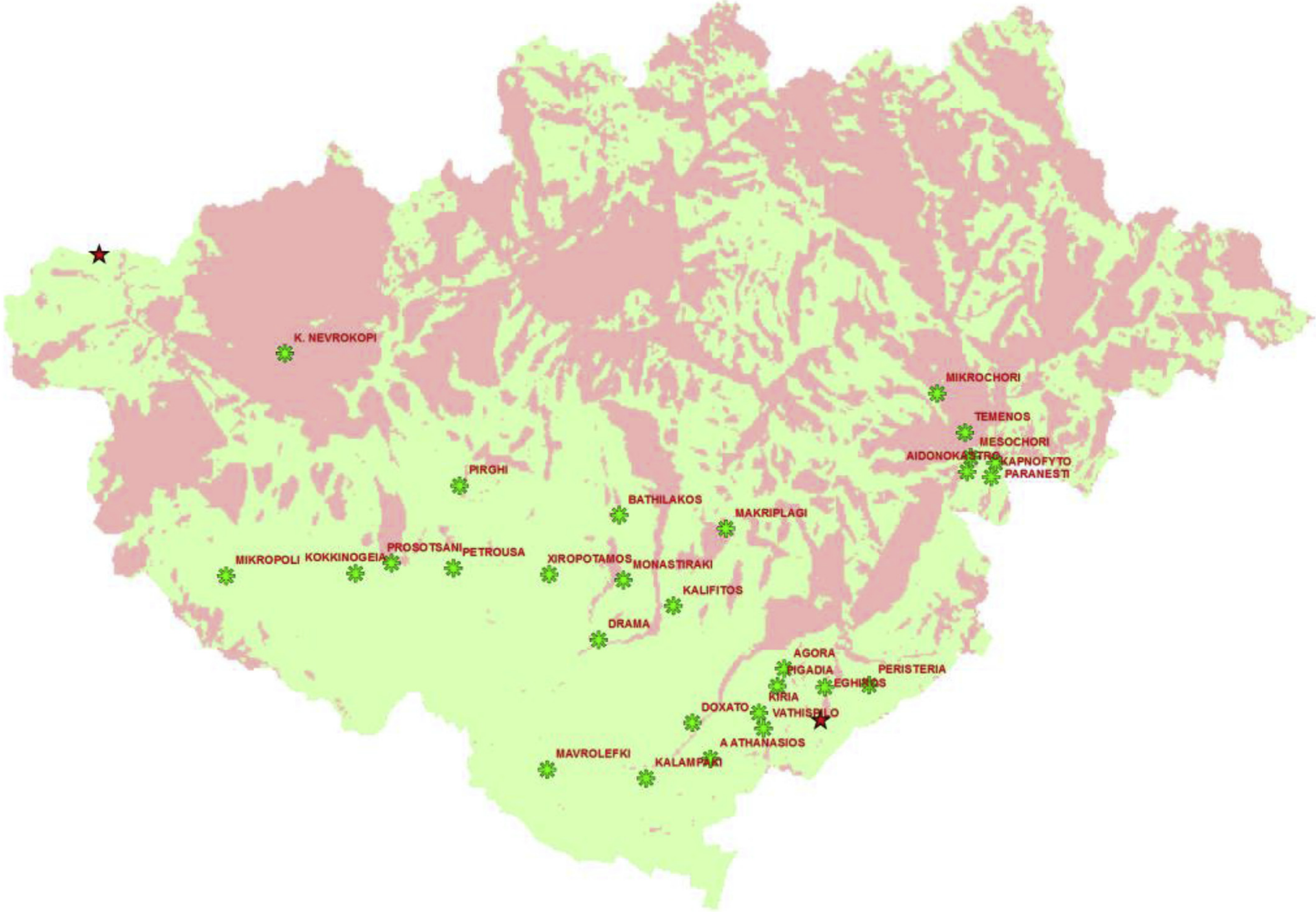

Fig. 11. The worst and the best wind farm locations.

the weight coefficient of the parameters.

$$CV = 0{,}43 * RN + 0{,}478 * WS + 0{,}168 * SL + 0{,}194 * LU + 0{,}117 * SU \tag{3}$$

Where CV is the cell value of the final map, RN is the Road Network Value, WS is the Wind Speed Value, SL is the Slope Value, LU is the Land Uses Value and SU is the Distance from Substations Value for each cell and map as calculated in the criteria analysis of the AHP.

In Fig. 9 left map the results from the application of Equation (3) are presented. Areas presented in red color are the most suitable for the installation of Wind Farms, based on the legislation and the criteria set in AHP whereas areas presented in green color are the least suitable for wind farms. On the right map of Fig. 9 the proposed locations are shown with grey asterisks.

In total 34 areas where selected and the results are shown in the table below. The coordinate values are expressed in EGSA 87 coordinate system.

4.3. TOPSIS ranking

The results provided by the AHP are presented on Table 2 These results include all the possible locations for the installation of Wind Farms inside the study area based on the analysis of the criteria and the parameters set in the AHP process. All the proposed locations from this analysis are considered to have an equal suitability value. The application of the Technique for Order of Preference by Similarity to Ideal Solution in the results provided by the AHP creates a ranking in the results based on three criteria: Distance from villages, Noise from wind turbines and Optical annoyance. These criteria represent the particularities of the specified study area and they can be easily adjusted in order to express other study areas. Additionally, the user can add or remove other criteria in order to perform analysis for other types of RES (see Table 3).

In the case of our study area the three criteria (Distance from villages, Noise from wind turbines and Optical annoyance) were defined as follows:

The criteria importance was set after consultation with experts, extensive literature review and the framework set by the statute 49828/2008.

After the definition of the criteria and their related importance values, we must determine the goal for each criterion. Either the criterion goal value must be maximized or minimized. In our case the value expressing the wind farm distance from villages must be maximized, the produced noise must be minimized and finally we must produce the least possible optical annoyance, therefore this criteria value must be also minimized.

The calculation of the distance from villages was easily performed using the distance tool provided by Arc Map.

The calculation of the Noise from turbines was expressed as buffer zones in each location. We created two buffer zones one for 43 dB at 200 m and one for 38 dB at 400 m, from this distance onwards the noise calculation was based on the assumption that noise is reduced inversely proportional to the square of the distance (inverse law for sound).

Finally, the optical annoyance criterion was calculated by performing visibility analysis for the proposed installation locations. For this analysis we assumed that the wind turbine height is 100 m and the azimuth used for this calculation was set to 360°.

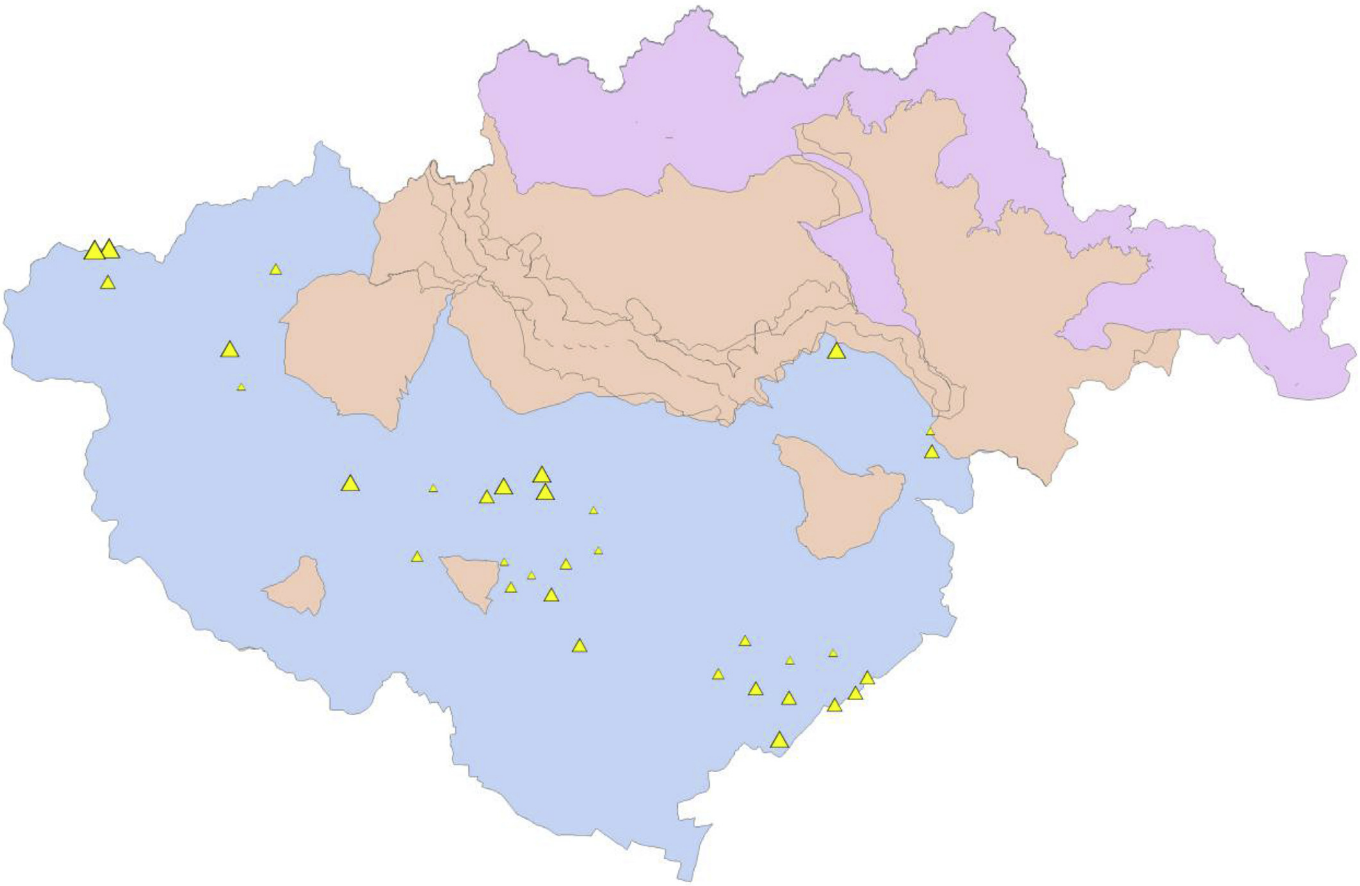

Fig. 12. TOPSIS ranking.

The results of the visibility analysis are shown on Fig. 10; areas in light green are visible whereas areas in pink are not visible.

After the calculation of the TOPSIS criteria values and the application of the methodology the results are shown on the following table:

It is evident from the above table that location 26 provides the best score whereas location 2 provides the worst score. These two locations set the upper and lower limit of the TOPSIS analysis. All of the remaining location scores are set between these two calculated values.

The next step of the methodology is to visualize the results of the TOPSIS analysis in order to check their validity. Fig. 11 represents with red stars the best and worst installation locations (Location Nr 26 and Location Nr 2) based on the provided AHP and TOPSIS results. The best location is situated on the North West portion of the map. This location is the most suitable because on this area there are no major settlements and therefore the wind farm can be easily installed without having to consider the noise produced by the operation or the resulting optical annoyance. The worst location is situated on the south east portion of the prefecture. This location is near to many settlements and additionally it is visible to them.

The following map (Fig. 12) presents all the proposed locations after the application of the TOPSIS methodology, the scores were divided in 5 classes. The size of each triangle depicts the ranking of the location, Larger triangles represent higher rankings.

5. Discussion

This paper presents a Decision Support System Methodology which allows the determination of the exact locations for the installation of Wind Farms and simultaneously overcame the problems related with this type of investment.

The methodology presented includes a combination of Multi Criteria Decisions Analysis tools (AHP and TOPSIS). These tools can help policy makers determine the optimal installation locations, after the initial selection, by organizing the locations in a hierarchy based on their social acceptability. Furthermore, it provides an innovative solution which allows policy makers to take under consideration the social parameters and the public attitudes which plays an important role in the selection of an installation site. Research's suggest that future developments on wind power should be directed in a more coherent body of theory and that it must also make usage of and make use of established concepts and methodological approaches of social science (Hammarlund, 2002).

The parameters studied are typical for wind farm installations and their selection was based on extensive literature review and the current legislation framework (Tsoutsos et al., 2007; Tampakis et al., 2013; Wolsink, 2007; Ek, 2005; Kaldellis, 2005; Firestone et al., 2009; Swofford and Slattery, 2010; Hammarlund, 2002; Krohn and Damborg, 1999; Jones and Eiser, 2009; Waldo, 2012). The social acceptance factors studied in this paper are based on researches that provide an insight towards the public acceptance of RES installation. The same methodology can be easily modified in order to express other types of RES and other social criteria by simply changing the parameters studied.

The first step towards the application of the methodology is the determination of the parameters and the criteria affecting the installation locations. These parameters are integrated in AHP and their weight coefficients are calculated allowing researchers to estimate their participation in the final goal (In our case the installation locations of wind farms) as well as the determination of their internal relations.

In the case of wind farm allocation, the parameters and criteria are specifically selected in order to provide the optimal solution to our problem. However, they are indicative. They are open to modifications and researchers applying the method can use different sets of parameters and criteria in order to express their study area, legislation and specific needs more accurately. As a result, each time, the calculated weight coefficients are more accurately determined expressing the specific study area.

The second step in the presented methodology allows the finalization of the location selection and the creation of a hierarchy by incorporating social criteria. The usage of TOPSIS in the results provided by the AHP allowed us to create a hierarchy of the locations providing each one with an exact ranking.

The social criteria included in this paper are indicative for our study area and therefore, can be easily adjusted in order to include more criteria or different weights expressing more accurately each case or other types of RES investments.

The results from the application of the DSS methodology allocated 34 possible locations for the installation of wind farms in Drama Prefecture. The application of TOPSIS created a hierarchy among these locations and provided the final optimal locations. The first location in the hierarchy is situated on the north east portion of the prefecture near the Greek-Bulgarian borders. This location is inside an area of low land use value, relatively close to the existing road and energy transfer network making it ideal for the installation of a wind farm. Furthermore, there are no significant settlements in the nearby area which can be affected by the installation.

6. Conclusions and policy implications

In general public attitude towards wind power can be considered as positive, however, the attitudes towards specific wind power projects is less positive and sometimes even negative. Therefore, any type of investment on renewable energy sources (especially wind power generation) must overcome local communities' attitudes (local culture, economy and social context), which has been proven to be particularly difficult especially for wind power installation locations (Wolsink, 2007).

Renewable Energy Sources are considered as a key factor for the sustainable development. The determination of the exact locations for the installation of RES plays a very important role in energy production as well as the acceptance from the general public.

Managers must determine the best possible solution based on a series of parameters that affect the installation location like current land uses, accessibility of the location, legislation framework, production potential etc.

Research on wind power has been based on five assumptions:

- The majority of the population has a positive attitude towards wind power.
- The opposition therefore is deviant.
- People that are against it are misinformed towards wind power.
- The oppositions must be understood in order to be overcome.
- Trust is a key aspect.

Therefore, the key in order to increase acceptance for wind power projects is to understand the social context of wind power (Aitken, 2010).

Simultaneously we must also take under consideration the public opinion and their acceptance towards RES installation, mainly because the proposed investments produce noise (especially in the case of Wind Farms), create landscape deformations and optical annoyance to residents etc.

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