GIS-BASED MULTI-CRITERIA APPROACH FOR LAND-USE SUITABILITY ANALYSIS OF WIND FARMS: THE CASE STUDY OF KARABURUN PENINSULA, IZMIR-TURKEY

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ABSTRACT

GIS-BASED MULTI-CRITERIA APPROACH FOR LAND-USE SUITABILITY ANALYSIS OF WIND FARMS: THE CASE STADY OF KARABURUN PENINSULA, IZMIR-TURKEY

This study presents a GIS-based multi-criteria approach to identify the most preferred or suitable site for wind farms development in Karaburun Peninsula, İzmir. Criteria for analysis have been identified based on literature review and experts' opinions. The selected criteria include environmental, technical, and economic as well as social factors. In order to estimate the weights or relative importance of the criteria, the pairwise comparison method in the context of Analytic Hierarchy Process (AHP) is implemented. The overall suitability of the study area is determined through the Weighted Overlay method, which is a sufficient weighted approach in geographical information system (GIS) environment. The outcome or suitability map is classified into five scored classes from the most suitable to less suitable and restricted area.

On the whole, as the selection of optimal site for the wind farm development is a multi-dimensional process, this thesis intends to consider the following three significant subjects; (a) evaluating and identifying the most influential criteria for land suitability analysis of wind farms, (b) applying AHP as a multi criteria decision-making method to determine the criteria weights, (c) utilizing GIS as a tool to overlay the overall criteria and consequently to identify the potentially suitable location for the wind farms development. Regarding to the above mentioned, eight the most influential available criteria, which are consisted of wind potential, distance from preservation area, distance from settlements, forest, slope, elevation, distance from roads, and agriculture area are identified. Base on pairwise comparison different weights for each criterion is determined. Finally, by using GIS the suitability map for the study area is provided and the result compared with the existing wind farm locations.

Keywords Wind farm, Suitability, Multi-criteria decision making method, Analytical Hierarchy Process (AHP), and Geographic Information System (GIS).

ÖZET

RUZGAR ENERJİSİ SANTRALLERİ İÇİN UYGUN ALANLARIN BELİRLENMESİNDE COĞRAFİ BİLGİ SİSTEMİ TABANLI ÇOK KRİTERLİ YAKLAŞIM: KARABURUN YARIMADASI ÖRNEĞİ, İZMİR-TÜRKİYE

Bu çalışmada, İzmir İli sınırları içinde yer alan Karaburun Yarımadası'nda rüzgar santrallarının yer seçimi için, Coğrafi Bilgi Sistemi (CBS) tabanlı çok kriterli karar verme süreci yaklaşımını kullanarak en uygun yer seçiminin belirlenmesi süreci sunulmaktadır. Yer seçim analizi için kullanılmış olan kriterler; literatür araştırması ve uzman görüşlerine dayanarak belirlenmiştir. Seçilmiş olan kriterler; çevresel, teknik, ekonomik ve sosyal faktörlere ilişkindir. Bu kriterlerin ağırlıklarını ve göreli önem derecelerini belirlemek için, çiftli karşılaştırma metodu, Analitik Hiyerarşi Süreci (AHS) bağlamında uygulanmıştır. Çalışma alanının bütünündeki uygunluk derecelendirmesi, CBS ortamında çalışılması uygun olan, Ağırlıklandırılmış Çakıştırma metodu ile belirlenmiştir. Analiz çıktısı olarak üretilmiş olan Uygunluk Haritasında en uygun alanlardan, en az uygun alanlara ve sınırlandırılmış alanlara dek 5 kademeli bir puanlandırma/sınıflamaya gidilmiştir.

Rüzgar santralları için optimal yer seçimi çok boyutlu bir süreçtir; bu çalışma üç konuyu dikkate alarak gerçekleştirilmiştir; (a) rüzgar tarlalarının yer seçimi için en önemli ve etkileyici olan kriterlerin belirlenmesi, (b) kriterlerin ağırlıklarını belirlemek için AHS metodunun uygulanması, (c) CBS, tüm kriterleri çakıştırmak amacıyla bir araç olarak kullanarak, potansiyel en uygun alanların belirlenmesi. Çalışmada etkili olan sekiz kriter tanımlanmıştır; bunlar, rüzgar potansiyeli/hızı, koruma alanlarına olan uzaklık, yerleşim alanına uzaklıkları, ormanlarının varlığı, eğim, yükseklik, yoldan uzaklıkları ve tarım alanı varlığıdır. Çiftli karşılaştırma ile her bir kriter, farklı ağırlıklandırılmıştır. Sonuç olarak çalışma için CBS kullanılarak, rüzgar santralları için uygunluk haritası elde edilmiş ve mevcut rüzgar santrallarındaki türbinlerin konumuyla karşılaştırma yapılmıştır.

Anahtar kelimeler Rüzgar santraları (RES), Uygunluk, Çok-kriterli karar verme metodu, Analitik Hiyerarşi Süreci (AHS), Coğrafi Bilgi Sistemi (CBS).

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LIST OF ABBREVIATIONS

AHP	Analytical Hierarchy Process
CO2	Carbon Dioxide
ELECTRE	Elimination and Choice Expressing Reality
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statement
GDEM	Global Digital Elevation Model
GIS	Geographical Information System
IBA	Important Bird Area
MADM	Multi Attribute Decision Making
MCDM	Multi Criteria Decision Making
MODM	Multi Objective Decision Making
MW	Mega Watt
NIMBY	Not In My Back Yard
NOx	Nitrogen Oxide
OWA	Ordered Weighted Averaging
PROMETHEE	Preference Ranking Organization Method for Enrichment Evaluations
SO2	Sulfur Dioxide
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
USA	United States of America
WLC	Weighted Linear Combination

CHAPTER 1

INTRODUCTION

Energy is a substantial and fundamental element in sustainable development of human society. Recently, the consumption of energy has been increasing rapidly. Increasing the consumption of energy has made concerns about demand of future global energy and environmental pollution. “Clean, domestic and renewable energy can be commonly accepted as the key for future demands” (Kahraman et al., 2009). Wind energy project as a renewable and green energy is one of the most possible ways for sustainable energy development and it would play a significant role to meet future energy demand and reducing the environmental pollution. However, the development of wind projects is interdepended with several planning and environmental restriction and conflicts. The development of wind energy generation has a complex process. Multiple factors can be affected in development of wind energy. The multiplicity of the factors and the complexity of energy projects make needs of multi-criteria analysis. Multi-criteria analysis becomes a valuable tool in the decision-making process of site selection for wind energy development (Baban and Parry, 2001; Saidur, et al., 2011). The environmental sensitivity of the study area and the trend of wind energy development have made a controversial debate between developers and stakeholders in this area. To minimize the negative impact of wind turbines and to reduce the opposition of the stakeholders, there is a need to determine suitable and restricted area for wind farm development.

Regarding above-mentioned problem and based on multi-criteria analysis, this study aims to identify the most suitable site for wind farms development within the study area (Karaburun Peninsula, Izmir-Turkey). Land-use suitability analysis of wind farm is the first and principle step of wind energy generation planning process. Suitability analysis of wind farms requires a comprehensive consideration and combined analysis of set of factors. These factors can be technical, economic, environmental and social (Szurek, et al., 2014). In this study, wind potential, proximity to settlement, proximity to preservation area, forest, agriculture area, slope, elevation, and the proximity to the roads are taken into consideration. These criteria, which include technical, economic, and environmental as well as social, selected based on literature review and experts' opinions.

Adopting a geographically referenced method, which is the integration of Analytical Hierarchy Process (AHP) and Weighted Overlay as a GIS-based Multi-criteria Decision-making (MCDM) method is applied in this study. AHP is an effective method for dealing with complex problem in decision-making process and it has the ability to take into consideration tangible and intangible multiple criteria. GIS-based multi-criteria approach has been successfully employed in different land suitability analysis. Aly et al. (2005), Dong et al. (2008), Lotfi et al. (2009), and Youssef et al. (2010) applied AHP as a multi-criteria approach to analyze land suitability of urban development by using GIS. And also different GIS-based MCDM methods have been employed for land suitability analysis of wind farms. Bennui et al. (2007) employed GIS-based MCDM method in the context of AHP for selection of large site wind turbines in Thailand. Linear Weighting Averaging (LWA) as a MCDM method was used in UK for locating of wind farms (Serwan and Parry, 2001). Ordered Weighted Averaging (OWA) was applied for wind farm environmental assessment in Western Turkey (Yonca et al., 2010). In regard to that, AHP is applied to determine weights of the selected criteria. After determining the weights of criteria, Weighted Overlay method, which is one of the linear methods in GIS environment, is used. By overlaying the individual layers, this approach evaluates the overall criteria. This approach unlike other overlay methods in GIS environment allows the analysts to re-scale the value of each criterion during the application process. Thus, based on the weights of the criteria, the method makes the analysis essay to identify the suitable areas (Tegou et al., 2010).

Consequently, with the assumption that 'the most suitable site for locating of wind farms will minimize the negative impacts on community, contribute the sustainable development, and support the economic growth while minimizing environmental contamination as well as reducing the stakeholders oppositions'. Based on multiple criteria this study tries to identify the most suitable area for wind farm development within the study area. In order to estimate the weight or relative importance of each criterion, pair wise comparison method in the context of AHP is applied. The overall suitability of the study area determine through the Weighted Overlay method, which is an appropriate weighted approach in GIS environment. The problems and the structure the study has described in the following tittles.

1. 1. Problem Definition

Following critical issues are worth to be considered: Suitability analysis of wind farms site selection is a multi-criteria decision making problem, which includes a set of alternative location and number of criteria. Wind farm development is interdepended with several planning and environmental restriction and conflicts (Baban and Parry, 2001). The landscape and environment as well as community life are affected directly by land use of wind energy systems. In regard to above-mentioned subjects, this study tries to consider on and evaluate the bellow problems:

1. What kind of criteria should be taken into consideration for the suitability analysis of the study area and what will be their relative importance?
2. Identifying the weights for each criterion and its influences on overall land suitability analysis.
3. Which multi-criteria decision making method can be relatively appropriate to analyze land-use suitability based on multiple selected criteria for wind farm siting.
4. As the existing of wind turbine locations have become controversial debts in Karaburun Peninsula, this study tries to test whether there is any conflict between the identified suitable area and the existing wind turbines.

5. According to Take Care of Karaburun Peninsula (2015) which is a non-governmental web page concerning with Karaburun environment and social-cultural texture of the Peninsula, Karaburun can be distinguished with its three main characteristics: The human activities less affected the ecosystem, it is biodiversity area, and Karaburun has potential to sustainable develop the rural developments.

In regard to the problems and opportunities (its wind potential), identifying the suitable site that can provide an approach to make balance between the natures we want and the trend of wind energy development in the study area is a principle problem of this study.

1. 2. Thesis Structure

This thesis is contained of five chapters. The chapters are briefly explained in the following:

CHAPTER 1. INTRODUCTION. This chapter briefly introduces the rapidly increasing in consumptions and future demand of energy and environmental concerns. Then, it shortly explains the complexity of energy project and the need for a comprehensive analysis of multiple factors. This chapter clarifies the aim of the study, define the problem, justify the method, and finally structure the overall of the thesis (figure 1. 1).

CHAPTER 2. STUDY BACKGROUND. This chapter explains in general the background information of the study. This chapter includes four main and fundamental concepts; the criteria assessment, methodology, which is Multi-criteria Decision Making method, Environmental Impact Assessment of wind farm, and finally regulations and Public attitude.

CHAPTER 3. CASE STUDY. This chapter tries to explain the geographical location, and major land cover, and sensitivity of the study area.

CHAPTER 4. APPLICATIONS AND ANALYSIS. This chapter is consisted of four substantial titles; a comprehensive evaluation of each selected criteria, application of Analytical Hierarchy Process as a Multi-criteria approach to determine the overall criteria weights, applying the Weighted Overlay method in GIS environment to identify the suitable and restricted site in study area, and finally it include the result and finding of the thesis.

CHAPTER 5. CONCLUSION AND DISCUSSION. This chapter concludes discusses the overall result of the study.

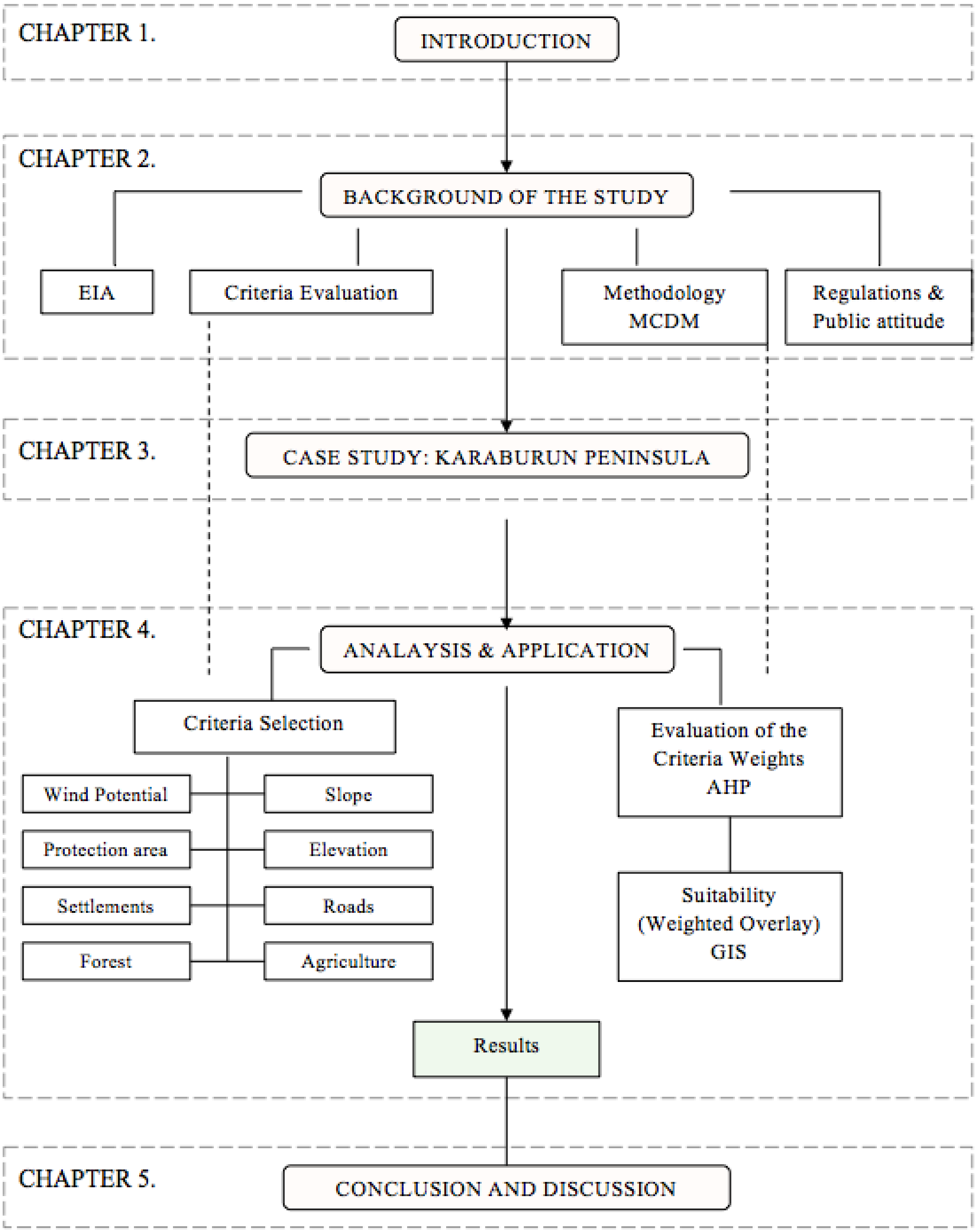

Figure 1. 1. Thesis Structure

CHAPTER 2

LAND SUITABILITY ASSESSMENT OF WIND ENERGY DEVELOPMENT IN GIS ENVIRONMENT

2. 1. Land Suitability Assessment

Land suitability assessment is a process, which determines the potential capacity of land for location of a particular activity. It is also a process of understanding the existing qualities of site and factors that will determine for defined uses. The suitability analysis tests how the factors fit into the design process to determine a suitable site. Land suitability involves a collective set of criteria such as physical, socio-economic, environmental, and ecological perspectives. It is therefore a multi-disciplinary subject that is consisted of physical science, ecological science, social science, and landscape. “Suitability analysis or assessment is made according to specific requirements preferences, or predictors of certain activities” (Malczewski, 2004). Land suitability in the context of planning is a holistic spatially view of independent set of multi-criteria evaluation of land capacity for optimal values of land developments, which is mostly based on experts’ opinion. Land suitability assessment becomes a standard practice in planning. GIS applications as a powerful and accepted tool has been widely using in suitability assessment of spatial analysis. In wind farm development the purpose of determining potential area is depend on the interaction of different factors such as environmental, technical and economic, and social factors. (Jain & Subbaiah, 2007; Marull et al., 2007; Liu et al., 2014).

In this study, land-use suitability assessment as a main purpose is fulfilled. The study presents a GIS-based multi-criteria approach to identify the most preferred or suitable site for wind farms development in Karaburun Peninsula. The identified and selected criteria include environmental, technical and economic, and social factors. After the above-mentioned criteria are weighted by pair wise comparison, they are applied in GIS environment to determine the most suitable site for wind farms development in the study area. Multi-criteria decision making as powerful method and GIS as a tool for land-use suitability is briefly explained as follow.

2. 2. Suitability Assessment Approaches and Tool

2. 2. 1. Multi-criteria Decision-making Methods

Analyzing the way, which people make decisions or the way people should make decisions is almost as old as the recorded history of human. Decision-making is the framework of identifying and selecting alternatives to discover the best solution based on various criteria. The decision frame includes the collection of information, alternatives, values and preference at the time when the decision is made. Theoretically decision making divides into three classes; decisions under certainty, decisions under conflict, decision under uncertainty. The decision under conflict, which multiple factors involved, is considered. In decision-making the critical point is the multiplicity of criteria, which are set for selecting the alternative. To facilitate the analysis that multiple criteria are involved, multi-criteria decision-making method as an efficient method can be used (Triantaphyllou, 2000; Mateo, 2012).

Multi-criteria Decision-making (MCDM) method is a branch of decision-making. It is a general class of operations research models, which can be addressed for complex problems with uncertainty and conflicting different forms of data. In other word, MCDM is an approach and a set of techniques, to provide an overall ordering of alternative. MCDM techniques identify a single the most preferred alternative. These techniques can rank, short-list a limited number of alternatives for evaluation, or simply distinguish acceptable from unacceptable possibilities. MCDM method can be divided into two major categories: Multi-attribute Decision-making (MADM) and Multi-objective Decision-making (MODM). These categories are involved several methods. Although each method has its own characteristics, the combination of MADM and MODM can be used. According to Mateo (2012) "These methods share the common characteristics of conflict among criteria[1], incommensurable units[2] and difficulties in design/selection of alternatives". The main difference between these two groups of methods is the number of alternative under evaluation. In MADM, a small number of alternatives are evaluated against a set of attributes, which is not easy to quantify.

1. Conflict among Criteria: Since different criteria represent different dimensions of the alternatives, they may conflict with each other. For example, cost and profit, etc.

2. Incommensurable Units: Different criteria may be associated with different units of measure. For instance, in the case of buying a used car, the criteria "cost" and "mileage" may be measured in terms of dollars and thousands of miles, respectively. It is this nature of having to consider different units which makes MCDM problems inherently difficult to solve (Triantaphyllou, 2000).

Furthermore, MADM methods are designed for selecting discrete alternative, while MODM methods are more adequate to deal with multiple objectives of planning problems. “In MODM, the alternatives are not predetermined but instead a set of objective functions is optimized subject to a set of constraints” Pohekar & Ramachandran (2004). The best alternative can be selected by making comparison between all alternatives (Mateo, 2012).

To sum up, MCDM method can be defined as a way of looking at complex problem, providing different ways of disaggregating a complex problem, measuring the extent to which alternative achieve objectives, weighting the objectives, and reassembling of all pieces. MCDM method contributes the analysts to evaluate complex, multi-dimensional trade-off between choice alternatives; location choice and suitability analysis can be one of the examples of them. MCDM is one of GIS based approaches that contribute decision-making in site selection, land-use suitability analysis, and resource assessment (Malczewski, 1999; Department for Communities and Local Government London, 2009; Meng et al., 2011). This study, attempts to apply the most compatible GIS-based Multi-criteria Decision approach for analyzing the existing status of wind farm and land-use suitability analysis of wind farms development in Karaburun Peninsula.

2. 2. 2. Selection of the MCDM Method

MCDM methods have been developed to support the decision maker in decision process. These methods provide disciplines and techniques to identify a single optimum alternative, to limit and rank the number of alternative or in short to distinguish acceptable from unacceptable possible alternative. In recent years several number of MCDM methods have been developed and their numbers are still rising. According to Department for Communities and Local Government of London (2009) there are several reason that cause to increase the number of MCDM methods; the type of decision which fit the broad circumstance of MCDM is vary, the available time to undertake the analysis is different, the amount and nature of available data is vary, the analytical skills is vary, and the administrative culture and requirement of organizations which support the decision are vary. Therefore, the number of MCDM has been increasing. Considering to the number of MCDM methods exist, the decision makers are faced with difficulties to select an appropriate method. None of the methods can be applied to all problems and each method has its own particularities, limitations, hypotheses, premises and perspectives. Furthermore, the other problem in selecting a MCDM method is that different method of MCDM method provides different result from the same input data, and there is no means to identify the best method. However, deciding whether one method has been perfect for specific problem than others have not been possible, there are different suggested ways for choosing the relatively appropriate MCDM methods to solve specific problems (Lahdelma et al., 2000; Nemery and Ishizaka, 2013).

Nemery and Ishizaka (2013) state that one way for selecting the MCDM method is, to look at the required input which is the data and parameters of the method and consequently the modeling effort as well as looking at the outcomes and their granularity. For example, if the utility function of each criterion in our analysis is known, 'Multi-attribute Utility Theory' method is recommended, but it needs a lot of effort, if it is too difficult there are other alternative ways. Other way is using pairwise comparisons between criteria and alternatives. Analytical Hierarchy Process can support this approach. Another way is to define key parameters. PROMETHEE requires indifference and preference thresholds, while ELECTRE requires indifference, preference, and veto thresholds. And also we can use TOPSIS method, which requires only ideal and anti-ideal alternatives. If the criteria are dependent, Analytical Network Process can be used. Generally, in choosing MCDM method it should be considered some initial requirements.

Lahdelma et al. (2000) suggested that the MCDM method should be well justified in real application, and it should satisfy the following requirements:

- The method should be well defined and easy to understand. The modeling of criteria and the definition of weights should be cleared.
- The method should be able to support the necessary number of decision makers.
- The method should be able to manage the necessary number of criteria and alternatives.
- The method should be able to deal with imprecision and uncertain criteria information.
- The need for preference information should as small as possible, because of the limitation time and economic sources.

Although, each method has their own characteristics, inherent, weakness and it is very difficult for any decision method to satisfy all above requirements, it seems that AHP method is capable to cover most of the above requirements. Therefore, in this study AHP as a proper method is used to determine the weights for selected criteria.

2. 2. 3. Analytical Hierarchy Process

The analytic hierarchy process (AHP) which introduced by Thomas L. Saaty in 1980 is a general theory of measurement (Saaty, 1987). AHP is an effective tool for dealing with complex problem in decision-making process. It helps the decision-makers to priorities and makes the best decision. By decomposing the complex problem into sub-problem and a series of pairwise comparisons, and synthesizing the results, the AHP contribute to capture both subjective and objective aspects of a decision. In other word, AHP decomposes the complex decision problem into sub-problems and constructs a rank for finite set of variants. Furthermore, the AHP provide a useful technique for testing the consistency of the decision maker's evaluations, which cause to reduce the bias in the decision-making process (Ching-Fu Chen, 2006). Among other MCDM methods AHP is flexible and it can easily implemented in GIS environment. AHP is an appropriate method for producing the criterion weights and its relative importance. AHP has been largely applied in different field of studies, and there are numbers of examples in locating facilities and land suitability analysis in literatures. It has been also widely applying in land-use suitability analysis, and regional planning (Yang, Liu & Wang, 2007).

Michal Szurek (2014) proposed a combination of AHP and Weighted Linear Combination (WLC) method in GIS to identify suitable land for wind farms in Poland. In that study AHP was used to determine weights associated with wind farm sitting criteria maps and then WLC method develops a composite suitability map from single-factor maps representing these criteria. Youssef et al. (2011) performed an integrated assessment of urban development suitability based on remote sensing and GIS by contribution of AHP. Tegou et al. (2012) develop a framework to evaluate land suitability for wind farm under the environmental management, and AHP is applied to estimate the criteria weights in order to establish their relative importance. Pohekar and

Ramachandran (2004) review the application of MCDM methods, they observed that AHP has been used in different field for about 20% of MCDM methods.

The application of AHP needs to complete four steps to achieve the ranking of the alternative.

1. Structuring the problem; it is set up as a hierarchical system by decomposing the problem into a hierarchy of interrelated component. This level indicates the goal for the specific decision problem. In the next level, the goal is decomposed of several criteria and the lower levels can follow this principal to divide into other sub-criteria. Therefore, the general form of the AHP can be depicted as shown in Figure 2. 1.

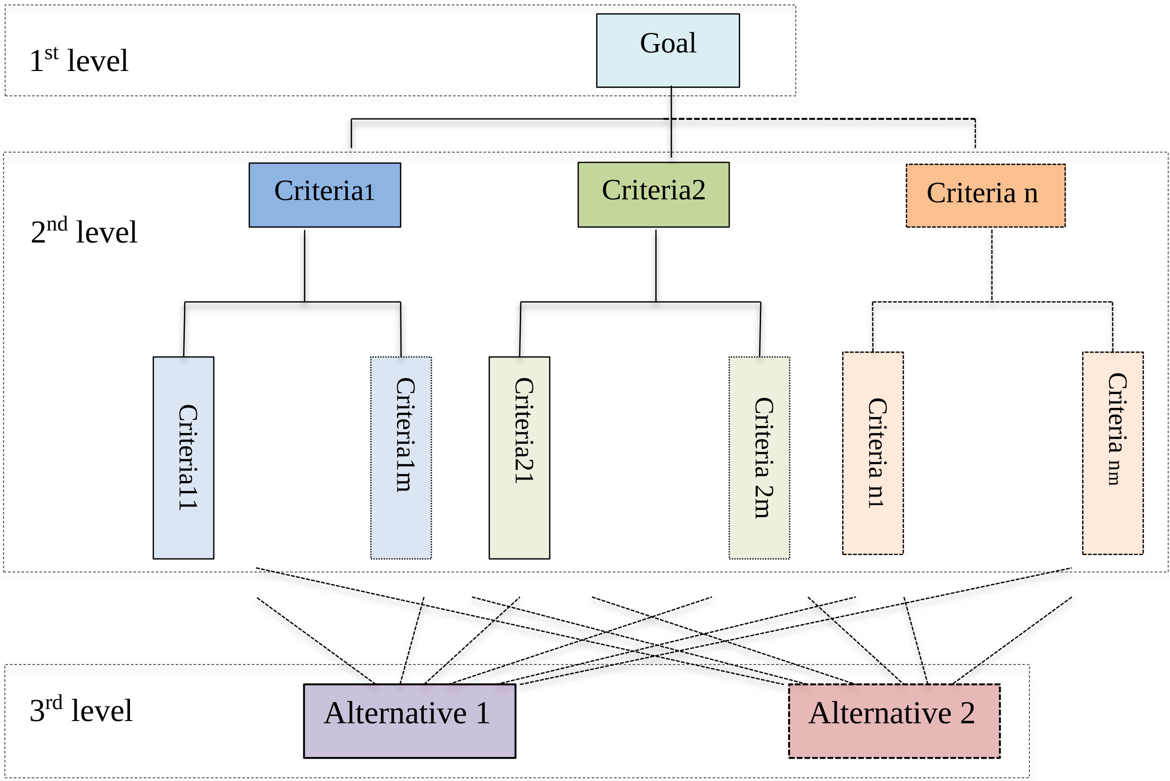

Figure 2. 1. The hierarchical structure of AHP
Source: Gwo-Hshiung Tzeng (2011)

2. Collecting and comparing the comparative weight between the attributes of the decision components to form the reciprocal matrix.

$$M = \begin{bmatrix} C_{11} = 1 & C_{12} & C_{1n} \\ C_{21} & C_{22} = 1 & C_{2n} \\ C_{n1} & C_{n2} & C_{nn} = 1 \end{bmatrix} \quad (2.1)$$

3. Synthesize the individual subjective judgment and estimate the relative weight to determine the priorities.

4. Aggregate the relative weights of each component to determine the best alternatives (Vaidya & Kumar, 2006).

AHP provides a numerical fundamental scale, which is shown in table 2. 1, and range from 1 to 9 to assess the quantitative and qualitative performances of priorities (Chandio et al., 2013).

Table 2. 1. The numerical fundamental scale in AHP
Source: Saaty (1987)

Intensity of relative Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to objective1
3	Moderate importance of one over another	Experience and judgment slightly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Very strong importance	An activity is strongly favored, and its dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent judgments	When a compromise is needed
Reciprocals	If activity I has one of the above numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i	
Rational	Ratios arising from the scale	If consistency were to be forced by obtaining a numerical values to span the matrix

The value of 1 indicates equal importance, 3 moderately higher, 5 strongly higher, 7 very strongly and 9 indicates extremely importance. The values of 2, 4, 6, and 8 are allotted to indicate compromise values of importance.

2. 2. 4. The Distinction of AHP

AHP is a flexible and easily implemented MCDM technique. The application of AHP has been largely explored in the literatures with numbers of examples in locating facilities and land suitability analysis. The popularity of AHP method is that it takes into consideration tangible and intangible criteria (Tegou et al., 2010). It is valuable to denote some specific characteristics of AHP, which can distinguish this method from other MCDM methods:

a. 'The construction of the hierarchy structure and the pair-wise comparisons between different criteria, in order to weight them with respect to the overall objective (Saaty, 1987).
b. AHP method employs a consistency test that can screen out inconsistent judgments (Kablan, 2004).
c. AHP relies more on the expert opinions or observations and less on the completeness of the data set about the different factors and their perceived effects on site suitability (Youssef et al., 2011).
d. Weighing the criteria with respect to overall included factors.

Due to its structure AHP allows the participation of both experts and stakeholders in providing the suitability measurement of a proposed site (Nekhay et al., 2009). Poheker and Ramachandran (2004) reviewed more than 90 published papers in different fields; they observed that AHP method is the most popular technique for prioritizing the alternative in MCDM. It is due to flexibility, re-visibility, its ability to integrate quantitative as well as qualitative criteria in the same decision framework. The flexibility of AHP enables the decision makers to integrate and combine the method with different techniques such as linear programming, quality function development, fuzzy logic, etc. Therefore decision makers can easily achieve the desired objectives in a better way (Vaidya & Kumar, 2006). In regard to above-mentioned, in this study, AHP is used to determine the weight of overall selected criteria and prioritize the alternative suitable site for wind farm development.

2. 2. 5. Geographical Information System and Land Suitability Analysis

There are a number of Geographical Information System (GIS) definitions. Most of the GIS definitions focus on the technology and problem solving aspect of the system. Technologically, a GIS system is defined as “a set of tools and input, storage and retrieval, manipulation and analysis, and output of the spatial data” (Malczewski, 1991). GIS systems have the ability to operate both spatial and attribute stored data. GIS is an integrated technology system. It can integrate a variety of geographical technology such as remote sensing, computer aided design, global positioning system, and automated mapping and facilities management. GIS can be defined as a process than merely software. GIS functions include four main components, which are consisted of data input, data storage and management, data manipulation and analysis, and data output (figure 3. 1). The aim of GIS is to provide support for decision-making and to help the user answering the questions concerning with geographical patterns and process. In terms of land suitability, GIS systems have been evolved in a historical period (Malczewski, 1991; Malczewski, 2004; Esri, 2015).

The GIS system evolution in the context of land-use suitability has been operated based on the development of the information technology and in particular on geographic information technology. Malczewski (2004) divides the evolution of GIS into three time-periods: innovation stage 1950-1970, integration stage in 1980, and development of the user-oriented GIS technology in last decades. The development and changes in GIS has been influencing the method and approach in planning and land-use suitability analysis. And there is wide range of analytical operation in GIS systems.

From the land-use suitability analysis the GIS available operations can be made distinction between two categories; basic or fundamental and advanced operations. The basic or fundamental operation includes: measurement, classification, overlay operation, and connectivity operations. The fundamental operations are the spatial data handling or “building blocks” for advance analysis. The provision of the theoretical models and the capabilities of the data manipulation and analysis are referred to as advanced or compound GIS operations. Cartographic modeling can be an example of the advanced operation in GIS system (Malczewski, 2004).

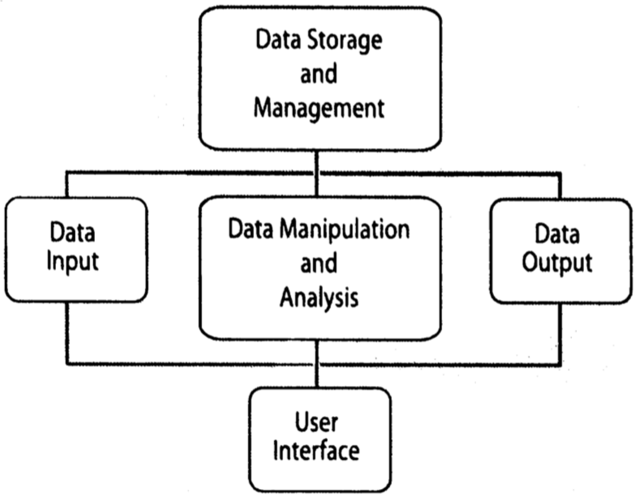

Figure 2. 2. Structure of a GIS
Source: Malczewski (1999)

2. 3. Criteria Identification

Suitability analysis for wind farm requires a comprehensive consideration of multi-criteria, which is consisted of technical, economic, environmental, and social factors. Each criterion involves multiple parameters and exclusion factors. Although the criteria themselves are subjective, in suitability analysis the relative importance of each criterion is dependent upon the viewpoint of analysts. For instance, planner, environmentalist, conservationist and so on may consider to various criteria. The determination of environmental criteria is a crucial one, it is individually, specified for particular site and region. From a planning viewpoint, the criteria for wind farms have been considered with respect to support economic growth while reducing the environmental risk and public opposition. The public acceptance of wind farms is dependent on minimizing the overall adverse impact of wind turbines (Sparkes and Kidner, 2001; Michal Szurek, 2014). A comprehensive literature survey is made to recognize the most substantial environmental, economic, and social criteria for wind farms development. In this regard, the major criteria, which are stated in the relevant literatures under the title of “suitability analysis of wind farms”, (table 2. 2) are considered. As the criteria for analyzing the land-use suitability for wind farms are dependent on the specific area. This study based on the literatures review with respect to the location of study area (Karaburun Peninsula) attempts to integrate the environmental, technical, economic and social factors, thus to determine the suitable site for wind farm development. In chapter 4 each of the selected criteria is individually justified and clarified. The table 2. 2. Illustrate the major criteria, which are usually under taken into consideration in land suitability analysis of wind farms. In this study, based on those criteria and experts' opinion the criteria are selected.

Table 2. 2. The major criteria for suitability analysis of wind farms with respect to their references

Criteria group	Criteria	References
Environmental	Protection area	1. Azizi. A., et al, (2014) 2. Baba and Parry, (2001) 3. Latinopoulos & Kechagia, (2015) 4. Al-Yahyai, et al, (2012)
	Vegetation	1. Baba and Parry, (2001) 2. Rodman and Meentemeyer, (2006)
	Forest	1. Rodman and Meentemeyer, (2006) 2. Gorsevski et al, (2013)
	Bird habitats and routes	1. van Haaren & Fthenakis (2011)
Economic & technical	Wind Potential	1. Al-Yahyai et al., (2012) 2. Abdul, et al, (2007) 3. Latinopoulos & Kechagia, (2015) 4. van Haaren & Fthenakis (2011) 5. Gorsevski et al., (2013) 6. Azizi. A., et al, (2014) 7. Vaggion and Karanikolar, (2012) 8. Baba and Parry, (2001) 9. Rodman and Meentemeyer, (2006) 10. Best practice guideline for WED (1994)
	Proximity to transportation	1. van Haaren & Fthenakis (2011) 2. Gorsevski et al, (2013) 3. Al-Yahyai, et al, (2012) 4. Latinopoulos & Kechagia, (2015) 5. Azizi. A., et al, (2014)
	Slope	1. Al-Yahyai, et al, (2012) 2. Abdul, et al, (2007) 3. Latinopoulos & Kechagia, (2015) 4. van Haaren & Fthenakis (2011) 6. Azizi. A., et al, (2014)
Social	Proximity to residential area (Visual, noise, shadow flicker, esthetical, etc.)	1. Baba and Parry, (2001) 2. Latinopoulos & Kechagia, (2015) 3. Al-Yahyai, et al, (2012) 4. van Haaren & Fthenakis (2011) 5. Azizi. A., et al, (2014) 6. Rodman and Meentemeyer, (2006) 7. Best practice guideline for WED (1994)

2. 4. Rules and Regulations in the Context of Wind Farm Site Selection

Suitable site for wind farms is carried out based on overall balancing of different factors such as wind potential, proximity to residential, noise and shadow, and other technical aspects in regard to landscape and nature. The balancing is brought through planning of wind farms. Although planning is an ambiguous term, in the context of wind farm development, it can be referred to a proper structured process, which carries significant regulation weight to determine certain suitable area for wind farms. Regulation is a legal framework, which is typically consisted of methods and standards (Committee on Environmental Impacts of Wind Energy Projects. 2007). Regulations in the wind farm planning, describe for authorities carrying out wind energy developments; "what procedure should be followed, what kind of information should be examined, and what criteria should be used to make decisions" (Danish Energy Agency, 2009). In regard to the importance of regulations in the content of wind farm planning and development, which is mentioned above, this study tries to briefly explain the wind energy regulation in two European countries (the United Kingdom and Denmark) and compare them with Turkish wind energy regulations. And also it is worth noting that the focus of this study will be on regulations, which are relatively in relation with site selection and its constraints in those countries.

In the United Kingdom (UK) there are energy, climate change and planning policies, which support renewable energy and attempt to mitigate carbon dioxide (CO_2) emissions. Based on these policies two scales of authorities (local and governmental authorities) are required to set renewable energy targets. Wind energy is one of the primary technologies for meeting these targets. For wind energy project implementations, planning permission is required. Wind farms, which is >50MW, governmental (Secretary of State for Business) permission and <50MW local authorities permissions is required. Base on the scale of wind farm projects/scheme the planning permission, may require Environmental Impact Statement (EIS) that identify environmental, social and economic impact of the projects. The large projects always require environmental impact assessment. However, other projects depend to the size, nature and implemented locations. Wind powers >50MW require Environmental Impact Assessment (EIA) (section 36 electricity Act application), but in sensitive natural area wind farms with more than 5 turbines or >5MW require EIA. Following section will clarify that EIA should be considered on what kind of factors and procedures in wind farm development (Stevenson, 2009).

Denmark has highly structured and comprehensive regulations for wind farm planning and developments. Ministry of Environment and municipalities are two responsible authorities in wind power developments. Danish Ministry of Environment establishes Wind Turbine Secretarial to develop an integrate framework of plan and regulation for wind farm development. The Wind Turbine Secretarial also provides guideline and practical help for the municipalities to identify suitable site in respect of neighbors and nature protection. In most case is the EIA is mandatory. If the project involve a group of more than three wind turbine and >80m in height must accompanied EIA. There are closely cooperation between Wind Turbine Secretariat and municipalities. Danish regulation allows the municipalities to be considered the public and stakeholders participation in planning process. Even in the case of wind turbine do not require an EIA, Danish regulation set out requirement for municipalities to inform the neighbors about the wind project. The main purpose of this information may be to ensure about traditional transmission system operation, to be able to realistically assess whether the project will cause the loss of their property values. Furthermore, alternative site must be investigated, and the developer should be ensured why the proposed site is preferred. To sum up, Danish wind power regulation involves environmental, social, technical and economic factors investigation under the national and regional authorities to identify the most suitable site for wind farm developments. According to Committee on Environment Impacts of Wind Energy Projects (2007), Danish regulations in the context of wind energy development is more holistic and applicant in most of the states in USA. Therefore, the states, which have similar environment with Denmark, use the Danish regulations in wind energy development (Danish energy agency, 2009).

2. 4. 4. Regulations in Turkey

In Turkey, there are two regulations with relevance to the renewable energy, the Electricity Market Licensing Regulation and the Utilization of Renewable Energy Resource Regulations for the Purpose of Generating Electrical Energy (Regulation Number 5346, 2005). According to Erdogdu (2009) studied wind energy in Turkey, in these two regulations define the wind power as a renewable energy resource and currently there is no specific regulation for wind power development.

The Electricity Market Licensing Regulation for Renewable Energy (Regulation Number 4628) started in 1984. This regulation includes three part; financing, excise and sales tax exemptions. The regulation with regard to environmental effect of the electricity generation and operations, states the measures to encourage the utilization of renewable and domestic energy resources (e.g., the entities applying for license of domestic and renewable energy shall pay only 1% of the total license fee, for generation of renewable energy should not pay annual license fees for eight years, and the Government should assign priority for renewable energy connection in transmission system). In this context, the regulation can be related to wind power development (Erdogdu, 2009).

The regulation on Utilization of Renewable Energy Resource aims "to increase the use of renewable energy sources as well as to diversify energy resource, reduce greenhouse gas emission, assess waste product, protect the environment, and develop the necessary manufacturing sector for realizing these aims" (Erdogdu, 2009). What may be related to wind energy generation is: The obligation to purchase electricity from renewable energy resource, purchasing of electricity from renewable energy with high price, and acquisition of land, which can be implemented for permission, rent, right of access, and usage permission in the investment period, etc. Although specific regulation for different aspects of wind energy development currently does not exist, the mentioned above regulations could be relatively related to wind energy development (Erdogdu, 2009).

2. 5. Environmental Impact Assessment of Wind Energy Development

Almost all wind energy development regulations considered on Environmental Impact Assessment (EIA) as an essential and comprehensive aspect in land-use assessment of wind farms. EIA in the content of wind energy is an interdisciplinary concept, which comprise the assessment of ecological, social, economic and technical aspect of the projects. Wind energy development regulations emphasize the EIA as a pre-required assessment for large projects. The scope of EIA in wind energy generation must be included:

1. The description of the project and establish that the site is appropriate for wind resource standpoint.
2. The description of landscape surrounding the site, with anything that may be affect during construction or operations.
3. The protection of species of flora and fauna as well as bird protections under national and international agreement.
4. Describe any adverse effect on water resource.
5. The EIA should also assess the project's positive environmental impacts (e.g., mitigation of CO_2, NO_x, and SO_2).
6. Describe the evaluation of the impacts on human environment (noise, visual, shadow flicker, property value, tourism, and other commercial activity in the vicinity, etc.)

EIA in the USA is prior in planning documents. EIA for project must be publicized at four weeks before to give opportunity for private citizens, organization and other stakeholder to submit suggestions and comments. After public hearings, the plans are presented to the authorities or governmental bodies, and they have the right to accept their suggestion or with evidence veto them. And the construction will begin after the plan has been approved (Committee on Environmental Impacts of Wind Energy Projects, 2007). The above-mentioned subjects are the major point in EIA of wind farm developments; it is just a short overview of EIA in the context of wind energy developments. Additionally, EIA is interdisciplinary concept, it can be considered in different perspectives, in this study the protection of bird and bats as a critical and substantial subject in wind farms development is considered.

2. 5. 1. Bird Habitats and Migration Routes

The adverse impact of wind farm to bird is a concern to any environmentalists, as wind farm may be built in the bird habitats and routes. The important point in bird assessment is to minimize avian collisions and fatalities of birds and bats during the operation of wind turbine. For local birds, Leung and Yang (2012) in their study "Wind energy development and its environmental impact", states that "local birds can quickly learn to avoid obstacles, and thus wind turbines would not be a serious problem for them". Although bird still is killing by wind turbine, the amount of birds, which are killing in this way, is negligible compared to the other human activities. According to U. S. Department of Agriculture and Forestry Service, wind farms cause fewer birds mortalities. In United State it is about 108000 birds a year, while buildings cause 550 million, power line is 130 million, cars 80 million, and radio cell tower 4.5 million in a year. U. S. National Academy of Science noted the mortality of bird by wind turbine is less than three out of every 100,000 human-related bird deaths (Erickson, et al., 2005; Wind Energy Foundation, 2015).

According to Erickson et al. (2005) for every 10,000 birds death, less than one is caused by a wind turbine (table 2. 3). The biggest danger to birds at present is global warming and wind energy plays a major role in the mitigation of the global climate changes.

Table 2. 3. Summary of predicted annual avian mortality in USA
Source: Erickson et al. (2005)

Mortality Source	Annual mortality estimate	Percent Composition
Buildings	550 million	58.2 percent
Power lines	130 million	13.7 percent
Cats	100 million	10.6 percent
Automobiles	80 million	8.5 percent
Pesticides	67 million	7.1 percent
Communications tower	4.5 million	0.5 percent
Wind turbine	**28.5 thousand**	**< 0.01 percent**
Airplanes	25 thousand	< 0.01 percent

The survey result (table 2. 3) illustrate that the number of bird mortality by wind turbine in comparison to building, power lines, cats, automobile, pesticides, communication tower, airplanes, and other source is the lowest in United State.

The Important Bird Area (IBA) and migration routes are essentially important in bird assessment of wind farm. IBA is an essential habitat, where one or more avian species use during their nesting season. According to Important Bird and Biodiversity Areas (IBAs) in Danger (2012), ‘IBAs are places of international significance of conservation of the world’s birds and other nature, with over 12000 having site for nature conservation. They are the largest global networks of important site for nature conservation'. Bird Life International Partnership during (2014) is provided the IBAs in danger maps. Below map shows the global IBAs in danger. The assigned red colors illustrate the in danger IBAs, which are critical places for any spatial changes. This map explicitly shows that the study area (Karaburun peninsula) does not only locate in that area, it is far away from the IBAs in dangers areas (figure 2. 4).

Although bird mortality is a concern in environmental protection, in regard to above-mentioned reports, in this sense the study area is not essentially in critical birds in danger location to be concern about bird habitats and routes. Beside that lack of local or small-scale bird's route map is the other reason, which this study does not add the bird migration route within the criteria of analysis.

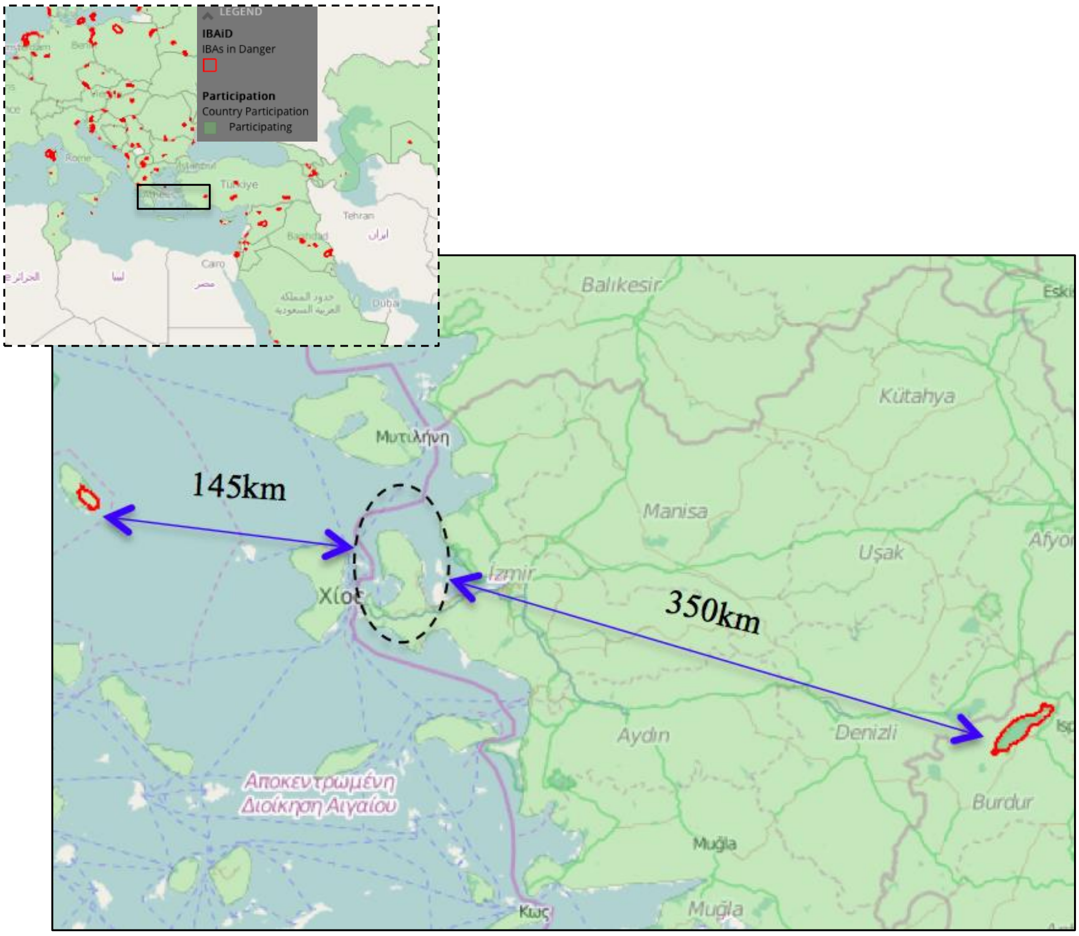

Figure 2. 3. IBA in danger map
Source: Impotant Birds Area (2015)

2. 6. Public Attitude Towards Wind Farms

Despite of the green image of wind energy, it is not easy to fine favorable locations for installation of wind farms. Some people see to wind energy as an obliteration of nature, while others see it as one of the clean energy source that can prevent climate change. The main reason, which is caused the opposition in many cases may depend on the possible impacts on environment and tourism, the extensive land use, the creation of territorial inequalities and their visual impact, as well as NIMBY (Not In My Back-Yard) attitude. NIMBY is a characterization, which residents oppose to a proposal for new development. Although the residents believe that the development is needed in society, it should be far away from their residences. Moreover, the policy process for decision of the locating of wind farms can be also controversy issue. Most of the wind farms assessment carried out subjectively, different countries have been surveying different impacts of wind farms to investigate the public attitude toward wind farms developments. For example, two case studies are reviewed here (Gamboa & Munda, 2007).

According to a survey in North Carolina U.S in 2011, which is fulfilled among 400 people, shows that 58% of the respondents did not think a problem with wind farm. The people who see problem, the majority of them (44%) said that visual problem is the main issue with wind turbines. Furthermore, the survey has shown that the people who had experience were more likely positive attitude than the others with no prior experience. Interestingly, this study illustrates that the attitude of people is changing during the wind farms construction. The people who change their attitude and turned their favor during construction become 27% of respondents. In short, public acceptances have increased with the level of information and experience (van Haaren & Fthenakis, 2011).

Warren et al. (2005) investigates two case studies in UK (Scotland and Ireland), to explore the public support or oppose of wind farms and base on literatures, to indicate the reason for these attitudes. The report mostly focuses on environmental concerns of wind farms, and it indicates that widespread international studies support the development of wind power to mitigate the threat of climate change. The public concerns and opposition in some studies are based on NIMBY syndrome, transformation of natural landscape into landscape of power, economic impacts, national and political environment surrounding wind farm, and institutional factors. In conclusion, the study has found that NIMBY-ism is in declining, and public acceptance increase with the level of experiences, and it is shown that large majority of residents in area with wind farms is in favor with both in practical and in principles.

Regarding the studies above-mentioned, in most cases the public support for wind farms development is high than oppositions. According to Groth and Vogt (2014) despite of the high levels of public support for wind farm development in principle, specific projects often experience local opposition. Therefore, the high level of acceptance does not mean there is no gap between social acceptances and it could not be ignored there is no oppositions. Some people have concerns about different impacts of wind farms development. As this study is carried out in Karaburun peninsula, which is an environmentally sensitive area, the public attitude toward wind farms development within this region is different.

The local people in Karaburun Peninsula are mostly opposite to the construction of wind turbines and they have made a lot of protest meetings and activities against to these developments. The public attitudes and oppositions can be seen easily in the web page of Karaburun City Council (Karaburun Kent Konseyi). They also try to stop the development/construction of wind turbines by using legal ways and applying to the administrative courts. 59 people in Karaburun Peninsula wrote an objection letter to the İzmir Administrative Court in 11. May. 2015 to stop the implementation of “Physical plans of Sarpıncık Wind Energy Farm” which were approved by Ministry of Environment and Urbanization. According to this official document; the basic objections of local people can be summarized as follows;

Total number of existing and projected wind turbines is very high and their total area is very large. Number of wind farms, which got license from EPDK is 6, and the number of wind turbines of these farms will be 115. This number will reach to 234 with new permissions, and 61% of the total area of Karaburun Peninsula will be devoted to the “wind energy production area”.

Because of the construction of new roads and wind turbines, natural life is diminishing and animal raising (especially goat raising) is being affected negatively. The closeness of the wind turbine to the existing settlements/villages affected the local people negatively because of noise, shadow flicker, visual of wind turbines.

Cumulative effects of all wind turbines development were not analyzed. Environmental effect assessment and physical planning processes of each separate development were realized separately, but their total effects on Karaburun Peninsula were not analyzed. Their total effects will damage the natural, social and local economic values of the Peninsula.

The judicial process still continues. On the other hand other Administrative Court completed the decision making process related with the same energy firm and related with its “Environmental Impact Assessment Report”.

İzmir 5th Administrative Court in 17. 9. 2015 has decided to stop the application of “Environmental Impact Assessment Report of Sarpıncık Wind Energy Firm” which was accepted by Ministry of Environment and Urbanization”. The main reasons of this decision can be summarized as follows;

Existence of olive trees, agricultural fields, vegetable gardens and seal living area, existence of settlements, existence of bird migration routes, existence of clean and protected natural environment.

CHAPTER 3

CASE STUDY AREA: KARABURUN PENINSULA, IZMIR

3. 1. Study Area

Karaburun Peninsula is located in the western part of the Aegean Region in Turkey. The Peninsula is covering an area of 436 km^2 between 26°21′ –26°38′ longitudes and 38°40′–38°25′ latitudes. The elevation in the area varies from sea level up to 1.300 m. The mountainous conditions in the most parts of the Peninsula have affected the settlements and land use in the area. Karaburun has typical Mediterranean climate with mild rainy winters and dry and hot summer. Mean annual temperature of the Peninsula is ranged between 15°C and 20°C. According to General Directorate of Renewable Energy (URL4) and “Wind Potential Atlas of Turkey” Karaburun is located in the windy region of Turkey, the average of wind speed in the height of 50m is between 5.5/sec to 9.5/sec, which is suitable for wind energy development (figure 4. 1). The land cover of Peninsula includes forest, maquis, grassland, agricultural field, and settlement areas (figure 3. 1). Topographic conditions and trade routes forced the people to build their settlement on the coastal line. There are 13 villages and two type of settlement developed within the Peninsula; agriculture-oriented that the people mainly involved in cultivations and summerhouses, which have been increasing rapidly since 1980. Agriculture area is less than 10% of the total area. More than two third of the agriculture area is olive plantations and rest is artichoke and grapes, and growing narcissus become an intensive agriculture activities. The classification of area has shown that 5% is covered by settlements, less than 15% agricultural, 75% forests and semi-natural areas, 1% wetlands, and 4% other uses (Nurlu et al., 2008; Erdoğan et al., 2011). The reason that Karaburun has been chosen as a study area is: the confliction between wind potential that area has and the environmentally sensitivity of the Peninsula. Recently wind energy developments within this area have become a controversial issue. This study tries to identify suitable area with respect to the sensitivity of the Peninsula.

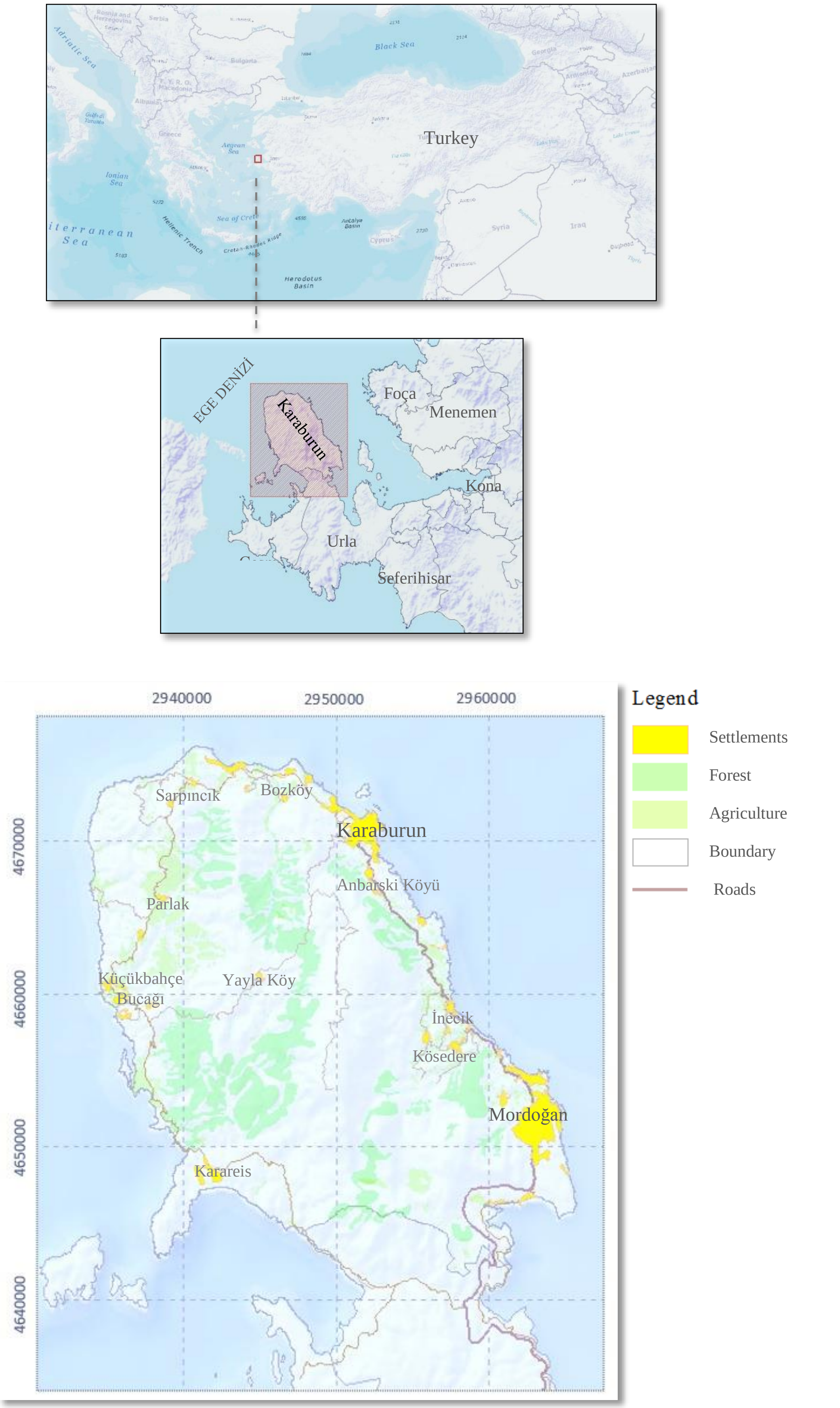

Figure 3. 1. Study area: Karaburun Peninsula, Izmir
Source: Esri (2015)

3. 2. Sensitivity of the Area

Karaburun Peninsula with its thousands of years old natural structure, windy climate, coasts and bays has a unique ecosystem. Therefore, it has a rich biodiversity that include different plants and animal species at national and international levels. Peninsula is covered with pinus brutia forests, shrubs and herbaceous vegetation, and many of sclerophyll species. Peninsula supports 384 taxa with 70 family (Fabaceae 42 taxa, Poaceae 35 taxa), Asteraceae 30 taxa, and 255 genera. This area is also home of some endangered mammals such as “the Eurasian Otter (Lutra lutra), the Mediterranean monk seal (Monachus monachus) and Audouin’s Gull (Larus audouinii). According to www.karaburunaiyibak.org, which is the web page supported by non-governmental agencies (looking at the Karaburun) is an important protection area. In Karaburun there are several under threat flora: “Plants used for medical purposes (Delphinium, Nigella, Papaver, Viola, Malva, Linum, Trigonella, Ferula, Quercus, Alkana, Hyascyamus, Origanum, Salvia, Satureja, Sideritis, Teucrium, Thymus, Verbascum, Rubia,Valeriana, Helichyrsum, Scolymus, Allium, Asparagus, Ruscus, Orchis cinsleri), Plants used as ornaments (Anemone, Delphinium, Viola, Dianthus, Cyclamen, Globularia, Centaurea, Allium,Fritillaria, Muscari, Ornithgalum, Scilla, Tulipa, Gladiolus, Iris cinsleri), Endemics (Erodium absinthhoides ssp. Absinthoides, Minuartia anatolica var. Anatolica, Colutea melanocalyx ssp. Davisiana, Trigonella smyrnea, Aristolochia hirta, Campanula lyrata ssp.lyrata)” (Erdoğan et al., 2011).

In open or non-vegetation area of the Peninsula, Euphorbia peplis, and Tribulus terrestris are existed. And species in salt marshes areas are: “Artrochnemum fruticosum, Halimione portulacoides, Halocnemum strobilaceum, Limonium bellidifolium, Salicornia europaea, Tamarix parviflora, and T. smyrnensis”. The agriculture is also important in this area, which is a bout 15% of the overall area. Cultivation of grapes and olives, citrus, artichokes, bay, narcissus and hyacinth is the major agriculture activities in the Peninsula. Tourism sector is other important source in Karaburun. In regard to those characteristics of Peninsula, Karaburun Peninsula seems an extremely sensitive and biologically rich natural reserve area in Turkey. In any kind of intervention in that area, a holistic assessment should be fulfilled in advanced, and then the proposal could be submitted (Nurlu et al., 2008; Erdoğan et al., 2011).

CHAPTER 4

APPLICATION AND ANALYSIS

4. 1. Data Collection and Processing

Data collection and processing is a crucial step in most case studies. Since, the land-use suitability analysis of wind energy development requires different spatial data, which may be included the integration of environmental, technical, and economic as well as social components. On other hand, the spatial analysis in GIS requires a standardized/normalized data in specified projection system of geographical coordination. In this study, geographic maps with their attribute values were required. Normally, governmental or other involved institutions have been preparing those types of data. The majority of the data were acquired from governmental agencies. Eight different types of data were considered in this study. Each data/layers was acquired and processed individually as follow:

Wind potential: This layer is the most fundamental and significant in the process of suitability analysis of wind farms. General Directorate of Renewable Energy (Yenilenebilir Enerji Genel Müdürlüğü), which is a governmental agency, prepared this layer by name of Turkish Wind Potential Atlas. Also it is available in their web page as an image format (REPA, 2015). In this study, it was acquired from that agency.

Protection and Agriculture areas: Three different degrees of protection areas exist in the study area. Yazdani (2014) in "Participatory Planning Support System for Assessment of Spatial Conflicts in Izmir Peninsula", based on Izmir land use plan was prepared and projected these layers. In this study, protection and agriculture layers were acquired from that source. The projection of those layers with respect to the study requirement is then fulfilled. For example, the size of pixel (30 x 30m), classification of the distance to wind farm, and projection of the coordinate system were fixed, which described in following chapters.

Settlements and Road: The existing settlements and roads were digitized based on Izmir land use plan and ArcGIS online satellite map in 2014. ArcGIS online source is an available provision satellite map. Then they were projected and fixed by Global Mapper (from KML to shape file and raster layers) as the study required.

Slope and Elevation: These data were acquired from ASTER GDEM geographic services web page. Then, by aiding GIS, the slope and Elevation layers were prepared.

Forest: By using Landsat 321-composition map, which is provided by IDRISI software and Global mapper, the forest map was obtained. The most dense forest area is distinguished, and excluded from analyzing process. The marginal and low dense forest area with respect in its buffer is defined as suitable area for wind farm development (chapter 4. 2. 4).

4. 2. Criteria Evaluation

Based on surveyed literatures (section 2. 3) it can be explicitly observed that the below criteria are the most popular and substantial for land suitability analysis of wind farm developments, especially in environmentally sensitive areas. In addition, it can be noted that in some countries the local authorities provide a list of factors, which should be taken into consideration for planning permission of wind energy developments. For instance, in the UK local authorities provide the list of factors, which are: proximity to residential areas, noise, shadow flicker, greenbelt, topography, ecology, agricultural land classification, conservation areas, and distance from electricity grid lines. And also private consultancies listed the following factors: wind speed, prevailing wind, terrain, adjacent terrain, vegetation, proximity to residential areas, noise and appearance (Baban & Parry, 2001). The criteria, which are selected in this study (table 4. 1), have been chosen with respect to the relevant literature review and experts' opinions (table 2. 2). The criteria cover environmental, economic and technical, and social constraint. In environmental aspect (preservation area, forest and agriculture area), it is attempted to minimize the risk of wind farms. In economic and technical aspect, the major constraint factors (wind potential, slope, elevation and roads) are considered. Socially (proximity to settlement) the study tries to minimize the wind farm annoyance on residences. The following criteria are selected in this study, and each of them will explain in detail.

1. Wind potential
2. Preservation area
3. Distance from settlement
4. Forest
5. Slope
6. Elevation
7. Distance from roads
8. Agriculture area

4. 2. 1. Wind Potential

Almost in all relevant literatures, the wind potential in the geographical region was considered as the most fundamental and primary criterion since it determines the output of the wind turbine. The distribution of wind energy resource in all places is not homogeneous; it is various in different places. Although Turkey is one of the windiest regions in European and Asian countries, the wind energy widely distributed at lands and coastlines. Technically, the average of wind speed should be able to generate energy. The threshold for wind speed in wind energy generation is set at about 5m/sec. The maximum wind speed is around 20m/sec. Therefore, the identification of potentially suitable area for wind farm is the initial stage of wind farm suitability analysis. In the study area wind energy potential is distributed in all area. However, the average wind speed is not the same (figure 4. 1). The highest speed is around 9m/sec, while the lowest is around 5.5m/sec in this area. Technically, all over the Peninsula has enough wind potential to generate energy, but the high speed wind is around the central and north west part of the Peninsula, which is more suitable for wind energy developments (Baban & Parry, 2001; Al-Yahyai et al., 2012; İlkiliç, 2012).

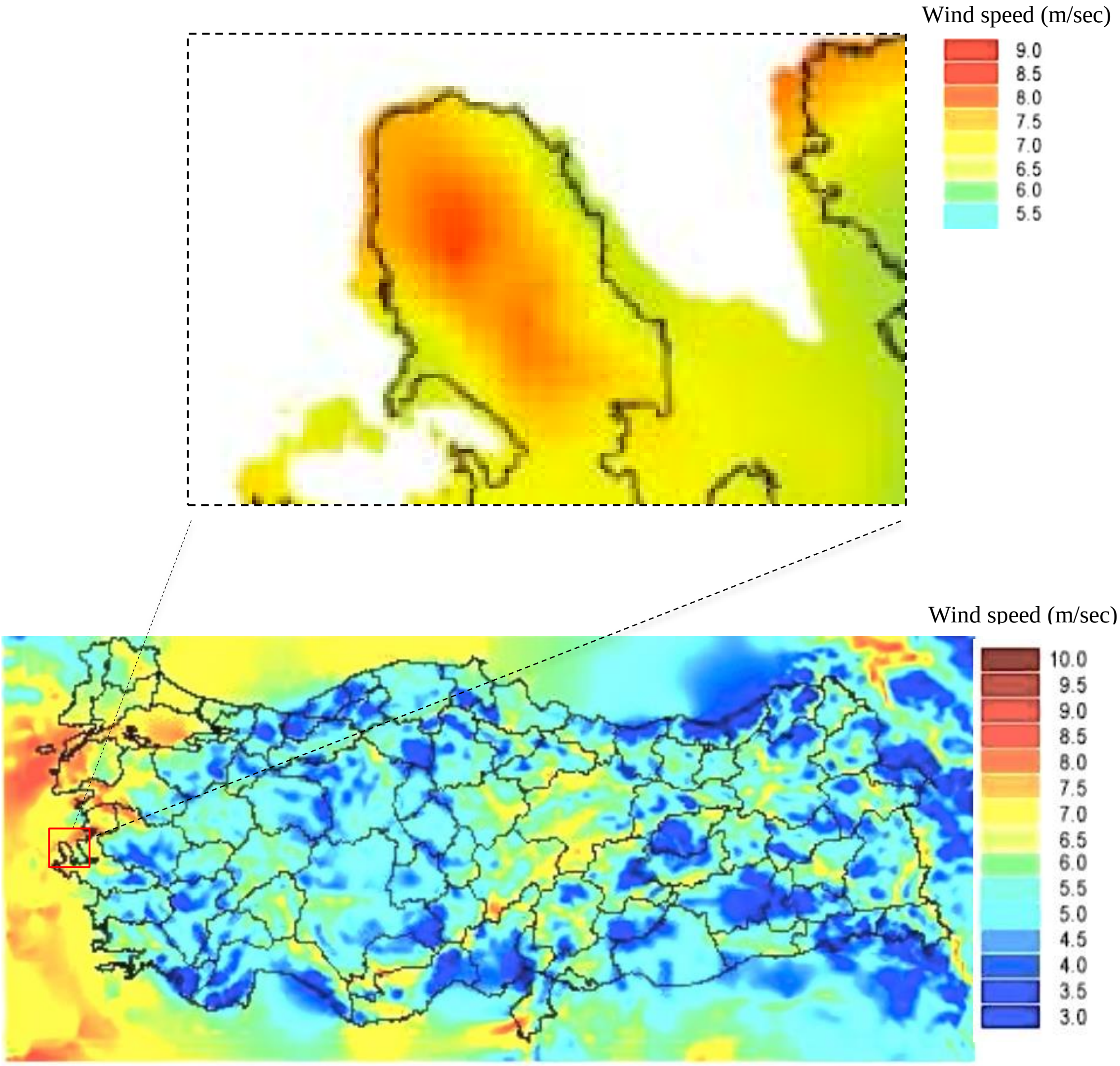

Figure 4. 1. Wind potential atlas in 50m heights
Source: REPA (2015)

4. 2. 2. Protection Areas

Preservation area is a critical problem in the context of wind farm developments. Preservation area is defined as an area where should be protected from any land changes and innovations. The value and the degree of individual preservation area are various. For instance, preservation area may have archeological and cultural value, biological importance, geomorphological and ecological importance, wildlife and special species importance, recreation and touristic values. In this regard these area may be defined as a constraint zone and exclusion area. The study area has different degrees of natural and archeological preservation areas, which are determined as a constraint zone in this study (figure 4. 2). The significant problem is the buffer zone for each preservation area. Latinopoulos and Kechagia (2015) suggested 1000m distances from the preservation areas, which has aesthetic value. As the study area is mountainous area, the visual impact is seemed limited. The distance in these areas can be changed. The typical radius impact shows 400m, radius buffer area for 50m height wind turbines. Base on that radius effect of wind turbine, this study tries to take into account at least >400m buffer constraint zone for wind farm development. After constraint zone the distance will take different values. Figure 4. 3. Shows the preservation area of Karaburun Peninsula and its buffer taken zones (Latinopoulos and Kechagia, 2015).

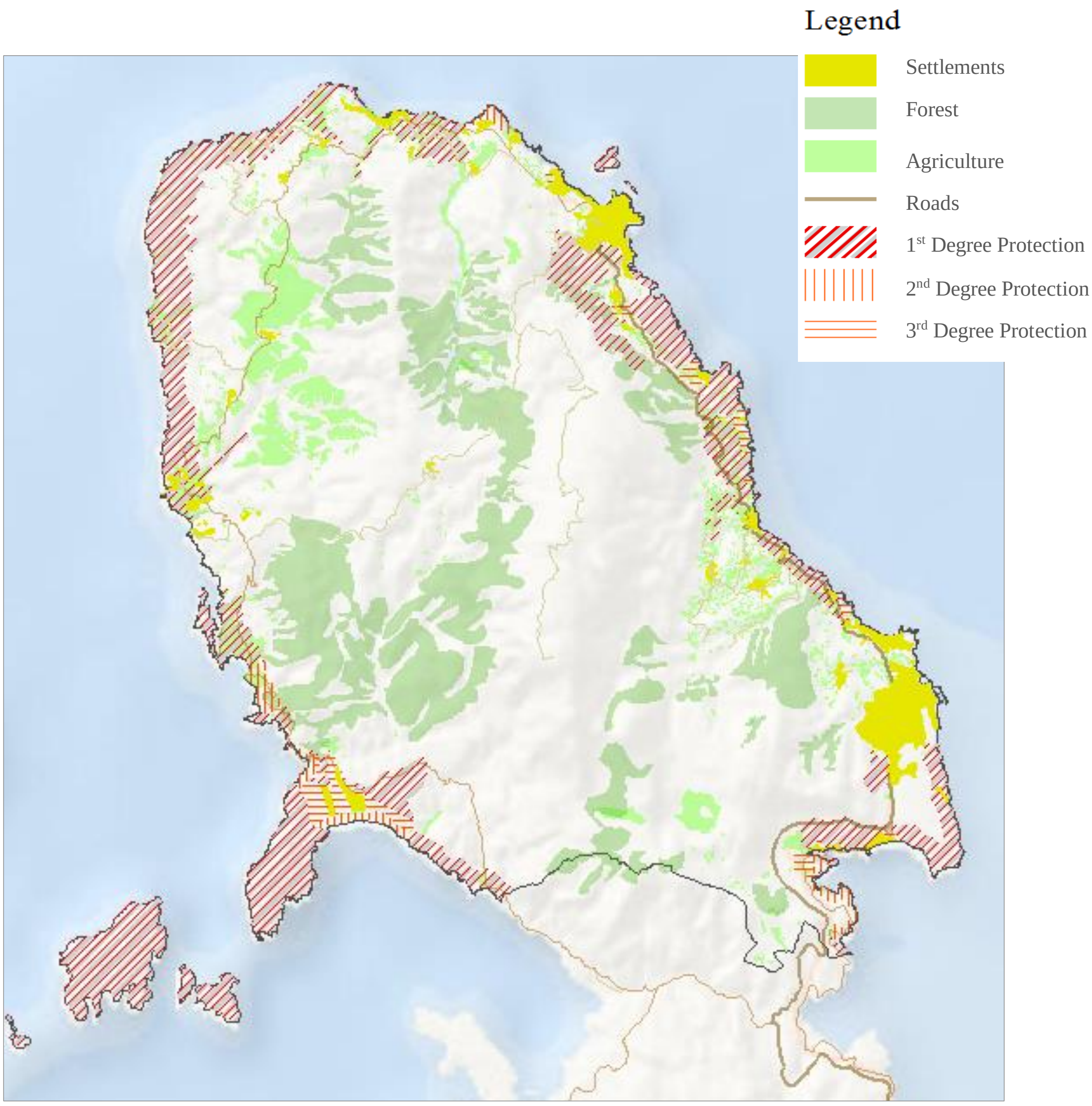

Figure 4. 2. Different degrees of preservation area
Source: Yazdani (2014)

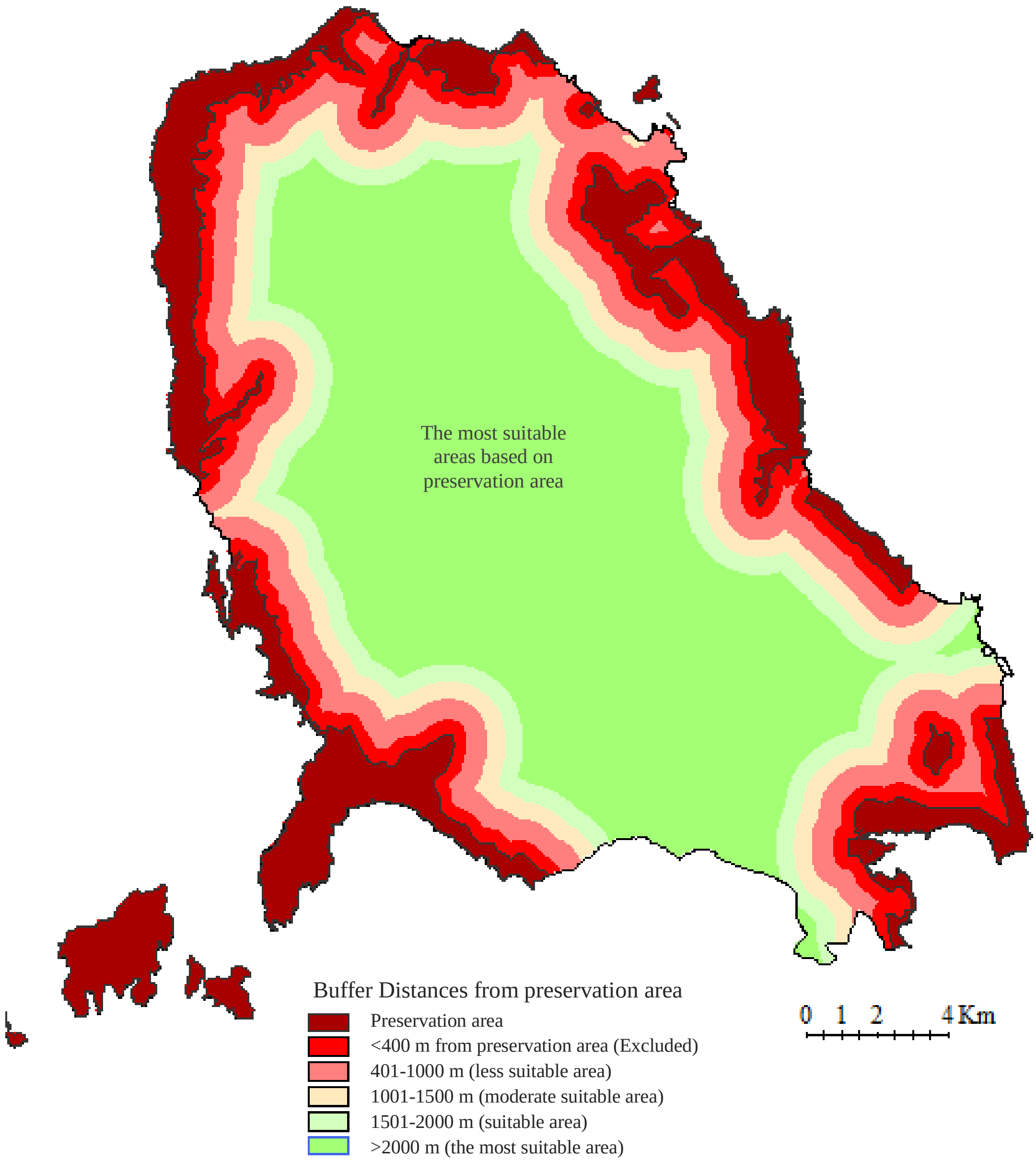

Figure 4. 3. Preservation area and its buffer distances

4. 2. 3. Settlements

Recently wind farm development has been growing rapidly. Due to the rapid growth of wind farms, in some case they are locating near to residential area. One of the important concerns in development of wind farm is the closeness of wind turbine to local residential area. The proximity of wind farms to residential area may be caused four significant problems. Noise, shadow flicker, visual aspects, and aesthetic are the major problems in wind farms development. For instance, the literatures mentioned on each of them as a problem in locating of wind turbine. Al-Yahyai, et al (2012) mentioned that the noise and vibration is one of the problems for residents. Leung and Yang (2012) focused on visual impact of wind turbines. Latinopoulos and Kechagia (2015) denoted that the noise, visual and aesthetic impact of wind turbine is the important constraint in wind farm suitability analysis. The flowing titles try to clarify each of these factors and their impacts on residents.

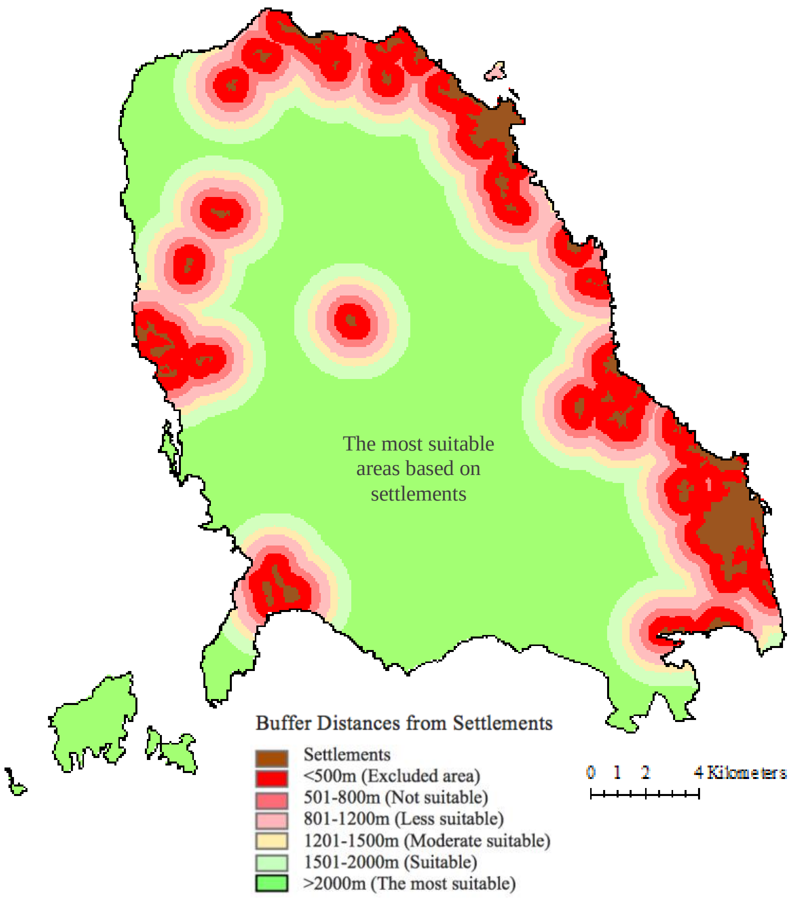

Figure 4. 4. Settlements and their buffer distances

4. 2. 3. 1. Noise

Perhaps the most important factor that may limit the installation of wind turbines in residential areas is their noises. Noise defines as unwanted sound in residential area. Wind turbine produce noise in two main ways: aerodynamic noise and mechanical noise. Although there is absence of enough evidence of its impact, aerodynamic noise is considered to be critical issue and its low frequency may cause annoyance in people lives (Leung and Yang, 2012). The positive aspect of noise among other constraint factor is its quantifiability, and there are many guideline and rules to reduce this impact. ‘Noise propagation can be explained by the logarithmic relations of sound power level at the source (L_W) and sound pressure level at a location (L_P), both measured in dB’(van Haaren & Fthenakis, 2011). The relation between L_P and distance to turbines is:

$$L_P = L_W - 10 \log_{10} (2\pi R^2) - R \quad (4.1)$$

Where:

$$R^2 = H^2 + X^2$$

H is the tower height and X is the observer’s distance to the tower. Sound pressure level at increasing distance to turbine tower is shown (figure 4. 4).

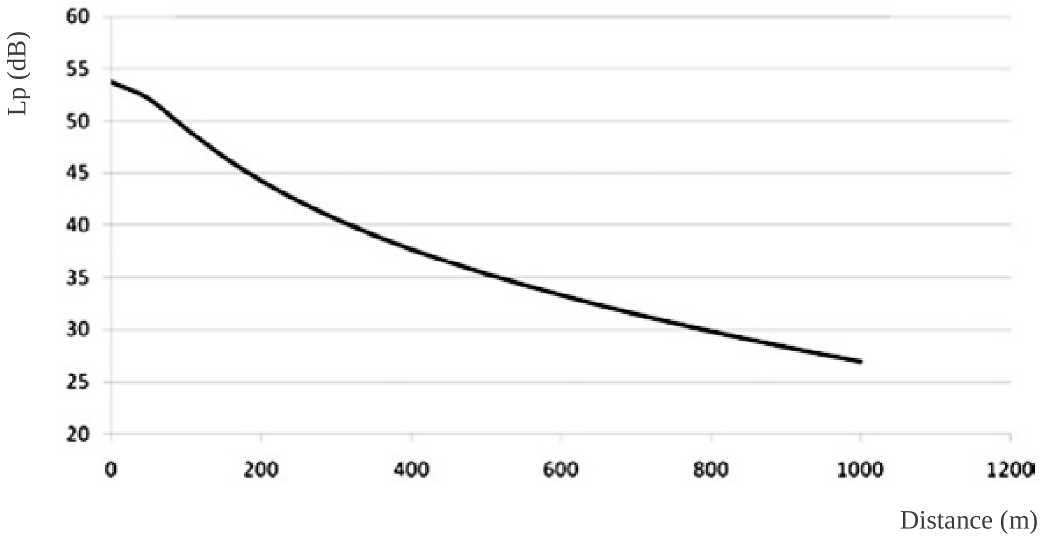

Figure 4. 5. Approximation of the sound pressure level as a function of distance to the turbine. Source: Van Haaren & Fthenakis, (2011)

The West Michigan Wind Assessment (2010) states a survey result from 691 responses and it shows that the responses in 400m distance from turbine, about 45 percent of those outside bothered by turbine noise, also bother when they are indoors, and 6 percent of them complained that turbine noise distribute their sleep. Table 4. 2, shows the reaction the residences in details.

Table 4. 1. Reaction to wind turbine noise outdoors in relation to noise level
Source: Grand Valley State University (2015)

	29-31 dB	34-36 dB	39-41 dB
Do not notice sound	80%	46%	18%
Notice, but not annoyed	14%	35%	44%
Slightly annoyed	4%	12%	20%
Fairly or very annoyed	2%	7%	18%
Number of respondents	294	318	79

Therefore, there are some suggestions for distention wind turbine to residential area. Van Haaren and Fthenakis (2011) suggest that the minimum wind farm distention from settlement boundary should not be less than 500 m. Michal SZUREK (2014) ranks the distance of wind turbine from settlement from 1 to 5. He gives zero value for less than 500m from settlements, which means the area with zero value should be excluded, and 5, which is high value for more than 2000 m, and it means the area with 5 value is the most suitable area for wind farms location.

Furthermore, it is worth noting that, as physical development of residential area is a dynamic and continuous process, it should be considered about the future development of residential area and minimum required distance of wind farms.

4. 2. 3. 2. Visual and Aesthetic

Before designation/changes of any landscape, developers should assess the visibility of the proposed scheme. Visual and aesthetic impact unlike noise is not quantifiable issue in wind farms development. In most cases, it seems that most of the people evaluate the visual impact subjectively. Some people think that wind turbine is looking impressively. While other people are opposing of this views. A relevant survey in UK has shown that more than 70% people do not have negative opinion on visual impact of wind turbine. While some others think visual effect may be negative for local tourism (Leung and Yang, 2012). Consequently, by making distance we can reduce the negative impact of wind turbine, although the size of distance is depended on the status of terrain. Aesthetic consideration of wind farms has often a significant role in assessment process. Aesthetic issue like visual impact in wind farm is subjective and some people see it positive and symbol of independent energy in local prosperity and they think that it may attract tourism. While other thinks that it may damage tourism by conflicting with the protection of historical areas (Latinopoulos & Kechagia, 2015).

4. 2. 3. 3. Shadow Flicker

Shadow flicker take place when the blades of the turbine pass in front of the sun. The location and radiation of turbine shadow is various, and it depends on the time of the day, seasons, and wind direction. Usually, shadow falls in a single building for a few minutes of the day and it may be disruptive. Shadow flicker has been a concern in wind farm planning process. “The flicker effect is a particular concern for people who suffer from photosensitive epilepsy and experience seizures in response to certain environmental triggers” (West Michigan Wind Assessment, 2010, page, 2). There is no single standard for acceptable amount of shadow flickers. To mitigate the impact of shadow flicker there are several ways; one way can be switching off when the sun is in low position, with vegetative buffers or window blinds, and by making distance from settlements (American Wind Energy Association, 2010). In this study, the last way, which is making distance between wind farm and settlements were considered (figure 4. 4).

4. 2. 4. Forest

Wind farm on forest area is one of the concerns among environmentalist. Forest fragmentation is the main concern, which is occurred when large continuous forests area divided into blocks by construction of roads, clearing for agriculture, urbanization, wind farm development, or any other human activities (Hurd et al., 2002). Forest fragmentation may damage species habitat and impact on sustainability of forest area. Denholm, et al (2009) studied the development of wind farm and its impact in different type of land such as cropland, pasture, shrub, grassland, and forestland. They found that the impact of wind farm is higher on grassland and forestland than cropland, pasture and shrub lands. For wind farm development we need road, turbine pads, and set back area, which all can be caused fragmentation in forest area. In regard to above-mentioned, in this study after identifying the forestry areas, these areas are defined as constraint areas, which are excluded from the analysis. Additionally, to minimize more the likely adverse impact of wind farm, different distance with different value is applied (figure 4. 6).

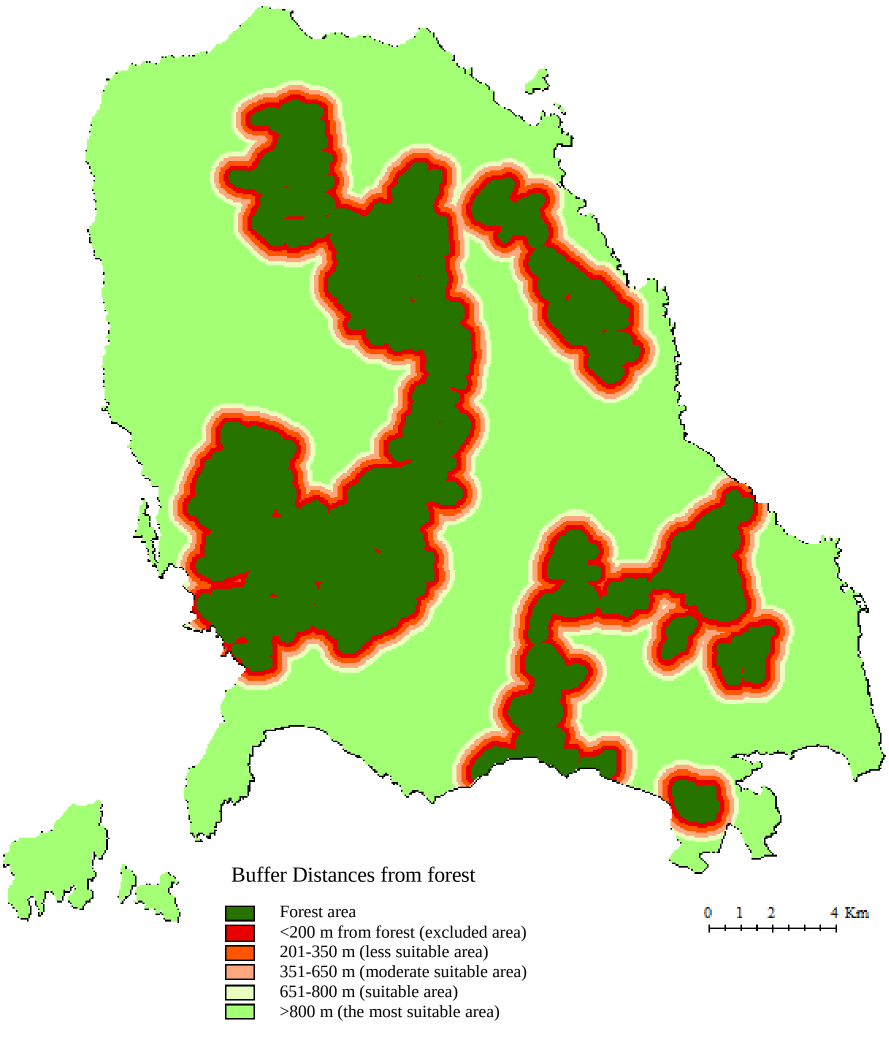

Figure 4. 6. Forest area and its buffer distances

4. 2. 5. Slope

One of the economic and technical factors, which have serious impact on land-use suitability analysis of wind farm, is land slope. The level of the land slope in land suitability for wind farm can be considered in several different ways: First, the percentage of the slope in land can affect the constructional cost, the more steepest land the more cost in construction stage (Azizi et al., 2014). According to Michal SZUREK (2014) “the land slope should be classified from the most suitable to the least suitable (0° to 2.5° is the most suitable and 10% is the least suitable) and >10% should be excluded”. Second, land slope can make difficulties in construction. The accessibility of the cranes, which is needed for heavy turbine components, is the problem in many cases. Therefore, the slope greater than 10% percent is excluded (van Haaren & Fthenakis, 2011). Third, the sharp changes in land slope can cause turbulences, thus the land slope should not be greater than 10% (Al-Yahyai et al., 2012). Regarding above explanations, in this study the land slope, which is obtained from GDEM classifies from 0 to 15% in five categories and the area with more than 15% slope is excluded (table 4. 6 and figure 4. 7).

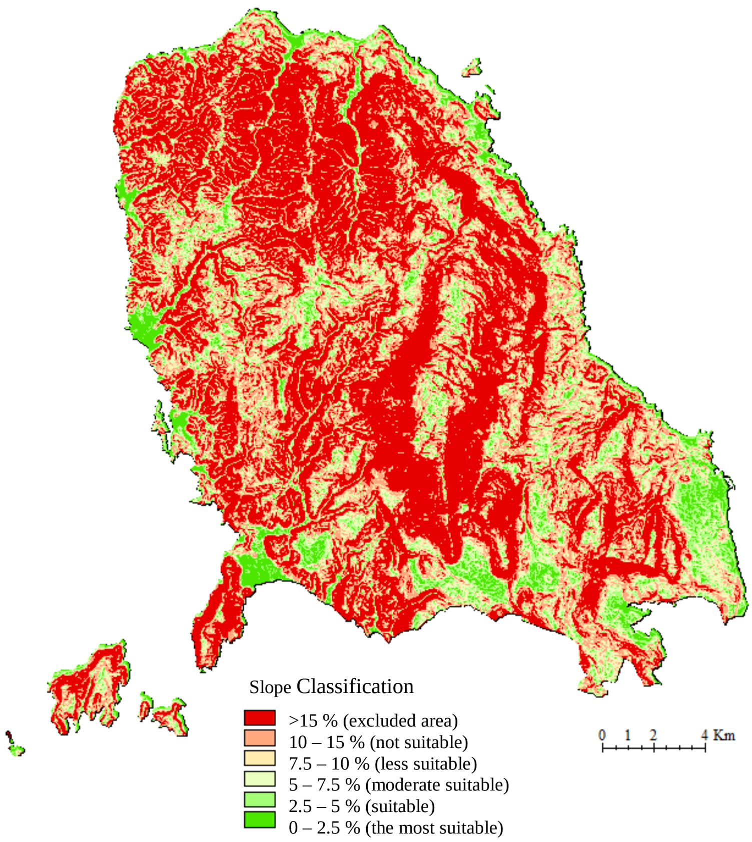

Figure 4. 7. Slope classification map

4. 2. 6. Elevation

The mountainous condition of terrain causes varies in wind speed. In flat land the wind speed changes place to place, but in mountain area, which is consist of hills, valley, river, and bluffs a complex variable of wind regime is created. Valley usually has sheltered and wind speed is low. However, all valleys are not poor wind speed. Although the valley that is in parallel to the wind flow has high potential of wind, the turbulence of wind is high in such area (Figure 4. 8). High terrain can accelerate the flow of the wind (Laura and Drews, 2011).

Karaburun Peninsula as case study area has a mountainous terrain in Izmir. It consists of valley, hill, rivers, and bluffs areas. To avoid the complexity and turbulence in wind flow the elevation of the area as a criterion layer is considered. Elevation layer, based on the condition of the terrain is classified in different value. In this layer there is no exclusion areas, and all area take the value from 1 to 5, the 1 value is less suitable while the 5 is the most suitable area in this study. Low number represent low level or bottom of the valley and the high value represent top and high elevation of areas (figure 4. 9).

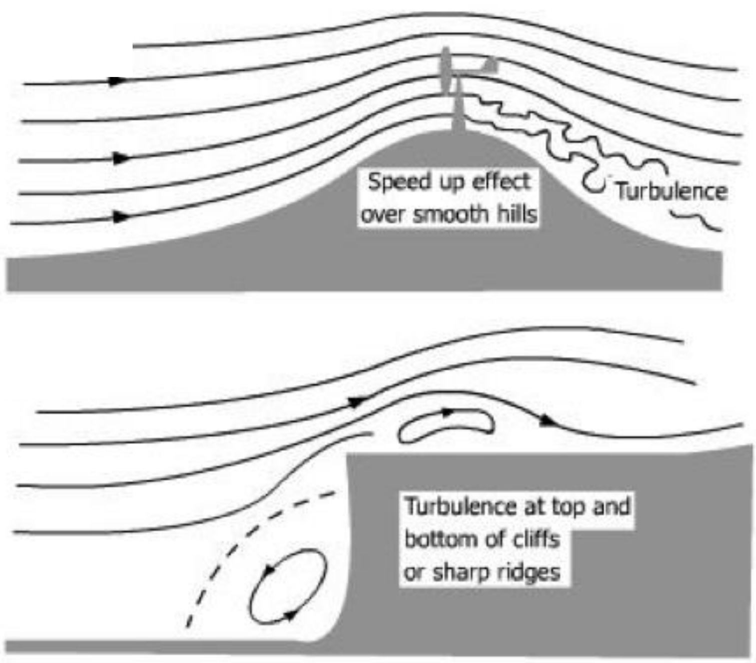

Figure 4. 8. Wind flow in different terrains and elevations
Source: Laura and Drews (2011)

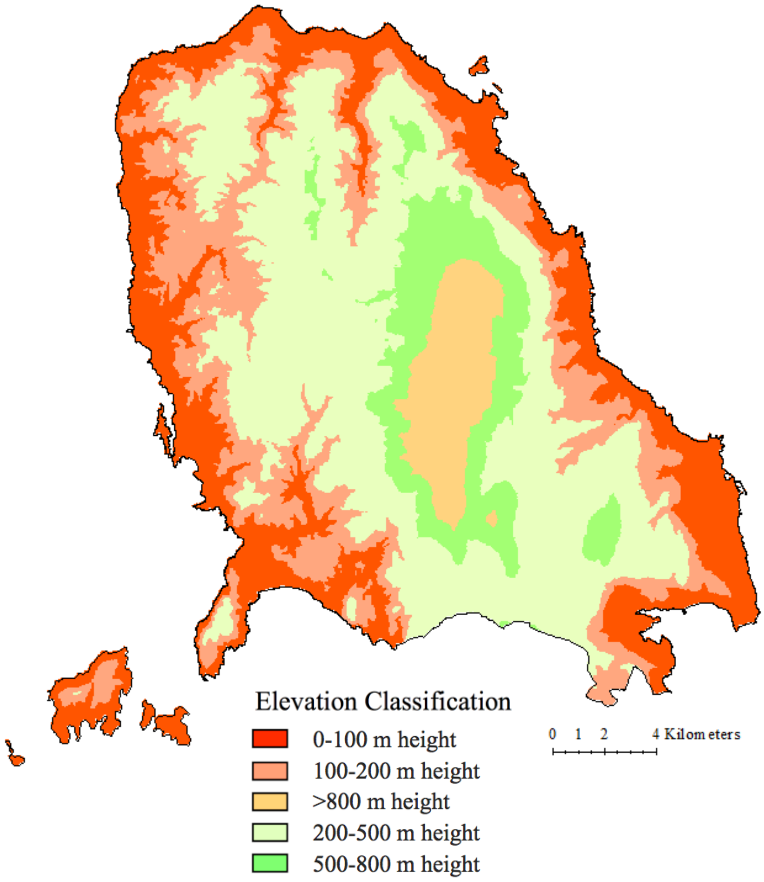

Figure 4. 9. Elevation classifications

4. 2. 7. Roads

The proximity to major transportation network is essential step in wind farm planning process (Gorsevski et al., 2013). Due to accessibility and safety transportation network in wind farm is important. Proximity to transportation from two viewpoints should be analyzed:

The loud noise and shadow of turbine blade affect on transportation network. Therefore, wind turbines should have proper distance and location from roads. Furthermore, it may change in visual landscape.

Due to the enormous weight of the equipment of wind turbine, it should be as much as possible closeness of the road. The cost of transportation establishment will be minimized (Azizi, Malekmohammadi, Jafari, Nasiri, & Parsa, 2014).

Articles suggest different distances from road for location of wind farm. Al-Yahyai, et al (2012) suggest that suitable location should not exceed from 10 km far away, and less then 500m close to main road because of safety consideration. The distance should not be more than 10 km and less than 1km (Gorsevski et al., 2013). In regard to these points of view, the proximity of wind farm from transportation network is important in suitability analysis.

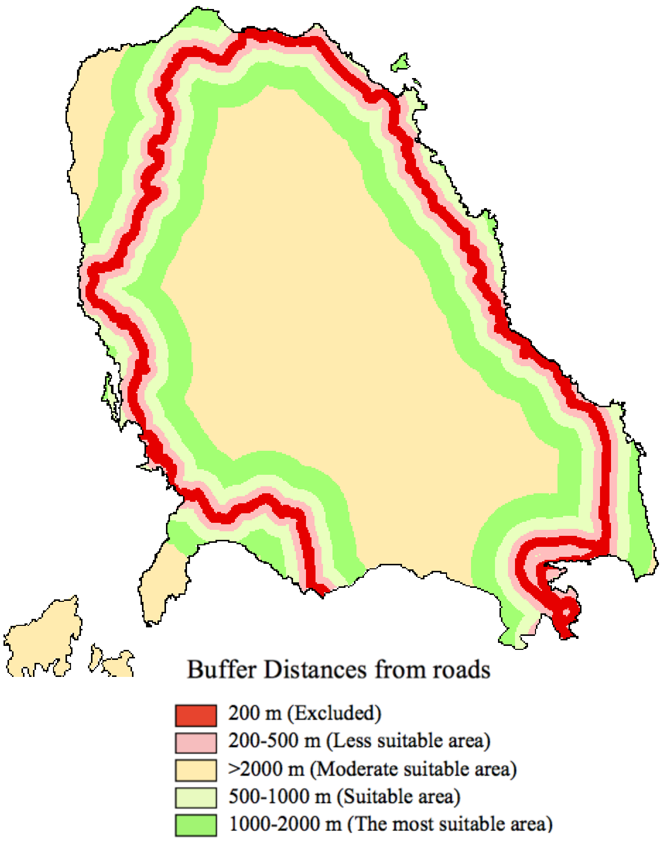

Figure 4. 10. Roads' buffer distances

4. 2. 8. Agriculture Area

Among other type of land cover, agriculture area seems more compatible with wind farm development. Several positive effect of wind farm development can be considered. Wind farm development in agriculture area can make alternative income stream for farmer, bringing down the higher CO2 air, stir the air, increasing nighttime temperature, decreasing daytime temperature and enhancing the evaporation. According to Takle (2014) whose is a professor of Climate Change and Atmospheric Science, "One of the effects of turbines is they stir the air, so the crop, the corn canopy itself is drawing down the carbon dioxide level in that part of the atmosphere so within the crop it’s getting lower and lower, so the extra turbulence brings down this higher CO_2 air from above and promoting more photosynthesis within the crop during the daytime period. So it’s a good thing and it looks like the turbines from our measurements are actually having a beneficial effect. Other benefits of turbines are increase nighttime temperatures, decreased daytime temperatures, and enhanced evaporation”.

There are concerns about negative impact of farm development in agriculture area. Usually, agriculture area is the field, which is mostly private. In most cases it is not large enough to develop wind farm project. The consensus among all property owners is a concern in projection of wind farms. The other concern is the properties values. There is an argument, which says that wind farm development may have negative affect on properties value, although some other believe that it may has positive impact on properties value (Energy department of Republic of South Africa, 2012). To identify the impact of wind farm it needs a deep research and investigation of wind farm in agriculture area. In this study, agriculture area is defined as second suitable area for wind farm after the other land area, which is out of the chosen criteria (figure 4. 10).

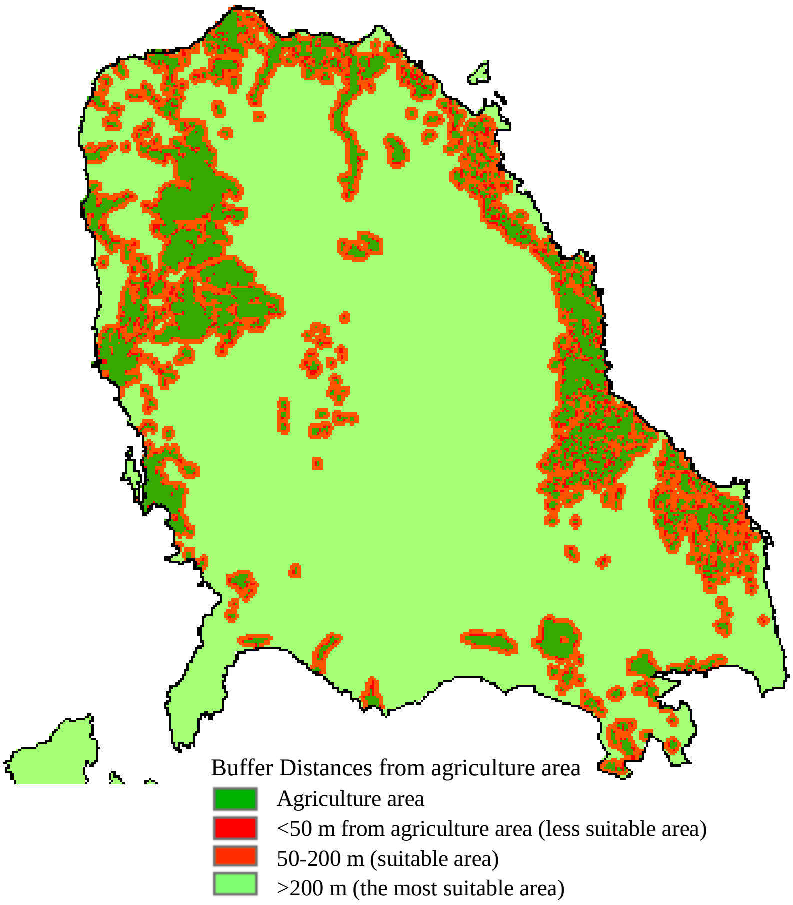

Figure 4. 11. Agriculture area buffer distances

Table 4. 2. Classification of single criterion pixels value (m)

Criteria	0 (Excluded area)	1	2	3	4	5
Wind Potential	-	6-7	7-7.5	7.5-8	8-9	>9
Distance from protection area	<400	400-1000	-	1000-1500	1500-2000	>2000
Distance from Settlements	<500	501-800	801-1200	1201-1500	1501-2000	>2000
Distance from Forest	<200	201-350	351-500	501-650	651-800	>800
Slope	>15°	10°-15°	7.5°–10°	5°–7.5°	2.5°–5°	0° – 2.5°
Elevation	-	0-100	100-200	>800	200-500	500-800
Distance from Roads	<200	-	200-500	>2000	500-1000	1000-2000
Agriculture	-	<50	-	-	-	>200

Different classification fulfill in each criterion. All the distances for criteria determine based on literature reviews. Overall criteria take 6 different values, which are started from 0 to 5. Each value illustrates the level of suitability in each pixel of raster maps. The pixels, which are taken 0 value, defined as unsuitable and restricted area, thus they are excluded from analysis. 1 is the least suitable, while 5 is the most suitable area for wind farm developments (Latinopoulos and Kechagia., 2015; Michal SZUREK, 2014; Al Yahyai, 2012; Gorsevski et al., 2013).

4. 3. Criteria Weights

After identifying the influential criteria (table 4. 3), one of the critical steps is determining the relative importance or the weighting of individual criteria. Recently, different weighted methods are used to determine the weights of criteria (chapter 2. 2. 2). In this study, AHP as a most popular and structured method is used (chapter 2. 2. 3).

Base on AHP, developing the weights for criteria require four basic steps:

- Developing a pairwise comparison matrix for each criteria
- Normalizing the resulting matrix
- Averaging the values in each row to get the corresponding rating
- Calculating the consistency ratio

The above steps are fulfilled as following:

Table 4. 3. Influential Criteria

C1	Wind Potential
C2	Preservation area
C3	Distance from Settlement
C4	Forest
C5	Slope
C6	Elevation
C7	Distance from main road
C8	Agriculture

First step: Developing the value for each criteria and pairwise comparison matrix. The value or the relative importance of each criterion than other criteria is determined based on experts' opinion and literature review (table 4. 4). The experts that participate in this study were planners, environmentalist and civil engineer (Assoc. Prof. Dr. Semahet OZDEMIR, Assist. Prof. Dr. Omur SAYGIN planners, Dr. Rahim MOLYEA environmentalist and Dr. Musa ALAMI civil engineer).

Table 4. 4. The criteria in the row is being compared to the criteria in the column

	C1	C2	C3	C4	C5	C6	C7	C8
C1	Equal	Equal	Moderate important	Strongly important	Very strongly important	Very strongly important	Very strongly important	Extremely important
C2	Equal	Equal	Equal	Strongly important	Very strongly important	Very strongly important	Strongly important	Extremely important
C3	Moderate less important	Strongly less important	Equal	Strongly important	Strongly important	Very strongly important	Strongly important	Extremely important
C4	Strongly less important	Very strongly less important	Strongly less important	Equal	Strongly important	Strongly important	Strongly important	Very strongly important
C5	Strongly less important	Very strongly less important	Strongly less important	Strongly less important	Equal	Equal	Moderate less important	Strongly important
C6	Very strongly less important	Very strongly less important	Very strongly less important	Strongly less important	Equal	Equal	Moderate less important	Strongly important
C7	Very strongly less important	Strongly less important	Strongly less important	Strongly less important	Moderate important	Moderate important	Equal	Strongly important
C8	Extremely less important	Extreme less important	Extremely less important	Very strongly less important	Strongly less important	Strongly less important	Strongly less important	Equal

Matrix:

The bellow matrix (1) shows a simple pairwise comparison between n number of criteria (Gow-Hshiun Tzeng, 2011).

$$W_j = \begin{bmatrix} C_{11} = 1 & C_{12} & C_{1n} \\ C_{21} & C_{22} = 1 & C_{2n} \\ C_{n1} & C_{n2} & C_{nn} = 1 \end{bmatrix} \quad (4.2)$$

Base on matrix (1) and (table 4. 5), the following matrix is prepared. This matrix tries to develop a completed pairwise comparison between all 8 selected criteria (figure 4. 12).

W_j =

	C1	C2	C3	C4	C5	C6	C7	C8
C1	1	1	3	5	7	7	7	9
C2	1	1	1	5	7	7	5	9
C3	0.33	0.2	1	5	5	7	5	9
C4	0.2	0.14	0.2	1	5	5	5	7
C5	0.14	0.14	0.2	0.2	1	1	0.33	5
C6	0.14	0.14	0.14	0.2	1	1	0.33	5
C7	0.14	0.2	0.2	0.2	3	3	1	5
C8	0.11	0.11	0.11	0.14	0.2	0.2	0.2	1
Sum	**3.06**	**2.93**	**5.85**	**16.7**	**29.2**	**31.2**	**23.8**	**50**

Figure 4. 12. Developed matrix of the pairwise comparison of the criteria

Table 4. 5. Illustrates the scale of importance between two pairs. Each numbers, which is started from 1 to 9, has the value of equal importance to extremely importance between each pairs.

Table 4. 5. Scale for comparison
Source: Saaty (1987)

1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extremely importance

Second step: Normalization of the resulting matrix.

a. Sum of the values in each column of the pair-wise matrix (figure 4. 11)

$$C_i = \sum_{i=1}^{n} C_i$$

$$C_i = [C_1 + C_2 + C_3 + C_4 + C_5 + C_6 + C_7 + C_8]$$

b. Dividing of each column in the matrix by its total to generate a normalized pair-wise matrix (table 4. 6)

$$X_i = \frac{C_i}{\sum_{i=1}^{n} C_i}$$

Third step: Dividing the sum of normalized column of matrix by the number of criteria used (n) to generate weighted matrix (table 4. 5).

$$W_i = \frac{\sum_{i=1}^{n} X_i}{n} \quad (4.3)$$

Forth step: Calculating the consistency ratio

$$CR = \frac{CI}{RI} \tag{4.4}$$

Where:

CI is the consistency index and RI is a random index.

In practice CR ≤ 0.1 is acceptable (Saaty, 1978). In this study the consistency ratio (CR) is 0.1, according to Saaty (1978) it is acceptable.

The result of the overall normalized value, criteria weights (averages), and consistency ration is shown in (table 4. 7). And (table 4. 6) represent the obtained individual criteria weights that applied in weighted overlay analysis in GIS environment.

Table 4. 6. Criteria weights

Criteria	Weight (%)
Wind Potential	30
Preservation area	25
Distance from Settlement	18
Forest	11
Slope	5
Elevation	4
Distance from roads	5
Agriculture	2

Table 4. 7. Standardization/normalization, average/weights, and consistency

Criteria		C1	C2	C3	C4	C5	C6	C7	C8	Total	Average	Consistency
C1	Wind Potential	0.32	0.34	0.51	0.29	0.23	0.22	0.29	0.18	2.38	0.29	Cr = 0.1
C2	Preservation area	0.32	0.34	0.17	0.29	0.23	0.22	0.21	0.18	1.96	0.25	
C3	Distance from Sett	0.1	0.06	0.17	0.29	0.17	0.22	0.21	0.18	1.4	0.17	
C4	Forest	0.06	0.04	0.03	0.05	0.17	0.16	0.21	0.14	0.86	0.107	
C5	Slope	0.04	0.04	0.02	0.01	0.03	0.03	0.01	0.1	0.29	0.036	
C6	Elevation	0.04	0.04	0.02	0.01	0.03	0.03	0.01	0.1	0.28	0.035	
C7	Distance from roads	0.04	0.06	0.03	0.01	0.09	0.09	0.04	0.1	0.47	0.058	
C8	Agriculture	0.03	0.03	0.01	.008	0.007	.006	.008	0.02	0.119	0.015	
Sum		1	1	1	1	1	1	1	1			

4. 4. Weighted Overlay Operation

"Overlay analysis is a group of methodologies applied in optimal site selection and suitability modeling" (Trodd, 2005). Suitability models identify the most preferred location for a specific phenomenon. There are three major overlay approaches in GIS environment; Weighted Overlay, Weighted Sum, and Fuzzy Overlay. Each of them has different assumptions. The most appropriate approach is depended on the problems, which is being solved. Weighted Overlay analysis unlike to other approaches can re-scale back the value to a defined scale. Therefore, the most suitable or restricted site can be determined in a simple operation. The assumption of the Weighted Overlay is that the higher number of value is the suitable and the less number of values represent the restricted area. In this study, Weighted Overlay is applied to solve multi criteria problem thus to identify the most suitable site for wind farm development within the study area. Weighted Overlay analysis follows by these steps (Esri, 2015).

- Defining the problem
- Breaking the problem into sub-models
- Determining significant layers
- Reclassify the data within a layer
- Weighting the input layers
- Combining the layers

This study follows all above steps in an appropriate order. First, the problem is defined and broken into sub-models (chapter 1). Then all criteria as layers are identified and reclassified (chapter 3). Weighting the input, which was the most critical one, determined by applying the AHP as multi-criteria analysis (chapter 4). Finally Weighted Overlay combines the entire weighted layers to identify the suitable area for wind farm development within the study area (figure 4. 13). An overall sample example of Weighted Overlay operation is shown below (figure 4. 12).

The overall suitability (S_i) is obtained by multiplying the sum of relative importance or weights of criteria (i) and the standardized score of cell (j) for factor (i).

$$S_i = \sum_{i=1}^{n} W_i \times C_{ij} \qquad (4.5)$$

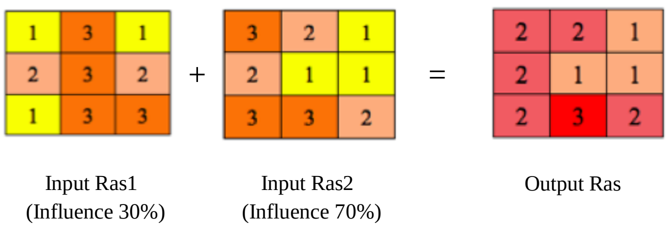

Figure 4. 13. Weighted Overlay model

Where:

S	Score of final map
W_i	Weight for criterion Ci
C_i	Value of criterion i
i	Number of criteria from 1 to n

The suitability (S_i) for wind farm development in Karaburun Peninsula is formulated as bellow:

$$S_i = (W_{Po}C_{Po} + W_{Pro}C_{Pro} + W_{sett}C_{sett} + W_{fore}C_{fore} + W_{slope}C_{slope} + W_{elev}C_{elev} + W_{roads}C_{roads} + W_{agri}C_{agri})$$

i = 8

4. 4. 1. Suitability Result

Below map represent different levels of land suitability for wind farm development in the study area. As it is shown in (figure 4. 13) a significant part of the study area (354 Km^2, which is about 81% of total study area), with respect to the selected criteria weights (table 4. 5), identified as a restricted site and they are excluded. The most suitable area is located in Northwest and central part of the Peninsula, cover 6.7 Km^2. The suitable area that is located in central part of Peninsula, cover about 50 Km^2, and in study area it is the largest area for wind farm developments. The moderate and less suitable areas are located is mostly located in boundary of restricted zone, and they cover about 24 Km^2 (figure 4. 14).

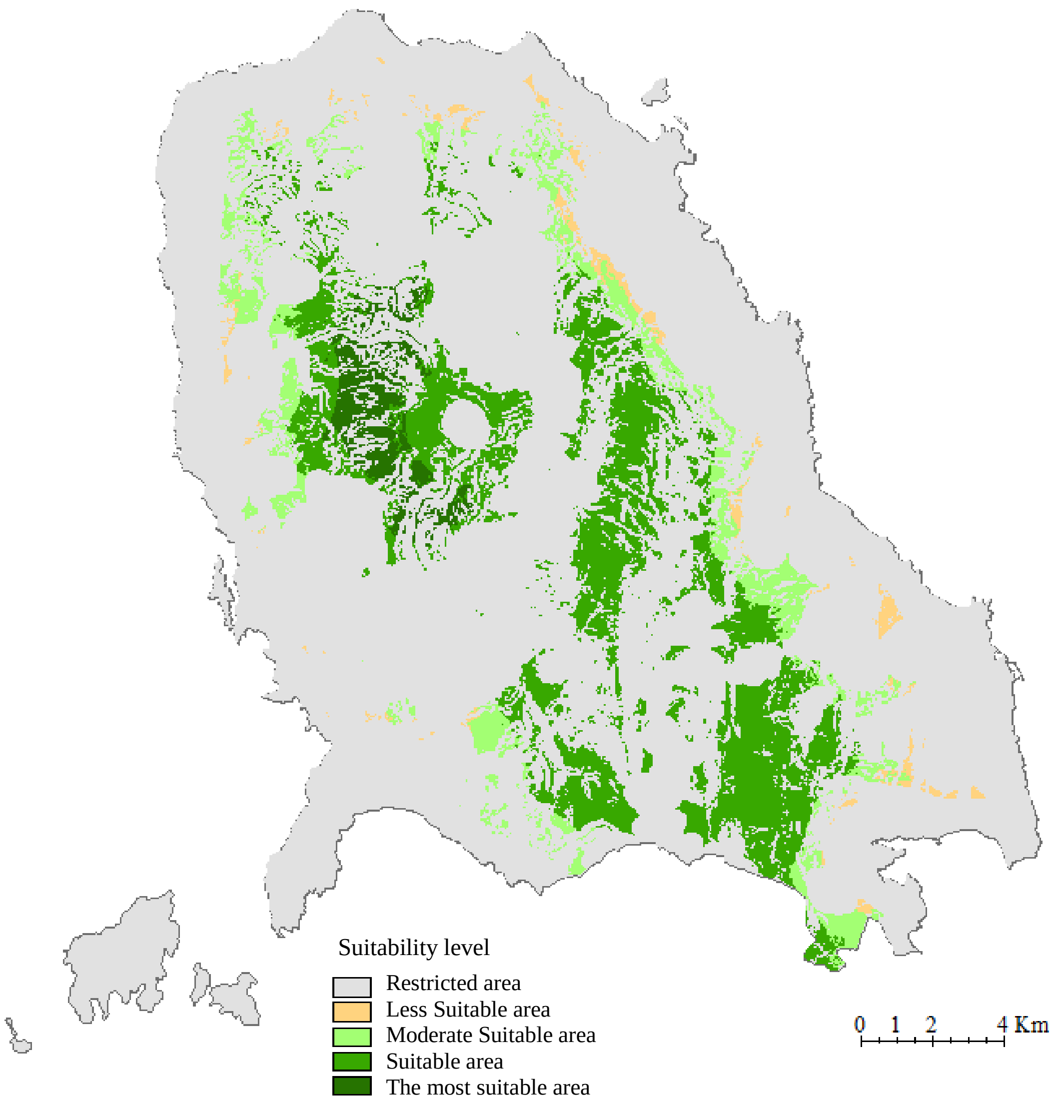

Figure 4. 14. Suitability map for wind farm development in Karaburun Peninsula

4. 4. 2. Suitability Map Based on Equal Importance of Criteria

Suitability analysis for wind farm siting in regard to equal weights for overall criterion has been analyzed. In compare to the suitability map with different weights, the most suitable area has been sharply decreased (from 6.7 Km^2 to 0.82 Km^2). The suitable area in terms of size and location does not change significantly (just it change from 50 Km^2 to 56.2 Km^2). The changes in moderate suitable and less suitable are also the same as the suitable area; it is changed, but not significant (from 24 Km^2 to 28 Km^2 in equal weights criteria) (figure 4. 15).

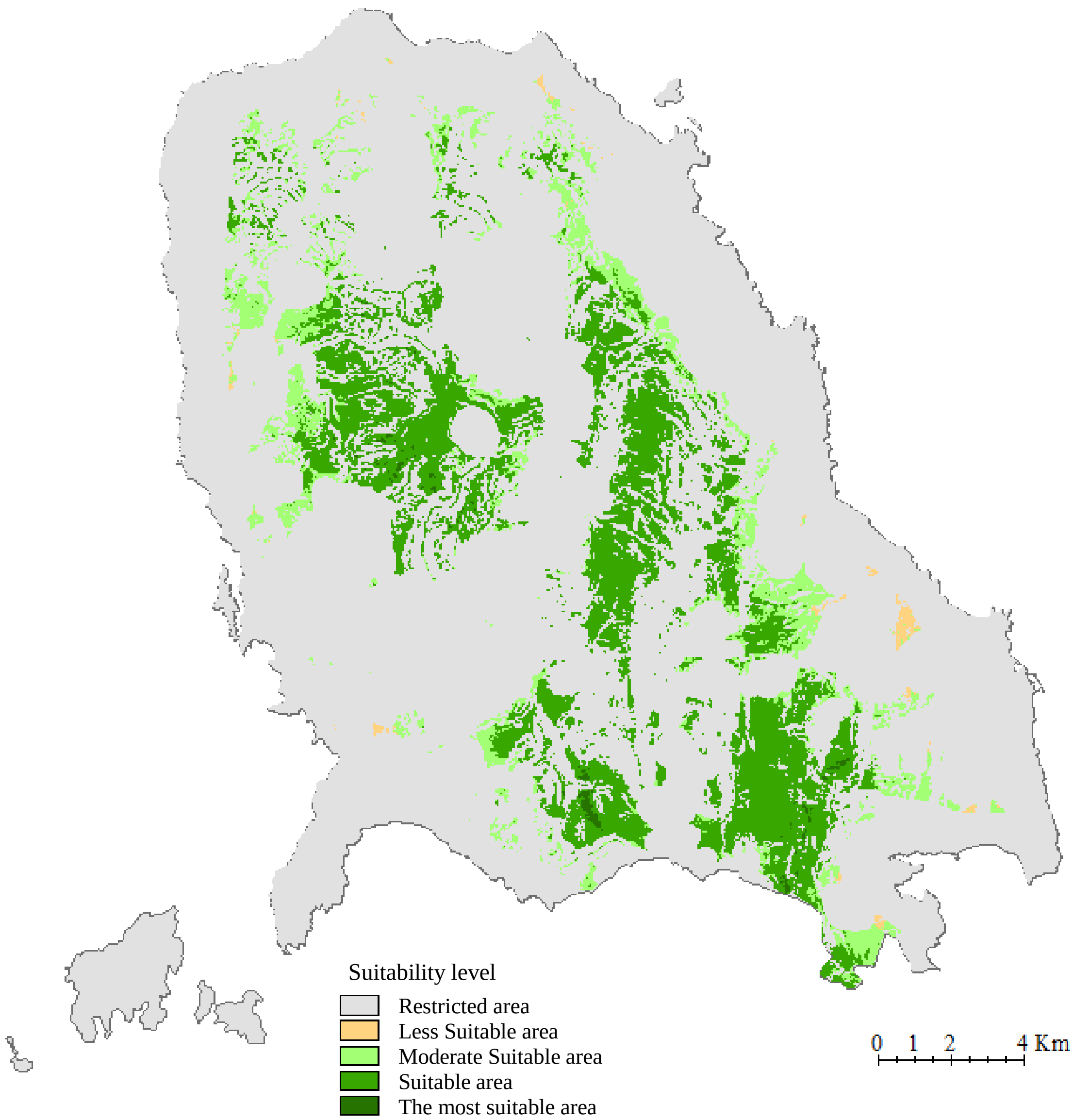

Figure 4. 15. Suitability map based on equal importance weights

4. 5. The Existing Wind Farms

In Peninsula two type of wind farms can be distinguished; existing wind farms, which area already exist and licensed wind farms. Based on this study, most of the existing wind turbines (50 turbines) located in suitable area, but in Modogan the turbines are in conflict with the suitable. Thirty turbines are located in unsuitable area. The licensed wind turbine also has such a problem. They are mostly in conflict in Northwest part (around Sarpıncık) village (figure 4. 17).

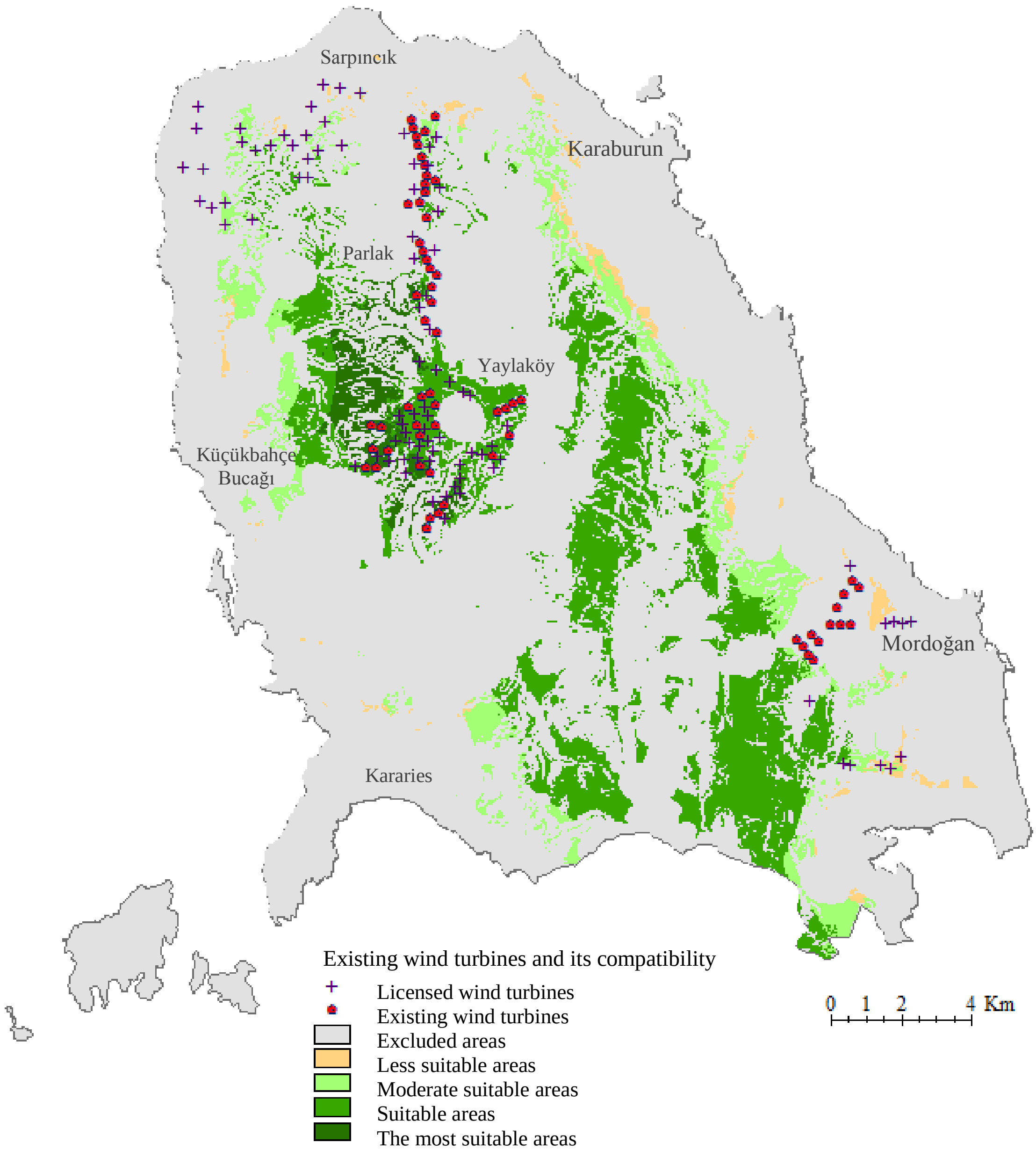

Figure 4. 16. Existing wind farms and their compatibility with identified suitable area

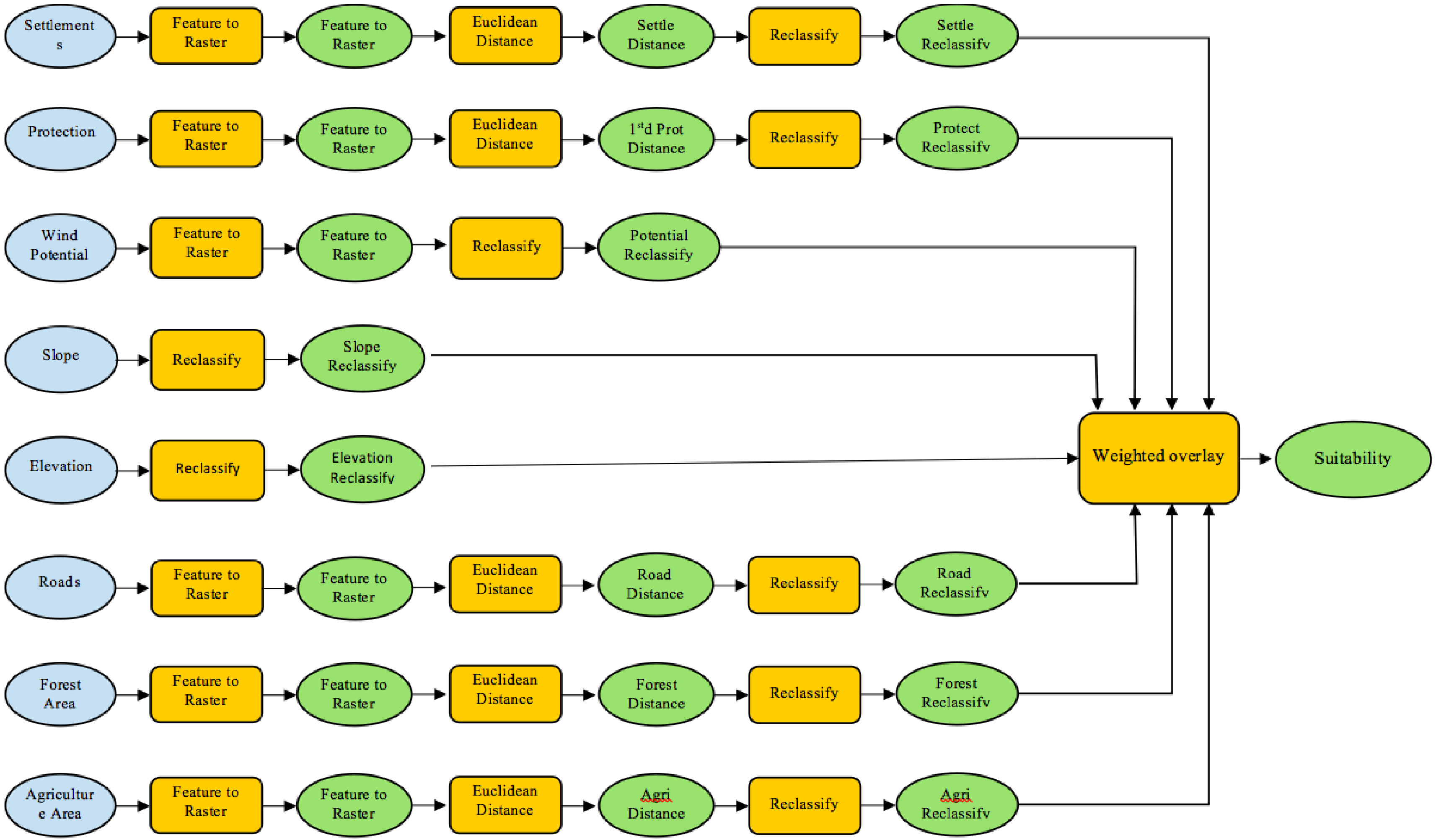

Figure 4. 17. The process model for land suitability analysis of wind farms development in the case study area

CHAPTER 5

DISCUSSION AND CONCLUSION

5. 1. Discussion

Although wind energy generation is one of the possible ways for future energy demand and reducing the environmental pollution, there are several planning and environmental conflicts. It is always a question “how to best balance between the environment we want and the energy we need” (Warren et al., 2005). In regard to that this study applied GIS-based multi-criteria approach to identify suitable site for wind energy development, thus to minimize the conficts between environment and wind energy generations. Identification and evaluation of the criteria, method and tools, and overall suitability/outcome of the study can be the significant issues to be discussed.

Land-use suitability analysis of wind farms requires a comprehensive study of multiple factors. The factors in land-use analysis of wind farms as an interdisciplinary term contain environmental, economic, technical, and social parameters. Regarding that this study considered on eight different factors, which are consisted of environmental (preservation area, forest area and agriculture area), economic and technical (wind potential, slope, elevation and proximity to roads), and social (proximity to settlement), to identify the most suitable site for wind farms development in the study area. Although identification of the criteria in land-use suitability analysis depend upon the viewpoint of analysts and the location of site, in this study with respect to the location of the study area the criteria were identified and selected based on the literature review, experts’ opinion (planners and environmentalist) and the local data availability. For further studies, the integration of environmental, economic and social factors need more deep studies. Social negotiation and participation in planning stage is one the appropriate ways to recognize the most influential factors. To determinate the weight for each criterion, AHP has been found as a flexible and easy to implement method. To combine the overall criteria, GIS as a powerful tool can contribute the analytical process.

Multi-criteria decision-making (MCDM) method as a set of techniques was implemented. The framework of MCDM method includes several numbers of approaches, and they are still increasing. The critical point for implementing of the MCDM method was the selection of an appropriate method to identify suitable sites for wind turbines. All MCDM method has its own characteristics and none of them could apply for all problems. For decision makers it is difficult to decide whether one of the MCDM is perfect than others. However, most of the studies used the AHP as a most popular and structured method for land-use suitability analysis. In this study, based on literature review and the applicability of the method, AHP has found as an appropriate method to determine the individual criterion weight. Despite of using AHP in regional scale, as a flexible method AHP can be applied for different purpose of planning in different scales. In short, AHP has been found as a proper and easy to implement method for identifying the weights of multiple criteria in suitability analysis of wind farm developments.

In land suitability analysis two types of data were expected to be analyzed; spatial and attribute data. GIS as an integrated technology system had the ability to operate both spatial and attribute stored type of the data/criteria. GIS with its functionality that includes four main components such as data input, storage and management, manipulation and analysis, and data output and its overall aim provides support for decision-making has concerned with spatial pattern and process problems. In this study different type of data with different resolutions were gathered and used. The functionality and the ability of GIS were allowed the study to use the already prepared data, manipulate the data and to create new data/criteria. Therefore, it was found that the GIS system is a powerful tool for land suitability analysis of wind farms. The system was able to solve the multiple and conflicting planning objectives and factors while selecting optimal locations for wind farm developments.

The outcome determined five degree of land suitability (the most suitable, suitable, moderate suitable, less suitable, and not suitable) for wind farm development within the study area. The most suitable area is in low percentage of all study area 1.7%, which is mostly located in northwest part of the Peninsula. The suitable area is noticeable; it covers about 12% of the study area, which is dispersed except coastal line and settlements in all part of the Peninsula. The Moderate and less suitable area cover 4% and 1.5% which are mostly located between suitable area and unsuitable area. Although in terms of wind energy overall Peninsula has enough wind speed, based on this study the large part (80%) of the Peninsula is identified as not suitable area for wind farm developments. Furthermore, in some parts especially in Mordogan there is a conflict between existing wind farm location and identified suitable area. The existing wind turbines in Mordogan, which are located on not suitable area, is close to the settlements and forestry area, but in most area the existing wind farms are in compatible with the identified suitable area.

To sum up, the presented methodology could be applied to different planning problems with multiple involved factors, and it allows the decision maker to incorporate a variety of criteria and constraints. The criteria, which were considered in this study, were consisted of the available layers. For further studies in wind farm development, it could be considered more detailed criteria. The tool (GIS) is also applicable to other studies and particularly in land suitability analysis of wind farm in other potentially suitable site of Turkey and it can apply for different scales (local, regional and nation).

5. 2. Conclusion

Recently, selecting the optimal location for wind energy projects have become a controversial subject among developers, environmentalists and the local peoples. Regarding this matter, this study proposed a GIS-based multi-criteria approach to identify the most potentially suitable location for wind farm developments. The framework of the study comprised five significant issues; the method of study, which is multi-criteria decision making approach in the context of AHP, identifying the most influential criteria for land suitability analysis of wind farms, weighted overlay operation in GIS environment, findings and outcome of the study, and finally testing the compatibility of the exiting wind farms location with the output of the study within Karaburun Peninsula. The overall statements of the study can be summarized in two significant subject matters; (a) identifying and evaluating the influential criteria and (b) integrating the identified criteria to obtain the overall suitability results.

The critical stage in this study was identification of the criteria. Based on literature review, experts' opinion and availability of the data the most influential criteria identified. To determine the level of importance/weight of each individual criterion, pairwise comparison in the context of AHP implemented. Weighted overlay operation in GIS environment was applied to integrate and combine the overall criteria, thus to obtain the suitability result. Regarding to the consequences of this study, for future studies the identified criteria for land-use suitability analysis of wind farm development is not sufficient. The detailed bird migration routes, specified and detailed local in danger species and avian, the negative impact of wind turbine on ecosystem by deep evaluating and monitoring, fault line, water body, and also by public participation and negotiation in planning stage it could be found some other criteria that local people may found it harmful should be considered. The presented methodology (AHP) as one of the most popular approach in MCDM has found a flexible, well documented and easy to implement method for weighting of the multiple criteria involved in an analysis. For further studies in the context of land suitability analysis, even the number of criteria become in high number, AHP can be applied. Despite of the environmental sensitivity of the area the outcome of the study indicates that 20% of the area is suitable for wind farm developments. Additionally, in some part of the study area there are conflicts between existing wind farm and presented suitable sites.

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