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Integrating Local Knowledge into the Spatial Analysis of Wind Power: The case study of Northern Tzoumerka, Greece

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Abstract

Increasing demand for incorporating renewable energy projects into the national energy mix, is associated with international and European efforts to tackle the negative effects of climate change and strengthen energy resilience. Greece, as a member country of the European Union, has acknowledged that necessity, by implementing a national program aiming to significantly reduce Green House Gas Emissions and upscale Renewable Energy Sources (RES) project development in upcoming years.

Wind farms are considered a major contributor to Renewable Energy Sources deployment due to their technological maturity and know-how, as well as to their ability to support a more sustainable and environmentally oriented energy production model. Nevertheless, their rapid growth has urged developers to look for new areas of installation, as an endeavor facing spatial planning limitations and public opposition. In Greece, such areas include, among others, by mountainous regions.

The aim of this study is to investigate and assess the wind power suitability of a mountainous municipality in Western Greece. This is possible by incorporating a comprehensive fuzzy GIS-Multi Criteria Decision Analysis (MCDA) approach that aims at minimizing environmental impacts, while incorporating the input provided by local stakeholders and decision-makers.

The proposed methodology forms a set of constraint criteria, which identify exclusion zones. The spatial dimension of local stakeholders' input was recorded through interviews, and then, utilized as a filter in this exclusion analysis. It was indicated that the exclusion character of the inputs gathered, was connected to the type of their activity. Six evaluation criteria were identified, which assessed the remaining availability areas based on weights derived from fuzzy Analytical Hierarchy Process (AHP).

Results of this analysis, indicate that only a very small portion of the municipality is suitable for wind farm development. This research suggests that the proposed framework and its outcomes could be utilized as a consultation tool by decision-makers in the future.

Keywords: Geography, Geographical Information Systems, MCDA, wind energy, local knowledge, Greece

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Moreover, I would like to express my appreciation to all participants on the interviewing procedure. Your input, feedback, and statements provided me with an incredible insight and a better understanding of what is at stake in the municipality. In addition, you proved, through your participation, that spatial planning is a democratic process that cannot succeed on its goals without listening to the people.

Finally, I would like to thank, once again, my wife Despoina that pushed me to complete this research during difficult times of self-judging.

This thesis is dedicated to Tzoumerka and its fearlessly mountains

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List of Abbreviations

AHP	Analytical Hierarchy Process
CI	Consistency Index
CR	Consistency Ratio
G.G.	Government Gazette
GW	Giga Watt
Ha	Hectares
km^2	Square kilometers
m.	Meters
m/s	Meters per second
MCDA	Multi Criteria Decision Analysis
MW	Mega Watt
RES	Renewable Energy Sources
SPSPSD-RES	Spatial Planning and Sustainable Development for Renewable Energy Sources
TFN	Triangular Fuzzy Number
WLC	Weighted Linear Combination

1. Introduction

Renewable Energy Sources (RES) are usually proposed as vital solutions to facilitate energy transition that also lead the way to establishing a more sustainable energy production and consumption model. Towards this direction, the European Union in collaboration with Member States, have ratified agreements (e.g., Green Deal and 2050 targets) to reduce the Green House Gas Emissions (GHGE) and increase RES penetration. Those goals are needed to be embedded in energy policies of all member countries, so that they can be fulfilled in the predefined timeframe (Tambakis et al., 2017). Greece, being one of the aforementioned member countries, has published the National Action Plan 20-20-20 which introduces certain provisions and development priorities for RES projects. Moreover, in 2019, the Greek government published the updated version of the previously mentioned plan, that revises the country's RES goals until the year 2030 (YPEN, 2019).

That being said, wind power can be considered as one of the most mature renewable energy options. Its maturity is achieved by advances in wind turbine technology, the cumulative international experience, and the low cost of wind power projects, measured by the Levelized Cost of Electricity (LCoE) index, making it significantly competitive over other RES alternatives and, more importantly, over fossil-fuel-based energy production methods (IRENA, 2017).

In Greece, the integration of wind power in the national energy mix, has increased during the last decade (HWEA, 2022a). In 2022, the installed capacity of wind farms reached 4.6 GW, while its contribution to the national energy mix was 21 % of the total energy production (third trimester of 2022) (HWEA, 2022b).

As wind power project development continues to increase in the country, it is of high importance that we address and analyze challenges associated with this development. Additionally, we must keep in mind the potential multifaceted spatial planning problem of wind farm design and development (Felber and Stoeglehner, 2014). Furthermore, wind farm planning can also be connected to major public opposition, that could be related to the absence of a comprehensive public consultation process, leaving local stakeholders unable to express their preferences and attitudes.

The study area of this research project is defined by the Municipality of Northern Tzoumerka, a mountainous area located in the prefecture of Epirus, in Western Greece. Upon deciding on the selection of this particular area, a number of reasons were taken into careful consideration. Firstly, "areas of wind priority", as have been provisioned by the national framework of regional planning for the development of RES (G.G. 2464 B'/2008), are considered to be highly suitable for wind power projects and have already been saturated by wind farms. As such, developers are looking into alternative locations in areas with rich wind potential, that, nevertheless, are usually located, among others, in the mountainous regions of Greece. This is evident in the prefecture of Epirus, characterized by its mountainous character, where wind energy capacity increased by 2 MW in 2018, to 110 MW in 2022 (HWEA, 2023). Secondly, developmental priorities for the study region settled by the Regional Plan of Epirus (G.G. 286 AAP'/2018), can mainly be found on the growth of the tourism sector, the preservation of environmentally sensitive and natural areas, the preservation of cultural heritage, and the development of agriculture. Taking into account those factors, we should consider that they could conflict with the development of wind power projects. Thirdly, limited public participation, occurred mostly during the environmental project licensing, common lack of municipalities' ability to provide a technically structured relevant opinion and general mistrust in developers has increased public opposition towards wind projects in mountainous areas. Moreover, the municipality has a rich hydrological network that may be suitable for the development of small hydro-stations (Exarchou et al., 2014). Even though that potential development could act as an alternative solution for renewable energy production in the region (Stergiopoulou and Stergiopoulos, 2020), it would come with public opposition (Aggeli, 2021). Scattering of small hydro-stations could not achieve economies of scale similar to wind farms, which are able to produce much more energy, while being spatially clustered. As such, wind farm development could be seen as a more viable option.

Based on the academic literature, a GIS-based Multi Criteria Decision Analysis (MCDA) methodology is selected for this study. Research questions examined under the proposed methodological framework are,

- How large are the areas available for wind power development in the municipality?
- How are available areas being assessed on their suitability under an environmentally oriented evaluation scenario?
- How sensitive is the applied methodology to changes on the importance of the selected evaluation criteria, expressed as fuzzy – AHP - derived weights?
- How are planned wind farms, in the study area, assessed by the applied methodology?

The novelty of this project can be highlighted by the fact that the designed methodology is incorporating local knowledge into the spatial analysis. As such, the main assumption is the following: «*The exclusion character of the locally defined zones (by local stakeholders), under the scope of wind power development, is based on the type of activity they exhibit* ».

Last but not least, the development of wind farms utilizing such high spatial detail, has never been examined before in the selected study region. That being said, the research has the potential of bridging an important knowledge gap relevant to the development of wind power projects in this area, as well as advancing its research field by highlighting advances that the proposed methodology has to contribute to the effective spatial analysis of wind power projects.

Finally, the proposed methodology aims at offering a comprehensive analysis tool that could enhance the outcome of decision-making processes, concerning the development of wind power projects in the municipality.

This research is organized as follows. In Chapter 2, the background of the study is presented where the relevant academic literature research is highlighted regarding the multiple aspects this study is examining. This is referring, amongst others, to the application of different GIS-MCDA approaches, both internationally and in Greece, on wind energy planning. In Chapter 3, the methodological framework is described based on which the spatial analysis of the municipality is applied. In Chapter 4, the produced results are presented and in Chapter 5 a comprehensive discussion on research's findings is performed. In addition, study limitations are provided. Lastly, in Chapter 6, major conclusions are made and a proposal for future research is suggested.

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2. Background

The apparent effects of climate change are forcing governments to take actions by establishing appropriate energy policies able to reverse their negative impacts and sustain energy security. The importance of RES technologies' contribution, and more importantly of wind energy, towards this direction is highlighted, on the European level, by the establishment of energy road maps that are targeting to maximize the incorporation of RES in the energy mix (European Commission, 2012).

2.1 Wind farm development under the energy planning nexus

Under this context, the notion of energy planning is getting increasingly imporant as it encompasses the strategic planning for covering future energy demands while considering energy production alternatives such as RES projects development, as well as environmental, social, and economic factors (Bush and Bale, 2019). At the same time, it has been discussed that energy planning should be combined with spatial planning at the urban level as urban plans could determine energy demands and potential resources to be utilized (Zanon and Verones, 2013).

The latter is of high significance if one is to consider the spatial dimensions of RES projects and more importantly of wind farms. Typically, wind farms are land demanding projects, and their locations could be found close to areas of environmental and community value. To this end, the design of wind power projects should be in line with the legal framework in effect while applying a set of siting criteria adapted to the character of hosting areas (YPEN, 2019). This set of criteria should be able to represent the four main domains of wind power influence; environmental, social, technical, and economic (San Cristobal Mateo, 2012). These domains include various factors related to wind farm development and operation naming shadow flickering, noise propagation, impacts on aviation fauna, and visual intrusion of wind turbines in the landscape (Baban and Parry, 2001; Tegou et al., 2010; Bengtsson Ryberg et al., 2013).

2.2 Multi Criteria Decision Analysis approaches in RES planning

The complexity of identifying the best location for RES projects such as wind farms consists of a Multicriteria Criteria Decision Analysis (MCDA) problem (Kumar et al., 2017). Multiple criteria reflecting the critical dimensions of RES energy planning, usually conflict with each other, are combined in a way enabling Decision Makers' (DMs) preferences to be represented, while their integration via a certain MCDA technique is aimed at reaching a decision (Shao et al., 2020). Normally, such a methodology would define multiple criteria and then it would incorporate them into an evaluation analysis of various scenarios where DMs' input will rank them accordingly (Polatidis and Morales, 2016).

As different stakeholders and decision makers may express different attitudes or preferences, wind farm planning may serve as a decision-making problem (Loken, 2007). To this end, one could state that reaching a consensus among participants and DMs is the outmost purpose of such planning procedures (Haralambopoulos and Polatidis, 2003).

There are numerous MCDA methodologies that have been proposed in RES research. The most common of them all, according to Shao et al., (2020) is the Analytical Hierarchy Process (AHP) developed by Saaty (1980). According to this concept, a decision problem can be hierarchically arranged in a way that forms a goal (San Cristobal Mateo, 2012). Other methods are related to Analytical Network Process (ANP) introduced by Saaty (1996), and fuzzy sets by Zadeh (1965) that is usually combined with other techniques such as AHP or TOPSIS (Sanchez-Lozano et al., 2016). In addition, Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) developed by Brans, Vincke and Mareschal (1986), VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) (English: *Multiple Criteria Optimization and Compromise Solution*) (Opricovic and Tzeng, 2004) and ELimination Et Choix Traduisant la REalité (ELECTRE) (English: *Elimination and Choice Translating Reality*) introduced by Roy (1968) are also well-known MCDA methodologies that have been applied in RES analysis (see Atici et al., 2015).

In general, wind farm planning, besides of a MCDA problem, also consists of a complex spatial problem where different aspects needs to be considered and evaluated (Sotiropoulou and Vavatsikos, 2021). The combination of MCDA techniques with the computer-based support of Geographical Information Systems (GIS) is forming what is known Spatial Decision Support Systems that enables DMs to solve spatial problems interactively and effectively (Malczewski, 1999).

2.3 GIS based MCDA applications in wind power planning

The synergy of GIS and MCDA techniques in wind power planning has been proved effective (Vavatsikos et al., 2019). To this end, there are numerous research papers that have implemented GIS-MCDA methodologies in wind farms' siting and evaluation for both onshore and offshore applications (Shao et al., 2020; Sotiropoulou and Vavatsikos, 2021).

More specifically, Peri and Tal. (2020), applied a GIS-MCDA approach in order to identify suitable sites for onshore wind farms in two regions in Israel. For their analysis they formed a set of exclusion criteria identified unsuitable locations for wind farms. Then, the available locations were evaluated under the scope of eight evaluation criteria after being normalized. Their results indicated that only 0.5 % of their study areas was suitable for wind energy projects.

Doljak et al., (2021) designed a GIS-MCDA approach to assess the spatial suitability of potential wind farm locations in Serbia. AHP methodology was implemented in order to assign weights on the defined criteria and fuzzy sets to normalize the evaluation criteria. Then, Weighted Linear Combination (WLC) approach was utilized to calculate the overall suitability of their study area. Their results indicated that 24.09 % of Serbia was deemed suitable for wind power development.

Raza et al. (2023), applied a GIS-MCDA framework to assess the suitability of Pakistan in terms of wind and solar development. They formed three scenarios examining either the fully development of utility scale wind farms or solar farms, as well as the implementation of small-scale solar farms in remote areas. In their procedure certain constraint criteria defined for both solar and wind installations, as well as corresponding evaluation criteria. The latter were ranked based on weights derived by AHP. Their results were then compared with existing installations.

2.3.1 GIS based MCDA applications in wind power planning in Greece

As far as Greece is concerned there are various research that have been published and investigated the suitability of wind power development both onshore and offshore.

Tegou et al. (2010), applied a GIS-MCDA technique to examine the suitability of the island of Lesvos regarding wind power development. After classifying the island into exclusion and available areas for wind farms, they assessed its suitability based on eight criteria. That was possible by applying AHP methodology. Their research concluded that only a small part of their study region was deemed as suitable.

Latinopoulos and Kechagia (2015), assessed wind power suitability of the region of Kozani in western Greece. They developed an GIS MCDA framework that was based on AHP and fuzzy sets. After defining exclusion areas, they normalized six evaluation criteria using Linear Fuzzy Membership Functions and ranked them through AHP. WLC was then implemented to evaluate the examined area. They concluded that only 12 % of the study region was found available for wind power projects.

Tsoutsos et al. (2015), suggested a methodological framework in order to evaluate suitable areas for wind power development in the island of Crete. This framework was solely based on the application of national legislation's provisions and more specific of the 'Specific Plan for Spatial Planning and Sustainable Development for Renewable Energy'. Their scale of analysis was the one at the regional level aiming at supporting strategic decisions. Their study was able to estimate the wind power carrying capacity for each of the four regional units of Crete.

Bertsiou, et al. (2020), applied a GIS based methodology in order to evaluate suitable location at the island complex of Fournoi in north Aegean Sea. In their analysis they assessed the island on their suitability regarding the development of wind farms. Then, they assessed potential locations under the scope of six evaluation criteria. AHP MCDA technique was applied to assign the relevant weights in the basis of three scenarios. The research concluded that, in all scenarios, exclusion areas account for the 27.9 % of total island's area.

Sotiropoulou and Vavatsikos (2021), proposed a GIS analysis of potentially suitable locations in Thrace region of north-eastern Greece. The evaluation of the available areas was based on the application of PROMETHEE framework. They recommended that the applied methodology could be utilized as tool for strategic planning decisions at regional and national level.

Spyridonidou and Vagiona (2022), performed a suitability analysis for both onshore and offshore wind farms in the island of Euboea. Firstly, they identified available areas for wind farms both in land and sea and then, evaluate them by applying three different MCDA approaches; AHP, VIKOR, and a combination of entropy and VIKOR. Their study resulted in creating six suitability indices and concluded that the study region offers great advantages in RES projects development.

Moreover, Karamoutzou and Vagiona (2023), proposed a GIS based methodology aiming at assessing the suitability of already installed onshore wind farms. The study area of this research concerns all administrative regions of Greece. Firstly, constraint areas were defined, after applying a set of exclusion criteria, and compared with the current location of existing wind farms. Then, the assessment of the suitability areas was achieved by applying two MCDA techniques; AHP and TOPSIS. In total, five sustainability scenarios were formed in the basis of assessing nine evaluation criteria. The results indicated that 81.4 % of installed wind projects are located inside availability areas. The authors suggest that this framework could be valuable in spatial energy planning applications.

Special attention is to be given to the social aspect of wind power projects. This is more related to the social acceptance of wind farms that could be seen as counteracting to people's resistance towards wind power development (Devine-Wright et. al., 2017). This topic has been discussed by various research such as in Sovacool and Ratan (2012), Wolsink (2013), and Hall et al. (2013). According to Scherhaufer et al. (2018), the absence of social acceptance in wind power projects may act as a restrictive factor to wind farms' development with negative impacts on the desired environmental and economic outcomes for the developers and communities. Moreover, the concepts of trust, place attachment, distributive and procedural justice come into play as they are heavily influencing social acceptance of wind farms (Gross, 2007; Hall et al., 2013; Walter, 2014). In Greece, a number of research papers have been published aiming at understanding people's attitudes and perceptions (Kaldelis, 2005; Oikonomou et al., 2009, Katsaprakis, 2012; Kontogianni et al., 2014; Tampakis et al., 2017). A recent research is the one of Skiniti et al. (2022) which was focused on Attica region, continental Greece, and islands. The results of the study indicated that the acceptance of projects was positively influenced by the openness and continuity of information provided by the developers, as well as the minimization of greenhouse emissions by the projects. On the other hand, it was negatively influenced by the potential impact on flora and fauna and lack of trust. Finally, another factor able to increase social resistance in Greece was related to landscape impacts (Suškevičs et al., 2019).

2.4 The incorporation of local knowledge in wind farm planning

The need for integrating local knowledge in research as a source of information able to fill the gaps of scientific knowledge has already emerged in resource, environmental and coastal management (Reed, 2008; Käyhkö et al., 2019) where the quality and quantity of information is closely related to decision making results (Close and Hall, 2006; Giordano and Liersch, 2012). By capturing local knowledge researchers are able to better define patterns of spatial behaviors, to understand the values and valuable places in the study area, to record the experiences and subjective evaluations of local stakeholders, as well as to locate development preferences (Czepkiewicz et al., 2018). While local knowledge protocols have been established in other scientific fields (Close and Hall, 2005; Palomo et al., 2013; Lopez-Juambeltz et al., 2020; Giordano and Liersch, 2012), its importance on renewable energy planning is gaining more attention (see Spyridonidou et al., 2021).

Participatory planning offers the tools that enables planners, policy, and decision makers to map local values and incorporate them into their decisions. The latter is of high importance when considering the social aspect of wind power projects and the public perceptions towards them (Wilson and Dyke, 2016). Those perceptions on wind power, often described under the Not in My Back Yard umbrella, could include political, personal, and socio-economic factors (Devine-Wright, 2005; Graham, et al., 2009). All these factors could be expressed through public participatory procedures able to foster the sense of communal fairness and trust (Toke, 2005) in the development of wind farms. In addition, achieving community fairness in public participation processes could potentially increase social acceptance (Gross, 2007).

In connection to the above, the role of Public Participatory GIS (PPGIS) as a meaningful tool in wind power public participation methodologies has been investigated by various research (Grassi and Klein, 2016; Ribe et al., 2018; Müller et al., 2020). Gousios et al. (2021), developed a 3D-PPGIS application in order to assess wind farm and photovoltaics' locations in two mountain regions in Greece and Cyprus, by combining local people's areas of territorial value, and visual impact indicators. They concluded that this process reinforced local communities stand on co-deciding the development of RES projects in their territories.

To the author's knowledge no similar research has been performed at the municipal level for the selected study region while incorporating, at the same time, local stakeholder's input. It should be mentioned that the study by Kati et al. (2021) which assessed Greece by classifying it into two zones -Wind farm-free zone and Investment zone-provides a broader view regarding wind power development, but not as detailed as the proposed methodology is suggesting. A detailed description of the methodological steps is provided in the next chapter.

3. Methodology

The identification and assessment of potential locations for the development of wind power projects consist of a multicriteria decision analysis problem where different criteria expressing multiple aspects of wind power's impact are combined (Sotiropoulou and Vavatsikos, 2021).

In this study a GIS-based MCDA methodology framework is proposed aiming at identifying availability areas for wind power development for a municipality in western Greece. The suitability of the potential wind farm locations is assessed by implementing a fuzzy AHP approach.

An important element in the proposed methodology should be considered the inclusion in the analysis of local knowledge. Here, local knowledge was utilized on identifying suitable locations for wind farms through a simple local participatory planning approach which combined interviewing stakeholders (Simcock, 2016; Delicado et al., 2016) with mapping (Käyhkö et al., 2019).

3.1 Study area

The study area at which the proposed methodological framework was applied is located in the the Municipality of Northern Tzoumerka, Greece (Figure 1). It is located in Western Greece and is part of the Prefecture of Epirus. It has an area of approximate 358 km^2 and a population of 5,058 residents, according to the 2021 census (Statistics, 2021), indicating a population density of 14 people per km^2.

The municipality is divided into seven distinct administrative areas and includes 44 settlements from which the settlement of "Pramanta" acts as the administrative center and municipality's "capital".

It is important to note that mountainous regions of Greece, like the municipality of Northern Tzoumerka, face a socially/economically connected phenomenon that is described as energy poverty (Papada and Kaliampakos, 2016). The negative effects of it could be counterfeited by the development of RES projects according to Sovacool and Drupady (2012).

The identification of suitable locations for wind farms is challenging as the municipality is characterized as mountainous while including vast areas that are environmentally protected on a national and international level. Those areas are the National Park of Tzoumerka, Natura 2000 zones (GR1300013, GR130007), Corine biotopes, Important Bird Areas (IBAs) etc. Moreover, locations with high wind speeds are mainly found in higher elevation, on the top of the mountains, which are difficult to access, and with steep slope that impose difficulties to construct wind farms.

To this end, it is important to form a methodological procedure that will reflect the environmental, social, and geomorphological characteristics of the study area and will efficiently incorporate them in the analysis. The implementation of a GIS based MCDA procedure can provide the necessary framework that can identify and assess suitable locations for wind power projects, in the Municipality of Northern Tzoumerka. The schema depicted in Figure A1 in Appendix A., offers a visual description of the dynamics that form wind power localization issues in the study area.

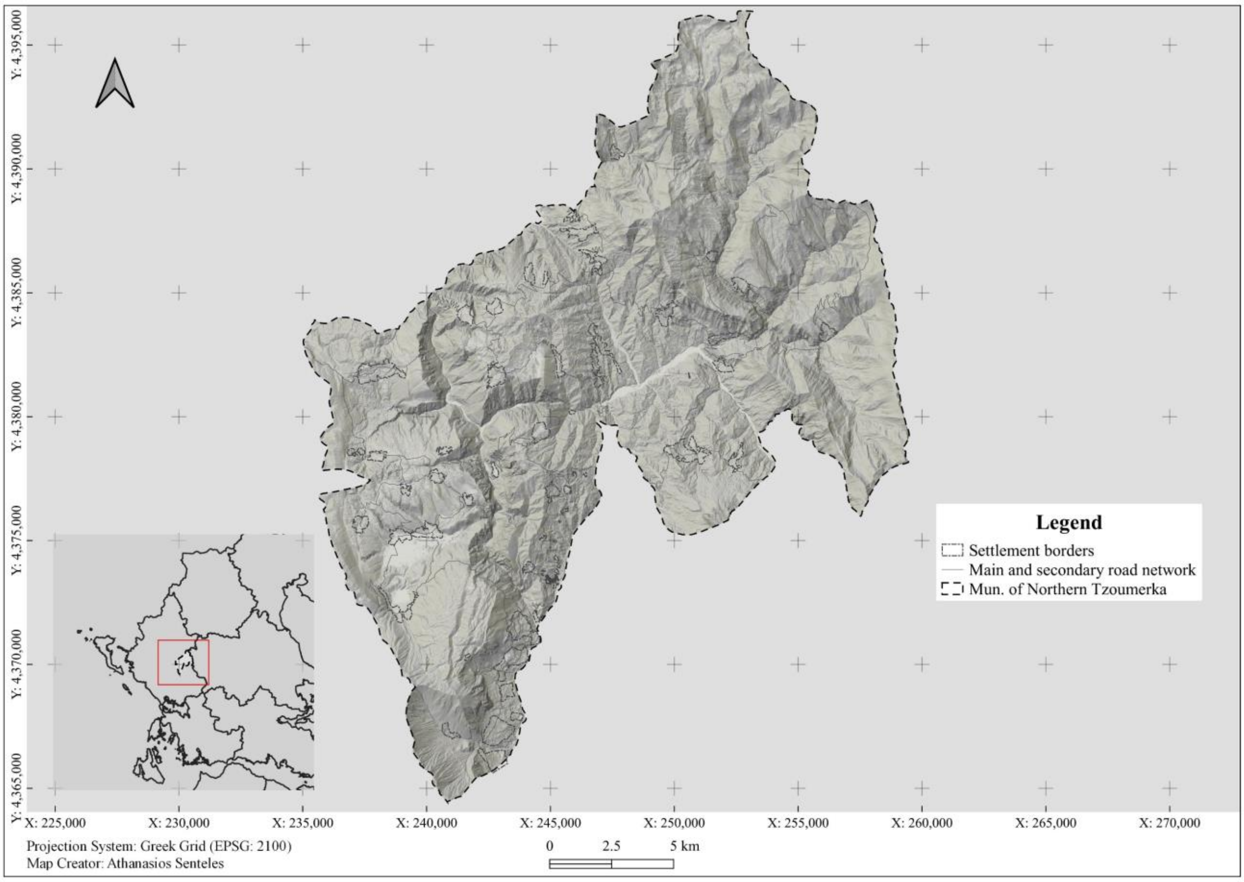

Figure 1. Overview of the study area

3.2 The Methodology Steps

The GIS-based wind farm planning analysis was founded on the formation of two types of criteria; (1) constraint criteria based on which the study area was classified as either suitable or unsuitable for wind farm development following Boolean logic (0 and 1). Those criteria defined availability areas as areas taking a value of one. (2) Evaluation criteria assessed the study area’s availability based on Fuzzy logic. It is important to note, that some of the constraint criteria were selected as evaluation criteria as well, following the relevant academic literature.

The fuzzy AHP approach was implemented to derive weights for each of the selected evaluation criteria following the example of previous studies (see Sánchez-Lozano et al., 2016; Ghorui et al., 2020). Moreover, the assessment of suitable locations was performed by applying Weighted Linear Combination or Weighted Overlay (Malczewski, 2006) in the GIS environment (Weighted Sum). Finally, the sensitivity of the proposed methodology was assessed after applying three sensitivity scenarios.

The methodological steps that formed and followed in order to assess the suitability of wind farm development in the study area are described in the methodology chart below (Figure 2). An analytical description of each step is provided in the subsequent subchapters.

Both ArcGIS 10.5.1 and QGIS LTR 3.28.6 GIS software were utilized to perform the various processing steps.

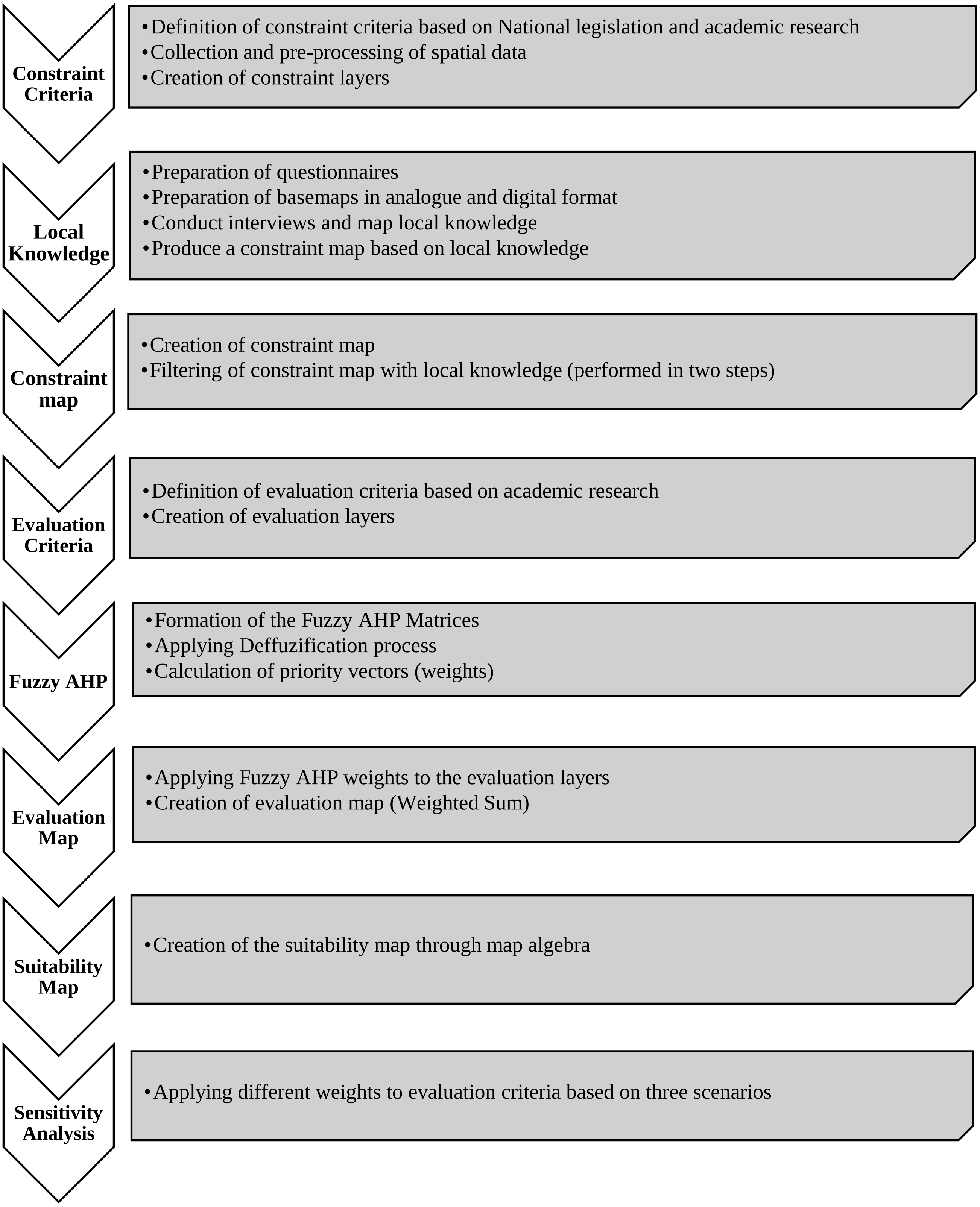

Figure 2. The proposed methodological framework.

3.2.1 Constraint Criteria

In the following sub-chapters, the methodological steps concerning both the definition of the constraint criteria and their application in the constrain analysis are described.

3.2.1.1. Definition of Constraint Criteria

The first step of the analysis, the definition of constraint criteria, is referring to the identification and selection of the parameters and factors that prevents the development of wind farms. Those factors are representative of the environmental, social, economic, and technical attributes of the Municipality of Northern Tzoumerka, and their spatial composition was able to classify the study area in two categories; namely areas that are suitable for wind power development and those that should be excluded from it.

Their definition was primarily based on the Greek legislative provisions regulating the development of RES projects known as Special Plan for Spatial Planning and Sustainable Development for Renewable Energy (SPSPSD-RES) instituted in 2008 (Tsoutsos et al., 2015). This document is providing developers with specific guidelines regarding the planning and positioning of wind farms. Its guidelines are referring, among others, to specific criteria to be accounted for while setting certain setback distances. Nevertheless, these guidelines are not exhaustive, and SPSPSD-RES (2008) does not distinguish space based on morphology (i.e., mountainous areas), but rather dictates a longitudinal application of its provisions. To this end, the most relevant academic research was investigated in order to form a comprehensive criteria catalogue better adapted to the mountainous character of the investigated Municipality.

In total, eight categories of constraint criteria were defined and further divided into sub-categories (Table 1).

3.2.1.2. Description of Constraint Criteria

Wind speed

The criterion of wind speed was of high significance as it regulates the potential energy productivity of wind farms. According to this, areas with an average wind speed lower than a predefined threshold were deemed as unsuitable for the development of wind power projects. Different wind speed thresholds have been proposed by different research authors. Voivontas et al. (1998) implemented a threshold of 6 m/s, Latinopoulos and Kechagia (2015) of 4.5 m/s, Tegou et al. (2010) 4 m/s, Spyridonidou et al., (2021) of 5 m/s, Sotiropoulou and Vavatsikos (2021) of 4 m/s. In this framework a wind speed threshold of 3 m/s was defined. This threshold was based on the technical specifications and power curve of Vestas V150-4.2 MW wind turbine model. This model has been installed and operated in a wind farm close to the investigated municipality with alike climate conditions. According to Vestas (2023), this model is able to operate in low wind speeds (Wind Class IEC IIIb and cut-in speed of 3 m/s).

Slope

The slope criterion expressed the technical challenges that terrain could impose to the construction of wind farms. To be more specific they could influence the installation of assembly cranes and the accessibility of heavy-duty vehicles while they could be associated to high installation expenditures (Sotiropoulou and Vavatsikos, 2021) and flow separation (Hyvarinen, 2018) leading to reduced revenue. Academic literature suggested various slope thresholds (Atici et al., 2010; Höfer et al., 2016; Gigovic et al., 2017). Nevertheless, in this study, the slope threshold was defined by also taking into consideration the mountainous character of the study area. This threshold was expressed in percentage, rather than in degrees. According to a research on wind farm development in mountainous areas of Korea (Kim et al., 2017), slope greater than 36 % were deemed unsuitable for wind farms, whereas installed wind farms located in areas with such slope or greater. The same applies to proposed wind farms in the study region. As Latinopoulos and Kechagia, (2015) suggested a slope threshold of 25 %, a slope threshold of 30 % was set, in this study, to reflect both mountainous morphology, academic research and applied experience.

Infrastructure

This criterion which combined three distinct criteria had a three-fold purpose. First, to exclude areas that were unsafe to the public due to potential technical failures of wind turbines such as rotor runaway or ice throwing in cold conditions. Secondly, to exclude areas that could increase connection costs with the main electrical grid and thirdly, to exclude areas for wind farms that could interfere with communications. Those areas were defined by assigning setback distances from main and tertiary road network, high voltage transmission lines, and antennas. As far as road network was being concerned, a setback distance of 225 m. was set. This was consistent with SPSPSD-RES's provisions which required a minimum distance of 1.5 D from roads, where D is the diameter of the selected wind turbine, in this case 150 m. The same setback distance applied to high voltage transmission lines which is consistent with SPSPSD-RES. Finally, a setback distance of 250 m. was set for Antennas following the one applied by Bertsiou et al. (2020) and Sotiropoulou and Vavatsikos (2021).

Settlements

The importance of this criterion is related to the social impact of wind energy to local communities. This is mostly referring to the visual and noise impact of installed wind farms and as such certain setback distances should be defined in order to mitigate them. According to SPSPSD-RES's (2008) provisions different setback distances were defined based on the classification of the settlement. This classification was based on settlements' population size and "traditional character". The traditional character was set by the government which assessed the cultural and architectural merits of settlements. In the study region there were three settlements characterized as traditional (G.G. 594 D'/1978). For settlements with population size of higher or lower than 2,000 people the setback distance was set to 1,000 m. For traditional settlements the setback distance was set to 1,500 m. Those setback distance have been adopted by Latinopoulos and Kechagia (2015).

Environmentally protected areas

The environmentally protected areas criterion was of high importance for the analysis as it denoted areas of high ecological value that should be excluded from the development of wind farms. Those areas were of high significance in terms of preserving the local flora and fauna and keeping their high standards of environmental quality. In this study, three sub-criteria were defined to represent those areas; National Park's Zones, Natura 2000 Priority Habitats, and river network. For the first two criteria no setback distances defined, but they were rather excluded. This was consistent with the SPSPSD-RES (2008) provisions which did not set specific distances from those areas, but rather noted that appropriate setback distances were to be decided during the environmental licensing of the projects. In the case of National Parks' zones, the relevant provisions, set by National Park's legislative framework (art. 2,3, and 4) (G.G. 49 D'/2009), implemented, which excluded from wind power development, Zones Ia, Ib, Ic, Id and Zones IIa and IIb. As far as river network was being concerned a setback distance of 150 m. was set according to Sotiropoulou and Vavatsikos (2021).

Land use

This criterion is related to possible environmental, and cost constrains (Latinopoulos and Kechagia, 2015). Those constrains could be represented as certain types of land uses. In this case the Corine Land Cover (CLC) (2018) dataset was used. To this end, land use type with CLC code of 112: Artificial surfaces excluded from the constraint analysis. In addition, a setback distance 500 m. was set for churches, according to SPSPSD-RES (2008) provisions.

Areas of cultural importance

This criterion consisted of three distinct criteria; namely areas of cultural heritage, historical sites, and archaeological sites. Similarly, to the settlements criterion, social acceptance of wind power projects is related to the distance from certain Points of Interest (POIs) in this case from those connected to the history and culture of hosting areas. As such the higher the distances were from those locations the better acceptance conditions could be achieved for potential wind farm locations. The setback distances to be set for those areas defined based on the SPSPSD-RES (2008) provisions. These distances were equal to 7 D or 1,050 m. For consistency reasons a 1,000 m. setback distance was set from all these areas.

Financial activities

The financial activities in the study region were represented by two criteria; Locations of Tourism Facilities and Locations of Livestock facilities. Due to the mountainous character of the study region tourism and livestock herding were the most common activities present in the area. As such certain setback distances needed to be defined in order to buffer those activities and mitigate negative impacts due to the installation of wind farms in their vicinity. Those impacts could be related to visual and noise impacts of wind farms that could either influence the attractiveness of tourism facilities or livestock production. To this end, SPSPSD-RES (2008) defined 1,000 m. setback distance from tourism facilities (also applied in Latinopoulos and Kechagia, 2015) and 225 m. (1.5 D) distance from livestock facilities.

Table 1. The constraint criteria and their respective constraint thresholds

a/a	Criterion	Constraint	Category
1	**Wind speed**	*< 3 m/s*	Technical / Economic
2	**Slope**	*> 30 %*	Technical / Economic
3	**Main roads**	< 225 *m.*	
	Tertiary roads	< 225 *m.*	
	High voltage transmission lines	< 225 *m.*	
	Antennas	< 250 *m.*	
4	**Settlements with population > 2000**	*< 1000 m.*	Social
	Settlements with population < 2000	*< 1000 m.*	
	Settlements with population < 2000 - no boundaries	*< 500 m.**	
	Traditional Settlements	*< 1500 m.*	
5	**Priority Habitats of Natura 2000 areas**	*Excluded - No buffer*	Environmental

	National Park Zones	*Excluded - No buffer*	
	Rivers	*< 150 m.*	
6	**Artificial Surfaces (CLC Code: 112)**	*Excluded - No buffer*	Social
	Churches	*< 500 m.*	
7	**Cultural Heritage**	*< 1000 m.*	Cultural
	Historical Sites	*< 1000 m.*	
	Archaeological Sites	*< 1000 m.*	
8	**Tourism Facilities**	*< 1000 m.*	Social / Production
	Livestock Facilities	*< 225 m.*	

3.2.1.3 Collection and pre-processing of spatial data

The data used for the formation of both constraint and evaluation criteria were primarily collected through publicly available datasets. The majority of the data were in vector format and in different coordinate system (Table B1 in Appendix B). Digital Elevation Model (DEM) was provided by the Hellenic Cadastral Service in the request of Municipality of Northern Tzoumerka specifically for the current study, whereas wind speed data were provided by Regulatory Authority of Energy (RAE) in raster format.

In this study the selected coordinate reference system is the Greek Grid (EPSG: 2100) and datasets with different coordinate systems were reprojected accordingly. For vector datasets, preliminary topology checks, and geometry fixing was executed to ensure their geometry robustness and prevent error propagation. Appropriate attribute handling and spatial joins were performed to format the vector data according to the specifications of the study, whereas overlay operations were implemented as part of the analysis. Moreover, as the spatial resolution of raster datasets was not similar resampling calculations were performed to acquire a 50 m. × 50 m. cell size grid by selecting nearest neighborhood or bilinear technique where suitable. All data were rasterized to produce the required layers in order to carry out raster analysis.

3.2.1.4 Creation of constraint layers

The constraint layers for each of the above-described criteria were formed after being rasterized and reclassified using Boolean Logic. The constraint layers were taking either a value of one indicating suitable locations for wind farms or zero indicating areas that were deemed unfeasible for the development of wind power projects (see Chapter 4).

3.2.2 Local Knowledge

An important methodological element of this study was to incorporate, knowledge and experience from local communities.

In this study a preliminary public participatory approach aiming at capturing local people's perception and attitudes towards wind power, as well as to map places of territorial value was implemented. This approach, primarily, stemmed from the fact that a) local people in Greece express opposition to the development of RES projects (Kaldellis 2005; Oikonomou et al., 2009) and b) mountainous communities face obstacles in participatory planning of RES projects (Gousios et al., 2021).

The first step of the applied methodology was to identify potential participants. This was possible through snowball sampling. According to Vogt (2005) snowball sampling is "*A technique for finding research subjects. One subject gives the researcher the name of another subject, who in turn provides the name of a third, and so on*". Generally, this form of sampling is suitable when trying to approach social groups that are difficult to reach (Attkinson and Flint, 2001) while it succeeds to to "[..] *both use and activate existing social network*s" (Noy, 2008: 332). In the proposed framework, the sampling tree or snowball stemma (Noy, 2008) started with the mayor of the municipality as of the starting contact with him proposing subsequent referrals. Next, semi-structured interviews were conducted in order to initiate a discussion on public participatory techniques and wind power development. The formatting of questions (Appendix. C) followed the examples of similar studies concerning public perceptions for wind power projects such on Walter (2014), Ribeiro et al. (2014), Simcock (2016), and Wilson and Dyke (2016).

The interviewing process was concluded by asking participants to map areas of personal importance. Those areas were related to a) environmental values and attributes, b) places of activities focusing on tourism and livestock herding. For the purpose of mapping analogue and digital maps were prepared. Those maps included basic information for the municipality such as administrative borders, road network, settlements, and local place names. That helped participants to orient themselves and locate their places of interest throughout the municipality. It should be noted that in the case of analogue maps, the local input was digitized into vector format after scanning the original maps and georeferencing them in a GIS environment.

Finally, the produced maps were overlayed with the constraint map (see Subchapter 3.2.3) to indicate the primary suitability areas that were overlapping with places of local interest. Moreover, a second round of interviews, taking into consideration the consensus among participants, was conducted for the verification of the final suitability areas.

3.2.3 Creation of constraint map

A preliminary constraint map was created by multiplying the previously created constraint layers. The outcome of this process was an initial raster taking values of either zero or one indicating exclusion areas and suitable areas for wind power development respectively.

The final constraint areas were identified after filtering the preliminary constraint map with the one produced by local participants through the two rounds of interviews. The local knowledge map was produced by rasterizing the local input, classified it using Boolean logic and then multiplying it with the preliminary constraint map. Last but not least, the final constraint map was further filtered with a power density map made available by DTU (Global Wind Atlas, 2023). This step applied to further examine the feasibility of suitability areas. In this case, suitability areas where power density was less than 225 W/m^2 were excluded. According to NREL (2022) those areas are not financially viable for the selected type of wind turbine (see Subchapter 3.2.1.2).

3.2.4 Definition of Evaluation Criteria

An important step to measure the suitability of the locations defined as available for wind power development was to determine the evaluation criteria. Those criteria evaluated the municipality of Northern Tzoumerka by assigning to them weights indicating their relative importance. The calculation of weights was based on Fuzzy AHP MCDA approach (see Subchapter 3.2.5) that has been applied in numerous studies concerning suitability analysis of wind power (see Sanchez-Lozano et al., 2016, Ahmadi et al., 2020, Zalhaf et al., 2021, Sanchez-Lozano et. al, 2022). It should be stated that the evaluation criteria were not defining constraint areas, in case of evaluating, for instance, the study area with zero score, but rather assessing them with the lowest suitability score possible.

In this study, six evaluation criteria were selected, and a normalization process took place. Normalization converts criteria of different nature (i.e., wind speed, slope, distances) into a common scale ranging from zero to one that it is easier to compare and handle in the analysis. For normalization purposes the theory of fuzzy sets was applied as presented by Zadeh (1965).

According to fuzzy set theory, problems could be described with vagueness and imprecision where no crisp boundaries persist (Sanchez-Lozano et. al, 2022) in the form of binary logic, zero or one. Thus, fuzzy sets were formed to cope with this ambiguity or uncertainty also known as degree of vagueness (Smithson and Verkuilen, 2006). This is possible by defining the degree of membership of an object X to a fuzzy set A through a fuzzy membership function f_A (Garcia-Cascales, and Lamata, 2011; Smithson and Verkuilen, 2006). The measurement of degree was on a scale [0,1] where zero indicated low suitability and one high suitability.

The membership function implemented in this study was linear as it was one of the most commonly used in analyzing renewable energy problems (Sanchez-Lozano et. al, 2022). This function was divided into two categories; The Increasing Membership Function (Equation 1) and the Decreasing Membership Function (Equation 2). It should be noted that for the linear membership function it was important to determine the parameters (**a**, **b**) which defined the degree of satisfaction of an object X. In this case, parameter **a** determined a low satisfactory level, while **b** determined a high satisfactory level.

Increasing Membership Function $f_A(x)$:

$$= \begin{cases} 0, & x < a \\ \frac{x-a}{b-a}, & a \le x \le b \\ 1, & x > b \end{cases} \qquad \text{(Equation 1)}$$

Decreasing Membership Function $f_A(x)$:

$$== \begin{cases} 1, & x < b \\ \frac{x-a}{b-a}, & a \le x \le b \\ 0, & x > a \end{cases} \qquad \text{(Equation 2)}$$

where, x is an object that belongs to fuzzy set A, and **a** and **b** are the low and high satisfactory thresholds respectively

One of these functions were applied for each of the selected criteria (Table 2) based on their relevant effect on wind power suitability (i.e., benefit or cost criteria) (Latinopoulos and Kechagia, 2015) (Figure 3).

An example of an Increasing Membership Function is wind speed. Compared to the defined high satisfactory threshold **b**, the higher the wind speed, the more suitable the location (defined as closer to one). Comparably, an example of a Decreasing Membership Function is slope. Compared to the defined low satisfactory threshold **a**, the higher the slope (in percentage), the less suitable the location (close to zero).

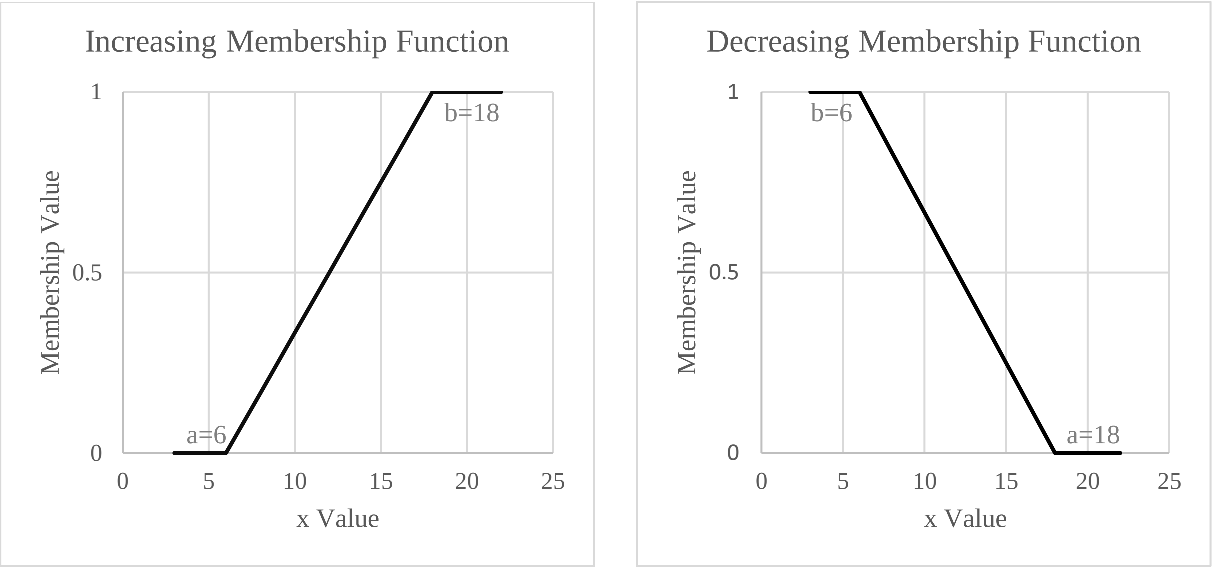

Figure 3. Graphical representation of Increasing and Decreasing Membership Function.

3.2.4.1. Description of Evaluation Criteria

Wind speed

The evaluation of the study area in terms of its wind speed conditions was very important as this criterion assessed the ability of wind farms to produce electricity and as such their financial feasibility (Vasileiou et al., 2017). The wind data to be utilized in the assessment were derived by RAE in a raster format of a 150 m. × 150 m. grid cell size. The average wind speed was measured at 120 m. height. For the normalization of this criterion an Increasing Membership Function was implemented as locations with wind speeds higher than the defined **b** threshold assessed as highly suitable (equal to one). To this end, the low satisfactory threshold **a** was set to 4 m/s based on the power curve of the selected wind power model and the **b** threshold to 7.5 m/s as proposed by Latinopoulos and Kechagia (2015).

Slope

The slope criterion was assessing the technical feasibility of the investigated candidate locations regarding the installation of wind farms. For this criterion a Decreasing Membership Function was used to normalize it as areas with slope higher than the predefined **b** threshold took a membership value close to zero. As mentioned earlier, in mountainous areas wind farms could be installed at high slope levels (Schallenberg-Rodríguez and Notario-del Pino, 2014). To this end, in order to reflect for the mountainous character of the study region and be consistent with academic literature (see Latinopoulos and Kechagia, 2015) **a** threshold was set to 25 % and the **b** threshold to 5 %.

Distance to road network

This criterion was assessing the suitability of a wind farm in terms of their ability to be easily accessed through the main road network. That was important as wind farms in remote location may face higher installation costs due to the increased need for constructing new roads so to facilitate the transportation of their components and for maintenance purposes (Jangrid et al., 2016). In addition, this criterion was also connected to the safety of the public as mentioned in Subchapter 3.2.1.2. In general, academic literature (Tegou et al., 2010, van Haaren and Fthenakis, 2011, Gigovic et al., 2017) suggest that the closer a wind farm to road network, the higher the suitability. To this end, for this criterion a Decreasing Membership Function was used where the low satisfactory threshold **a** was set to 5,000 m. (Latinopoulos and Kechagia, 2015) and high satisfactory threshold **b** to 300 m. according to SPSPSD-RES (2008) provisions.

Distance to high voltage transmission lines and substations

This criterion was related to wind farms' connection costs to power grid. To be more specific, the further the connection point to a substation and high voltage transmission lines, the more technical works will be required in the form of constructing intermediate substations and cable spreading so to ensure power connectivity (van Haaren and Fthenakis, 2011). For the normalization of the criterion a Decreasing Membership Function implemented where the low satisfactory threshold **a** was set to 10,000 m. (Doljak et al., 2021) and high satisfactory threshold **b** was set to 300 m. according to SPSPSD-RES (2008) provisions.

Distance to environmentally protected areas

This was one of the most important evaluation criteria as it assessed the vulnerability of potential wind farm locations with regards to their impact to the environment. This criterion was including the core protection zones of the National Park that is Zone I and II where, due to their legislative provisions (G.G. 49 D'/2009), no wind farm installation is permitted on their premises. According to Gharaibeh (2021) and Zahedi (2022), certain setback distances need to be kept from environmentally protected areas in order to retain their environmental quality and minimize potential impacts. Nevertheless, SPSPSD-RES (2008) provisions did not specify setback distances from these areas, but they denote that any safety distances should be determined during the Environmental Licensing of the projects.

For the normalization of the criterion an Increasing Membership Function implemented where the higher the distance from National Park's zones a wind farm had the higher the suitability of its location was. In this case, the low satisfactory threshold **a** was set to 0 m. (SPSPSD-RES, 2008), and high satisfactory threshold **b** was set to 3,000 m., according to Latinopoulos and Kechagia (2015).

Distance to settlements

This criterion was related to evaluating the suitability of wind farm areas in relation to their distance from municipality's settlements. That was important as social acceptance of such projects could be connected to their proximity from residents and dwellings (Jangrid et al., 2016). To this end, for the normalization of this criterion, an Increasing Membership Function utilized. The low satisfactory threshold **a** was set to 3,000 m. while the high satisfactory threshold **b** was set to 10,000 m. Those membership values were consistent with threshold values suggested by Sotiropoulou and Vavatsikos (2021).

The following table (Table 2) presents the evaluation criteria utilized in this study and their corresponding fuzzy membership function.

Table 2. The evaluation criteria and their respective fuzzy membership function

a/a	Criterion	Description	Category
1	**Wind speed**	*Increasing Fuzzy Membership Function* a-value (least suitable threshold value): 4 m/s b-value (most suitable threshold value): 7.5 m/s	Technical / Economic
2	**Slope**	*Decreasing Fuzzy Membership Function* a-value (least suitable threshold value): 25 % b-value (most suitable threshold value): 5 %	Technical / Economic
3	**Distance to roads**	*Decreasing Fuzzy Membership Function* a-value (least suitable threshold value): 5,000 m. b-value (most suitable threshold value): 300 m.	Technical / Economic / Social
4	**Distance to high voltage transmission lines and substations**	*Decreasing Fuzzy Membership Function* a-value (least suitable threshold value): 10,000 m. b-value (most suitable threshold value): 300 m.	Technical / Economic
5	**Distance to protected areas: Zones I and II of National Park**	*Increasing Fuzzy Membership Function* a-value (least suitable threshold value): 0 m. b-value (most suitable threshold value): 3,000 m.	Environmental
6	**Distance to settlements: Settlements < 2,000 and Traditional Settlements**	*Increasing Fuzzy Membership Function* a-value (least suitable threshold value): 3,000 m. b-value (most suitable threshold value): 10,000 m.	Social

3.2.4.2. Creation of evaluation layers

The evaluation layers to be implemented in the evaluation analysis of the municipality were created in ArcGIS environment using the Fuzzy Membership tool for the Spatial Analyst toolbox. Depending on the fuzzy membership function described in Table 2 for each criterion the relevant evaluation map was produced. It should be noted that for the distance-dependent criteria (e.g., distance to roads) the first step was to produce a distance matrix using the Euclidean Distance tool and then applying Fuzzy Membership. In addition, the evaluation criterion "distance to high voltage transmission lines and substations criterion" were created based on two individual criteria; transmission lines and substations. For each of those criteria, a fuzzy raster was formed and then, in order to form a compact matrix, a weight equal to 0.5 applied to them indicating equal significance. Finally, the weighted linear combination method (see Subchapter 3.2.6) was used to combine the individual criteria and their weights to form a uniform criterion.

3.2.5 Calculating weights with Fuzzy AHP

The estimation of weights for each of the selected evaluation criteria was based on AHP methodology. In this process a set of alternatives and criteria formed which were compared to each other through pair-wise comparisons (Liu et al., 2017; Sánchez-Lozano et al, 2016). This process resulted a positive reciprocal matrix (Saaty, 2003). Generally, those comparisons reflect the relative preferences of a decision maker (DM) of an alternative/criterion over another. It should be stated that the preferences were expressed at a scale ranging from 1 to 9 known as the fundamental scale of Saaty (Saaty, 1987). Based on these comparisons a decision matrix was structured of n dimensions and priority vectors estimated, ranking the judged criteria (Ghorui et al., 2020). Those priority vectors were representing the weights of the judged criteria.

Finally, the consistency of judgements was estimated. That was possible by calculating the Consistency Index (CI) and Consistency Ratio (CR) (Saaty, 1980). The CR calculated by dividing the CI with Random Index (RI). The latter is a number depended on the number of criteria used (Liu et al., 2017). In order for the judgment to be consistent, CR should be less than 0.10 ($CR < 0.10$). In case of $CR = 0$, then judgements are fully consistent (Liu et al., 2017).

In this study, a fuzzy version of AHP was applied in order to derive the weights for each evaluation criteria as proposed by Ghorui et al. (2020). As mentioned in Subchapter 3.2.4.

fuzzy sets are expressing “[..] *the uncertainty and impreciseness of the decision experts*” (Ghorui et al., 2020: 178).

In fuzzy AHP developed by Saaty (1994), the relevant preference scale for the judgements was expressed in a form of Triangular Fuzzy Numbers (TFN) (Table 3) as proposed by Sánchez-Lozano et al. (2016). A TFN was expressed as $S_{kl} = (p_{kl}, r_{kl}, t_{kl})$, where S_{kl} represents the relevant preference of a criterion k over a criterion l, p_{kl} represents the lower value of a preference, r_{kl} represents the middle value, and t_{kl} the largest value of a preference.

Table 3. Triangular Preference Scale (Sánchez-Lozano et al., 2016)

Saaty’s Scale	**Verbal Description**	**TFN**	**Reciprocal of TFN**
1	C_k is equally important to C_l	1,1,1	1,1,1
3	C_k is slightly more important to C_l	2,3,4	1/4, 1/3, 1/2
5	C_k is strongly more important to C_l	4,5,6	1/6, 1/5, 1/4
7	C_k is very strong more important to C_l	6,7,8	1/8, 1/7, 1/6
9	C_k is extremely more important to C_l	8,9,9	1/9, 1/9, 1/8

The first step of this process was to form the comparison matrix of the selected criteria based on the fuzzy AHP approach and using the TFN scale of Table 3. Then, a defuzzification process took place which transformed the triangular values into crisp ones. That was possible by implementing the equations (3, 4, and 5) below (Chang et al., 2009).

$$(S_{kl}^{\alpha})^{\beta} = [\beta \times p_{kl}^{\alpha} + (1 - \beta) \times t_{kl}^{\alpha}], 0 \leq \beta \leq 1, 0 \leq \alpha \leq 1 \quad \text{(Equation 3)}$$

where, α represents the preference display of the evaluator and β signifies the risk factor of the uncertain conditions (Ghorui et al., 2020: 179). The closer α is getting to zero the higher the uncertainty is, while the closer β is getting to one the more pessimistic the judgment is. In this study both α and β were set to 0.5, so to express a moderate stand on preferences and judgements, similar to Ghorui et al. (2020).

In Equation 3, the p_{kl}^{α} is derived using Equation 4, $p_{kl}^{\alpha} = (r_{kl} - t_{kl}) \times \alpha + p_{kl}$

In Equation 3, the t_{kl}^{α} is derived using Equation 5, $t_{kl}^{\alpha} = t_{kl} - \alpha \times (t_{kl} - r_{kl})$

The next step was to form the decision matrix containing the previously de-fuzzified TFN values, normalized it and estimated the priority vectors (Ghorui et al., 2020). That was possible by following a typical AHP procedure described in Cabala (2010).

Finally, the CI was estimated, and the CR was calculated to check the consistency of judgements. In this proposed methodology the comparison of the criteria followed an environmentally oriented scenario similar to Latinopoulos and Kechagia (2015).

3.2.6 Creation of evaluation map

The evaluation map was created by mathematically combine the evaluation layers while assigning to them their respective weights estimated through fuzzy AHP. That was possible through WLC or weighted summation approach which is described by the following equation (Equation 6):

$$S_i = \Sigma_{J=1}^{n} W_J v_{iJ} \qquad \text{(Equation 6)}$$

where Si is the suitability score for a cell i, Wj is the respective weight for criterion j and Vij is the evaluation score for a cell i for each selected criterion j (j=1,2,..,6) (Tegou, et al., 2012; Malczewski and Rinner, 2015).

In order to perform the above-described process, the Weighted Sum tool utilized in ArcGIS in order to calculate the evaluation map of the municipality.

3.2.7 Creation of suitability map

The creation of the suitability map was achieved by multiplying the evaluation map created in the previous step with the constrain map, using map algebra. That permitted to assign a suitability score at each cell of the constraint map having value of one.

Then, the suitability map was reclassified into suitability classes (Table 4)

Table 4. Suitability Classes based on suitability score

Suitability Score	**Suitability Class**
0	*Unsuitable*
0 - 0.5	*Low Suitability*
0.5 - 0.75	*Moderate Suitability*
0.75 - 1	*High Suitability*

3.2.8 Creation of sensitivity maps

In order to test the sensitivity of the applied methodology three sensitivity scenarios were applied. Each scenario was expressed through applying different weights to the evaluation criteria. In the first scenario, all evaluation criteria were assigned equal weights, while on the second scenario environmental criteria were assigned with zero weight (not accounted).

Finally, in the third scenario distance from roads, transmission lines, and substations were assigned with zero weights. This sensitivity analysis approach was consistent with Tegou et al. (2010).

3.2.9 Comparison of suitability map with proposed wind farms

As final step of the described methodology was to compare the calculated and assessed suitability locations with proposed wind farm locations in the municipality.

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4. Results

4.1 Creation of constraint map

This section presents the results of the applied methodology regarding the identification of exclusion and availability areas for the development of wind power projects in the study area. Firstly, the constraint layers created for this part of the analysis are presented. Those results highlight the exclusion areas as defined based on each constraint criterion. Then, the preliminary constraint map is presented that is the product of combining the previously created constraint layers. Furthermore, the cartographical results of the local knowledge process are depicted. As mentioned in Chapter 3 the purpose of this methodological step was to capture areas of territorial value based on the input and perception of local stakeholders. Those stakeholders were representing the two major economic sectors that are prevailing in the municipality; livestock herding and tourism. This is important as those types of activities could be essentially impacted by wind power projects as they are closely connected to the underlying quality of environment (natural, visual, social). The spatial input of the participated stakeholders is translated into a spatial filter which is contributing to the calculation of the final constraint map and the identification of suitability areas. The aforementioned outcomes are presented in the following sub-chapters.

4.1.1. Creation of constraint layers

As far as the constraint layers are being concerned, the results indicate that four criteria play an important role into identifying exclusion areas for wind power development in comparison to other investigated criteria (Figure D1, D2, D3, D4 in Appendix. D). Those are slope, distance from settlements, power density of wind, and distance from National Park's zones (I and II). To be more specific, slope assessed 84.0 % of the municipality as unavailable for wind farms while the respective percentage for distance from settlements was 56.3 %, for power density criterion was 40.8 %, and for national park criterion was 38.0 %.

As mentioned in Subsection 3.2.3 of the methodology, the created constraint maps are combined to create a preliminary constraint map of the study area. It is important to note that these results present the constraint map without being evaluated under the prism of local knowledge. It rather presents the results of solely spatially combining the created constraint layers. To this end, the produced constraint map was further filtered based on local knowledge results as shown in Subsection 4.1.2 of this chapter.

The preliminary constraint map indicates that the areas that are suitable for wind farms account for only 1.1 % of the total investigated region which is equivalent to 406 ha or 4.1 km^2 of land (Table 5). Those areas are generally dispersed throughout the municipality with some major clusters located in the western and south-western parts (Figure 4).

The table (Table 5) below numerically presents the initial municipality classification into areas of exclusion, meaning areas which assigned a zero value and areas of feasibility for the development of wind farms.

Table 5. Municipality's initial classification into constraint and feasible areas for wind power

Value	Category	Pixel Count	Area in km^2	Area in Ha	Percentage
0	***Restricted***	141,628	354.1	35,407	**98.9 %**
1	***Suitable***	1,623	4.1	406	**1.1 %**
	Sum	143,251	358.2	35,813	**100 %**

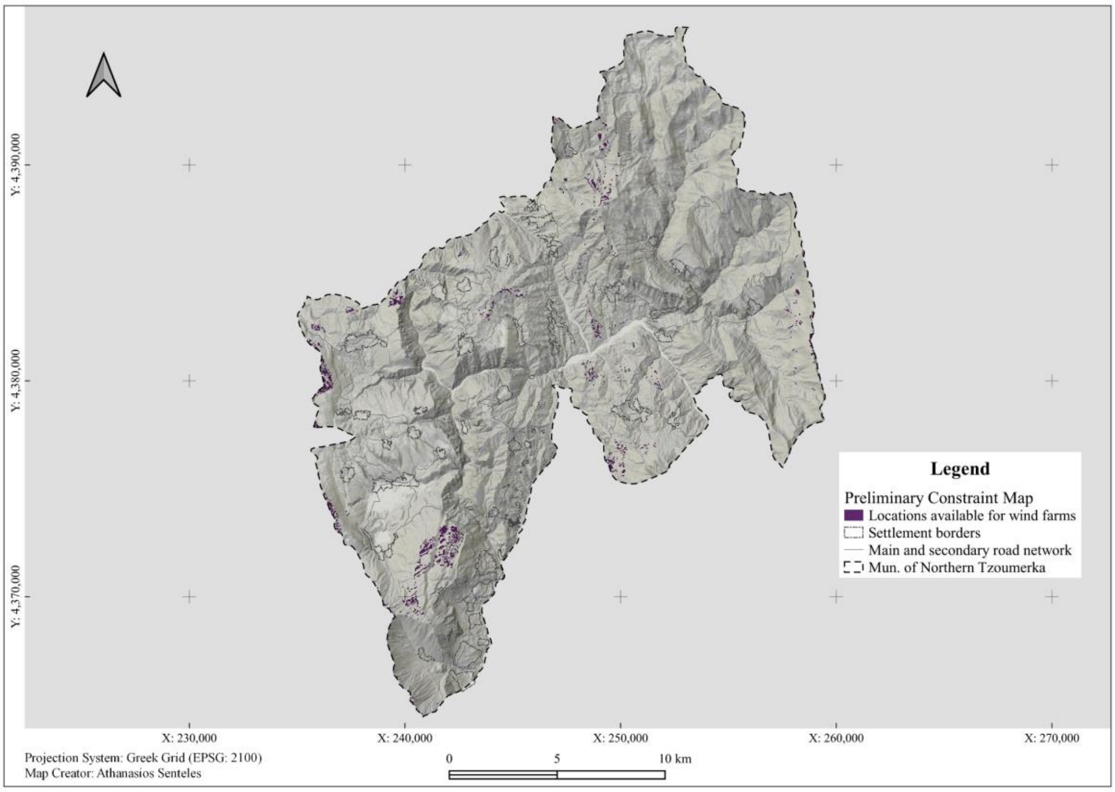

Figure 4. The preliminary constraint map to be evaluated based on local knowledge input

4.1.2 Local Knowledge

In total, 17 stakeholder, at 10 locations, participated in the interviewing process that was held between 24th and 30th of August 2022 in different locations throughout the municipality. It should be noted that some stakeholders were not residing in the municipality, however, their activities are expanding into it. As such, separate interviews were conducted in their locations. The table below (Table 6) presents the number of participants per location and sector.

Table 6. The list of stakeholders participated in the interviews

Nr. of Part.	Location	Municipality	Sector/Occupation
3	Tsopelas Settlement	N. Tzoumerka	Tourism / Hotel Owners
1	Pramanta Settlement	N. Tzoumerka	Tourism / Mountain Refuge Owner
2	Melissourgoi Settlement	C. Tzoumerka	Tourism / Mountain Refuge Owners
1	Agnanta Settlement	C. Tzoumerka	Tourism / Outdoor Activities
2	Kalarrytes Settlement	N. Tzoumerka	Livestock Herding
4	Syrrako Settlement	N. Tzoumerka	Livestock Herding
1	Ioannina City	Ioannina	Scientist
1	Ioannina City	Ioannina	Inhabitant / Hiking
1	Ioannina City	Ioannina	Tourism / Hotel Owner
1	Pramanta Settlement	N. Tzoumerka	Mayor
17			

The map on Figure 5 illustrates the areas that were identified as of high importance by the participated stakeholders and DM. Those areas are divided into two major sections; areas that are important for both livestock activities and tourism, as well as areas that are important to tourism. This division was performed based on stakeholder's verbal input and its cartographically expression through the interviews. That was possible by providing to the participants both digital and analogue maps of the municipality. The final local knowledge map was created based on a personal interview with the mayor held on 10th of April 2023 on which the initially created constraint map and local stakeholders' raw cartographical product were discussed upon. To this end, based on map on Figure 5 a new constraint layer was created (Figure D5 in Appendix. D) that was used to filter the preliminary constraint map and define the final exclusion and availability areas in the municipality.

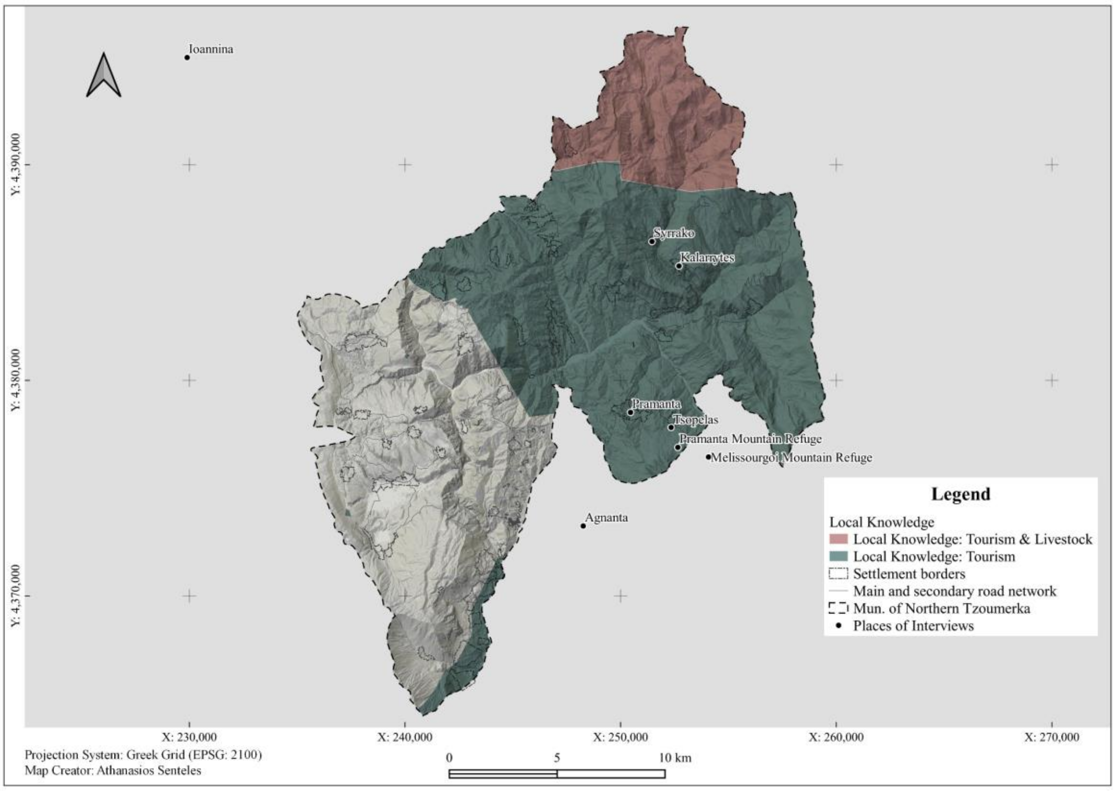

Figure 5. The final local knowledge map as expressed by local stakeholders and DM.

4.1.3 Creation of the final constraint map

The final constraint map is presented in Figure 6. According to this, the vast majority of the municipality is still assessed as unsuitable for the development of wind power. The final exclusion areas' quota was increased by 0.4 % in comparison to the initially created constraint map. That leaves 0.7 % of the municipality available for wind farm development, which measures 2.5 km^2 or 246 ha of suitable land. It should be noted that the relevant percentage of areas excluded from wind power development due to local stakeholders' input is 51.2 %.

The table below (Table 7), presents the final classification of the municipality.

Table 7. Municipality's final classification into constraint and feasible areas for wind power

Value	Category	Pixel Count	Area in km^2	Area in Ha	Percentage
0	***Restricted***	142,267	355.7	35,567	**99.3 %**
1	***Suitable***	984	2.5	246	**0.7 %**
	Sum	143,251	358.1	35,813	**100 %**

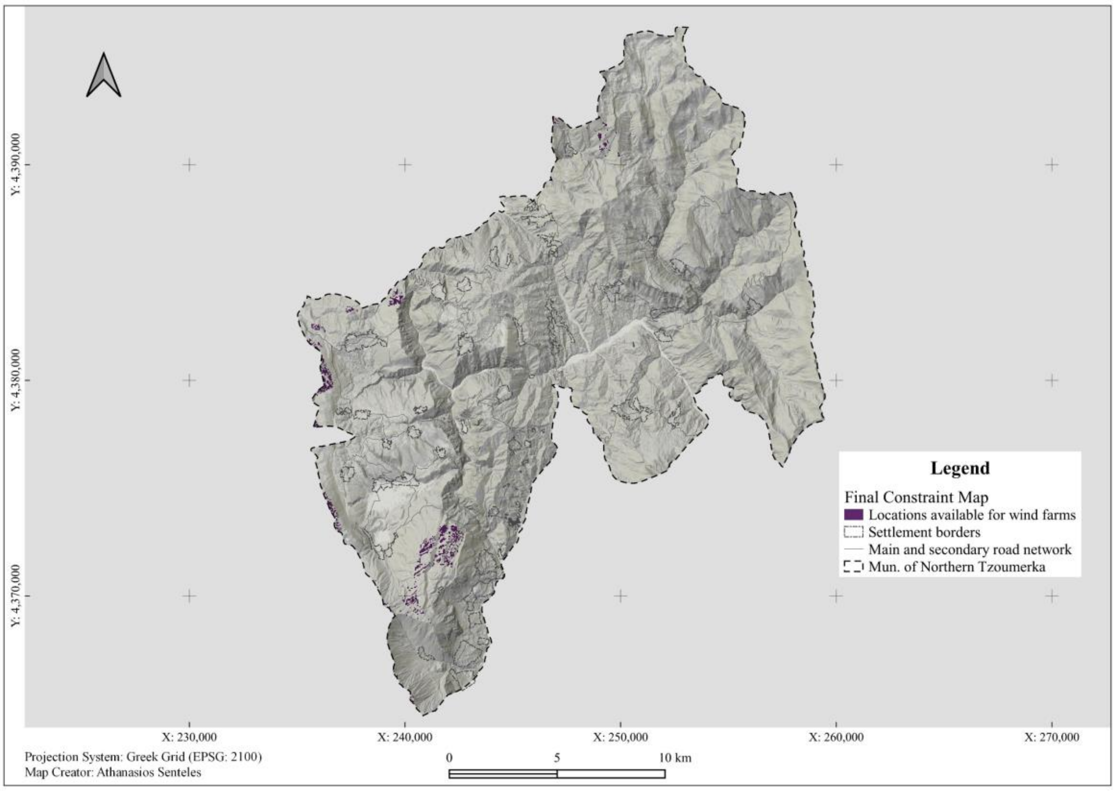

Figure 6. The final constraint map.

4.2 Creation of the suitability map

The creation of the suitability map which utterly assesses the suitability of the areas found available for the development of wind farms is based on the process of the selected evaluation criteria. Those evaluation layers were normalized by applying the fuzzy membership function which evaluates the municipality in a range between zero and one. Then, based on fuzzy AHP approach weights were calculated indicating the relative importance of the criteria. The produced evaluation map combined the previously created evaluation layers after assigning to them the estimated weights. Finally, the suitability map for the municipality was created by combing the evaluation map with the constraint map.

4.2.1 Creation of the fuzzy normalized evaluation layers

The evaluation layers created for each of the six selected criteria are presented in this subsection. A representative result of this process is highlighted by Figure 7.

Based on the estimation of their mean fuzzy value, the majority of criteria (Figure D6 – D10 in Appendix. D) evaluate the municipality with low suitability (Table 8). Those criteria are “Wind”, “Slope”, “Distance to high voltage transmission lines and substations”, and “Distance to settlements: Settlements < 2,000 and Traditional Settlements”. It is only the “Distance to roads” criterion that evaluates the study area relatively high (mean value of 0.74) whereas the “Distance to protected areas: Zones I and II of National Park” provides a moderate suitability assessment (mean value of 0.42).

Table 8. The mean fuzzy value of the created evaluation layers

Criteria	Mean fuzzy value
Wind	0.24
Slope	0.04
Distance to roads	0.74
Distance to high voltage transmission lines and substations	0.07
Distance to protected areas	0.42
Distance to settlements	0.06

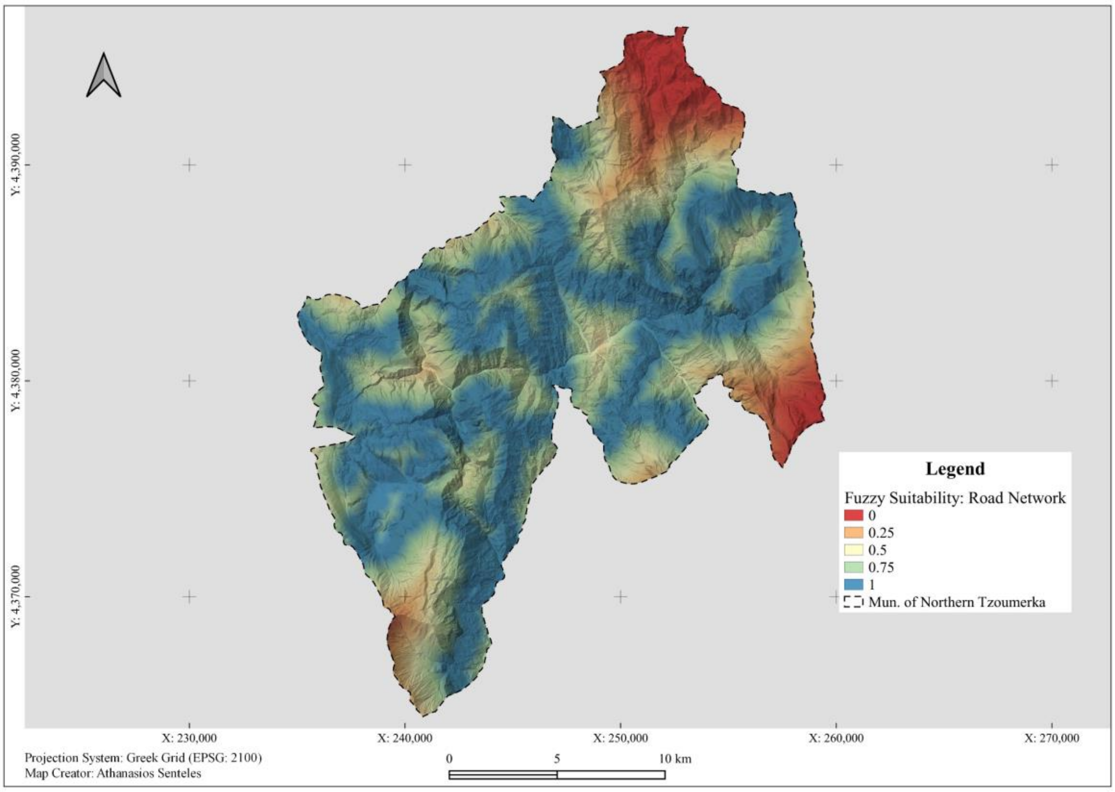

Figure 7. Fuzzy normalization of “Distance to roads” evaluation criterion. The criterion has a mean fuzzy value of 0.74.

4.2.2 Fuzzy AHP results

In this section the fuzzy AHP results are presented. Table 9 presents the fuzzy AHP matrix where the preference of a criterion over another is described as a TFN. These preferences were expressed in a manner highlighting the importance of environmental protection. The de-fuzzified decision matrix is described in Table 10. The consistency ratio (CR) is 0.05 < 0.1 meaning that the comparisons are consistent. Finally, the normalized de-fuzzified matrix and the calculated priority vectors (weights) for each evaluation criteria are presented in Table 11.

Table 9. Fuzzy pairwise comparison matrix

Criteria	**W**			**S**			**DR**			**DTL**			**DPA**			**DS**		
	p	*r*	*t*	*p*	*r*	*t*	*p*	*r*	*t*	*p*	*r*	*t*	*p*	*r*	*t*	*p*	*r*	*t*
W	1.00	1.00	1.00	4.00	5.00	6.00	4.00	5.00	6.00	4.00	5.00	6.00	1.00	1.00	1.00	2.00	3.00	4.00
S	0.17	0.20	0.25	1.00	1.00	1.00	2.00	3.00	4.00	2.00	3.00	4.00	0.17	0.20	0.14	2.00	3.00	4.00
DR	0.17	0.20	0.25	0.25	0.33	0.50	1.00	1.00	1.00	1.00	1.00	1.00	0.13	0.14	0.17	2.00	3.00	4.00
DTL	0.17	0.20	0.25	0.25	0.33	0.50	1.00	1.00	1.00	1.00	1.00	1.00	0.13	0.14	0.17	2.00	3.00	4.00
DPA	1.00	1.00	1.00	7.00	5.00	6.00	6.00	7.00	8.00	6.00	7.00	8.00	1.00	1.00	1.00	6.00	7.00	8.00
DS	0.25	0.33	0.50	0.25	0.33	0.50	0.25	0.33	0.50	0.25	0.33	0.50	0.13	0.14	0.17	1.00	1.00	1.00

Where **W**: Wind, **S**: Slope, **DR**: Distance to Roads, **DTL**: Distance to high voltage transmission lines and substations, **DPA**: Distance to protected areas, **DS**: Distance to Settlements

Table 10. The de-fuzzified comparison matrix

Criteria	***De-fuzzification of comparison matrix***					
	WP	**S**	**DR**	**DTL**	**DPA**	**DS**
W	1	4.75	4.75	4.75	1	2.75
S	0.19	1	2.75	2.75	0.19	2.75
DR	0.19	0.31	1	1	0.14	2.75
DTL	0.19	0.31	1	1	0.14	2.75
DPA	1	5.5	6.75	6.75	1	6.75
DS	0.31	0.31	0.31	0.31	0.14	1
Sum	2.89	12.19	16.56	16.56	2.61	18.75

CI	0.06
RI	1.25
CR	0.05

Table 11. The Normalized de-fuzzified matrix

Criteria	***Normalization of the de-fuzzified Matrix***						
	W	**S**	**DR**	**DTL**	**DPA**	**DS**	**Weights**
W	0.35	0.39	0.29	0.29	0.38	0.15	0.35
S	0.07	0.08	0.17	0.17	0.07	0.15	0.07
DR	0.07	0.03	0.06	0.06	0.05	0.15	0.07
DTL	0.07	0.03	0.06	0.06	0.05	0.15	0.07
DPA	0.35	0.45	0.41	0.41	0.38	0.36	0.35
DS	0.11	0.03	0.02	0.02	0.05	0.05	0.11
Sum	1	1	1	1	1	1	1

4.2.3 Creation of the evaluation map

The evaluation map (Figure 8) was created by multiplying the evaluation layers with their respective weights and then adding them together using the weighted sum method. The municipality was evaluated in a fuzzy range between 0 and maximum 0.77, while the mean value is 0.3.

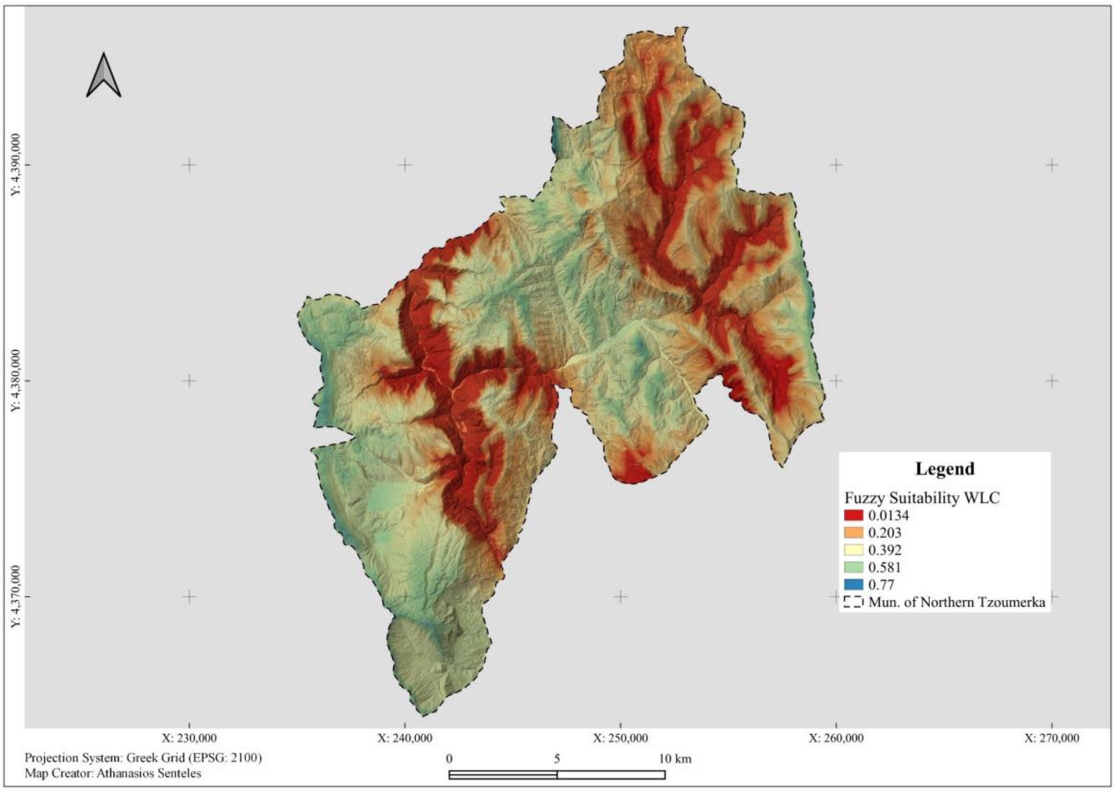

Figure 8. The evaluation map after applying the WLC method

4.3 Creation of the suitability map

The resulted suitability map for the municipality is illustrated in Figure 9. The table below (Table 12) highlights the classified suitability of the municipality. Based on this, one can notice that the majority of suitable areas were indexed as of moderate suitability (56.8 %) while only 0.4 % (1 ha) accounts for high suitability areas. The rest 42.8 % was indexed as of low suitability.

Table 12. Suitability Class of the municipality

Value	Category	Pixel Count	Area in km^2	Area in Ha	Percentage
1	***Low Suitability***	421	1.05	105	**42.8 %**
2	***Moderate Suitability***	559	1.40	140	**56.8 %**
3	***High Suitability***	4	0.01	1.00	**0.4 %**
	Sum	984	2.46	246	**100 %**

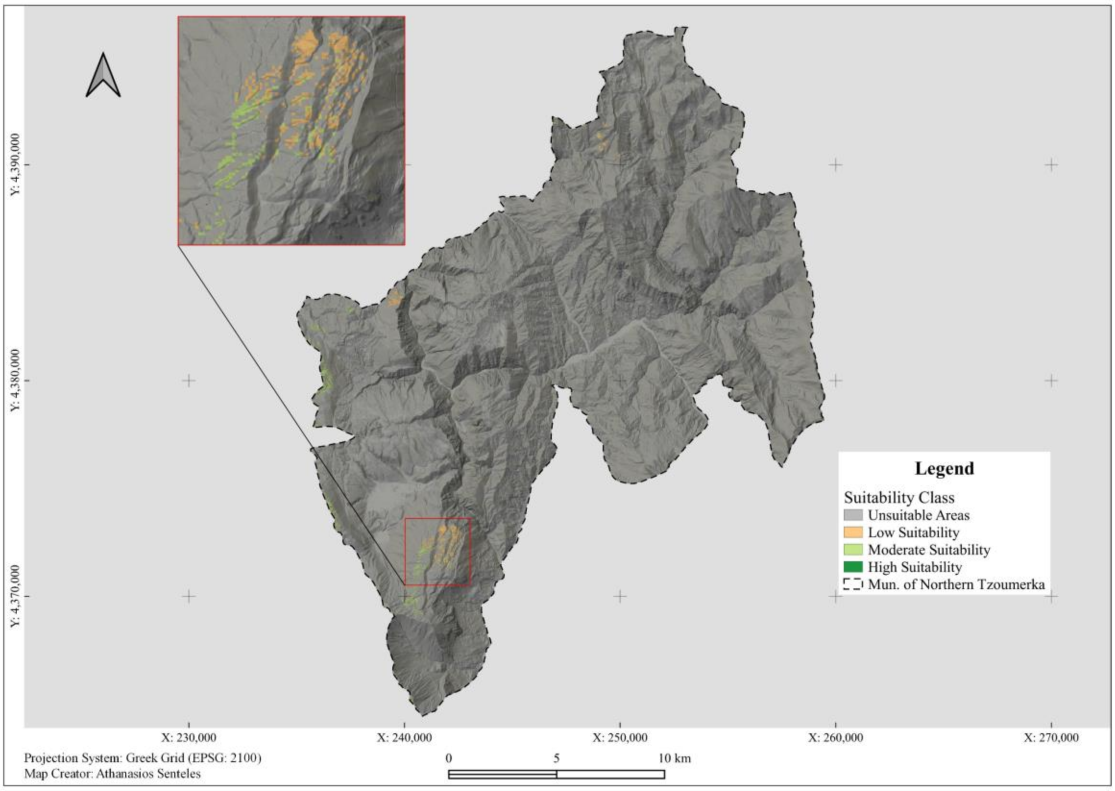

Figure 9. The suitability map of the municipality

4.4 Sensitivity analysis results

The results for the three selected sensitivity analysis scenarios are presented in Tables 13 - 15. Based on the depicted results, there is no scenario where high suitability areas are identified. On the other hand, the vast majority of the suitable areas (higher than 93 %) in the municipality is shown to have low suitability for all selected scenarios. Finally, moderate suitability is, in overall, ranging from a minimum of 0.8 % (for scenario 2) to a maximum of 6.4 % (for scenario 3) of the total suitable areas. The corresponding maps are found in Appendix (Figure D11, D12, and D13 in Appendix. D).

Table 13. Sensitivity analysis results for Scenario 1

Value	Category	Pixel Count	Area in km2	Area in Ha	Percentage
1	***Low Suitability***	934	2.34	233.5	**94.9 %**
2	***Moderate Suitability***	50	0.13	12.5	**5.1 %**
3	***High Suitability***	-	-	-	-
	Sum	984	2.46	246	**100 %**

Table 14. Sensitivity analysis results for Scenario 2

Value	Category	Pixel Count	Area in km^2	Area in Ha	Percentage
1	***Low Suitability***	976	2.44	244	**99.2 %**
2	***Moderate Suitability***	8	0.02	2	**0.8 %**
3	***High Suitability***	-	-	-	**-**
	Sum	984	2.46	246	**100 %**

Table 15. Sensitivity analysis results for Scenario 3

Value	Category	Pixel Count	Area in km^2	Area in Ha	Percentage
1	***Low Suitability***	921	2.3	230.3	**93.6 %**
2	***Moderate Suitability***	63	0.2	15.8	**6.4 %**
3	***High Suitability***	-	-	-	**-**
	Sum	984	2.46	246	**100 %**

4.5 Comparison of suitability map with proposed wind farms

The suitability map is further compared to proposed wind farms in the study area (Figure 10). According to their point locations provided by RAE there are 13 wind turbines belonging to different wind farms polygons that are proposed in the vicinity of the municipality. It should be stated that there are only three of them that are classified as of moderate suitability, according to the produced suitability map. The rest of them are proposed in areas that have been assessed as unsuitable for the development of wind power projects.

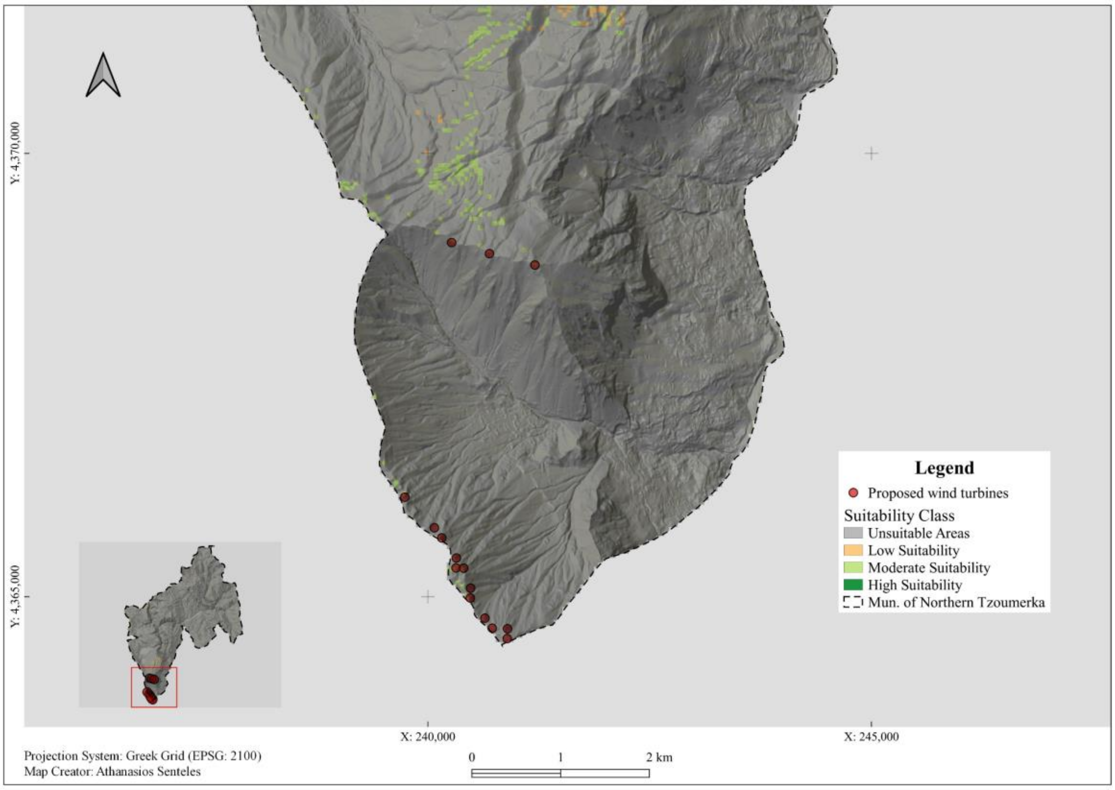

Figure 10. Overlapping of proposed wind farms with the suitability map

5. Discussion

5.1 Analysis of the final constraint map

As described in the Methodology chapter of this study, the first step in the analysis of the municipality regarding its ability to host wind power development is to classify it into (1) areas suitable for wind farms and (2) areas that should be excluded from it. This distinction is based on the selection of constraint criteria the combination of which enables this classification.

The eight categories of criteria included were derived from the Greek national guidelines regulating the development of RES projects (SPSPSD-RES, 2008) despite the fact that academic literature provides vast and rich options for such types of criteria dedicated to wind power planning. This approach, which was also applied by Tsoutsos et al. (2015), was selected for a very important reason; to apply in this study as much realism as it was possible so to produce legally rigid results. Nevertheless, the list of criteria provided by the Greek legal framework was not exhaustive neither the type of setback distances ruled through it. As such, for the types of criteria that the national framework either did not provide as guidelines, such as slope limitations, or did not specify specific setback distances, the relevant academic literature suggestions applied to fill those gaps. In total, the combined determination of constraint criteria aimed at representing the four fundamental sectors wind power impacts, environmental, social, technical, and economic.

It should be stated that the selection of the constraint criteria, in terms of their nature, number, type, and extent of constraint influence highly affects the final outcome. This has been generally discussed by Malczewski and Rinner (2015) as they were referring to the “scale” and “zone” effect of criteria. An example of it should be considered the environmentally oriented constraint criteria applied in this study. For this type of criterion which consisted by National Park’s Zones I and II where no major development is permitted according to its legal provisions, no setback distance was set. That was due to the SPSPSD-RES’s (2008) guidelines where safety distances from them are determined on the Environmental Licensing stage of the projects. This is important as setback distances would probably expand the exclusion areas in the municipality. In addition, despite the fact that the municipality is overlapping with a Natura 2000 zone which includes Specially Protected Areas (SpA) - sub-zones for birds' protection - it was not selected as an exclusion criterion as SPSPSD-RES (2008) is permitting wind farms to be developed in them.

Furthermore, the selection of a specific wind turbine in this study directly influences the setback distances of the criteria, that according to SPSPSD-RES's provisions are connected to the diameter of the wind turbine (e.g., distance from roads or livestock facilities). As such, a wind turbine model with different geometrical dimensions could influence the results. This remark is in line with the discussion of Schallenberg-Rodríguez and Notario-del Pino (2014).

As mentioned in the Results chapter, slope criterion excluded 84.0 % of municipality's areas from wind power development. In other studies, such as in Tegou et al. (2010) the wind criterion was the main constraint factor. That was due to the fact that the study region is considered mountainous where high slope and rough terrain exists that makes technically challenging to install wind turbines. The most suitable places were found on the western and south-western part of the municipality where slope are lower and wind speed still remained sufficient for wind energy production. However, wind speed's exclusion threshold (< 3 m/s) was set based on the technical characteristics of a wind turbine model that is utilized in areas with medium wind speed conditions and has been installed in a wind farm project close to the study region (i.e., Kasidiaris Project) with similar wind conditions. That entails that a higher wind speed threshold (e.g., < 5 m/s) could probably further limit the available areas. In any case, the wind criterion was one of the most contributing criteria to the identification of availability areas as it assessed 84.4 % of the municipality as suitable for wind farms.

Furthermore, the distance from settlements criterion was the second contributing to the identification of constraint areas. That is consistent with the findings of Baban and Parry (2001) which also discussed the influence of settlements (in their case urban areas) to constraint areas. The setback distances implemented in this study in combination with high dispersion of settlements in the municipality justifies the exclusion of suitability areas. In addition, setback distances from neighboring settlements were also implemented that further excluded potential areas for wind power. Those excluded areas are found in the periphery of the municipality in the central and western part of it.

The contribution of local stakeholders' input to the constrain map was an important element of this study. According to the results presented in Chapter 4.3. local knowledge increased constraint areas by 0.4 %. That was due to the elimination of clustered and dispersed patches of suitable areas found mainly in the central and north-eastern part of the municipality. Those areas have different morphological characteristics and are located in different altitudes. The ones in the central part were found in locations near rivers or in hill sides where dense coniferous forests can be found. On the other hand, the ones in the northern parts of the municipality are found in "bald" mountain areas with low vegetation and pastures forming a distinct landscape typology. Both those areas mainly consist of the tourism product of the municipality and as such are important to tourism activities according to local stakeholders.

In total, the current constraint analysis revealed that the vast majority of the municipality is unavailable for the development of wind power projects (0.69 % is available). This is contradictory to other studies such as in Ifkirne et al. (2022) where availability areas account for the 6.98 % of their study area, or in Schallenberg-Rodríguez and Notario-del Pino (2014) where 12.5 % of the study region was deemed as suitable. Nonetheless, this difference does not imply that the applied methodology is not rigid. As mentioned earlier, the produced results are influenced by the type, number, and extent of criteria as well as the natural and technical characteristics of the selected study area.

The areas remaining available are mainly found in the western part of the study region in a location that is widely known as Xerovouni. This is consistent with the Regional Spatial Planning Framework of Epirus (G.G. 286 AAP'/2018), which is proposing this area as potentially available for the development of wind farms. As such, the results of the applied methodology are also consistent with high-level regional planning provisions. Moreover, those areas are adjacent to the Ionian motorway (A5), part of European route E55. This increases their availability value as coexistence with major motorways could possibly counterbalance visual and noise impacts of wind farms.

5.2 Analysis of local knowledge approach

An important element of this study was to include the input of local stakeholders. The aim of this participatory exercise was to eventually link their attitudes towards wind power development with the zones of activities defined by them.

The selection of local stakeholders was based on the representation of the two prevailing economic and social activities in the study region, tourism, and livestock herding. That meant that people involved in other activities (e.g., academia, wind power, engineering, N.G.Os etc..) based on which could possibly expressing different preferences were neither selected nor included in the interviews. As such, the social representation of the municipality should be considered limited. That was a preliminary application of public participation in the municipality with a potential to be further expanded. Nevertheless, the results of this process are valuable as no such approach has been implemented before focusing on energy planning problems.

The aim of this methodology was to firstly understand through the interviews the overall attitude of the participants towards wind power projects. This entails that all participants should be aware of what consists of a wind farm and what could be its potential impacts. The majority of the participants for both economic groups were aware of wind farm technology and of its impacts. The latter could be, mainly, categorized as of two types: environmental and economical. As far as the environmental impacts are being concerned, participants of both groups were arguing that wind farms impact mainly aviation fauna with a dramatic effect on their population numbers, as well as they mentioned the danger of being forced to move outside of their natural habitats. On the other hand, the tourism grouped highly considered that the economic benefits towards the public and the municipality (if any, according to some stakeholders) cannot offset the potential environmental impacts. In addition, the same group stated that the presence of wind farms could severely damage the tourism product of the municipality as the sight of wind farms itself deteriorates the natural characteristics of the landscape and negatively affect the high ecological quality of natural environment. As it was stated by one tourism participant "*…visitors from Netherlands and Israel are expecting to experience an undisturbed connection with nature…This cannot happen with wind turbines operating in the area*" or more strongly stated by another, that "*…no wind turbine fits on these mountains*". In connection to that it was mentioned the issue of generally lacking an energy planning strategy, not just in a local, but rather at a national level able to justify the necessity of placing a wind farm in the municipality.

Another important element expressed by participates of both groups was related to the ownership of the projects. The ownership status of a wind farm could possibly influence their perception towards it especially if this project was to be community owned. Furthermore, other issues related, for example, to road construction into mountains, pastures depletion due to change in local climate by wind farms' operation, disturbance of livestock due to the presence of wind farms were also expressed by the participants.

In total, if a mental aggregation of the attitudes expressed could be valid, one could suggest that tourism professionals were negatively inclined towards development of wind farms in the municipality. On the other hand, livestock herders were more willing to accept a wind power project in the vicinity of their activities, under the condition that its operation could have financial benefits to their enterprise.

Their perceptions and attitudes through the interviews were then spatially expressed as wider zones on a map. Those zones were representing both their areas of activities and emerging areas where their activities could expand to. Based on the previous categorization of their input it was decided that the zones defined as important to tourism should be considered as unsuitable for wind power projects. That was due to the fact that an installation of a project at them could come with potential opposition from this group. At the same time, the zones being important for livestock herding decided to be handled as suitable for wind farms, as their suitability could be judged under certain conditions (value for tourism) but cannot be totally excluded.

A discussion with the mayor was followed that enable to discuss both on the constraint map results and the input given by the participants. Despite the fact that the mayor is not generally opposed to the development of wind turbines, he stated that the lack of spatial planning at the local level takes out the decision power of municipality’s administration over wind power projects. More importantly, he indicated certain areas that could be potentially examined on their suitability and defined others that should be definitely excluded. Those areas were mostly found on the central parts of the municipality (areas of tourism interest) and were concerning some small availability clusters found on low elevation sites. Mayor’s input was important as it is reflecting the political statement of the municipality towards not only wind farm development, but generally, all forms of RES projects.

Finally, as stated in Section 5.1, local knowledge mapping contributed to a 0.4 % increase of constraint areas in comparison to the initially calculated exclusion map. This contribution may generally seem small but is rather important. That is, it reduces the availability of wind farms by almost 50 % in comparison to the initial constraint map. In addition, as the constraint areas of local stakeholders’ input are coinciding with the zones important to tourism activities they are reflecting, at the same time, the environmental, and landscape quality of these areas. These qualities are directly connected to the financial viability of the sector and as such any development there could jeopardize tourism business.

5.3 Analysis of evaluation maps

The evaluation of the municipality was, firstly, based on defining evaluation criteria and secondly normalizing them on their fuzzy membership. This resulted in the production of six evaluation maps which evaluated the municipality in a score range from zero to one. Nevertheless, not all evaluation criteria assessed the municipality with a high score of one. It was distance to settlements and distance to high voltage transmission lines and substations where the maximum score they assigned was 0.82 and 0.5 respectively. That was due to the threshold values assigned to their fuzzy membership function. For the settlements' criterion, which was using an Increasing Membership Function, the most suitable threshold value was set to 10,000 m. This is important if one is to consider that the minimum distance of a settlement close to municipality's borders is normally less than 5,000 m. while settlements are dispersed. Depending on the calculation extent used in GIS environment, which was the extent of the municipality, there were very limited settlements located in a distance larger than 10,000 m. As such, the majority of the municipality, based on this criterion was assessed with low score while the maxim score could not reach one. A lower best threshold value more adapted to municipality's size and settlements' dispersion around its borders could possibly provide an assessment closer to one, however that would not be in line with other academic work (i.e., Sotiropoulou and Vavatsikos, 2021). The same principles apply for the distance from transmission lines criterion which implements a Deceasing Membership Function. In this case, the majority of areas inside the municipality are very distant from high voltage transmission infrastructure and substations and as such no part of it could receive a high score value equal to one.

Nevertheless, it should be stated that the mean fuzzy value for all selected evaluation criteria remains relatively low. That essentially means, that the majority of the criteria evaluate moderately to low the municipality. It is only distance to road network that gets a high mean fuzzy value equal to 0.74. On the other hand, slope criterion had the lowest mean fuzzy value equal to 0.04. That is contradictory to Latinopoulos and Kechagia (2015) findings where wind criterion provided the lowest evaluation of their study region.

The production of the evaluation map was the result of combing the created evaluation layers after applying to them their respective weights. The weights were estimated through fuzzy AHP. The criterion that got the highest weight was the one representing environmental protection due to the environmentally oriented approach adapted by this study. Then, the WLC method applied through which the relevant influence of its criterion was spatially combined. The resulted evaluation map indicated that environmentally protected areas, meaning National Park’s Zones I and II, where assessed with a very low score value. This is reasonable as this criterion got the highest weight (i.e., criterion with the highest influence) while on the same time it was assigned with an Increasing Membership Function. That means, that the closer a project is developed to those areas the lower the value score is gets. In comparison to other studies such as in Latinopoulos and Kechagia (2015) it was wind criterion the most contributing factor to low suitability.

Areas with higher value scores ranging between 0.5 to 0.8 were identified on the borders of the municipality. This is consistent to the findings of Latinopoulos and Kechagia (2015) which identified the best scored locations on the eastern borders of their study area. Leaving aside the fact that areas, mainly, closer to western borders of the municipality were getting a higher score due to their distance from National Park’s zones, it was also due to the influence of wind speed criterion which assessed areas close to municipality’s boundaries with medium to high value scores. Wind speed criterion has the second higher influence or importance in comparison to other criteria. To this end, minimizing or maximizing the value score of a certain location is highly depending on two main factors; the first one is relevant to the importance a criterion is having in the analysis, after applying the fuzzy pair-wise comparison with other criteria. The second one is based on the type of membership function is implemented in the fuzzy analysis of each criterion. As the second factor is considered as constant in this analysis, it is the weights that alters the evaluation of the municipality (see Subsection 5.5).

Finally, despite the fact that the maximum score is 0.82, the mean fuzzy value score is 0.058 which generally indicates that the majority of the municipality was assessed with low suitability. This could be attributed to three main criteria which poorly assessed the municipality; Slope (mean fuzzy value: 0.04), distance to high voltage transmission network (mean fuzzy value: 0.07), and distance to settlements (mean fuzzy value: 0.06). Moreover, it also indicates that there are locations throughout the municipality that are getting a relatively high score, however they are acting more as outliers.

5.4 Analysis of suitability map

The suitability map of the municipality was the result of combining the previously created constraint map with the evaluation map. That is, areas with a value of one in the constraint map were assigned with the matching value scores deriving by the evaluation map.

As presented in Chapter 4, the area available for the development of wind farms accounts only for the 0.7 % of the total area of the municipality that is equivalent to 246 ha or 2.5 km^2. This is mostly contributed to the mountainous character of the study region which is characterized by high slope and rough topography.

The majority of the available areas are classified as of “Moderate Suitability” (56.8 %) and only 0.4 % of them are taking a “High Suitability” index. This is consistent with the findings of previous research such as in Tegou et al. (2010), Jangrid et al. (2016), and Höfer et al. (2016). In all three papers the majority of their study region was classified as “Medium Suitability”.

In addition, despite the fact that “High suitability” areas are accounted for a very small portion of the total availability of the municipality this result is also consistent with the findings of Watson and Hudson (2015) where areas of “High Suitability” (i.e., SI > 0.7) are accounted for less than 0.1 % of the available areas for wind power projects.

The areas of “Moderate suitability” are mainly found in the western and south-western part of the municipality close to its borders. This due to the fact of that in those locations moderate to high wind speeds are prevailing, while at the same time there are in a higher distance from environmentally protected areas. That is important because these two criteria received the highest weights and as such are influencing the most, the suitability of available locations (see Subsection 5.3). An example of such an observation could be considered the assigning of “Low suitability” index of available areas found on the northern part of the municipality. These areas are very close to the environmentally protected zones of National Park and as such they were classified as of “Low suitability”. The effect of the criteria weight in the assigned suitability degree of available areas is also discussed in Latinopoulos and Kechagia (2015). The authors commented that the spatial allocation of suitability classification is displaying the impact of the most influencing criterion, in their case wind speed. Therefore, our remark is consistent with their findings.

Finally, the locations classified with “High Suitability” are found on the western part of the municipality surrounded by areas of medium suitability. These areas are taking the highest evaluation score, despite the assigned weights, from all selected evaluation criteria. Nevertheless, the total area of those locations taking a high score is equal to 1 ha or 0.01 km^2.

5.5 Analysis of sensitivity scenarios

In this study three sensitivity scenarios were formed in order to test the sensitivity of the applied methodology. For all scenarios the relevant sensitivity maps were produced and combined with the constraint map in order to assess the available areas for wind power development.

In the first scenario all evaluation criteria assigned with an equal weight. That resulted in classifying the majority of the non-constraint areas with a “Low Suitability” index. To be more specific the “Low Suitability” areas accounted for 94.9 % of the available areas while 5.1 % of the available areas classified with “Moderate Suitability”. Those results were expected as all criteria were having the same influence over evaluating the municipality. As discussed in Subsection 5.3. the evaluation of the study area is highly influenced by the weights and type of criterion used. In this case, the majority of the criteria were assigning very low suitability scores and by considering them, in this scenario, as equal it was anticipated to assign low suitability scores. That is the reason, why no areas of “High Suitability” score were found.

In the second scenario the environmental protection criterion took zero weight while all other criteria shared the same weight. In this case, the areas assigned with “Low Suitability” scores increased in comparison to the first scenario (99.2 %) and areas of “Moderate Suitability” decreased (0.8 %). This was expected as well, as the rest of the criteria they were taking a higher weight compared to the first scenario, meaning that their influence was increased. Therefore, under the absence of the environmental criterion they poorly assessed the examined area.

In the third scenario, distance to roads, and distance to high voltage transmission lines and substations were assigned with zero weights. The available areas for wind power were still assessed with “Low Suitability” score (93.6 %), nevertheless their percentage was increased in comparison to the second scenario. The same applies for the areas assessed with “Medium Suitability” which also increased (6.4 %). Those results could be explained if one is to consider that the absence of the criterion that assesses the best the municipality is counterbalanced by the second-best assessing criterion that is distance to National Park’s zones. This is important as the increase in the weight due to lacking the influence of the two criteria was also increasing the influence of the environmental criterion which was able to slightly increase the overall moderate suitability of the available areas.

It is important to mention that none of the three selected sensitivity analysis scenarios were assessing the suitable areas for wind farms with “High Suitability”. In addition, some evaluation criteria were utilized as constraint criteria, as well. For the “extreme” cases in which they were already excluded, one could imply that the sensitivity would be relatively low.

In total, the suitability analysis supports our observation that the degree of influence (i.e., weights) as well as the number and type of criteria are highly influencing the assessment of the study area. This is also in line with the discussion made in Tegou et al. (2010) who also commented the sensitivity of this type of methodology on weights and type of criteria.

5.6 Comparing the suitability map with proposed wind farms

The last step of the proposed methodology was to compare the suitability map results with the proposed wind farms. To begin with, there are two wind farm polygons proposed in the municipality. The total number of wind turbines including in them is 13. As presented in the results, there are only three wind turbines located in areas available for wind power projects. The rest of them are located in areas classified as unsuitable. Those three wind turbines are assessed as of moderate suitability. In all three sensitivity scenarios were assessed as of “Low Suitability”.

Despite the fact that the majority of the proposed wind turbines are located in areas deemed unfeasible for wind farms, the validity of the applied methodology still remains valuable. As mentioned earlier, the dominant constraint criterion is Slope. If one is to examine the slope percentage per proposed wind turbine will observe that they are mainly locating in areas with slope higher than 30 % and thus were excluded. That essentially entails that those proposed wind farms may come with higher construction costs and more road works. In addition, some proposed wind turbines are coinciding with areas that are important to local stakeholders for tourism activities and thus had been excluded from the development of wind farms. That is, those wind farms may face major public opposition.

Last but not least, in contradiction to other research studies where a coarse spatial resolution (e.g., Tegou et al., 2010; Latinopoulos and Kechagia, 2015) was implemented (e.g., 150 m. x 150 m. cell grid), in this analysis a finer resolution was selected (50 m. x 50 m.). That was important in order to better capture the topography and produce more spatially accurate results. A coarser resolution "averages" the cell grid values meaning that potential exclusion areas could be assessed as suitable.

5.7 Limitations

The proposed methodology, and as such the produced results, are the product of systematic work that nevertheless came with limitations.

Firstly, the difference in spatial resolution of the raster datasets was vastly varying. The spatial resolution of the DEM was 5 m. whereas the spatial resolution of wind speed map was 150 m. and of wind power density map was 250 m. A cell size of 50 m. × 50 m. was used in order to better align the wind speed and wind power density raster dataset with the DEM. Bilinear resampling was used in order to scale down those datasets to 50 m. resolution. Nevertheless, the spatial accuracy and precision of them did not change with resampling. Moreover, the spatial accuracy of the data implemented in the analysis was not measured and could not be guaranteed by the author. The majority of the vector and raster datasets derived by open sources.

It should be noted that the current methodology is not classifying the municipality based on its morphometric terrain characteristics, such as planes, ridge peaks, and channel pits (Kim et al., 2017). This is important for mountainous areas as - slope wise - accepted locations might still not be suitable for wind power development. For instance, channel pits are not considered as acceptable locations for wind farms (Kim et al., 2017). As such, the application of a morphometric classification of the municipality and the incorporation of its results into the proposed methodological framework could lead to more exclusion areas.

In connection to the above, the identified suitable locations for wind power development were not cross validated with local visits (direct field observations) as proposed in Spyridonidou et al. (2021:10). This process could lead to excluding more areas from wind power development, as well.

The number of participants for local knowledge approach was seventeen people. According to Kempton (2005) a sample of twenty people is sufficient to capture population perspectives. However, due to time limitations it was not possible to reach this number of participants. In addition, the local knowledge approach implemented by this study was a preliminary one and by no means can substitute a rigid methodological framework solely structured for the social analysis of wind power. It was rather an “informal” approach aiming at enabling stakeholders to participate into an initial participatory mapping exercise as well as to gain an initial understanding on their stands against wind power development in their areas of activities. Furthermore, only two types of economic activities were represented by the participants. Nevertheless, the participation of people of other activities or interests could potentially produce different results.

In addition, the author of this study has his origins on the investigated municipality. Despite keeping a high academic and research integrity, he cannot rule out any impartiality during the analytical process due to close connections with his homeland.

Finally, the methodology formed provided a framework that could be applied on other regions in order to identify and assess areas for wind power projects. Nevertheless, it cannot replace the role of a comprehensively designed public participatory framework that will be able to include a wider variety of participants and map local stakeholders’ attitudes using other visualization tools such as 3D modeling (Wrozynski et al., 2016).

Last but not least, as a future step, the methodology should include a morphologic terrain analysis able to better capture the mountainous characteristics of the study area, crucial to wind farms installation, and consequently to assess more effectively wind farm development suitability. Furthermore, the identified locations could be cross checked with in-field observations and 3D software.

6. Conclusions

The aim of this study was to develop a methodological framework in order to spatially analyze the municipality of Northern Tzoumerka, Greece on its ability to facilitate the development of wind power projects. An important element of this analysis was the incorporation of the spatial input of local stakeholders in wind farm development.

Results of the applied methodology indicate that the majority of the municipality is deemed unsuitable for wind farms. The area of suitable locations is equal to 246 ha or 2.5 km^2 of land that accounts for 0.7 % of the total study region.

Furthermore, suitable areas were mostly assessed as “Moderate Suitability”, while a small proportion of them (0.4 %) was assessed as “High Suitability”. Important contribution to this result was the slope criterion application that reflected the mountainous character of the municipality, as well as the local knowledge zones and specifically those dedicated to tourism activities.

The sensitivity analysis indicated that the applied methodology was not only sensitive to weight changes, but also to changes on the type and number of criteria. That was evident through the application of three sensitivity analysis scenarios that lead to this remark.

Finally, only three of the total thirteen wind turbines proposed in the municipality were located in available areas for wind power development. The three wind turbine proposed locations were assessed as of “Moderate Suitability”.

It is believed that the presented results could be utilized as consultation material for the municipality, during the environmental licensing of wind power projects. In any case, this study’s results cannot substitute for an in-depth analysis of a wind farm at a largest scale.

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Appendix. A – Case Study Dynamics

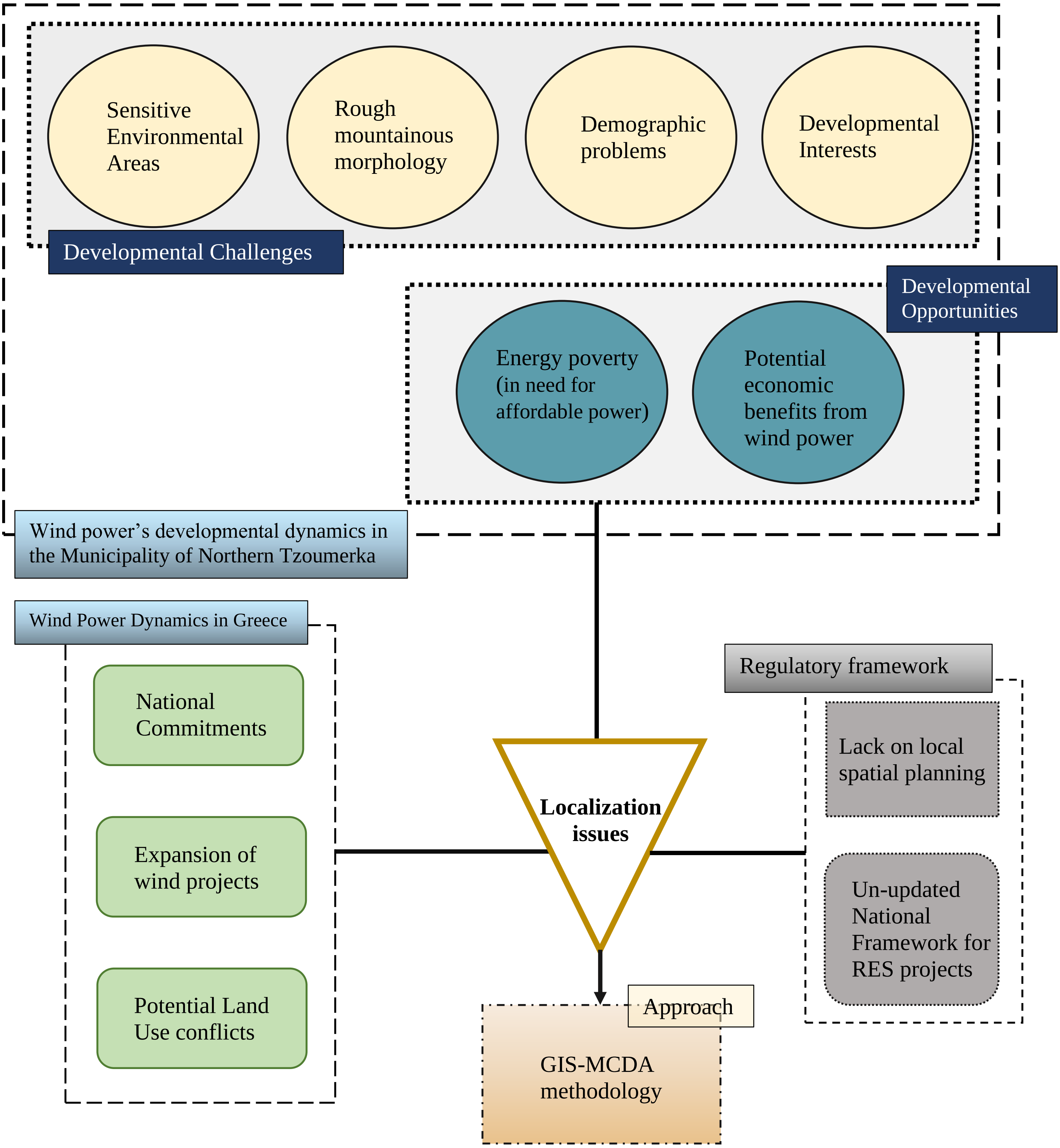

Figure A1. Diagram of wind power dynamics in the study area

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Appendix. B – Data Catalogue

Table B1. Data Catalogue

Category	**Name**	**Data type**	**Cell size**	**Source**	**Original Coordinate Reference System**
Wind Resources	Wind Speed at 120 m.	Raster	150 m.	RAE	EPSG:2100-GGRS87/Greek Grid
	Wind Power Density Map	Raster	250 m.	Global Wind Atlas, DTU	EPSG:4326-WGS84-Geographic
Technical	DEM	Raster	5 m.	Hellenic Cadastral Organization – ΕΠΨΣ 2007 – 2013, ΕΠΑΝΕΚ 2014 - 2020	EPSG:2100-GGRS87/Greek Grid
	Antennas	Vector	-	OSM	EPSG:4326-WGS84-Geographic
	High Voltage Power Lines	Vector	-	OSM	EPSG:4326-WGS84-Geographic
	Substations	Vector	-	OSM	EPSG:4326-WGS84-Geographic
	Substations Point	Vector	-	OSM	EPSG:4326-WGS84-Geographic
	Wind Turbines	Vector	-	RAE	EPSG:2100-GGRS87/Greek Grid
	Wind Farm polygon	Vector	-	RAE	EPSG:2100-GGRS87/Greek Grid
Environmental	Natura 2000 end of 2021	Vector	-	European Environmental Agency	EPSG:3035-ETR/LAEA Europe
	CDDA 2022-Nationally Designated Areas	Vector	-	European Environmental Agency	EPSG:3035-ETR/LAEA Europe
	Priority habitats	Vector	-	Greek Ministry of Environment and Energy	EPSG:4326-WGS84-Geographic
	Rivers	Vector	-	Geodata.gr and EAGME	EPSG:2100-GGRS87/Greek Grid
Land Use	clc2018_clc2018_v2018_20	Geopackage	-	Copernicus Program	EPSG:3035-ETR/LAEA Europe
	Churches	Vector	-	Greek Archaeological Cadastre and personal editing	EPSG:2100-GGRS87/Greek Grid
Social	Settlements	Vector	-	Statistics.gr	EPSG:2100-GGRS87/Greek Grid
	Settlements' borders	Vector	-	Municipality of Northern Tzoumerka	EPSG:2100-GGRS87/Greek Grid
	Administrative Borders	Vector	-	Statistics.gr	EPSG:2100-GGRS87/Greek Grid
Cultural	Cultural Heritage	Vector	-	Greek Archaeological Cadaster	EPSG:2100-GGRS87/Greek Grid
	Historical Sites	Vector	-	Greek Archaeological Cadaster	EPSG:2100-GGRS87/Greek Grid
	Archaeological Sites	Vector	-	Greek Archaeological Cadaster	EPSG:2100-GGRS87/Greek Grid
Production	Tourism Facilities	Vector	-	Greek Ministry of Tourism	EPSG:900913 - Google Maps Global Mercator

Livestock Facilities	Vector	-	Personal editing from Google Maps	EPSG:2100-GGRS87/Greek Grid

Appendix. C – Questionnaire

Questionnaire’s Main Sections

Section 1 – General Questions

Q1. *What is your professional occupation?*

Q2. *What is your permanent residence?*

Q3. What is the place of your origin?

Section 2 – Questions regarding wind power

Q1. *What do you know about wind power?*

Q2. *Have you heard of any of their impacts?*

Q3. *How would you feel about a wind power project being developed in the area of your activities?*

Section 3 – Questions on public participation

Q1. *Have you ever heard about public participatory processes in decision making?*

Q2. *How important do you believe is active participation?*

Q3. *How much information would you need in order to participate?*

Q4. *What kind of information that would be?*

Q5. *How important do you think is local knowledge in project development?*

Q6. *Who do you think has the responsibility of ensuring local knowledge inclusion in decision making?*

Section 4 – Questions on mapping local knowledge

Q1. *What is the extent of the area you are using for your activities?*

Q2. *Can you identify the area you are using on a map?*

Q3. *How do you use the area of your activities?*

Q4. *For how long are you using this area?*

Q5. *How much time are you spending in this area?*

Q6. *Why do you use this specific area?*

Q7. *What does this area mean to you? / How important is this area to you?*

Q8. *What values are associated with this area?*

Q9. *Are there any other areas that you may utilize for your activities?*

Q10. *Are there any locations where you may have encounter/saw wild species (birds, bears, wild goats etc.)?*

Q11. *Do you have anything else to add?*

Section 4i – Concluding Questions

Q1. *What is your age?*

Q2. *What is the length of your education?*

Appendix. D – Map Inventory

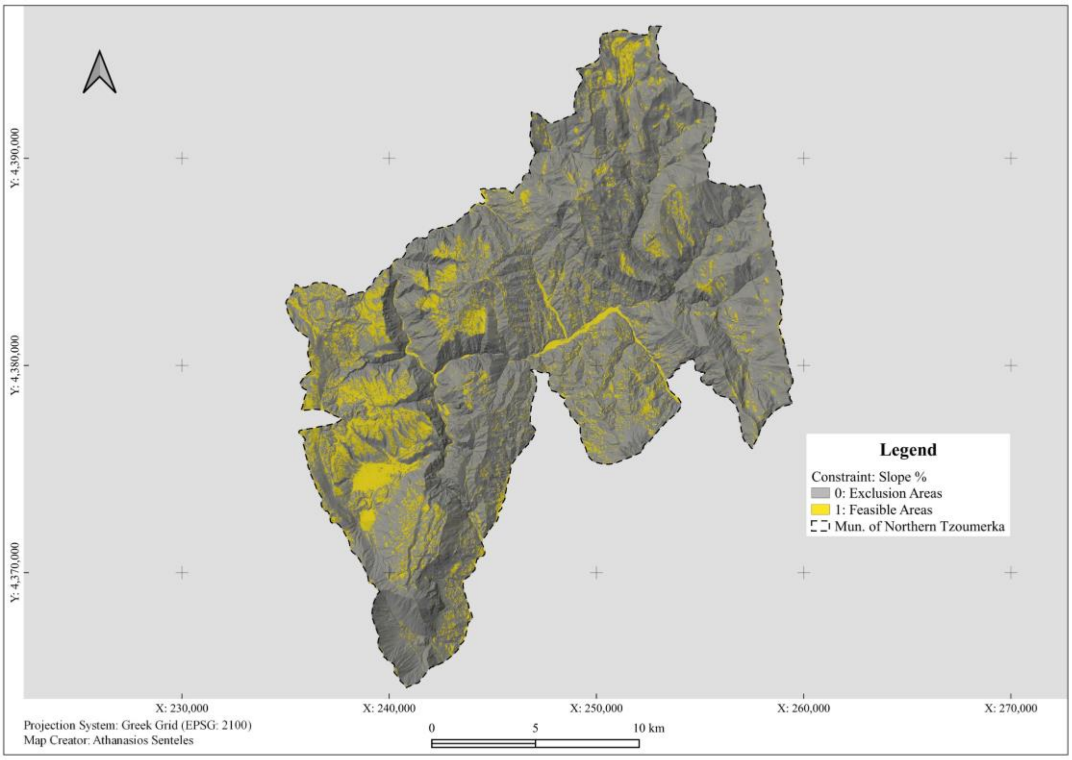

Figure D1. The “Slope” constraint criterion

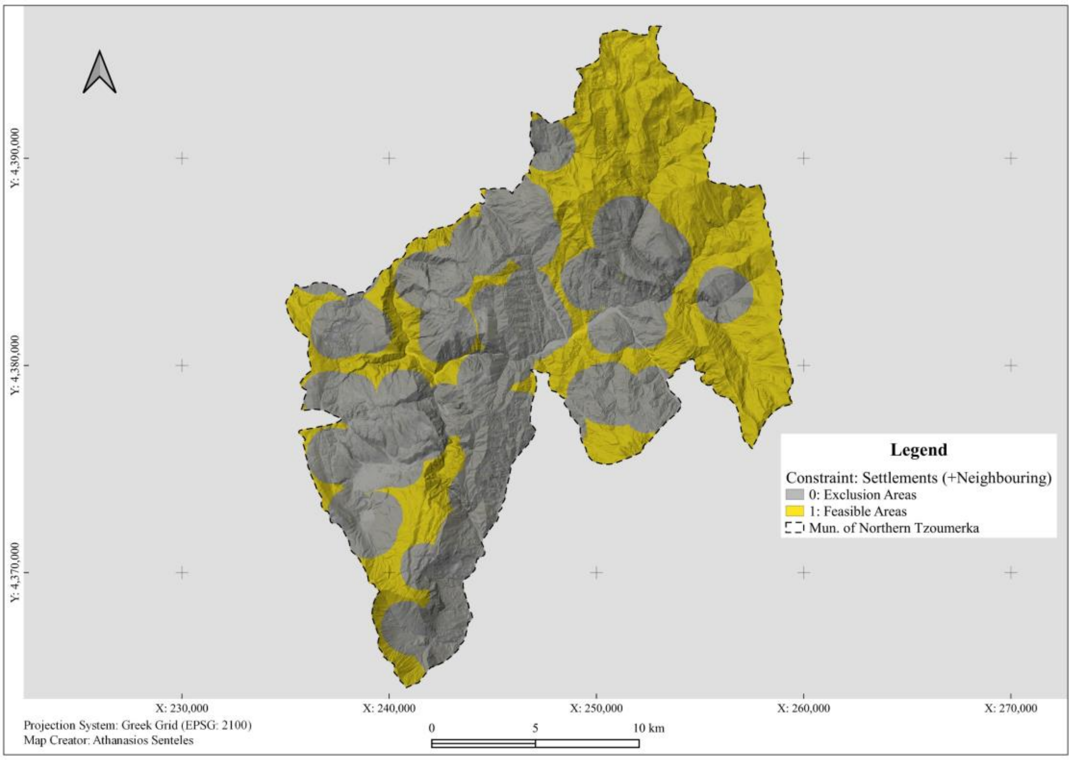

Figure D2. The “Distance from settlements” constraint criterion

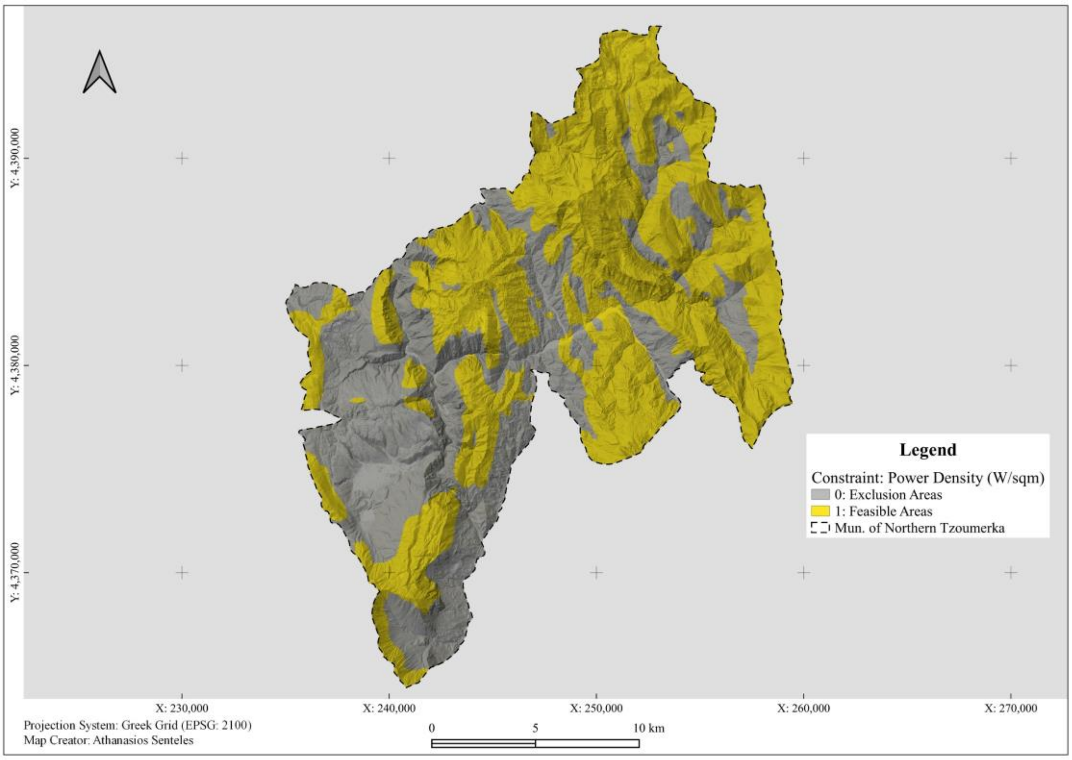

Figure D3. The “Power density of wind” constraint criterion

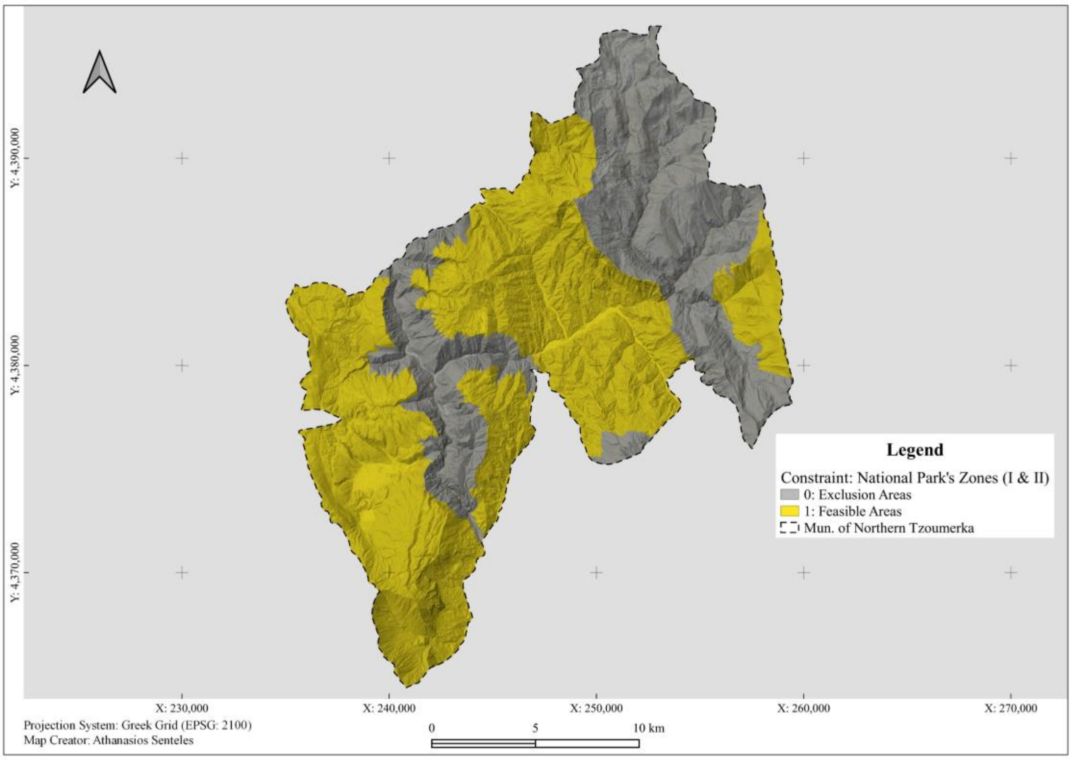

Figure D4. The “National Park’s Zone I and II” constraint criterion

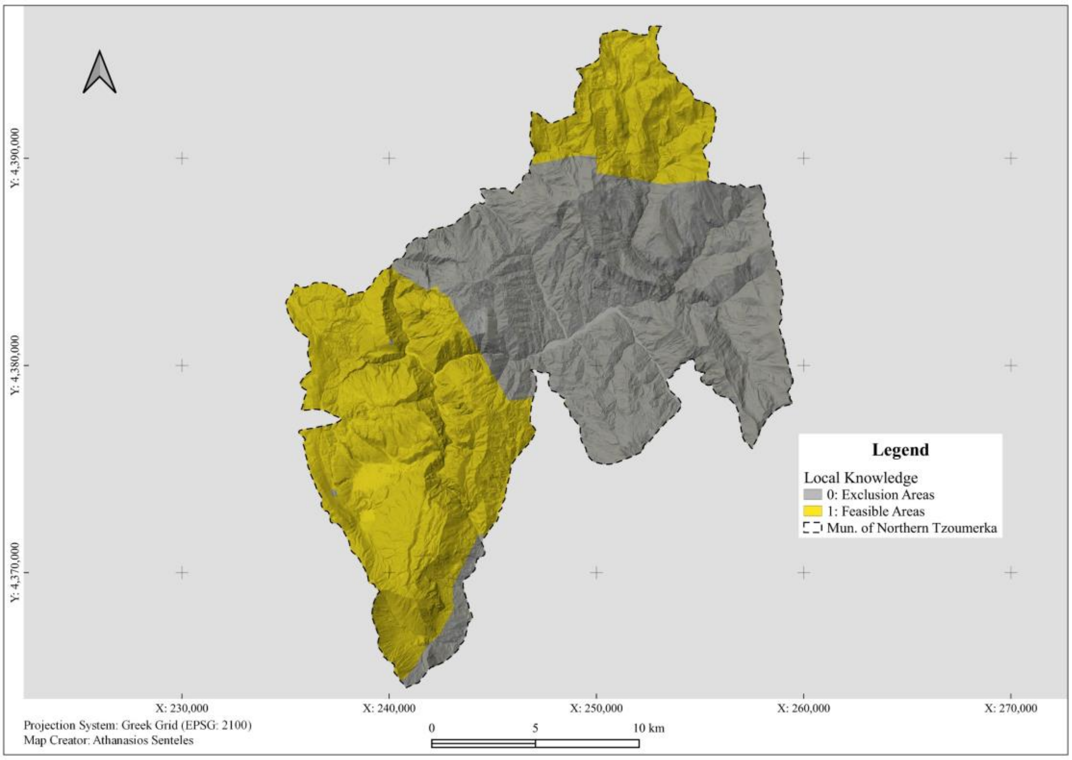

Figure D5. The zones defined by local stakeholders as constraint criterion

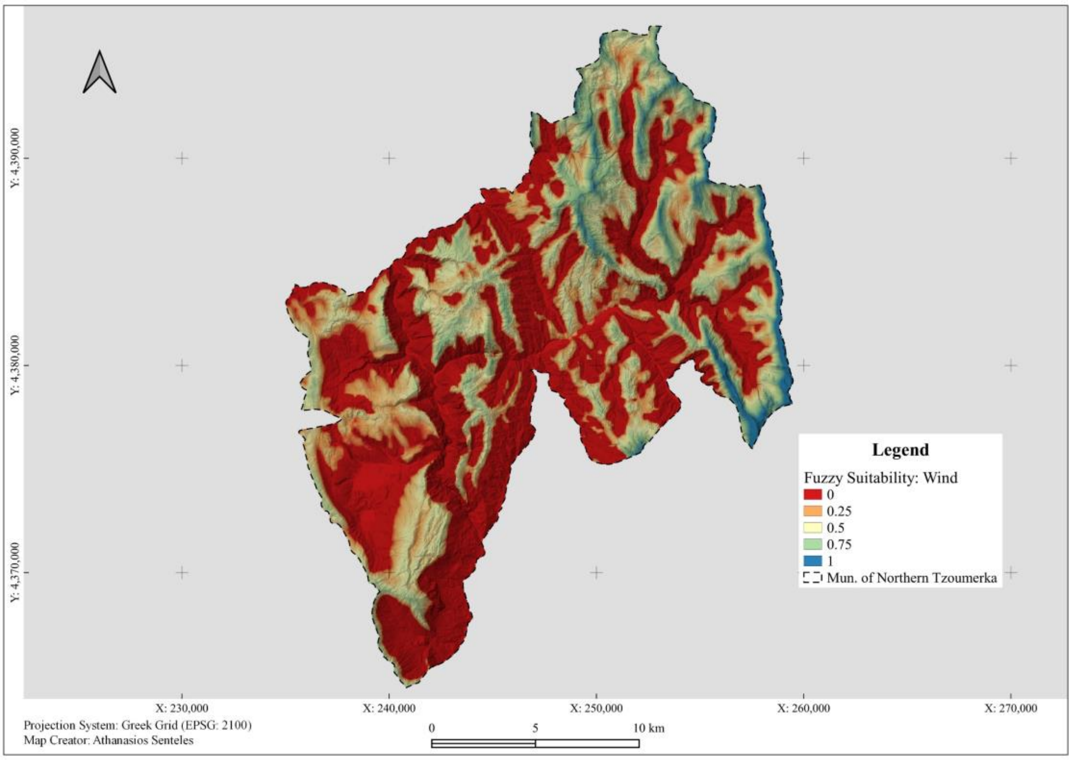

Figure D6. Fuzzy normalization of “Wind” evaluation criterion

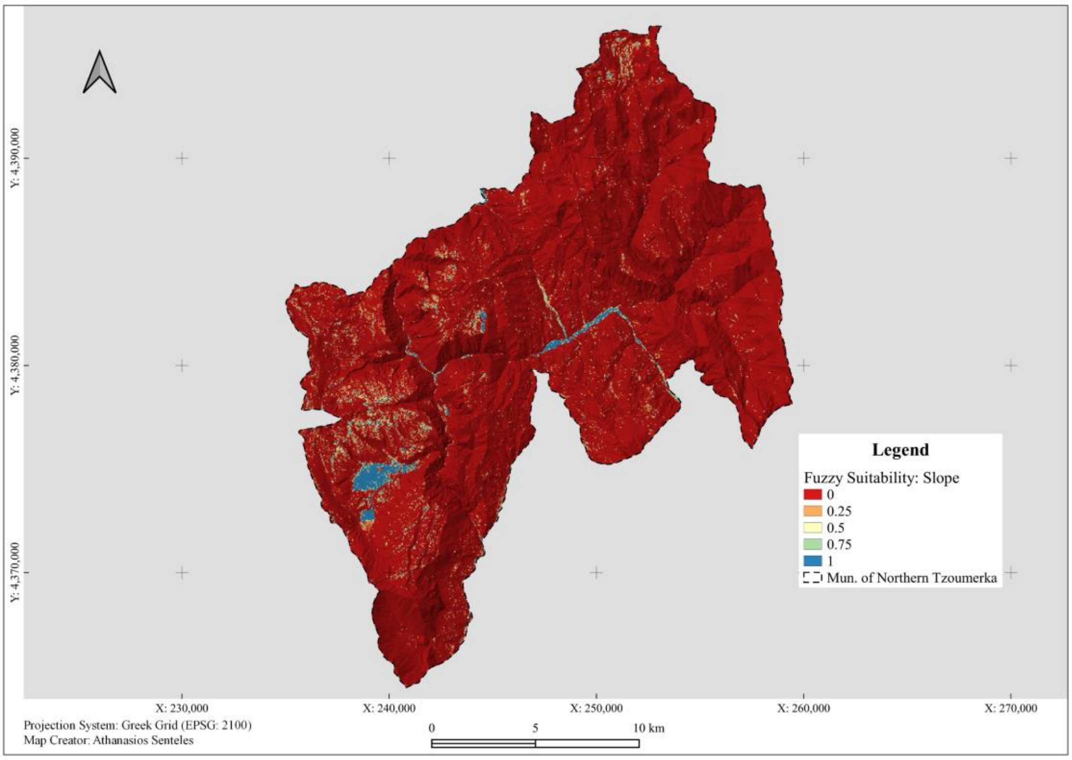

Figure D7. Fuzzy normalization of “Slope” evaluation criterion

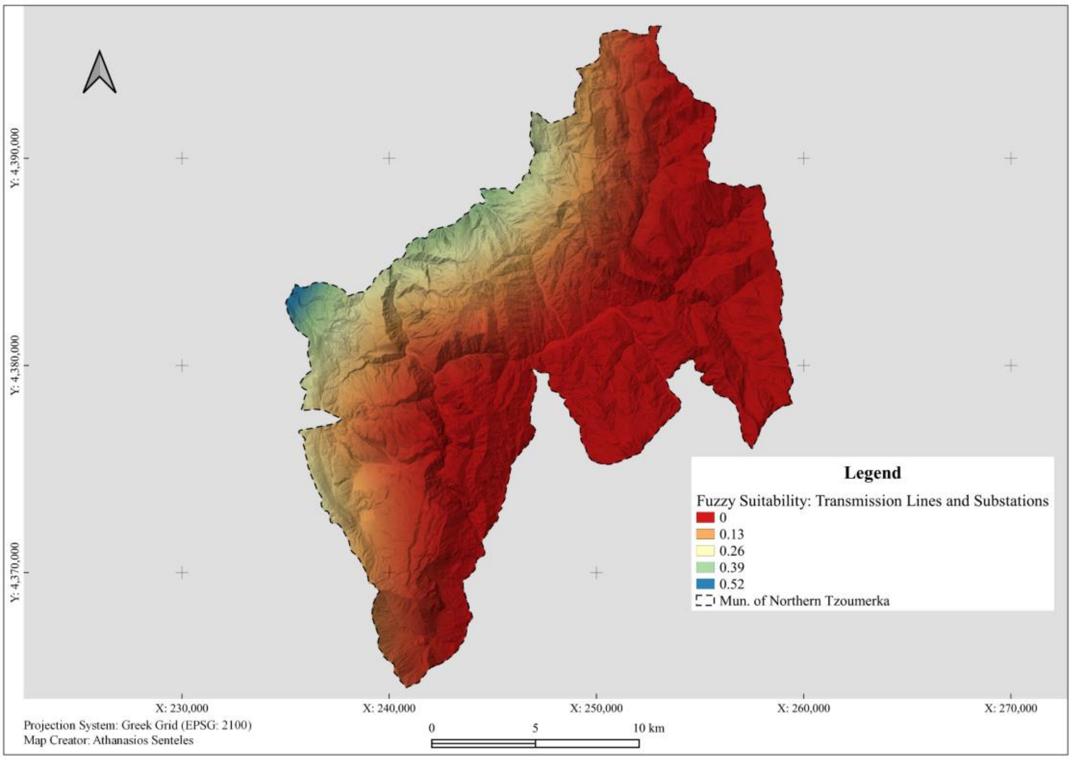

Figure D8. Fuzzy normalization of “High voltage transmission lines and substations” evaluation criterion

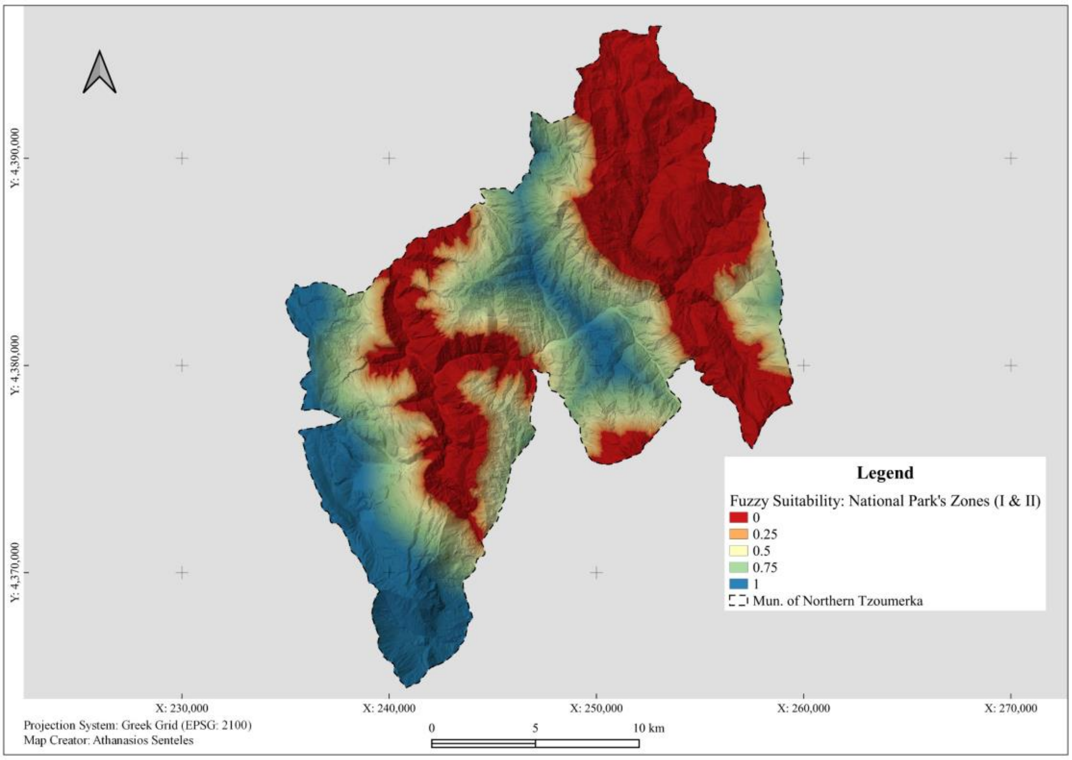

Figure D9. Fuzzy normalization of “National Park’s Zones I & II” evaluation criterion

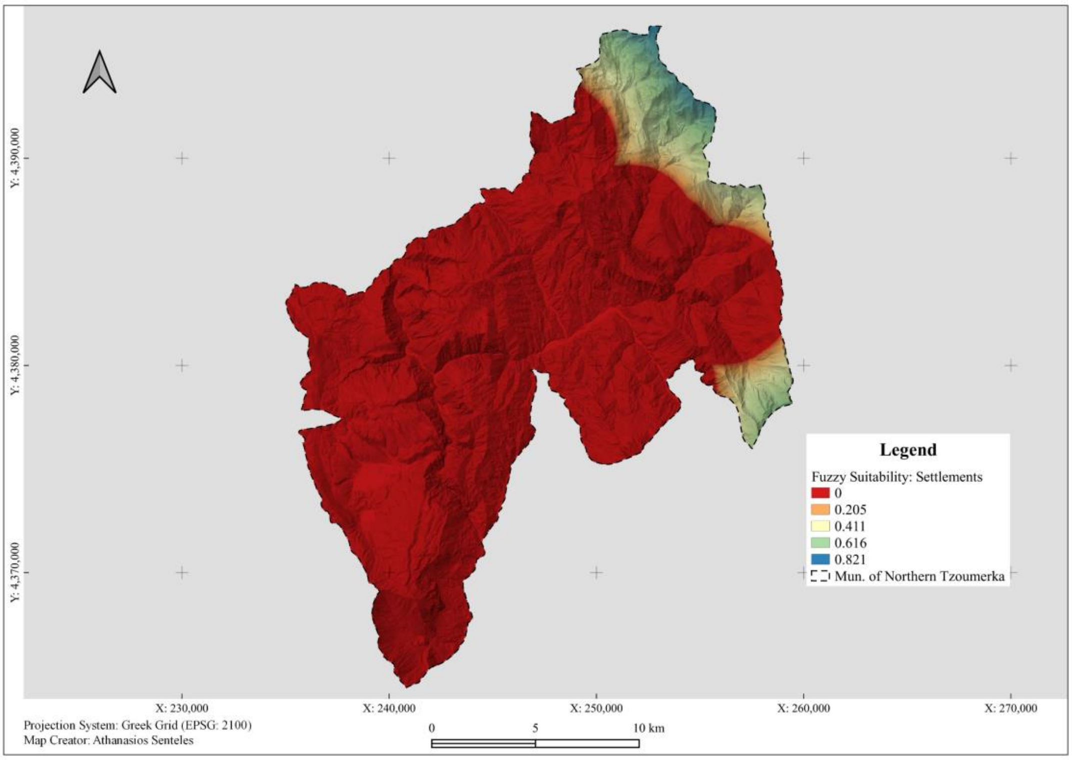

Figure D10. Fuzzy normalization of “Settlements” evaluation criterion

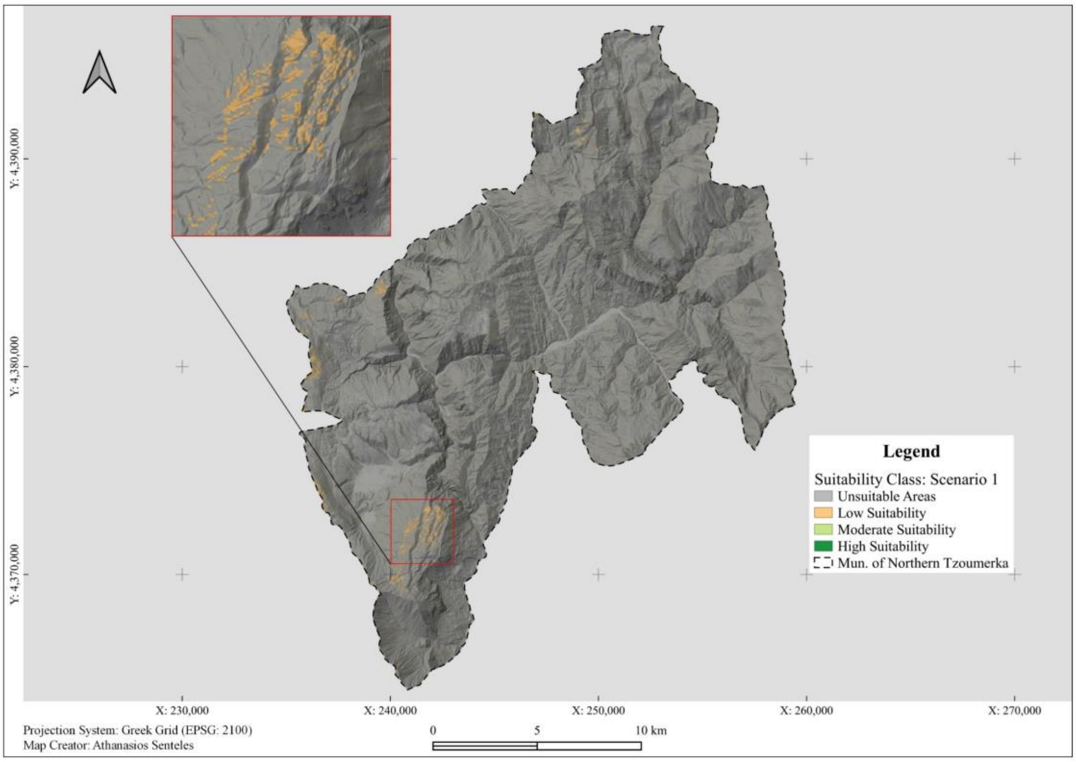

Figure D11. Suitability Class – Sensitivity analysis Scenario 1

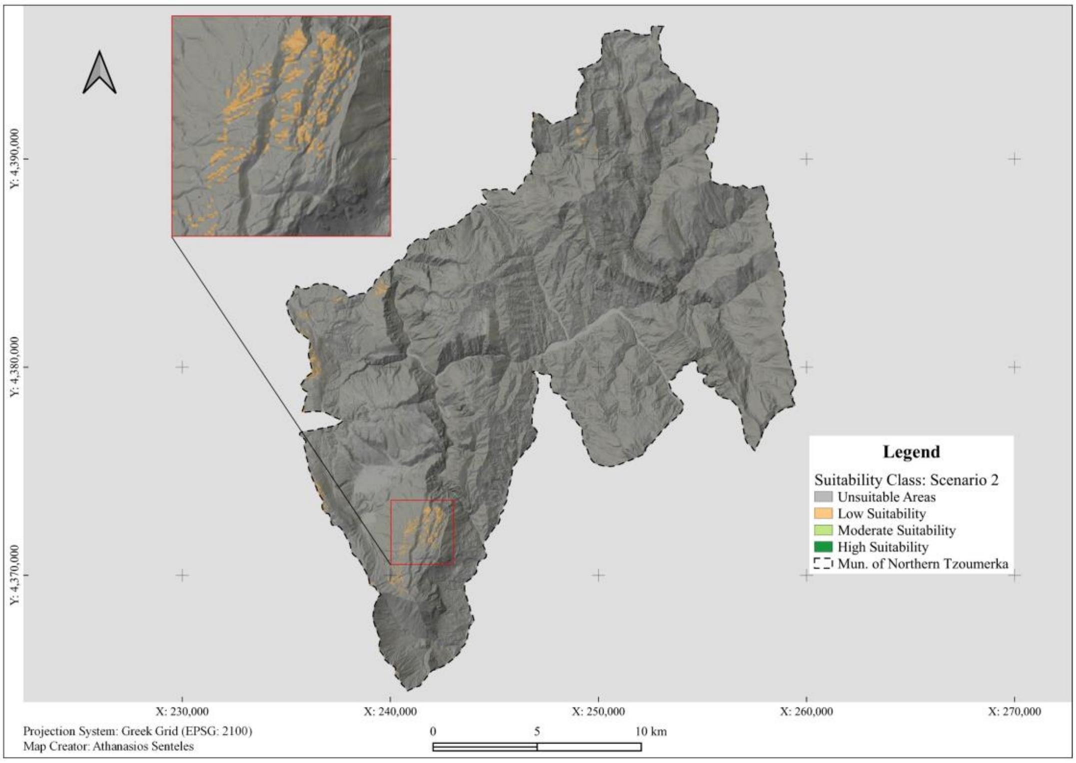

Figure D12. Suitability Class – Sensitivity analysis Scenario 2

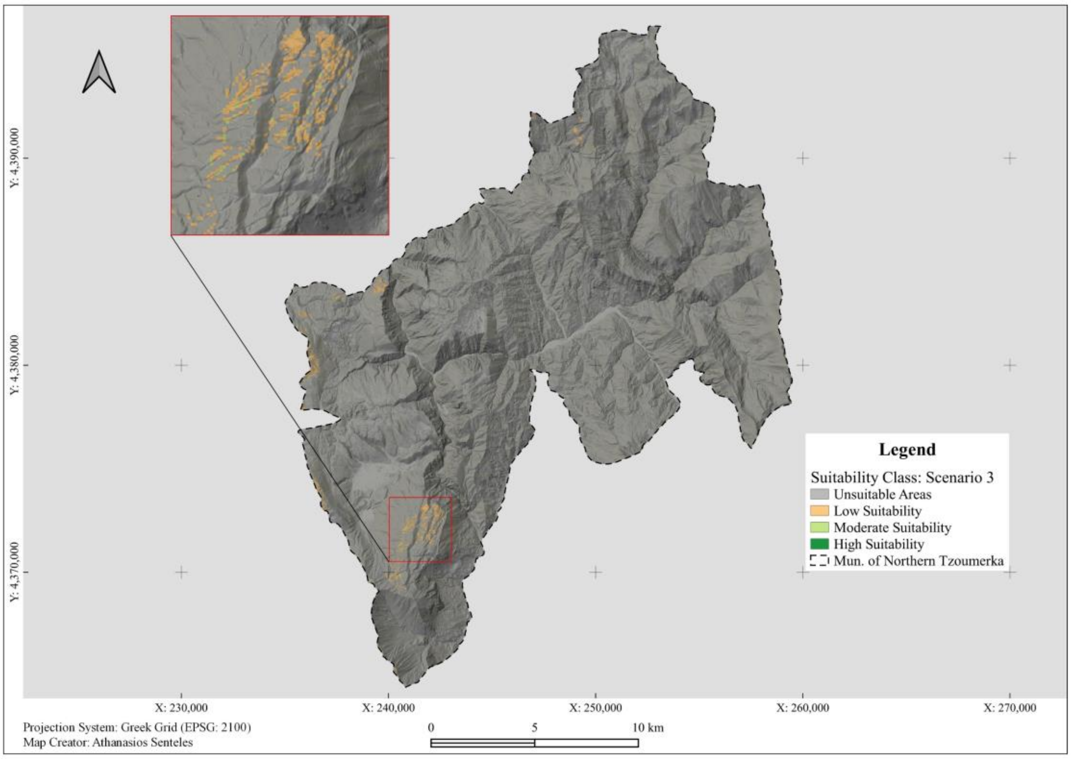

Figure D13. Suitability Class – Sensitivity analysis Scenario 3

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