ENVIRONMENTAL IMPACT AND CAPACITY ANALYSIS OF RENEWABLE ENERGY RESOURCES: CASE STUDY OF WIND ENERGY IN TURKEY

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ABSTRACT

ENVIRONMENTAL IMPACT AND CAPACITY ANALYSIS OF RENEWABLE ENERGY RESOURCES: CASE STUDY OF WIND ENERGY IN TURKEY

The majority of electricity in Turkey is generated from coal and natural gas; however, renewable energy, especially wind power, is a promising energy source for Turkey. Development of new wind energy project requires complex planning process involving many social, technical, economic, environmental, political concerns and different agents such as investors, utilities, governmental agencies or social groups. To address the proper site selection, a Geographic Information System (GIS) based Multi-Criteria Decision-Making (MCDM) method has been used in previous studies. The aim of this study is to develop a GIS-based multi-criteria decision making application which can be updated by the changing regulations to identify potential sites for wind power plants in Turkey. A variety of constraints and factors were identified based on a literature review, regulations and gathered from variety of agencies. After excluding of infeasible sites, pairwise comparisons was carried out using analytic hierarchy process (AHP) as MCDM method by the study group to estimate relative importance of the criteria. The suitability map obtained from MCDM analysis was divided into four classes from the low suitable to extremely suitable area. As a final stage, decision making was carried out with the objectives by environmental impact approach.

The output of this study can be used by energy planners to estimate the extent that wind energy can be developed based on public perception, administrative and environmental aspects.

Keywords: Environment, Energy, Wind, Geographic Information System, Multi-Criteria Decision-Making, Analytic Hierarchy Process, Turkey

ÖZET

YENİLENEBİLİR ENERJİ KAYNAKLARININ ÇEVRE ETKİSİ VE KAPASİTE ANALİZİ: TÜRKİYE RÜZGAR ENERJİLERİ UYGULAMASI

Türkiye, enerjisinin büyük bir çoğunluğunu kömür ve doğalgazdan karşılanmasına rağmen, yenilenebilir enerji özellikle rüzgar enerjisi, Türkiye için gelecek vadeden teknolojilerdendir. Ancak rüzgar enerji santrallerinin yer seçimi çok boyutlu bir süreçtir ve planlama aşaması çoklu kriterler ve farklı karar verici mekanizmaları kapsar. Bu aşamayı kolaylaştırmak adına Coğrafi Bilgi Sistemi (CBS) tabanlı Çok-Kriterli Karar Verme yöntemi yaygın olarak kullanılmaktadır. Bu çalışmanın amacı, Türkiye için sosyal, teknik, ekonomik, çevresel ve politik kriterleri bir araya getirerek kanun ve bilimsel gerçeklere dayalı yasalar değiştikçe değişebilecek bir karar verme mekanizması geliştirmektir. Yer seçim analizi için kullanılmış kriterler, literatür araştırmasına ve yürürlükteki yasalara göre belirlenmiştir; ayrıca veriler çok farklı kaynaklardan tedarik edilmiştir. Bu kriterlerin önem derecelerini belirlemek için, çiftli karşılaştırma tekniğine dayanan Analitik Hiyerarşi Süreci (AHS) metodu uygulanmıştır. Bu adımda CBS kullanılarak, kurulubilecek rüzgar çiftlikleri için uygun alanlar belirlenmiştir. Elde edilen sonuçlar işletmedeki rüzgar santrallarındaki türbinlerin konumuyla karşılaştırılmıştır. Elde edilen uygunluk haritası, uygunluk indekslerini dört eşit aralığa bölecek şekilde en az uygundan en çok uyguna kadar sınıflandırılmıştır. En son aşamada ise, çevre dostu bir yaklaşımla karar verilmesi durumunda Türkiye'nin uygun yerleri değerlendirilmiştir. Bu çalışmanın çıktılarının proje geliştiricilerinin kullanımına uygun olduğu düşünülmektedir.

Anahtar kelimeler: Çevre, Enerji, Rüzgar, Coğrafi Bilgi Sistemi, Çok-Kriterli Karar Verme Metodu, Analitik Hiyerarşi Süreci, Türkiye

To my family..

Aileme..

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CHAPTER 1

INTRODUCTION

Energy is classified as two different alternatives; non-renewable (coal, oil, natural gas) and renewable (solar, wind, hydro, wave, biomass) sources. Since 1891, when Danish scientist "Poul LaCour" succeeded in generating electricity from wind in the way we use today, wind energy has become a promising alternative to non-renewables. The underlying reason of popularity of using the energy of the wind is its potential to reduce CO_2 emissions and other greenhouse gases (GHG), the reduction of air pollutants (SO_2, NO_x, etc.) and other toxins, water conservation, domestic job creation, landowner revenue generation and rural tax revenue, and perhaps most importantly, reduced reliance on foreign sources of fuel for electricity generation [1]. Additionally, the impacts of wind energy are low, local, and manageable [2]. Therefore, wind energy has become a promising alternative to non-renewables. As of the end of 2015, total cumulative installed capacity of wind power in the world is 433 GW and increased by 17% compared to the previous year (370 GW) (Figure 1). According to the installed wind power capacity development, the top 10 countries are listed in order of capacity as China, USA, Germany, India, Spain, United Kingdom, Canada, France, Italy, Brazil [3]. Turkey is one of the fastest growing power markets in the world and takes place in global wind energy market as the 10^{th} largest annual market in 2015.

Increament in number of wind farms around the globe causes to decrease in potential locations of wind farms every year. Consumption by real estate market has caused opposition in the courts, legislatures, and controlling state and federal agencies [4]. The proper siting of wind power systems becomes issue since geographical limitations, public opposition, wildlife conservation and electricity grid integration pose challenges for planners and developers. Although wind speed is the most important requirement in site selection for wind turbine positions, not only technical requirement, but also economical, social, environmental and political requirements start to be considered in order to manage the land use restrictions of energy source successfully while determining wind farm site suitability.

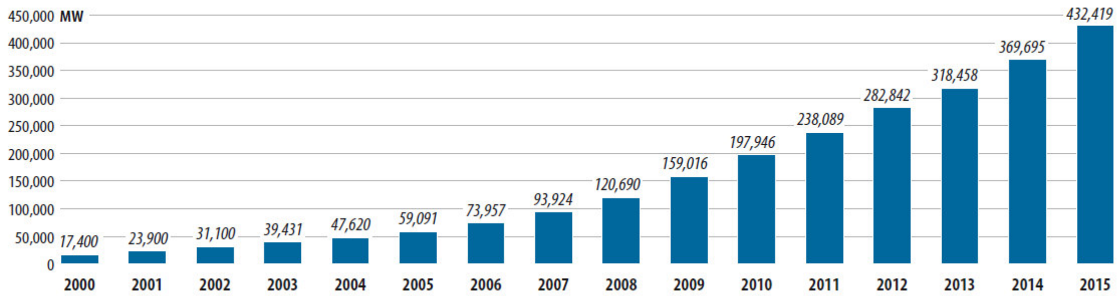

Figure 1. Global cumulative installed wind capacity 2000-2015 [3]

Environmental concerns are important for wind farm establishment and some environmental impacts of wind farms include impacts on humans (e.g. turbine noise, visual effect) and effects on ecosystems (e.g. the damage to the wildlife, especially birds and bats and habitat loss). Economical considerations in the siting of wind farms are related with the land costs, road construction cost and forestation cost. Social and political considerations are concerned with the acceptance of a wind project by residents and regulatory compliance, respectively. These complex decision making process requires a tool that can incorporate a set of decision alternatives and the decision maker's preferences effectively. In GIS-based decision making process, the alternatives are evaluated by preferences of individuals (decision makers, managers, stakeholders, interest groups). Geographical Information System (GIS) provides processing of the geographic data, whereas Multi-Criteria Decision-Making (MCDM) contributes a methodology for guiding the decision maker. Therefore, GIS and MCDM methods combines and transforms geographic data and the decision maker's preferences into a resultant decision and allows to reach optimal solutions for highly complex spatial decision-making problems [5].

1.1. Problem Statement

The process of developing wind projects typically takes 5 years for onshore projects in Turkey from project initiation to the wind farm has been commissioned and some rear cases even longer, up to 10 years. The main reason is that energy and environmental analysis at proposed location and getting permission from the proper authorities take long time duration. If a planning tool was available so that the planning process can be shortened, it will save time and investment. Currently there is no such models in use in Turkey for wind farm planning. Majority of the studies generally focus on feasibility of wind energy project or policy makers concentrate on restrictions for wind farm development defined by the governmental regulations.

The goal of this thesis project is creating a model that quantifies the existing technical, environmental, economic, and socio-political parameters depending on their order of importance, and visualize the suitability map for wind energy installation by gathering the current regulations and scientific studies.

1.2. Literature

Geographical information system has allowed decision makers, planners, stakeholders, policy makers to identify the suitable areas where wind power plants take place and to quantify the potential wind energy production. GIS incorporated into a spatial MCDM model, can provide convenience on evaluating land suitability for wind farm locations in terms of technical, economic, social and environmental criteria. Planning and permitting of wind farm installation involve multistage process that a variety of factors play a role in. The constraints and factors regarding the site selection of wind turbine farms have been identified by means of literature review and regulations.

In the literature, there are several studies of GIS applied to site selection of wind farms in Turkey and around the world (Table 1). Studies differ from each other with respect to chosen the study area, the criteria based on, the methodologies applied. The following section provides a literature review regarding site selection of wind power plant installation using GIS and MCDM.

Several studies regarding the site selection of wind farms in Turkey could be found in the literature. However, these are the regional case studies and their parameters and metedologies show differences with this study.

Atici et al. [6] have analyzed Balıkesir and Çanakkale provinces as having the highest wind energy potential in Turkey. GIS were used to generate layers of data and to apply the elimination criteria and constraints. Criteria of infeasible sites were identified in accordance with the literature, legislation and considering the data availability which were related to the construction of wind power stations. After an elimination of infeasible areas, %3.6 of total area were remained as technically feasible area. The Elimination and

Choice Translating Reality (ELECTRE) and Stochastic Multiobjective Acceptability Analysis (SMAA) methods were applied for ranking by the expertise of the consulting firm in wind power plant location selection.

Aydin et al. [7] have developed a spatial multi-criteria decision system composed of Usak, Aydin, Denizli, Mugla, and Burdur provinces in Turkey to identify the most suitable locations for wind turbines. Wind energy potential and various environmental concerns were evaluated together according to the Turkish legislation and previous studies using GIS. Different aggregation operators were tested in this study (‘‘order weighted averaging (OWA)’’, ‘‘and’’, ‘‘or’’). The map of priority sites for the study area demonstrated that some of the existing wind turbines were located in these parts; this was explained that locations of these existing turbines were acceptable with respect to the procedure presented in this study.

One of the recent thesis study was conducted by Sediqi [8] with the title of ‘GIS-Based Multi-Criteria Approach for Land-Use Suitability Analysis of Wind Farms: The Case Study of Karaburun Peninsula, Izmir-Turkey’. The thesis was performed by using Analytic Hierarchy Process and criteria were gathered from the previous studies. The study proved that 20% of the area is suitable for wind farm developments in Karaburun Peninsula.

By favour of the enhancement of the GIS software, the number of GIS-based MCDM studies analyzing potential location for wind farms around the world have been increased significantly. Some of them are reviewed below.

Wind farm land suitability evaluation based on Analytical Hierarchy Process with Ordered Weigh Averaging (AHP-OWA) aggregation function under GIS environment has been applied over Oman by Al-Yahyai et al. [9]. It was thought that the usage of OWA operators to calculate the local score at each level of AHP hierarchy can create an effective decision making tool. The selection criteria were considered based on economic, social, environmental and technical issues. The authors did not explain by whom the relative importance (weights) for the criteria were assigned. Results of the study demonstrated that lands with mostly suitable classification were located in Dhofar and Wusta regions; this land class represented about 0.2% of the total area of Oman.

Baban et al. [10] used the outcome of questionnaire conducted with public and private sectors and the available published literature to develop simple GIS-assisted wind farm location criteria in the UK. The constraint factors for wind farm location encompassed physical, planning, economic, and environmental and resource considerations. Two different weighting were performed; i) equal weighting and ii) grading each group according to perceived importance. This study showed differences in terms of that weights were not directly assigned to the criteria; the factors were classified into first-, second-, third- and fourth-grade factors and the authors did not explain the reason behind this assignment of the criteria. This study proved that a weighting scheme based on the relative importance of the criteria was more effective than an equal weighting scheme in order to find suitable areas for wind energy development. According to results, the most suitable areas represented the smallest group, occupying only 3.79% of the total study area while the least suitable sites covered 73.34% of the area.

Bennui et al. [11] have applied GIS integrated with MCDM for effective site selection for large wind farm in five provinces in Thailand. Criteria selections were performed depending on the guideline and regulations with respect to the physical, socioeconomic and environmental quality and amenities. The AHP was used to establish weights for a set of criteria according to importance. This study demonstrated that the extremely suitable areas, high suitable areas, moderate suitable areas, low suitable areas, unsuitable areas covered 0.03%, 40,4% 57,9% 1,6% , 0% percent of total studied area, respectively.

Aim of the study performed by Gass et al. [12] was not only to assess economically viable wind turbine sites under current feed-in tariffs and current legislation considering constraints but also to develop a GIS based decision system for wind turbine site selection in Austria. This study has explicitly focused on the policy perspective when analyzing the wind power potential of the country. The analyses of the efficiency gains of an improved feed-in tariff system were done based on Levelized Cost of Electricity (LCOE). The results indicated that an area of 5800 km^2 was technically available for wind power production in Austria. The noise and aesthetic effects arising from wind turbines, however, have not been considered.

Table 1.Overview of wind farm site selection studies

		Atici et al. (2015)	Aydin et al. (2010)	Al-Yahyai et al. (2012)	Baban et al.(2001)	Bennui et al.(2007)	Gass et al. (2013)	Georgiou et al. (2012)	Gorsevski et al. (2013)	Grassi et al. (2012)	Hansen (2005)
	Country	Turkey	Turkey	Oman	UK	Thailand	Austria	Cyprus	USA	USA	Denmark
	Case study region	Balıkesir, Çanakkale	Usak, Aydin, Denizli, Mugla, Burdur	Whole country	Lancashire and Yorkshire	Nakhon Si Thammarat, Pattalung, Songkhla, Pattani, Narathiwas	Whole country	Larnaca	27-county region in Northwest Ohio	Iowa	Northern Jutland
	Criteria based on	Literature, Legislation	Literature, Legislation	Literature	Questionnaire, Literature	Literature, Legislation	Literature, Legislation	Experts, Legislation	Graduate and Undergraduate Students	Legislation	Legislation
	Method	GIS, ELECTRE, SMAA	GIS, OWA	GIS, AHP-OWA	OWA, AHP, GIS	AHP, GIS	GIS	AHP, SAW, GIS	SDSS, WLC, GIS	GIS	WLC, GIS
1	Elevation (m)	1500				200	2000				
2	Transmission lines (m)	250			<10000			150	1000, 20000		200, 500
3	Lakes & rivers (m)	3000	400		400	200		150	Constraint	240	150, 500
4	Protected areas (m)	2000	300, 900			2000				300	Constraint
	National Park										Constraint
	Natural Reserve Areas										Constraint
	Natural Monuments										
	Nature Park										
	Wildlife Protection and Development Areas										
	World Heritage Sites										
	Archeological sites				1000	1000		500			Constraint
	Special Protection Areas		250	2000	1000			300			Constraint
	Ramsar Sites		2500					Constraint	Constraint		Constraint
	Biosphere										Constraint
5	Roads (m)	500		500, 10000	<10000	500	150	150	1000 , 10000	240	150, 300
6	Airports (m)	5000	3000			3000		4000	Constraint	2000	5000, 7500
7	Urban areas (m)	2000	1000, 2000	2000	2000	2500	1000	850		240	500, 1000
8	Fault lines (m)	200									
9	Electromagnetic interference	600									1000, 1500 m
10	Bird Habitat/Routes		2500, 5000	2000			200	500	5000 , 30000		Constraint
11	Noise		400, 500								
12	Wind Resource (m/s)			5	5			5			
13	Forest				500			200		300	300, 500
14	Visual İmpact		1000		2000			850			
15	Installed Wind Farms										
16	Wind Resource (m/s)			5	5			5			

Table 1 (cont.). Overview of wind farm site selection studies

		Haaren et al. (2011)	Höfer et al. (2016)	Latinopoulos et al. (2015)	Lejeune et al. (2008)	Noorollahi et al. (2016)	Sanchez-Lozano et al. (2014)	Schallenberg-Rodríguez et al. (2014)	Sliz-Szkliniarz et al.(2011)	Tegou et al. (2010)	Watson et al. (2015)
	Country	USA	Germany	Greece	Belgium	Iran	Spain	Spain	Poland	Greece	the UK
	Case study region	New York State	Städteregion Aachen	Kozani	Wallonia	Markazi	Region of Murcia	The Canary Islands	The Kujawsko–Pomorskie Voivodeship	Island of Lesvos	Bristol, Oxford, Reading and Southampton
	Criteria based on	Literature, Legislation	Legislation	Literature, Legislation	Literature	Literature, Legislation	Legislation	Literature, Legislation	Literature, Legislation	Legislation, Literature	Literature
	Method	GIS	GIS, AHP	SDSS, GIS, AHP	SDSS, GIS	GIS, WIO	GIS, ELECTRE-TRI	GIS	GIS	AHP, GIS	AHP,GIS
1	Elevation (m)					2000					
2	Transmission lines (m)		100		150	250	<5000	120	200	100	
3	Lakes & rivers (m)	3000	50			500	Constraint	Constraint	250		
4	Protected areas (m)	Constraint		1000	2000	2000	Constraint		500		
	National Park	Constraint	Constraint					1000	500		1000
	Natural Reserve Areas	Constraint	Constraint		0	700		Constraint	500		1000
	Natural Monuments							Constraint	100		1000
	Nature Park										1000
	Wildlife Protection and Development Areas										1000
	World Heritage Sites						Constraint				1000
	Archeological sites	Constraint	Constraint	1000		700	Constraint	Constraint	1000	500	1000
	Special Protection Areas	Constraint	Constraint	Constraint	0	700	Constraint	Constraint	500	Constraints	1000
	Ramsar Sites	Constraint	300	Constraint		500		Constraint	500	Constraints	1000
	Biosphere	Constraint	Constraint			700		Constraint	500		
5	Roads (m)	500	Constraint	150		250	<5000	120	100	100	
6	Airports (m)	Constraint		3000	5000	2500	>7000	3500	3000	Constraints	
7	Urban areas (m)	1000	550	1000		2000	>1000	250	500	500	500
8	Fault lines (m)					500					
9	Electromagnetic interference				600		>400				
10	Bird Habitat/Routes				150				1000		
11	Noise	500			350						
12	Wind Resource (m/s)		6	4.5			>3.2	4.8		4	
13	Forest		Constraint						200		
14	Visual İmpact	2000		1000						2000	
15	Installed Wind Farms			Constraint				12D & 4D		3D	
16	Wind Resource (m/s)		6	4.5			>3.2	4.8		4	

Georgiou et al. [13] have developed a decision analysis methodology for wind energy resource assessment and applied to Larnaca, Cyprus. Several operational tools were used; The Wind Atlas Analysis and Application Program (WAsP) model for the estimation of the wind potential; AHP for weighting the evaluation criteria; the simple additive weighting (SAW) method for the aggregation of the criteria; and GIS as an integrated platform of presentation. The relative importances of the evaluation criteria were provided by laws and interviewing experts. It was found that only 0.58 km^2 (0.1%) of the Larnaca region were the most suitable sites for wind farm siting.

Gorsevski et al. [14] carried out a spatial decision support system by integrating environmental and economic criteria to design a prototype tool with an easy-to-use interface for the assessment of the wind farm site suitability. Weighted linear combination (WLC) techniques and GIS functionality were applied over 27 county region having relatively high winds in Northwest Ohio, US. The authors conducted a survey among 30 students to assign importance and attribute weights to environmental and economic decision factors. The results obtained by ranking demonstrated that the most suitable locations covered 2.4% of the total area, these areas were characterized by locating near high population densities, close proximity to both transportation and transmission lines, and where wind speed was at least 5.6 m/s. Besides, this study also classified 78.3% of the total area as suitable areas. This study might have been improved by adding the parameters of natural reserves and distance from residential areas into the restrictions and the criteria.

Grassi et al. [15] intended to develop a tool which was capable of reducing the uncertainties in estimating the power generation and taken into account policy and financial framework with a GIS customized tool. A group of technical, economic and policy factors based on state/federal environmental regulations, financial support and incentives were incorporated to identify the eligible areas for wind farms in Iowa, U.S. Analysis showed a potential annual installed capacity of 302 GW, maximum average AEP of 914 TWh and the optimized net average capacity factor of 33.49%. Additionally, the 87% of the eligible areas had a potential capacity factor greater than 30% and represent a significant wind resource.

The aim of Hansen [16] was to present multi-criteria evaluations, which can provide tools for identifing the best sites for new wind farm development in terms of environmental and socio-economic impacts by using GIS and weighted linear combination (WLC) over the Baltic Sea. The site selection criteria were developed by interviewing spatial planners in that according to national and regional legislation, local conditions, local restrictions and economic viability. The criteria weights were scored based on common sense of author and the study did not include technical suitability of the wind farm siting. This study obviously revealed that there was not much area for new onshore wind farm development. Since Denmark has already a lot of wind turbines, and most new wind farms will be located offshore.

Van Haaren et al. [17] conducted a study in the State of New York, USA by focusing on ecological criterion such as the avoidance of important bird areas. The criteria evaluations were performed in three stages; exclusion of infeasible sites, economic evaluation and bird impact evaluation. In the last stage, a map of important bird areas was intersected with the highest ranked sites. The study proved that the total capacity of wind that can be installed in NYS amounts to 86 GW, based on 4 MW/km^2 of feasible sites. When the result were compared with the locations of existing wind turbine farms, it was stated that none were located in or close to infeasible areas according to the model.

Höfer et al. [18] have improved the site assessment by providing a holistic MCDM approach that incorporates techno-economic, socio-political and environmental criteria in compliance with legal restrictions and factual reasons in the Städteregion Aachen, Germany. In order to derive reliable criteria weights for GIS-based AHP approach, a survey was conducted among different regional stakeholders and experts from wind energy-related fields. For this study, it was assumed that the visual impact of wind farms can be neglected due to increasement in the social acceptance of wind farms. The results pointed out that 9.4% of the study area were available for wind energy installation, whereas only 1.74% of the region were considered as high suitability, 7.37% as medium suitability, and 0.3% as low suitability. Validation performed with the location of existing wind farms verified the reliability and accuracy of the model results.

Latinopoulos et al. [19] have conducted the study at the regional level in Greece with the aim of evaluating land suitability for wind farm siting by combining GIS with AHP. Criteria selections were based on literature data and on national legislation. Three different scenarios were designed to perform the ex-ante evaluation of potential new wind farm investments and an ex-post evaluation process aiming to appraise the already licensed sites. Same weights were given for all factors in the first scenario. Additionally, second scenario focused on environmental and social criteria, whereas third scenario was taken into consideration in terms of technical and economic criteria. Assigning the criteria weights based on author’s own expertise and experience instead of integrating the knowledge of experts. The results of this study indicated that 17% of the studied area satisfies the constraint objectives and none of already licensed wind farms was infeasible with respect to the overall suitability.

Lejeune et al. [20] conducted a spatial decision support system that can be used by regional planners to analyze the many wind farm projects proposed by private investors in Wallonia, Belgium. Environmental criteria were based on the regional government framework, whereas landscape criteria were defined with a research team that was producing a landscape map of the Walloon Region. The system was evaluated under three constraint levels (exclusion, highly sensitive and sensitive) by the software application designers and the regional planning experts responsible for evaluating wind farm projects whether the installation of wind turbines were prohibited. According to results, constraint-free areas represented 4.94% of the region studied. The wind potential of the region was not taken into consideration. Additionally, since the buffer zone distances were based on the incidence of the corresponding potential risk or nuisance, it was partly subjective.

Noorollahi et al. [21] implemented a multi-criteria decision support system for defining wind energy resources in Markazi province, Iran. The criteria were taken into consideration into two parts containing restrictive and classifying layers. The environmental and geographic standards were evaluated based on possibility of and not possibility locating wind farms using Boolean logic approach. Besides, technical and economic standards were analyzed with specific weights for each class according to the importance of the criterion using the Weighted Index Overlay (WIO) method. The outcomes showed that 28% of the study area had capacity for installing large wind farms (2% belonged to priority 3, 10% for priority 2, and 16% for priority 1), whereas 72% of the areas were unsuitable.

Sánchez-Lozano et al. [22] used the tools of GIS and ELECTRE-TRI methodology in order to select the best locations to host onshore wind farms on the coast of the Region of Murcia, in the southeast of Spain. Owing to obtain suitable sites, identidying administrative restrictions and assigning weights were carried out by an expert in wind energy (a doctor engineer with over 10 years of experience in the field of renewable energies). It was concluded that even neither of the feasible areas had all the criteria situated in the best category, 19.94% of the area were defined as a high percentage of suitable areas.

Schallenberg-Rodríguez et al. [23] described a methodology based on GIS and adapted to the island/regional requirements to determine wind potential of The Canary Islands. Four steps were followed; determination of available areas, wind farm configuration and location, calculation of wind production and cost resources curves. Territorial constraints were identified by means of literature review, government laws and regulations review. Besides, the buffer values selected were mostly average values. The results demonstrated that only 12.5% of the territory from the total regional surface can be used for wind energy production and the marginal wind generation changes from island to island, since the islands were not interconnected.

Sliz-Szkliniarz et al. [24] build a developmental vision to support the decision making process for wind power site selection on the case study of the Kujawsko–Pomorskie Voivodeship. Possible wind turbine sites were identified according to technical, ecological and economic criteria using GIS. Since there were no specific mandatory recommendations relative to the site assessment for wind farms in Poland, the related criteria and constrains were derived from relevant polish legislations and literature for this study. The application of a GIS-based approach represented that 41.7% of the studied area remained available for wind siting after excluding the infrastructural and ecological related barriers.

Tegou et al. [25] have integrated AHP with GIS to find suitable areas for wind energy development on the Greek island of Lesvos in the five steps. Selection criteria was set up based on literature review, experts' judgment, and personal experience, whereas weighting criteria was performed depending on the authors' opinion, without consulting experts or other stakeholders. The results identified that 56.8% of entire study area were restricted from wind farm installation, while only 1.4% of the island were evaluated as most suitable for siting wind farms.

Watson et al. [26] have adopted a GIS-MCDM approach to identify suitable locations for wind farm and solar farm developments within South Central England. Factors were selected based on a review of the existing literature, and the buffer distances used in this study were also adopted from reviewed literature. MCDM methods carried out with AHP, for which the weightings of the variables were established by seven experts from the renewable energy sector. The results indicated that much of the regions were unsuitable for wind energy generation and only 0.003% of studied area were defined in the ‘most suitable’ category.

To summarize previous studies regarding to site selection for wind farms, there are many criteria that need to be taken into consideration in a wind farm site assessment. However they can be categorized into three categories; administrative issues, economic issues and environment issues. While administrative criteria are related to regulations and requirements set by government, the economic issues are associated with maximizing economic benefit, and environmental concerns target to decrease the adverse impact of the wind farms. Additionally, from the literature review, most studies followed similar basic steps; identifying the methods, selection of criteria, excluding infeasible areas, weighing and validation of remaining areas. Almost the same procedure were followed for the study except for the inclusion of environmental impact analysis. By addition of this step, this study tries to minimize the environmental impact of wind farm.

The main difference of this study and the others are i) to be conducted in Turkey based on national legislation, ii) to be changeable by the current regulations, iii) addition of more environmental criteria and approach and iv) to include some new criteria to investigate.

1.3. Goals of the project

The main goal of this thesis is to present a GIS-based multi-criteria decision making application which can be updated by the changing regulations for evaluating potential site suitability of wind power plants in Turkey in order to quick, spatial and visual access to this information for investors, developers, decision makers, planners, stakeholders.

The specific objectives of the study are;

- to compile the current regulations and to create a GIS database,
- to exclude infeasible sites from the map according to the regulations,
- to derive the relative importance of each criterion through the series of pairwise comparisons by a study group,
- to set environmental evaluation criteria and to give a preliminary environmental impact assessment.

CHAPTER 2

WIND ENERGY

Wind power, is available from the kinetic energy of the mass of moving air, can be converted into mechanical or electrical energy. The earliest uses of wind energy were pumping water, grinding grain, sawing, pushing a sailboat. The first person who generated electricity from wind in 1891 was the Danish scientist Poul La Cour, who lived in small village of Askov, Denmark and worked as the local high school teacher. The Danish scientist improved the technology during World Wars I and II and built more than 100 electricity generating turbines in the 20–35 kW size range between 1891 and 1918 [27]. However, the interest in usage of wind power has always fluctuated with the price of fossil fuels. The oil shortages of the 1970s changed the energy picture of the world. It created an interest in wind energy source [28]. In the 1980s, the first wind farms were erected in California [2]. Power plant technology has been improved rapidly and produced larger wind farms. Recently, converting wind energy into electricity is supplied by wind turbines for homes and businesses and for sale to utilities.

Modern-day wind turbines are classified into two general types: horizontal axis and vertical axis (Figure 2). Horizontal axis wind turbine (HAWT) stands horizontal to the ground, whereas the rotational axis of the vertical axis wind turbine (VAWT) stands perpendicular to the ground. VAWT are close to the ground and can not benefit from the high wind speeds just at 60 to 100 m above ground level. That’s why, horizontal axis wind turbine are common commercially.

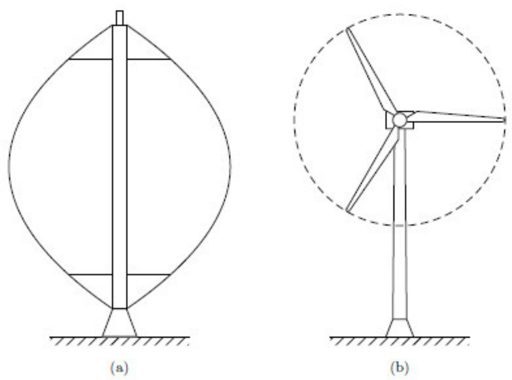

Figure 2. (a) Vertical-axis and (b) horizontal-axis wind turbines [29]

HAWT rotors can be classified according to the direction of receiving the wind (upwind or downwind of the tower), hub design (rigid or teetering), rotor control (pitch or stall), number of blades (single bladed, two bladed, three bladed or multi bladed), and how they are aligned with the wind (free yaw or active yaw) [27]. Most of turbines have upwind rotors with three blades. Single bladed turbines are cheaper due to having fewer blade. However, single bladed turbines have problem to balance the blade. Two bladed turbines rotate faster and appear more flickering to the eyes also creating high vibration, whereas three-bladed turbines are less disturbing in a landscape and the optimum for the radial speed. Three bladed and more bladed wind turbines having same rotor diameter theoretically produce the same power, however aerodynamic losses are higher in more than 3 bladed due to the fact that each blade wake will effect the nearest other blade. Therefore commercial turbines, are optimized to three bladed design [30].

The main operating systems of a wind turbine include [31]:

- aerodynamic subsystem, consisting mainly of the turbine rotor, which is composed of blades, and turbine hub, which is the support for blades;
- drive train, generally composed of: low-speed shaft – coupled with the turbine hub, speed multiplier and high-speed shaft – driving the electrical generator;
- electromagnetic subsystem, consisting mainly of the electric generator;
- electric subsystem, including the elements for grid connection and local grid.

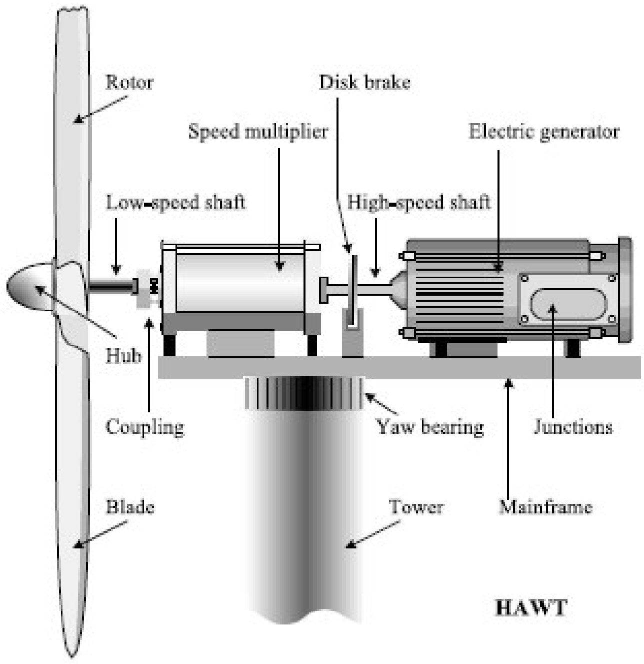

Figure 3. Main elements of a two-bladed HAWT [31]

2.1. Turkish Wind Energy Development

Studies of producing electricity from wind energy in Turkey were started in 1990s. Turkey's first commercial wind farm was commissioned on the 28th of November 1998, in Alaçatı, Çeşme by Alize Co. and has a capacity of 1.5 MW [32]. Even though the first wind turbine started operation in Turkey as early as 1998, these investments significantly increased after 2006 by the adoption of "The Renewable Energy Law of Turkey". The law provides tariff support for electricity produced by renewable sources. Figure 4 shows that the total installed wind power capacity of Turkey year by year. According to the report released from Turkish Wind Energy Association (TWEA) in January 2016, there are 113 wind power plants under operation with an installed capacity of 4.718,30 MW in Turkey [33]. The majority of the operational wind power plants are located in the Balıkesir, İzmir and Manisa provinces. Aegean region has the highest installed wind capacity with a total of 1.779,55 MW, followed by the Marmara region 1.743,25 MW and the Mediterranean region with 717,2 MW (Figure 5). There are also 61 wind turbines under construction with 1.868,85 MW capacity.

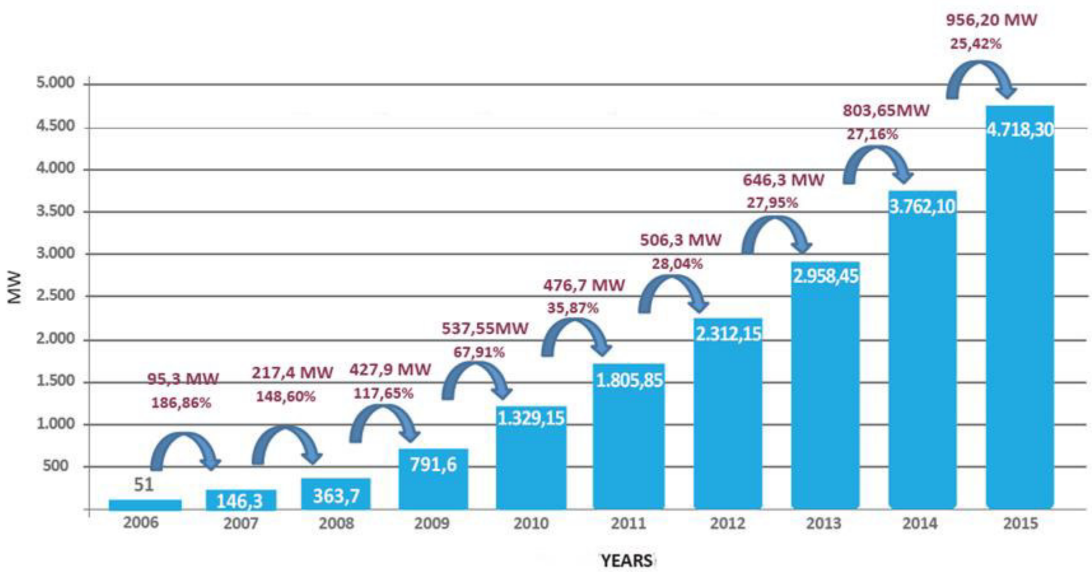

Figure 4. Cumulavite Installations for wind power plants in Turkey [33]

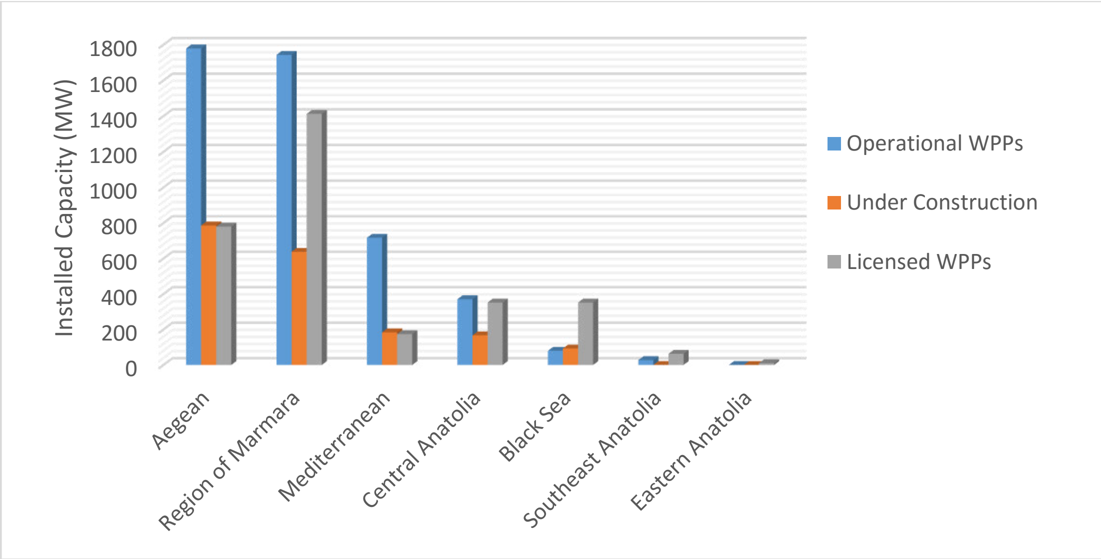

Figure 5 . Installed capacity of regions in Turkey

Turkey has great wind energy potential in compared to some of the other European countries [34]. Turkey Wind Map, prepared from Turkish State Meteorological Service in 2002, demonstrated that the economic potential was 10,000 MW and the technical potential was 88,000 MW. The Wind Energy Potential Atlas (REPA), prepared using numerical weather prediction methodology by the General Directorate of Electrical Power Resources and Development Administration, calculated the wind energy potential at 50 m above ground level in land regions as 131,756 MW, which is equivalent to a wind power density greater than 300 W/m^2 [34].

Some important acts and regulations regarding wind energy are as follows:

- Law on the Use of Renewable Energy Sources for Electricity Generation Purposes (Law no: 5346) was established in 2005 to encourage and expand the use of renewable energy sources, such as wind, solar, geothermal and biomass, for the purpose of electricity generation. The law was amended in 2010. The new law is called Amendment Law (Law no: 6094) changed the feed-in tariffs for each renewable energy sources and increased the wind energy tariff from 5-5.5 Euro ct/kWh to USD 7.3 cent/kWh with a maximum additional incentive of 3.7 US$ cent /kWh for domestic equipment for a period of 10 years [35].
- The Electricity Market Law with the law no. 4628 was enacted in 2001 to set the stage for liberalization of power generation and distribution activities [34]. According to the new Turkish Electricity Market Law numbered 6446 (2013),

generating electricity in the Turkish market requires an electricity generation license to be obtained from the Energy Market Regulatory Authority (EMRA). EMRA recently enacted the License Regulation determining the detailed requirements of the regulatory approval process to obtain a pre-license and license.

The process of developing wind projects typically lasts 5-10 years for onshore projects from project initiation to the wind farm has been commissioned, and lifetimes of a wind turbine are generally 20 years in Europe [36]. The main steps of developing a project are demonstrated in Figure 6. The project development stage comprehends site assessments based on technical, administrative and financial criteria. After that stage, a preliminary financial model is built in order to assess if the investment case can be expected to be economically feasible.

The following stages are construction of measurement system, participating in tender, getting pre-license and license. Before investors construct a wind farm, they must obtain measurement of the wind resource on a possible site by erecting temporary measurement towers for at least one year. The output of that measurement gives preliminary feasibility of the project.

After that, since technical insufficiencies of the transmission system in Turkey provide limited connection capacity to transmission system, Turkey's Energy Market Regulation Authority (EMRA) implemented a selection process through tenders. In accordance with the 'Tender Regulation on pre-License Applications for Wind and Solar Energy Energy Generation Facilities', each participants submits a contribution fee to be paid for each unit's MW to the Turkish Electricity Transmission Corporation (TEİAŞ). Environmantal Impact Assessment and all permits required for construction are taken during the pre-license phase to get license. The licensing mechanism for wind energy applications is presented as a flow diagram in Figure 6. Licence which is coupled with permissions from the proper places, allow to reach agreements. As a final, the project goes into the final stages of the project lifecycle, which include construction and afterwards operation.

Some of the institutions of wind energy in Turkey are as follows:

- Ministry of Energy and Natural Resource (MENR), prepares and implementats energy policies, plans, and programs in general and renewable energy in particular [37].
- The General Directorate of Energy Affairs (EIGM) conducts studies and develops policies on renewable energy within MENR and responsible for the co-ordination of the electricity and natural gas reform programs. It also deals with the consequences of the past efforts to bring private investments into the electricity sector [35].
- The General Manager of Renewable Energy (EIE) is responsible for surveys and research on energy potential renewable energy source [35].
- The Energy Market Regulatory Authority (EMRA) regulates and supervises the electricity market and monitors the progress in the renewable energy segment of the market, as well [35].
- Grid capacity prediction for future installation made by Turkish Electricity Transmission Company (TEIAS), based on the demand estimations prepared by the distribution companies enters into effect after it approved by the authority [38].

2.2. Future National Goals

In the perspective of global wind energy development, the GWEC predicts that 360 GW of new capacity will be added to installed capacity until 2020 [3]. Similarly, Europe and spesifically EU states have a goal of at least 27% renewable energy in final energy consumption at European level wind until 2030 [39]. Paralel to this global goals, Turkey has a similar targets.

On account of a rapid increment in Turkey population, the electricity demand has been continuously increasing. To meet increasing electricity demand, government has focused on Turkey's geographical advantages, rich renewable energy sources, especially for wind energy. According to the "Revised Strategy Paper" which was published in 2009, Turkey targets [34];

- Raising the total installed power capacity to 120 GW
- Increasing the share of renewables to 30 percent
- Increasing the installed capacity based on wind power to 20 GW

Regarding all the current development in the Turkish wind market, it is expected that rate of increase in the wind energy installed capacity will get higher in the following years. This makes possible to achieve the targets for 2023 by providing grid capacity upgrades.

Table 2. Competent Authorities in wind energy in Turkey [40]

MINISTRY OF ENERGY AND NATURAL RESOURCES REPUBLIC OF TURKEY	The Energy Market Regulatory Authority (EMRA)
MINISTRY OF ENERGY AND NATURAL RESOURCES REPUBLIC OF TURKEY	The General Manager of Renewable Energy (EIE)
MINISTRY OF ENERGY AND NATURAL RESOURCES REPUBLIC OF TURKEY	Directorate-General for Mining Affairs
REPUBLIC OF TURKEY MINISTRY OF ENVIRONMENT AND URBANISATION	Ministry of Environment and Forestry
DSİ	DSI, Directorate-General of State Hydrolic Works
REPUBLIC OF TURKEY MINISTRY OF FOOD AGRICULTURE AND LIVESTOCK	Ministry of Food, Agriculture and Livestock
Republic of Turkey Ministry of Culture and Tourism	Ministry of Culture and Tourism
	General Directorate of National Estate
TCK	General Directorate of Highways
TEİAŞ	Turkish Electricity Transmission Company (TEİAŞ)
EÜAŞ	Electricity Generation Company (EÜAŞ)
DIRECTORATE GENERAL OF CIVIL AVIATON TURKEY	General Directorate of State Airports Authority/Directorate General of Civil Aviation

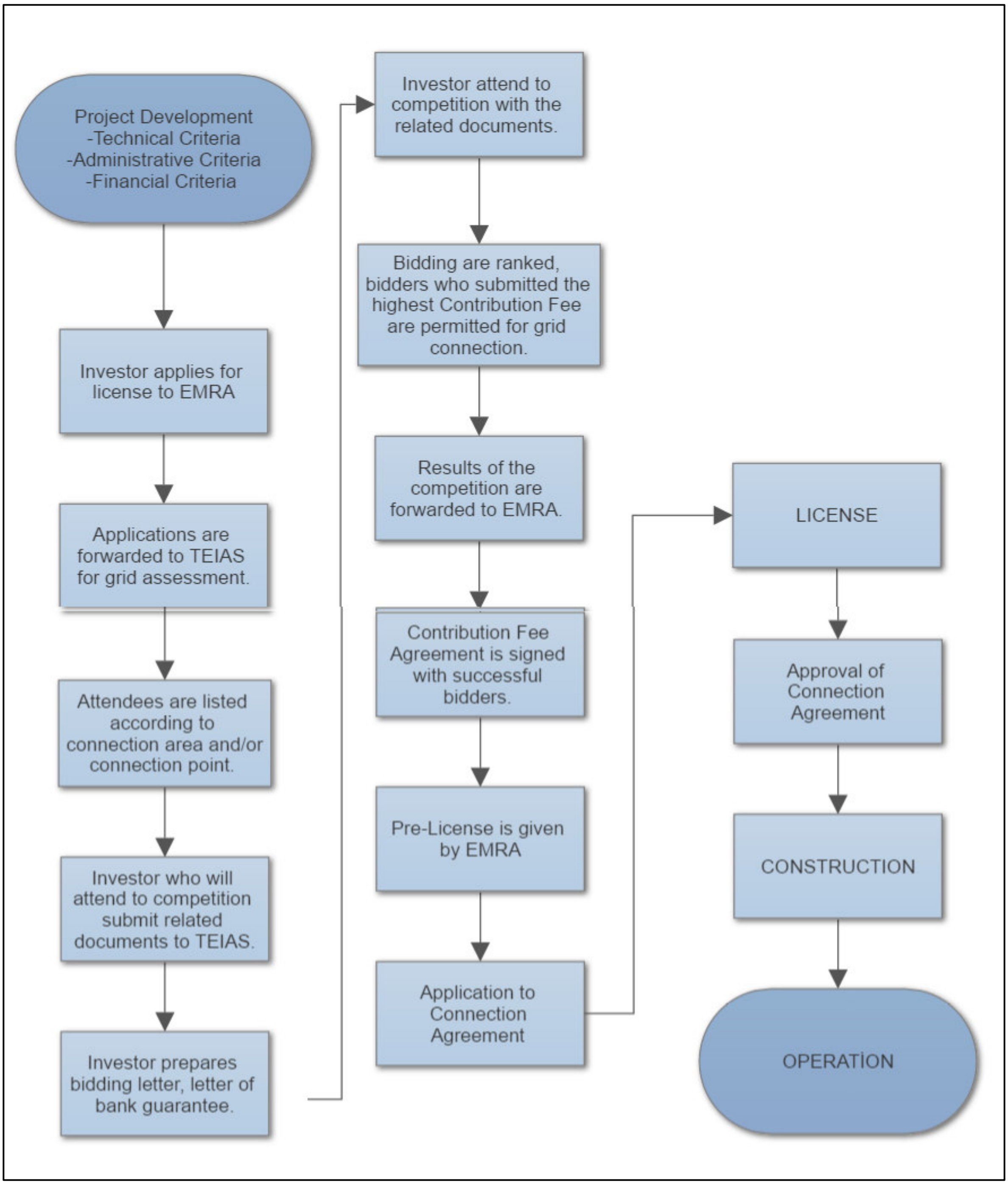

Figure 6. Progress of wind farm installation

CHAPTER 3

GIS IN WIND ENERGY

3.1. Geographic Information Systems (GIS)

Geographic information systems is useful computer-based tools for the input, the storage and management, the manipulation and analysis, and the output of spatial data [5]. It is function of four integrated components: location, attribute, spatial relationship, and time.

The major advantages of using GIS-based approach for siting is to reduce the time and cost of site selection and also to provide a digital data bank for long-term monitoring of the site [41]. Other benefits may comprise the following: i) selection of an objective exclusion zone process according to the set of provided screening criteria ii) zoning and buffering iii) Performing 'what if' data analysis and investigating different potential scenarios related to population growth and area development, as well as checking the importance of various influencing factors, etc. iv) handling and correlating large amounts of complex geographical data v) visualization of the results through graphical representation.

The term of geoprocessing means to use a spatial data as input and process the data by given criteria finalizing with a new spatial dataset. It is the common backbone of the GIS based approach and it is one of the most powerful components of GIS. Geoprocessing allows to perform several tools. One of the most useful applied geoprocessing tool is the map overlay (Figure 7). It enables to overlap all the layers so that the optimum area satisfying all criteria can be generated. Therefore, GIS is widely used in the decision and management situations such as environmental planning and management, transportation planning and management, urban and regional planning, waste management, hydrology and water resource, agriculture and forestry, geology and natural hazard, and real estate and industrial facility management [5].

Several open source and commercial GIS toolboxes are used in this study. A short list can be found in Appendix A.

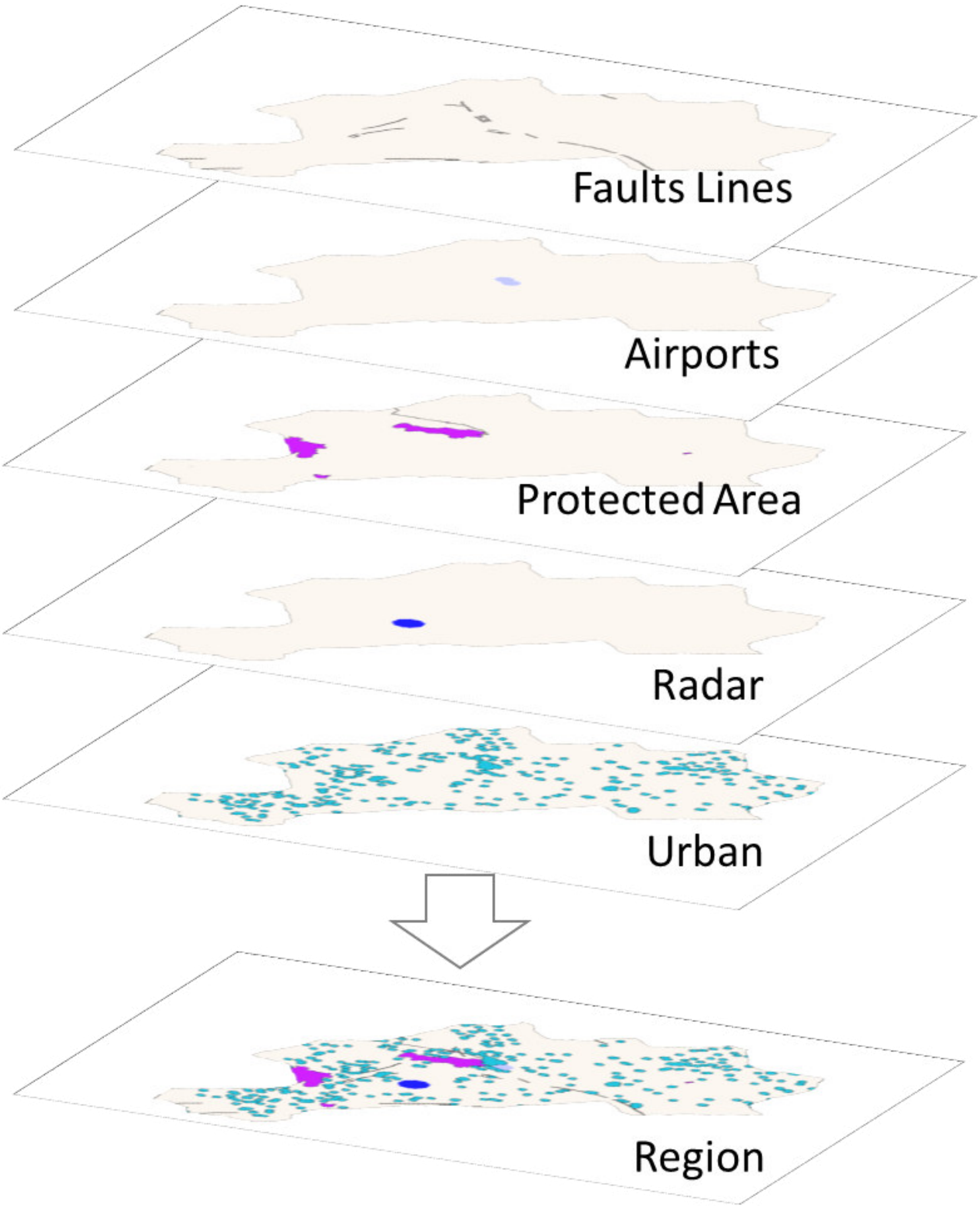

Figure 7. Map overlay function in GIS

CHAPTER 4

THEORY & METHOD

4.1. Study area: Turkish Territory

Turkey, located between 36º–42º North latitude and 26º–45º East longitude, is a large peninsula that bridges the continents of Europe and Asia. The country is partly in Europe and partly in Asia (Figure 8), called Thrace and Anatolia, respectively. Turkey is surrounded by sea on three sides; the Black Sea, the Mediterranean Sea, and the Aegean Sea. The neighboring countries are Greece and Bulgaria to the northwest, Armenia and Georgia to the northeast, Iraq and Iran to the southeast and Syria to the south. Turkey is divided into 81 provinces. The country has seven geographical regions: Marmara, Aegean, Mediterranean, Southeast Anatolia, East Anatolia, Black Sea and Central Anatolia. Its total area is 78 million hectares of which 21.7 million hectares are designated as forest area [42].

Turkey is in the category of emerging markets with respect to population, industrialization and the economy. While Brazil, Russia, India and China are classified as four largest emerging and developing economies, followed by South Korea, Mexico, Indonesia, Turkey, and Saudi Arabia. Turkey's population reached the value of 78.7 million. Istanbul is most populated and crowded city in the country with a population of 14.3 million residents, while Konya, the country's largest city geographically, had only 2.1 million people [42]. The rapid growth of population affects Turkey's energy demand. Turkey's primary energy reserves are not enough to meet the on-rise energy demand. The 74% of total energy consumption of Turkey are supplied by imported fuels such as oil, natural gas and hard coal. Turkey, being a poor country in terms of fossil fuels, is a rich country in renewable energy sources. The utilization of domestic renewable energy sources has significant importance for Turkey to reduce its dependence on foreign energy supplies, provide supply security and also prevent the increase in greenhouse gas emission. To support usage of renewable energy, Turkish government started to apply a minimum price system and guaranteed purchase of energy generated by renewable energy in 2005. As a result of incentive package [43], the installed capacities of wind power plants increased from 51 MW in 2006 to 4718 MW as end of 2015. Currently, there are more than 100 wind farm in operation, 61 farm under construction and 98 licensed wind power plants [33]. The capacity of wind power plant under construction is 1.868 GW. Besides, the capacity of licensed wind power plant is 3.144 GW, they are primarily installed in Marmara and Aegean regions, especially provinces of Çanakkale, Istanbul, and Izmir.

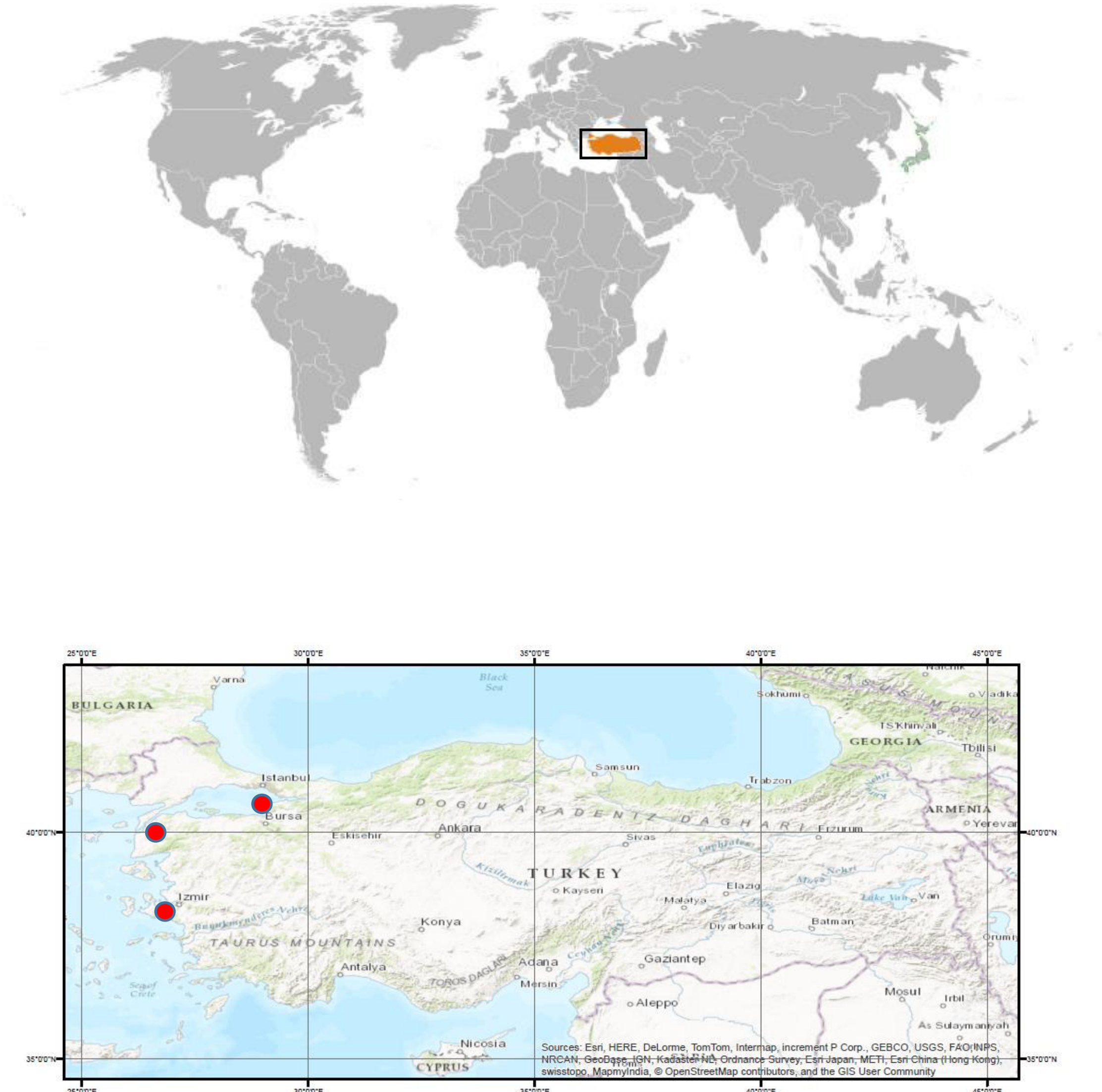

Figure 8. Study area: Turkey. Red discs are the common regions with wind farms

4.2. Multi-Criteria Decision-Making Methods

We all make decisions about substantial issues consciously or unconsciously during our daily lives. Decision-making is a fundamental process for we do. Multiple-criteria decision-making is an analytical methods to deal with conflicting decision problems under the evaluation of several criteria. According to Pohekar et al. [44], "the rationale of MCDM models is based on decomposition of a complex problem into a hierarchy with goal at the top of the hierarchy, criterions and sub-criterions at levels and sub-levels of the hierarchy, and decision alternatives at the bottom of the hierarchy". The criteria usually have different importance and the alternatives are varying with peoples' preferences.

MCDM techniques are classified into multi-objective decision-making (MODM) and multi-attribute decision-making (MADM) [45]. Although these categories have used individually, their combinations are also applied for decision making. The difference between MADM and MODM is that MADM is related with problems of which numbers of alternatives have been predetermined [45]. MADM deals with discrete decision spaces and alternatives are compared by decision makers in terms of their attribute to select the best alternative. In MADM, alternatives need to be studied, analyzed and prioritized with respect to relate the attributes. On the other hand, MODM is not associated with the problems in which alternatives have been predetermined. In other words, MODM presents optimization of alternatives on the basis of prioritized objectives. Since the decision space is continuous, the most satisfactory solution is tried to find.

MCDM techniques are gaining popularity in renewable energy management [44]. The aim of traditional single criteria decision making in energy investments was to maximize benefits with minimization of costs. As the energy management problems are getting more complex, economical considerations are complemented with "environmental and social considerations in energy planning, resulting in the increasing use of multicriteria approaches and the improved quality of decisions" [44]. There is a substantial number of methods based on weighted averages, priority setting, and outranking, fuzzy principles.

The short description of the most widely used methods for renewable energy studies are listed below:

1. SAW – Simple Additive Weighting / also called WLC – Weighted Linear Combination: SAW is a simple MCDM technology based on the concept of the simple multiplication of the criteria scores with the preassigned weights. Overall scores for all alternatives are calculated and the alternative with the highest score is chosen.

2. AHP – Analytical Hierarchy Process: The method was introduced by Saaty [46] is considered an effective approach to quantify the qualitative factors. It constructed with different hierarchy levels; the goal on the top, the criteria in the middle and alternatives at the bottom. The input of experts is a pair-wise comparison of the criteria values, which multiplied by the performances of the alternatives will result in the choice of the best scoring solution. This method was chosen for critera evaluation of this study.

3. ELECTRE I-IV. - Elimination and Choice Expressing Reality: ELECTRE is an outranking method and uses pairwise comparison by using concordance and discordance indexes to handle both, qualitative and quantitative discrete criteria. This method avoids compensation for criteria, eliminating the distortion associated with normalization.

4. PROMETHEE I. and II. – Preference Ranking Organization Method for Enrichment Evaluations: This method results in the ranking of alternatives based on the decision maker's preference degrees. Its main steps are the calculation of preference degrees for each criteria and the computation of different flows (groups of alternatives). The method is characterized by simplicity and ease of use.

5. TOPSIS - Technique for Order Preference by Similarity to the Ideal Solution: The idea of TOPSIS is based on measuring the distance of each alternative from a theoretical best and worst solution. It applies a simple concept of maximizing distance from the negative-ideal solution and minimizing the distance from the positive ideal solution.

6. Fuzzy set applications: Fuzzy theory was designed to handle uncertainties and to deal with non-statistical, qualitative or unquantifiable information. The theory classifies the results with linguistic quantifiers (e.g. "good", "fair", or "poor").

Pohekar et al. [44] reviewed more than 90 published paper to analyze the applicability of various MCDM techniques in energy planning. It was stated that Analytical Hierarchy Process is the most popular technique for prioritizing the alternatives, followed by outranking techniques PROMETHEE and ELECTRE. The reasons of the wide useage of Analytical Hierarchy Process are its simplicity, flexibility, intuitive appeal and especially its ability to mix qualitative as well as quantitative criteria in the same decision framework (45). For this reason, AHP is selected to determine the weights of selected criteria in this study.

4.2.1. The Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process, developed by Thomas Saaty, is an effective tool to enable the taking of complex decisions. A hierarchy is not the traditional decision tree in such a way that each level may represent a different cut at the problem. For instance, one level may represent social factor and the others might represent technical, economic, environmental or political factors. The alternatives can be evaluated in terms of combination of concerning requirements. Owing to its simplicity and flexibility, AHP has used in a wide variety of applications such as alternative selection, resource allocation, forecasting, business process re-engineering, quality function deployment, balanced scorecard, benchmarking, public policy decisions, healthcare, and many more in every part of the world [45].

The method derives priority scales through the series of pairwise comparisons [46]. To rank the alternatives of a decision, the need and purpose of the decision, the criteria of the decision, their subcriteria, stakeholders and groups affected and the alternative actions to take should be known by decision-maker [47]. The rationale of AHP is based on how much more, one element dominates from another with respect to a given attribute.

To make a decision in an organised way in the AHP, following processes are performed [47];

Step 1: Define the goal, criteria, sub-criteria and alternatives of the problem. Saaty suggest that structuring the decision hierarchy should start with the goal of the decision through the alternatives, until the levels of the two processes are linked in such a way as to make comparisons possible.

Step 2: Construct a set of pairwise comparison matrix with decision-makers. The matrix is m×m real matrix, where m denotes the number of evaluation criteria.

$$A=\begin{bmatrix} a_{11} & \cdots & a_{1m} \\ \vdots & \ddots & \vdots \\ a_{m1} & \cdots & a_{mm} \end{bmatrix}$$

Step 3: Rank the criteria using the Saaty's fundamental scale of 1–9. Table 3 exhibits the scale and the numbers indicate how many times more important or dominant one criteria than another. Elements are indicated by a_{ij}. The criterion in the i^{th} row is better than criterion in the j^{th} column if If $a_{ij} > 1$; whereas the criterion in the j^{th} column is better than that in the i^{th} row if $0 < a_{ij} < 1$. If two criteria have the same importance, then the entry a_{ij} is 1. The diagonal elements of the matrix also equal to 1. The (j, i) element of the matrix is the reciprocal of the (i, j) element, all the values in matrix satisfy the following constraint:

$$a_{ij} * a_{ji} = 1 \tag{4. 1}$$

Step 4: Construct a group choice from individual choices. Saaty [47] proved that the geometric mean is the only way to combine judgements of several individuals for obtaining a single judgement for the group.

Step 5: Derive the normalized pairwise comparison matrix by dividing each column to their summation as;

$$w_{ij} = \frac{a_{ij}}{\sum_{i=1}^{m} a_{ij}} \tag{4. 2}$$

Step 6: Built the criteria weight vector (w) by averaging the entries on each row of the normalized pairwise comparison matrix;

$$w_i = \sum_{i=1}^{m} w_j a_{ij} \qquad w_j = \frac{\sum_{i=1}^{m} w_{ij}}{m} \tag{4. 3}$$

Step 7: Calculate a Consistency Ratio (CR) to measure how consistent the judgements. Saaty suggests the value of CR should be less than 0.1 to be evaluated as the inconsistencies are tolerable, and a reliable result may be expected from the AHP (47).

The CR is calculated as;

$$CR = \frac{CI}{RI} \tag{4. 4}$$

The random index values (RI), used to calculate CR, vary with the matrix size and are provided in Table 4. Consistency Index (CI) is obtained by first computing the scalar λ as the average of the elements of the vector whose jth element is the ratio of the jth element of the vector A·w to the corresponding element of the vector w. Then,

$$CI = \frac{\lambda - m}{m-1} \tag{4. 5}$$

Step 8: The rating of each alternatives are multiplied by the weights of the criteria and aggregated to get global ratings.

Table 3. The Saaty Rating Scale [47]

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgement slightly favour one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgement strongly favour one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation

Table 4. Values of the Random Index (RI) [48]

Order of Matrix	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

4.3. Methodological Framework

The proposed methodology for site selection of wind power plant installation in Turkey, which is illustrated in Figure 9, was handled under four stages. In the first stage, decision-making objectives associated with energy generation of wind turbines were identified based on a literature review and regulations. Then, boundaries and geographical coordinates of objectives were collected and processed in GIS. In the next step, infeasible sites were excluded depending on regulations and planning constraints. In the third stage, the remaining sites were evaluated based on the economical and technical characteristics of the study area. In the last stage, the areas were evaluated with the environmental objectives to show potentially problematic sites and suitable locations for wind turbines.

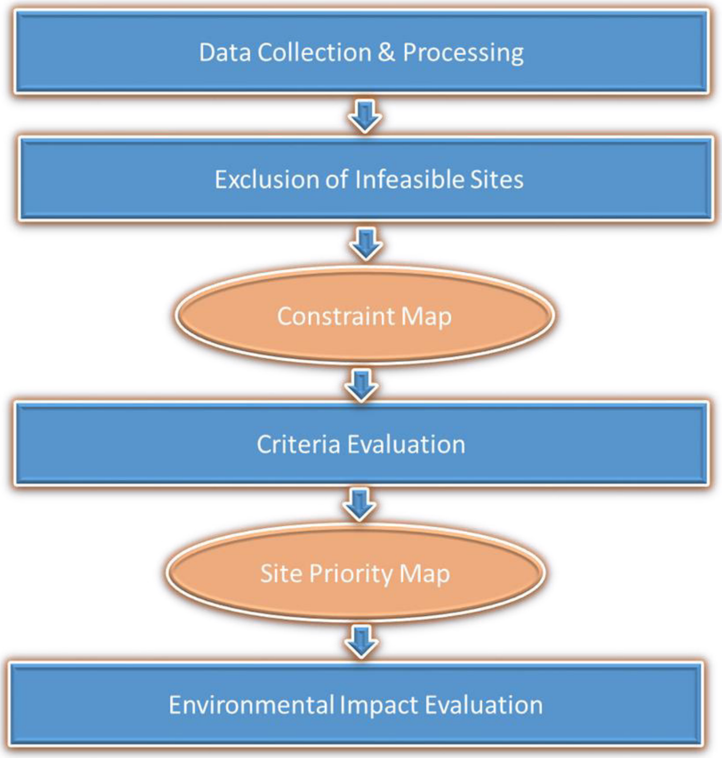

Figure 9. Overview of the methodology

4.3.1. Data Collection and Processing

All land with a good or better wind energy resource may not be suitable for wind energy development, since it might be declared as protected land by the governmental regulations, or it can be very distant from main roads that cause a very costly construction process. Therefore, all objectives associated with site selection for wind turbines were identified based on national legislation related to wind turbine development and literature research. A set of 21 criteria were finally selected and the boundaries and geographical coordinates of those criteria were collected from government agencies, web-based dataset, scientific studies and voluntary agency (Table 5) and processed in GIS. A detailed description of these factors is given below.

These criteria were divided into factors and constraints for further steps. Factors increase or decrease suitability of a given element and were assessed on a continuous scale. Constraints determine the qualification of a given element and are usually of logical character expressed as 1 – suitable, and 0 – restricted.

4.3.1.1. Generic Wind Turbines

The potential wind energy production, the minimum distance between two wind turbines and greenhouse gas emissions can vary with the dimensions of wind turbines. More than fifty wind turbine models have been developed over the last decade. Since to evaluate wind potential based on all turbine models is imposible, this study focuses on two different wind turbines representing the 0.9 MW and 2.1 MW classes, which are frequently used. Additionally, since Global Wind Atlas shows wind speeds at heights of 50, 100 and 200 metres and wind turbine at 200 m as hub height has not been existing yet, site selection in this study was performed at 50 m and 100 m hub heights.

The wind turbines have different characteristics concerning swept area, rated power, capacity factor and economical aspects. Their properties collected from the currently available turbine models having 50 m and 100 m hub height regardless of their manufacturer. For the implementation of the current study, the first generic turbine selected had a capacity of 900 kW, hub height at 50 m and rotor diameter of 45 m, whereas characteristics of the second turbine were power rate - 2.1 MW; hub height - 100 m; rotor diameter - 80 m. Capacity factors of the defined turbines were acquired from the study of Hughes [49] collected onshore wind datasets on substantial installations in Denmark with an age range from 0 to 19 years. Capacities were calculated by taking the averages of lifetime efficiency of the turbines that have the same power rate with the generic turbines, and found as 0.22 for 900 kW and 0.31 for 2.1 MW. The detailed cost accounting of the generic turbines are given in Appendix B.

Table 5. Layers of GIS

Layer	Source of data	Objective
Electromagnetic interference	Turkish Republic Official Journal (Number: 29033)	Exclusion Parameters
Airports	EMRA	
Fault lines	Kandilli Observatory and Earthquake Research Institute	
Urban areas	CORINE	
Protected areas	Directorate of Nature Conservation and National Parks, Turkish Republic Official Journal (Number: 20702, 24218, 24055, 27793, 26551, 25339, 28737), UNESCO	
Air Density	The study of 'Computation of Air Density for Wind Energy Use'	Evaluation criteria
Wind Speed	Global Wind Atlas	
Frozen Period	WorldClim	
Land Cost	The Revenue Administration	
Roads	OpenStreetMap	
Grid Capacities	TEİAŞ	
Terrain Complexity	The study of 'A spatial averaging method to calculate the weighing factors of wind atlas interpolation'	
Forest	CORINE	Evaluation criteria / Environmental Impact Constraints
Agricultural Lands	CORINE	Environmental Impact Constraints
Bird Habitat	Doğa Derneği	
Visual Impact	Various Scientific Articles	
Noise	Regulation on Assessment and Management of Environmental Noise	
Bankability of Wind Farm Projects	Personal Communications with Bank Official	Not Quantified
Greenhouse Gas Emissions	Various Scientific Articles	
Feed-In Tariff for Wind Energy	Ministry of Energy and Natural Resources/ Republic of Turkey Energy Market Regulatory	
Farms Areas	EMRA	To Validate Results

Table 6. Properties of the generic wind turbines

Characteristic	Generic Turbine 1	Generic Turbine 2
Hub height (m)	50	100
Diameter (m)	45	80
Swept Area (m^2)	1590.4	5026.5
Power (kw)	900	2100
Capacity Factor (%)	0.22	0.31
Total Turbine cost (million TL)	2.7	6.3
O&M Cost (million TL)	2.7	6.3
Gross yearly income from electric sale (million TL/year)	0.5	1.5
Net Income Annually (million TL)	0.1	0.7

4.3.1.2. Electromagmetic Interference

Wind turbines may cause electromagnetic interference distorting the transmissions of existing radar, radio or television stations, and generating their own electromagnetic radiation. That undesired echoes (clutter) may reduce the detection performance of the radar. Wind turbine clutter is composed of two identifiable sources: the tower and the blades. The turbine towers have a constant zero return velocity that can be easily minimised with an appropriate clutter cancellation method [50]. However, echoes from the turbines' rotating blades can be much more problematic due to have very large and variable radial velocities, escaping the suppression of the clutter filter.

Lack of interference with weather radars is a serious consideration because of the vital importance of the acquired data for weather forecasting and related public safety issues. Turkey has ten weather radars operated by Turkish State Meteorological Service, while seven more radars will be installed until 2017 to meet the need for detailed weather radar data. Coordinations of these radars were taken from Official Journal (No: 29033) [51]. According to official statement [51], no wind turbine should be placed closer than 5 km to both under construction and operational weather radars. The safeguarding zone benefits both radar and turbine electrical components.

4.3.1.3. Airports

Installation of wind farms near an airport might not be suitable for planes due to causing a physical obstruction for the continued safety of flight. Therefore, takeoff and landing from or to airport become more difficult. Another direct physical impacts of wind turbines on aviation are turbulence and reducing performance of communications, navigation and surveillance equipment. Eventually, wind turbine siting around airports is banned due to safety reasons.

Among the studies surveyed, it has been declared that distance from airports is a restriction that needs to be taken into account while selecting the location of wind farms. Buffer zones in previous studies vary from 2000 m to 5000 m. A buffer distance of at least 3000 m and 5000 m were suggested by four [7, 11, 19, 24], and three studies [6, 16, 20], whereas distances of 4000 m [13], 3500 m [23], 2500 m [21], and 2000 m [15] were suggested by one study, each.

Currently, 55 airports are run by Republic of Turkey General Directorate of State Airports Authority [52]. Besides that, there are 19 more airports operated by civil and military aviation according to Corine Land Cover 2006 Seamless Vector Data (Figure 10). Directorate General of Civil Aviation in Turkey is primarily responsible for land use planning around all airports. According to the legislation [53] to protect flight security, human lives, and property, any structure such which may shine should not be constructed in the first 3000 m zone from departure end of taking-off and landing [53].

Energy Market Regulatory Authority (EMRA) announced the new regulation regarding the distances from navigational aids and aeronautical stations which are run by Republic of Turkey General Directorate of State Airports Authority on 12^{th} of May, 2016. According to the announcement, wind power project developer should take into account of 2 km and 15 km buffer zones around aeronautical stations and navigational aids, respectively (Figure 11).

Figure 10. The CORINE airport layers with old regulation buffers

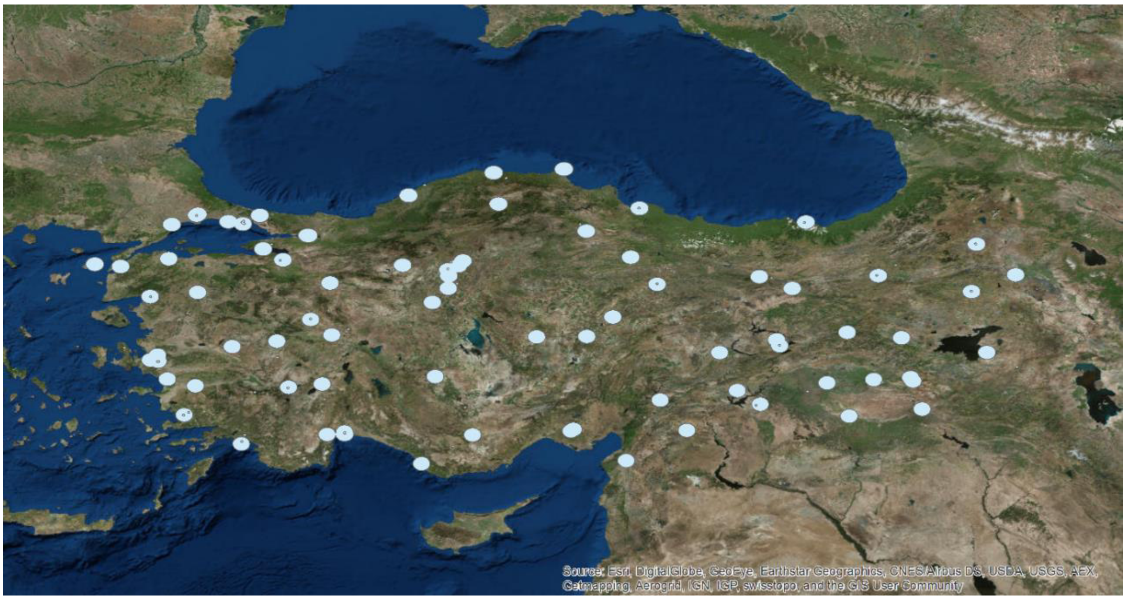

Figure 11. Location of the aeronautical stations and navigational aids

4.3.1.4. Fault Lines

Seismic risk of wind farms is related to the geographic location. In past years, turbines were installed in regions of low seismicity. As the installed wind farms expand, the regions moves through area around fault lines, seismicity has became in a concern. Most turbines having a design life as 20 years did not expose a strong earthquake, but there is no doubt that the wind turbine will expose to some level of seismic risk like all civil structures in the future [54]. According to Ozcep et al. [55], the seismicity of the project area, topographic conditions at the site, the type and detailed construction of the wind energy system should be considered for wind energy system to withstand earthquake forces. Since the lack of regulations or performed scientific research regarding obligatory distance between wind farms and fault line, structural durability of wind energy turbines near the fault lines has kept its uncertainty. One study from Turkey [6] set the minimum threshold to 200 m, whereas one from Iran [21] assigned the minimum distance between wind farm and fault lines as 500 m.

By the reasons of Turkey being earthquake prone country and the lack of regulations, risk is need to be accounted by utilizing standard design methodologies for seismic loading of wind turbines. However, it was announced that Republic of Turkey Prime Ministry Disaster and Emergency Management Authority will establish legislation concerning buffer zones around the active faults to reduce risk causing loss of lives, public safety, economic loss, energy crisis and adverse impact on environment [56]. In order to enact the law, the regulation and guide book associated with width of buffer zone and how far away from the fault to be safe structuring are prepearing based on the legislations in the USA and New Zealand as a model. The buffer zones according to the law of California (USA) are changing within 60-90 m for short fault line and 150 m for major fault line [57]. Although the regulation still has not been published in official journal of Turkish Republic, buffer distance from fault line in Turkey was acquired from Kandilli Observatory and Earthquake Research Institute [58] was accepted as 150 m for this study.

4.3.1.5. Feed-In Tariff for Wind Energy

Feed-in Tariff (FIT) is support mechanism which set a premium price for renewably generated electricity. Government has regulated and assured the tariff rates for a specific period of time. The success of applying FIT experience in Germany have been often used as a model for other countries. The German FIT was introduced in 1979 and it was followed by the first Feed-in Law (the Stromeinspeisungsgesetz (Electricity Feed Act)) in 1990. Under favour of the Law, wind power generation was developed. The Erneuerbare-Energien-Gesetz (EEG) (Renewable Energy Sources Act), implemented in 2000, regulates tariff rate standards according to the type of renewable energy, scale and position [59]. Nowadays, at least 50 countries and 25 states-provinces have offered

Figure 12. Fault lines map (Kandilli Observatory and Earthquake Research Institute)

purchase guarantee by feed-in-tariffs for electricity generated from renewables in the world [60].

The implementing clear energy in Germany is also followed by Turkey. Turkey has taken remarkable steps in renewable energy development and manufacturing to meet its target for 2023 over the past decade. The main incentive mechanism, the Law on the Utilization of Renewable Energy Sources for Electricity Generation, was enacted in 2005 [43] and revised in 2011 [61]. This law involves a feed-in tariff mechanism to incentivize the utilization of domestic renewable sources for the first 10 years of their operations. The regulated price for wind energy projects is set as \$0.073/ kWh (Table 7).

Moreover, in order to shift the responsibility from foreign imports to domestic production, Renewable Energy Law [61] provides non-tariff incentives as well. If the production of the equipments that will be utilized in the renewable energy facilities are produced in Turkey will be granted to the producers. Extra payments are \$0.008/kWh for blades, \$0.01/kWh for generator and power electronics, \$0.006/kWh for tower, \$0.013/kWh for the mechanical equipment in rotor and nacelle groups (Table 7). To sum up, domestically produced turbines can be paied up to \$0.11/kwh based on percentage of domestic production; for foreign turbines is paied a fixed feed-in tariff for all electricity exports to the grid as \$0.073/kWh. The incentive package [43], has encouraged investments and provided rapid increments for the installed capacity of wind energy. The installed capacities of wind power plants increased from 51 MW in 2006 to 4718 MW at end of 2015 [33].

Table 7. Feed-in tariffs for renewable energies specified in Turkey [61]

Chart 1		
Facility type Based on Renewable Energy Sources	Prices to be applied (USD cent/kWh)	
Hydroelectric Power	7.3	
Wind Power	7.3	
Geothermal Energy	10.5	
Solar Energy	13.3	
Biomass production	13.3	
Chart 2		
Facility Type	Domestic Production	Contribution (USD cent/kWh)
Wind Power	1-Blades	0.8
	2- Generators and Power Electronics	1
	3-Tower	0.6
	4-The mechanical equipment in Rotor and Nacelle Groups	1.3

The feed-in tariff policies specified in Turkey does not categorize renewable energy souces according the intended location to install power plants. Therefore, the criterion of feed-in tariff is not included as a factor in this study, because of having equal weight for all the places.

4.3.1.6. Forested Terrains

Forestry is an important subject in eviromental protection due to its nature of lowering CO_2 and being habitat for many spieces. Furthermore, forestry areas around wind turbines is a source of turbulence to be avoided. It is well studied that the change in the wind velocities and turbulence in the atmospheric shear layer can cause differences in the performance of wind turbines, therefore the wind flow around trees has been always a very complicated issue [62].

National regulations play an important role in defining the environmental objectives. There has been a contention about the forested terrain since 2011, as developers have been defending different ideas. According to the current Turkish Law on utilization of renewable energy resources for the purpose of generating energy, construction of wind farms on forested terrain can be allowed to rent out with the cost defined by Ministry of Environment and Forests or the Ministry of Finance. The prices comprehend below cost for renewable energy resources;

- Cost for land permission (annualy)
- Cost for forestation (only once at the beginning of the project)
- Additional cost for forestation (only once at the beginning of the project)

Costs for land permission are taken once a year and it is related with the cost for a unit value of forestation for the current year, acreage, ecologic balance coefficient and coefficients of cities. The details of the classification for regions are shown in Figure 13. Under this law, an 85 percent discount is applied to the lease for 10 years to the power plants that are in operation or to be in operation until 31 December 2020. The other two cost are taken only once during facilities' lifetime. Cost of forestation is related to acreage and cost for a unit value of forestation. On the other hand, additional cost for forestation which is related with the density of forested terrain must be paid by wind power plants, biomass power plants, and thermal plants. These costs make possible to assign the weight of region referring to their locations and compare with each other regarding their investibilities.

A sample cost calculation for forested terrain was performed for a wind farm with 8 wind turbines having 80 m rotor diameter and 2.1 MW capacity for each. Its net income annually is about 5.3 million TL as calculated in the section of 'Bankable Wind Farm Projects' and 11,5 ha is required area for that wind farm to minimize the wake effect. The calculation was carried out with an assumption that a unit value of forestation is not changing during the life time (20 years) to make it easy, although it will change. As it can be understood from the results (Table 8) an investor who wants to install wind farm in densest forested terrain in Istanbul has to pay 7.2 % of the profit from the project. To sum up, since the prices paid for forested terrain to install wind power plant does not sharply affect the total cost, wind farms are still located in forested terrain.

Figure 13. Classification of cities according to the forest regulation. Cost; 1 (light) being highest and 6 (dark) being lowest

Additionally, Bingöl et al. [63] suggested that wind turbines located at least 500 meters away from forested land avoid the turbulence effects and early performance degradation. If wind farms located in the forested terrain, not only the turbulence effects but also early performance degradation occurs. Getting out of the forest allows to get away from the turbulence but performance degredation continues. It is necessary to be as far as 500 m to get rid of them but regulations does not require this limitation. Therefore, although this study does not suggest to erect a wind turbine 500 m closer to a forest, in this study the regulation by the forest ministry is followed.

Table 8. Cost for the permission within the forested terrains

Cost for Permission (million TL/ha.year)						
Density of Forested Terrains	**1. Region**	**2. Region**	**3. Region**	**4. Region**	**5. Region**	**6. Region**
Glade	0.17	0.16	0.14	0.12	0.09	0.07
< 10%	0.19	0.18	0.16	0.14	0.11	0.09
%11-40	0.25	0.24	0.21	0.18	0.15	0.12
%41-70	0.31	0.29	0.25	0.22	0.18	0.15
> %71	0.38	0.35	0.31	0.27	0.23	0.18

According to Republic of Turkey General Directorate of Forestry, Turkey forests covered % 27.5 percentages of the land area of Turkey (about 22 million hectare) [64]. Because of its consistency, forest areas were acquired from CORINE 2006[1] dataset for

[1] http://www.eea.europa.eu/data-and-maps/data/clc-2006-vector-data-version-3#tab-gis-data

this study [65]. CORINE categorizes forests into broadleaves, conifers and mixed forests. This study considered forests corresponding to the following CLC classes: 311 (broadleaved forests), 312 (coniferous forests) and 313 (mixed forests). The three different forest types are combined into a single category because there were no difference in terms of cost per m^2 regulation and all these different density forests were assumed to be the same under the law.

4.3.1.7. Urban Areas

Society's acceptance of the wind farm is the primary barrier to any new development because of the visual impacts, shadow flickering effects and noise generated from wind turbines. The correct placement of wind farms nearby habitat settlements will allow reducing the number of serious accidents and increasing of public acceptance. Conducted literature survey proved that some of the studies [7, 12, 17, 19] suggest wind farms should not been located within 1000 m buffer zone around city centers because of safety and visibility concerns, whereas as some of them belived that it should be within 2000 m buffer zone [6, 9, 10, 21] for the same reasons. According to the legislation of the General Directorate of Renewable Energy (dated as 22/05/2009) about the method for determining the power plant [66], there must be buffer zone as 1000 m in radius around the power plant. This gives us a circle of land with a diameter of 2000 m to be eliminated for wind power plant establishment due to distances between residential areas. Data about the urban area was obtained from the CORINE dataset (CLC: 111, 112).

Settlements nearby to wind power plants might suffer from the wind turbines' shadow flicker [67]. The shadow flicker is produced by interruption of sunlight by the turbine blades and moving shadows cast by the blades on windows can affect illumination inside buildings and causing an undesirable feeling. Since sun-path changes during the days and years, the route of a wind turbine's shadow also changes with them. This adds another difficulty to the problem of finding sites for locating wind farms and the point was not included in this study.

Figure 14. CORINE forested terrain layer for Turkey (CLC 311, 312 and 313)

Organized Industrial Zones are designed to allow companies to operate within an investor-friendly environment with ready-to-use infrastructure and social facilities and there are no differences between urban areas and that zones. However, the existing structure in the zones can benefit from no the value added tax for land acquisitions, low water, natural gas, and telecommunication costs and investor can construct small wind power plant in that zone. Industrial zones were also not incorporated into this study.

Figure 15. CORINE urban layer for Turkey

4.3.1.8. Bankability of Wind Farm Projects

The majority of the costs for wind farm installation are needed at the beginning. Bankability of a project is basically depends on a guarantee for project completion and/or a guarantee for project owner. Besides that, if there is no problem about data which were given to lender from investor to prove the bankability of project, funding procedure for wind farms can be performed easily [27].

Revenue estimation from the energy production based on the turbine type is calculated with available incentives, since the lender wants to see the realistic project outcomes. Wind turbine installation costs vary significantly with power rates. The average turbine cost is estimated to be 1.000.000 $ /MW [68] and operation and maintenance costs are nearly equal to this cost [40]. It is stated that 25 % of the project investment is provided by equity capital, and 75% by debt. Higher equity informs lenders about the investor's liquidity situation and financial strength. The Renewable Energy Resources Support Mechanism (YEKDEM), being a support mechanism for electricity manufacturers from renewable energy resources, is milestones of funding for the project. YEKDEM gives a guarantee of paying their debts for lenders. Therefore, nearly almost all wind power project are named as 'bankable'. The support mechanism has been extended until 2020, the legislation after 2020 is not regulated yet. If it changes, the entire development suffers; the amount of loan would be less than the stipulated credits and the capital which must be provided by investor would be much more than now.

Sample feasibility analysis for the wind farm with 16.8 MW installed capacity is calculated below. Considering the results of the calculations, investor can pay whole bank loan in 9 years with 0.31% capacity factor. The banks are supporting the projects with minimum 25% capacity factor in order to be sure about the rate of return and finance the project for 12-14 months.

This criteria were not included as a factor or constraint into this study. Since banks do not differentiate regions from each other, there is no parameter to digitize and all regions have equal weight.

Expected lifetime=20 years

Turbine rated power= 16.8 MW

Total Turbine cost=1.000.000 $ /MW [68]

16.8 MW $\Longrightarrow$ 1.000.000 $/MW x 16.8 MW= $16.800.000

O&M Cost=1.000.000 $ /MW [40]

16.8 MW $\Longrightarrow$ 1.000.000 $/MW x 16.8 MW= $16.800.000

Total expenditure = Total Turbine cost + O&M Cost over expected lifetime

Total expenditure =16.800.000 $ + 16.800.000 $= 33.600.000 $

= 33.600.000 $ x 3 TL/ $ = 100.800.000 TL

= 25.200.000 TL (equity capital=%25) + 75.600.000 TL (bank loans=%75)

Interest rate = 75.600.000 TL x 0.42 = 31.752.000 TL

Bank loans=75.600.000 TL+31.752.000 TL= 107.352.000 TL

Money needed= 107.352.000 TL+ 25.200.000 TL =132.552.000 TL

Income

Capacity factor= 31 percent = 0.31 [49]

Energy produced in a year = 16800 kW x 365 day/year x 24 h/day x 0.31 = 45.622.080 kWh/year

When tower and blades produces in Turkey;

Price of electricity= 0,087 $/kWh [61] =0,087 $/kWh X 3 TL/$

= 0,261 TL/kWh

Gross yearly income from electric sale = 45.622.080 kWh/year x 0,261 TL/kWh = 11.907.362,88 TL/year

Income over lifetime = 11.907.362,88 TL/year x 20 year

= 238.147.257,6 TL

Net Income over lifetime

Net Income= Income over lifetime - Bank Loans with interest rate

= 238.147.257,6 TL - 132.552.000 TL = 105595257.6 TL

Net Income Annually=105595257.6 TL Income in 20 years= 5.279.762,88 TL

4.3.1.9. Natural Reserve Areas

“A protected area is a clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values” by the International Union for the Conservation of Nature (IUCN) [69]. The IUCN was established in order to provide international standards for classifying the many different types of protected areas around the world and Turkey joined the union in 1 January 1993 [70].

Turkey, located between Europe and Asia and bordered by the Black Sea, Mediterranean Sea and Aegean Sea, possess rich ecosystems and biodiversity. The protected areas are categorized into eleven classes; National Parks, Nature Reserve Area, Natural Monuments, Nature Parks, Wildlife Protection and Development Areas, Protection Forests, World Heritage Sites, Special Environmental Protection Areas, Natural Sites, Ramsar Sites and Biosphere Reserve Areas. All these areas are managed under different laws and regulations by different governmental institutions and covers 3.5 million hectares area (Table 9). This field’s ratio to the country's surface area is 4.52 %.

The legal experience of Turkey on national park and protected areas date back to 1956. Turkey’s first national park (The Yozgat Pine Grove National Park) designation and nature conservation studies was started by the “Forest Law” in 1956 and established in 1958 [71]. By adopting the “National Parks Law [72]” in 1983, the number of National Parks and other protected areas has continuously increased. Areas protected by the law of National Parks are divided into four categories; National Parks, Nature Reserve Area, Natural Monuments and Nature Parks. As of 2016, Turkey had 40 National Parks, 219 Nature Parks, 31 Nature Reserve Areas and 112 Natural Monuments which are protected by National Parks Law. Also, Special Environmental Protection Area, Protection Forests, Ramsar Sites, Natural and Cultural Sites, Wildlife Protection and Development Areas and Biosphere Reserve are the other protected area categories. In this study, natural reserve areas in Turkey were handled as nine categories, since information about the location of Protection Forests, World Heritage Sites and Natural Sites, could not be obtained.

According to National Parks Legislation, there is no permission for any construction which have adverse impacts on habitat within the boundaries of the National

Park, Nature Reserve Area, Natural Monuments and Nature Parks under the responsibility of Ministry of Forestry and Water Affairs, General Directorate of Nature Conservation and National Parks [73]. Only digging, restoration and scientific research in the archeological and historical sites and the structures with the touristic purpose are allowed; hunting or any activity/structure disrupting the ecological system, dangering wildlife are not allowed in the boundaries of these areas [70].

Additionally, Special Environmental Protection Area (SEPA) are under the responsibility of Ministry of Environment and Urbanization. Essential mission of the Authority are to determine the protection and management priorities for the SEPA; to make arrangements regarding international protection criteria and environmental legislation; to support the protection of the area in accordance with the purpose of the decree; to carry out research and investigations to cooperate with all public services, non-governmental organizations and international organizations [74]. According to [75], because of being ecologically sensitive to natural resource degradation, only constructions which are compatible with the nature such as restaurants, shops, maintenance and repair facilities etc. are allowed within the Special Environmental Protection Area.

The Wildlife Protection and Development Areas were established to protect natural habitats and endangered species in their own natural environment as a result of The Bern Convention on the Conservation of European Wildlife and Natural Habitats. According to [76], investments in any field except which are compatible with ecotourism and scientific studies in wildlife habitat protected by Hunting Act are restricted by legislation in Turkey. There are 81 Wildlife Protection and Development Areas, covering about 1.2 million hectares, declared by the Hunting and Terrestrial Law.

Signed at Ramsar/İran in 1971 and aiming at the conservation and wise use of wetlands, Ramsar Convention has included Turkey in 1994. Under the Ramsar Convention, 14 sites in Turkey have been listed as Ramsar Sites; adding up to a total of 184.487 hectares. Ramsar Sites are covering almost 20% of the Turkish wetland area. The legistration of Ramsar site states that wind power plants investments below 10 MW installed capacity are not prohibited [77]. For this reason, Ramsar Sites were not considered as exclusion zones.

The United Nations Educational, Scientific and Cultural Organization (UNESCO) seeks to encourage the identification, protection and preservation of cultural and natural heritage around the world considered to be of outstanding value to humanity. This is embodied in an international treaty called the Convention concerning the Protection of the World Cultural and Natural Heritage, adopted by UNESCO in 1972. Turkey has 15 properties inscribed on the UNESCO World Heritage List as of 2016 [78]. These properties have an adequate protection and management system to ensure its safeguarding by the World Heritage Convention and Law of Protection of Cultural and Natural Assets, under the responsibility of Ministry of Tourism and Culture.

The conservations of the nature of all the above mentioned protected areas are primary issue. Unlike these protected areas, each biosphere reserve is intended to fulfill three basic aim; i) conservation of biodiversity, ii) sustainable development, iii) support for logistics. Turkey registered its first UNESCO Biosphere Reserve (Camili) which is located in the Province of Artvin in 2005 “due to the existence of mixed temperate rain forests with pristine old-growth communities, threatened species, species endangered in Europe, overall botanical richness and presence of threatened habitats. The most important value of Camili is its virtually closed ecosystem, whose habitats and waters remain in a near pristine state and whose human communities and agro-ecosystems are harmonious with nature (82). The Camili Biosphere Reserve is managed under multi-stakeholder governance system; the Ministry of Forestry and Water Affairs, the General Directorate of Nature Conservation and National Parks, and the General Directorate of Forestry [79]. The two strict nature reserves within the Camili Basin (Efeler Strict Nature Reserve, Gorgit Strict Nature Reserve) were designated in 1998 and are managed according to National Parks Law. The forested areas outside the two strict nature reserves are managed according to Forestry Law [80].

Coordinates and/or boundaries regarding natural reserves were acquired from substantial government institutions. National Park, Nature Reserve Area, Natural Monuments, Nature Parks, Wildlife Protection and Development Areas and wetland protection zones were received from Directorate of Nature Conservation and National Parks. Data concerning boundary latitude and longitude of Special Environmental Protection Area were collected from related the official journals (Official journal number: 20702, 24218, 24055, 27793, 26551, 25339, and 28737). The latitude and longitude of The Camili Biosphere Reserve were obtained from official webpage of UNESCO [78, 79].

Table 9. Protected areas in Turkey

	Protected Areas	Number	Value of Protected Areas	Related Law	Percentage of Total area Protected (%)	Institution
1	National Park	40	National	Law on National Parks	23.5	Ministry of Forestry and Water Affairs
2	Nature Reserve Area	31	National	Law on National Parks	1.8	Ministry of Forestry and Water Affairs
3	Natural Monument	112	National	Law on National Parks	0.2	Ministry of Forestry and Water Affairs
4	Nature Park	219	National	Law on National Parks	2.8	Ministry of Forestry and Water Affairs
5	Wildlife Protection and Development Areas	81	National	Law on Terrestrial Hunting	33.8	Ministry of Forestry and Water Affairs
6	World Heritage Sites	15	Global	Law on Conservation of Cultural and Natural Heritage	Not Avaible	Ministry of Environment and Urbanization
7	Protection Forests	58	National	Law on Forest	Not Avaible	Ministry of Forestry and Water Affairs
8	Special Environmental Protection Area	16	Regional	Law on Environment	37.8	Ministry of Environment and Urbanization
9	Natural Sites	1273	National	Law on Conservation of Cultural and Natural Heritage	Not Avaible	Ministry of Environment and Urbanization
10	Ramsar Sites	14	Global	Ramsar Convention by-law on Conservation of Wetlands	0.0	Ministry of Forestry and Water Affairs
11	Biosphere Reserve	1	Global	Law on National Parks-Law on Forest	0.0	Ministry of Forestry and Water Affairs
	TOTAL	**1860**			**100**	

Figure 16. Protected areas, including National Park, Natural Reserve Areas, Natural Monuments, Nature Park, Wildlife Protection and Development Areas, Special Protection Areas, Biosphere, in Turkey

4.3.1.10. State Aids for Investments and Grid Capacity

Turkish government designed investment incentives scheme to encourage investments which have potential to reduce dependency on the importation of intermediate goods vital to the country's strategic sectors. The Decree numbered 2002/3305 has entered into force on 19 June 2012, which was published in the Official Gazette of Turkey with title "The Decree on State Aids for Investments" [81]. The primary objectives of the investment incentives scheme are i) to reduce the current account deficit, ii) to boost investment support to lesser developed regions, iii) to increase the level of support instruments, iv) to promote clustering activities, and v) to support investments that will create the transfer of technology. In that incentive system, local and foreign investors have equal rights. The State Aids for Investments System is divided into four sub-headings and the framework of investment incentives schemes are demonstrated in Table 10 and explained briefly below;

1-General Investment Incentives Scheme: Regardless of the region where investment takes place, all projects meeting both the specific capacity conditions and the minimum fixed investment amount are supported within the framework of the General Investment Incentives Scheme. The minimum fixed investment amount is 1.000.000 TL in Region 1 and 2 and 500.000. TL in Regions 3, 4, 5 and 6. Some types of investments are excluded from the investment incentives program and would not benefit from this scheme.

2-Regional Investment Incentives Scheme: The sectors to be supported in each region are determined in accordance with regional potential and the scale of the local economy, while the intensity of supports varies depending on the level of development in the regions. Investments related to energy production are not supported under that scheme.

3-Large-Scale Investment Incentives Scheme: Twelve investment subjects are supported by the instruments of the Large-Scale Investment Incentives Scheme. Investments concerning energy production are also not benefit from Large-Scale Investment Incentives Scheme.

4-Strategic Investment Incentive Scheme: According to this Scheme, production of intermediate and final products with high import dependency within the concept of reducing current account deficit are supported regardless of the region and sector. Investments meeting the criteria below are supported within the framework of the Strategic Investment Incentives Scheme;

- Minimum investment amount must be 50 Million TL,
- The domestic production capacity for the product to be manufactured with the investment shall be less than the import of the product
- Investment should be create minimum 40% value added
- The goods, invested on to be produced must have a minimum importation which is $50 Million, in the last one year period,
- Investments that are not supported by the new incentive regime, listed in the Attachment No: 4 of Decree, also cannot get benefit from this scheme.

Within the limits of the State Aids for Investments, wind energy investments can benefit from General Investment Incentives Scheme and Strategic Investment Incentive Scheme. For both, incentives are provided regardless of regions, therefore to use grid capacity of Electricity Distribution Companies allow to expand the subject and assist the decisions.

It is important to be interconnected directly to the grid to sell the electricity generated from wind turbines. However, the limitations of the grid capacity constitute a significant problem for installation of wind power plants. Grid Capacity of Electricity Distribution Companies not only gives the information about the current capacities of Electricity Distribution Companies but also predicts the capacity after 5 and 10 years [82]. Since both supply and demand are not equally distributed among regions, expansion in grid capacity are varying region to region. The expanding grid capacity are planned based on demand forecasts prepared by the distribution companies to meet electricity supply forecasts. However, the highest capacity increment in İstanbul is explained with its economic aspects, despite the fact that this is not environmentally-friendly approach to develop a strategy.

Table 10. The framework of investment incentives schemes

Support Instruments	**General**	**Regional**	**Large-Scale**	**Strategic**
VAT Exemption	✓	✓	✓	✓
Customs Duty Exemption	✓	✓	✓	✓
Tax Reduction		✓	✓	✓
Social Security Premium Support (Employer's Share)	✓	✓	✓	✓
Income Tax Withholding Allowance[1]	✓	✓	✓	✓
Social Security Premium Support (Employee's Share) [1]		✓	✓	✓
Interest Rate Support [2]		✓		✓
Land Allocation		✓	✓	✓
VAT Refund				✓

[1] Provided that the investment is made in Region 6.

[2] Provided that the investment is made in Region 3, 4, 5 or 6 within the framework of the Regional Investment Incentives Scheme.

The projection of grid capacity for 2025 was used to make a decision about that subject. In order to carry out this, the estimated grid capacities of the Electricity Distribution Companies for 2025 were divided into total grid capacities of Turkey in 2025. The one having higher that ratio was weighted with the higher score. The classification of distribution campanies are illustrated in Figure 17 and the name of numbered region and their capacities are given in Table 11.

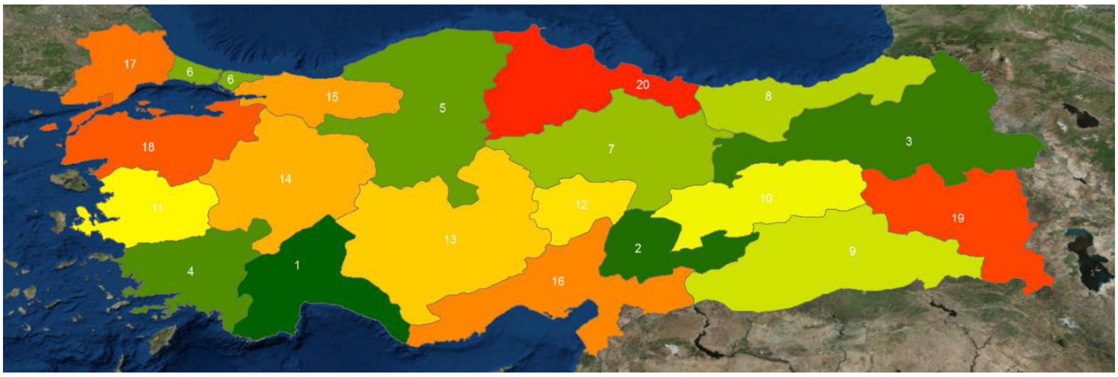

Figure 17. The regional map of Electricity Distribution Inc.

Table 11. Installed capacities and grid capacities for 2025 [82]

Number of regions	*Electricity Distribution Companies*	*Installed Capacities (MW)*	*Grid Capacities for 2025 (MW)*	*Ratios*
1	Akdeniz Electricity Distribution Inc.	2236	800	0.0714
2	Akedaş Electricity Distribution Inc.	4322	300	0.0268
3	Aras Electricity Distribution Inc.	886	500	0.0446
4	Aydem Electricity Distribution Inc.	3939	300	0.0268
5	Başkent Electricity Distribution Inc.	4152	0	0.0000
6	Boğaziçi and Anatolian Side Electricity Distribution Inc.	3037	2000	0.1786
7	Çamlıbel Electricity Distribution Inc.	1192	200	0.0179
8	Çoruh Electricity Distribution Inc.	3775	0	0.0000
9	Dicle Electricity Distribution Inc.	6668	1200	0.1071
10	Fırat Electricity Distribution Inc.	2623	400	0.0357
11	Gediz Electricity Distribution Inc.	5553	0	0.0000
12	Kayseri Electricity Distribution Inc.	517	500	0.0446
13	Meram Electricity Distribution Inc.	981	1000	0.0893
14	Osmangazi Electricity Distribution Inc.	2255	700	0.0625
15	Sakarya Electricity Distribution Inc.	5214	1300	0.1161
16	Toroslar Electricity Distribution Inc.	7780	0	0.0000
17	Trakya Electricity Distribution Inc.	3454	1200	0.1071
18	Uludağ Electricity Distribution Inc.	6624	0	0.0000
19	Vangölü Electricity Distribution Inc.	391	600	0.0536
20	Yeşilırmak Electricity Distribution Inc.	4850	200	0.0179
	TOTAL	**70449**	**11200**	**1.0000**

4.3.1.11. Roads Accessibility

Making new roads is a positive effect on humans in terms of transportation but it is a negative effect on animals and plants due to the loss of habitat. From another perspective, it is well known that the existence of the road up to the wind farm provides profits for investors because of decreasing the cost of construction and maintenance. To minimize the cost, the wind farms should be placed close to a road.

Besides that, during wind farm development, road access should be suited to the transport of large pieces of equipment to the site. The access may differentiate from place to place based on requiring earthworks and upgrading to allow passage of large loads. Grassi et al. [15] supported that it is needed that roads must have a width of at least 12–15 and minimum radius of 45 m to allow safe passage of large cranes and transporters carrying turbine blades and towers. On the other hands, blade lifting technologies makes enough to have a width of 8 m for road.

According to KGM [83], road construction cost comphrehends costs for clearing and grubbing, earthwork and surfacing. It is varying based on platform width and the type of the terrains; flat terrain, modaretely complex terrain and complex terrain (Table 12). Because the complexity of terrains affect the development cost and requires detailed engineering calculations, it was not included for this study.

Table 12. Road construction cost (TL/km) [83]

	Platform Width (m)		
Types of the Terrain	8	10	12
Flat Terrain	506421.6	601959.9	701663.9
Modaretely Complex Terrain	587860.2	680135.9	795491.3
Complex Terrain	1039902.7	1253107.9	1470478.8

According to legal regulations of Germany, 20 - 40 m is required as a minimum distance from roads must be provided [18]. Since there is no such a legal regulation in Turkey, the assignments of the score for roads were ranked with respect to denser grids are more preferable than the other ones and get the higher the score. The map of roads used in this study was obtained from webpage of OpenStreetMap[2]. This dataset includes substantial types of roads, however unsuitable classes for the transportation of large pieces of equipment were eliminated in this study. The lists of selected road classes and brief information regarding them are given in Appendix C.

4.3.1.12. Wind Farms

The locations of existing wind turbines are primarily constraint for further investigation and also allow to validate the results obtained with the locations of existing wind turbine farms.

One of the most important issues concerning location of wind farms is the wake effect. For the aim of avoiding power reduction by wake effect, turbines on a wind farm are typically spaced further apart in the direction parallel to the prevailing wind direction (downwind spacing) than in the perpendicular direction (crosswind spacing) (Figure 18). Although the exact distances chosen vary significantly with geography and other factors, Manwell et al. [27] stated that array losses of turbines, spaced 8 rotor diameters apart in the prevailing downwind direction and 5 rotor diameters apart in the crosswind direction, are typically less than 10%.

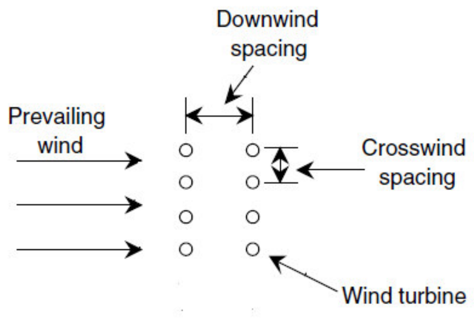

Figure 18. Wind farm array schematic

To obtain wind farm configuration (5D and 8D), properties of wind turbines should be known. Calculation was performed based on the diameters of generic wind turbines. Since the rotor diameters of generic wind turbines are 45 m and 80 m, the distance between wind turbines in the downwind direction is 360 m and 640 m; and in the crosswind direction is 225 m and 400 m according to the predominant wind direction,

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[2] http://www.openstreetmap.org/

respectively. The locations of wind farms were used only to validate the results obtained with the locations of existing wind turbine farms.

4.3.1.13. Land cost

The commercial wind turbines are getting bigger in size. This makes the profitability of larger turbines to be driven by economic considerations. As the required fields for wind farms are proportional to the swept area of the turbines, increasing size of wind turbine has generally resulted in increment in the cost of acquiring a turbine site. Although the cost of land account for only a minor share of total costs, it is one of the parameters in wind farm design to minimize the cost, besides of being permissible sites. According to the related legislation [84], forested terrains, public properties, lands belonging to a national government are allowed to use with the aim of producing electricity from renewable energy sources with the payment of required fees. Besides, personal properties are either obtained through a land lease agreement or outright purchase of the land. One of economic advantages of wind energy is to assist in revitalizing rural economies. As Wüstenhagenet al. [85] stated that, at first, landowners are excited about the project. As they learn more about the potential downsides of participating in the project, such as impacts on crops and potentially obstructed views, the support for the project decreases. As the project proceeds and the details are finalized, support increases again.

The cost of acquiring a turbine site varies significantly between projects based on the topography of the land. After determining the type of land in which wind farm is planning to establish, local land costs should be acquired. Revenue Administration is reliable source to predict land costs. The costs provide us to make decision for this study. It includes the minimum land costs in m^2/TL [86]. The lands are classified under three groups;

- Barren land; characterized by having high altitude, been non-irrigated land and with little or no "green" vegetation. These areas are not good enough for plants to grow on it.
- Base land; generally flat and smooth area in the bottom position of collected rainfall and rivers
- Wetlands; areas are irrigated by barren and bottom lands.

This study used barren lands to compare the lands cost, since it is more suitable for wind farm installation.

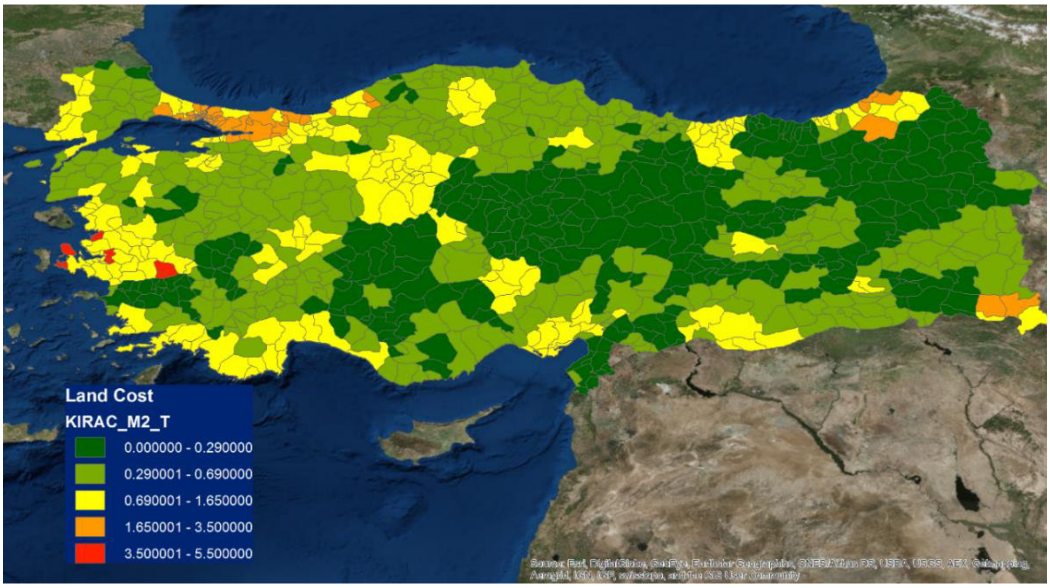

Figure 19. The barren land cost for regions

4.3.1.14. Terrain Complexity

Topography is an important ecological component affecting wind speed, since the wind is influenced by the surrounding hills and changes of roughness. A Digital Elevation Model (DEM) is a quantitative model used in capture surface features data in digital form and provides a starting point for further analysis with global datasets [87]. Until now, there have been series of attempts to obtain global and local elevation assessment. However, none of them has not used much frequently for a wide range of applications than SRTM and ASTER datasets [88].

The ruggedness index (RIX) of a given site is clarified as the fractional extent of the surrounding terrain which is steeper than a certain critical slope [89]. The RIX concept, has been employed in wind resource assessment for 10 years in the WAsP program, determines complexity of terrains in order to improve wind speed and power production predictions [89]. The RIX value for one site is calculated by equally separated wind sectors the terrain slope changes of each sector within a certain radius [90]. The result of RIX provide information concerning complexity of terrain.

RIX values reported for the study were collected from the study of Bingöl [90] that determined the RIX by conversion of the DEM data into vector maps, split into several zones, generating 25 km buffer zone around each layer to make the RIX calculations cover the whole zone. SRTM3 version 2 was used by Bingöl [90] as DEM dataset because of its consistent profile and high accuracy quality.

4.3.1.15. Wind Power

The wind is affected by several factors, e.g. geographic location, climate characteristics, height above ground, and surface topography. Determination of the wind resource at potential project is an important task of the siting process. Therefore, this criteria was taken into consideration for this study.

The power from the wind can be defined as [91];

$$P = \frac{1}{2} * \rho * A * V^3 \qquad (4.6)$$

Where ρ is air density (kg/m^3), A is rotor swept area (m^2), and V is mean wind speed (m/s).

The ratio between the mechanical power extracted by the converter and that of the undisturbed air stream is called the “power coefficient” (C_p). A German physicist Albert Betz proved that that no wind turbine can convert more than 16/27 (59.3%) of the kinetic energy of the wind into mechanical energy turning a rotor. However, the power coefficient of modern commercial wind turbines reaches values of about 0.45, well below the theoretical limit [91]. Therefore, extractable power from the wind is given by [91];

$$P = \frac{1}{2} * \rho * A * V^3 * Cp \qquad (4.7)$$

Since the wind power was calculated based on the annual average speed for this study, the C_p values were obtained from the study which was investigated annual capacity factor for different wind turbines [49] as 0.22 and 0.31 for wind turbine of 0.9 MW and 2.1 MW.

Besides, the power output of a wind turbine is directly related to the area swept by the blades. The larger the diameter of its blades, the more power it is capable of extracting from the wind. Swept areas of first and second generic turbine are calculated from the equation for the area of a circle and obtained as 1590.4 and 5026.5, respectively.

According to equations, the most important parameter is the mean annual wind speed [91], since the power available in the wind varies with the cube of the wind speed. To estimate energy output at the intended location, the available large-scale wind maps give a preliminary opinion for the average annual wind velocity before carrying out measurements taken at the site [91]. The Global Wind Atlas are used as a tool for determining a site for wind turbines, calculating economic viability and predicting the energy yield. The wind resource maps of the Global Wind Atlas provides a high resolution wind climatology at the height of 50, 100, 200m for the whole world. It has been developed by IRENA and the Technical University of Denmark (DTU). The dataset uses microscale modeling in the Wind Atlas Analysis and Application Program (WAsP) to capture wind speed variability on small scales, allowing for better estimates. The spatial resolution of the data is 1 km^2.

In recent years, wind farms in Turkey and over the world began to be established in areas having high wind speed potential. Although the wind power, as illustrated in Equation (4.3.1.), is also a function of air density, the air density is usually considered as constant in time and taken as a standard value (ρ = 1.225 kg/m^3 being at sea level, 15°C) [92]. The most important point regarding air density is to be inversely related to elevation and temperature [91]. It decreases with increasing altitude and increasing temperature. The decrease in air density might be significant at a few hundred meters and, as well as the variation in the temperature range between summer and winter, so that its influence on turbine performance can not be neglected [91]. The air density map of Turkey was obtained from the study of Bingöl [93] that combined SRTM DEM dataset with the temperature to acquire air density varying with elevation.

4.3.1.16. Operation in cold temperatures

Operation in cold temperatures is one of the problems that wind energy has encountered. It requires special design considerations to avoids many potential problems [27]. In cold climate regions, low air temperature and especially icing conditions may causes large load imbalances; creates excessive turbine vibration; can change the natural frequency of blades; promotes higher fatigue loads, and increases the bending moment of blades [94]. Icing can also significantly affects wind turbine in safety aspect due to falling ice and economic aspect due to downtime period [91]. The reduction in the energy output at sites with a particularly high risk of icing can decrease up to 30% of the annual energy delivery [91]. Therefore, by conducting research on wind turbines operating in cold climate areas, it is significant issue to be considered.

WorldClim provides a set of global climate dataset with a spatial resolution of 1 km^2 [95]. The minumum values of climate for Turkey were acquired to show temperature of regions how many months below 0 degrees Celsius. The mean value of the month which is below 0 degrees Celsius was expressed as ‘1’ and the months which does not drop that temperature was scored as ‘0’. Then the summation were divided into 12 months to calculate frozen period ratio. The higher the ratio, the lower the score it gets in this study.

4.3.1.17. Agricultural Land

Wind energy power plants require lands for installation and generation electricity that causes problems with agriculture, forestry, and urbanization in the Turkey and world. Wind power plants consume agricultural space, competing with a fundamental use of the land that is food crop production. Turkey has more than 20% of the EU agriculture land, so it makes Turkey to be an important player in agricultural sector [96]. To demonstrate this issue with numerical representation, the agricultural sector in Turkey represents 11% of the Gross Domestic Production; employment in agriculture is 33 % of total employment; rural population 39%. Therefore, national agricultural plans focuses on soil conservation, pollution revention, land consolidation, and legal regulations [97].

The main legal act governing the agriculture sector in Turkey is "Law on soil conservation and land use" (No. 5403) [98]. Absolute agricultural lands, special produce lands, planted agricultural lands and wet agricultural lands are protected from utilization of agricultural fields in projects for non-agricultural purposes by the law. However, if there is no alternative site and approval of the authority is obtained, permission may be granted for investments in defense-related strategic needs, oil and gas exploration and drilling, and for investments related to the utilization of energy resource areas.

Agricultural lands are not considered environmentally acceptable in this study to prevent the continued fragmentation of agricultural lands. Agricultural areas were acquired from CORINE 2006[3] Class 212 (Permanently irrigated land) dataset for this study [65].

4.3.1.18. Greenhouse Gas Emissions

Global warming and climate change have been one of the most important environmental problems in the last two decades. The reason lies behind that is the increment in greenhouse gases in our atmosphere. To decrease the adverse impacts, worldwide organizations such as the United Nations, have been attempting through intergovernmental and binding agreements, such as the Kyoto Protocol. The Kyoto Protocol is an international agreement linked to the United Nations Framework Convention on Climate Change to stabilize greenhouse gas concentrations in the atmosphere. The Kyoto Protocol was adopted in Kyoto, Japan, on 11 December 1997 and entered into force on 16 February 2005 [99]. The Protocol requires developed countries to reduce their GHG emissions at least 5% against the baseline of 1990 within a five-year time frame between 2008 and 2012. Turkey signed Kyoto Protocol in 2009 as an observer, and was not obligated to undertake any emissions reductions at the time.

The UN Climate Change Conference in Paris, France, took place in December 2015. According to the Conference [100], Turkey promised to reduce its emissions by 21 percent over the next 14 years. The target will enable Turkey to step on low-carbon development pathways compatible with the long-term objective of limiting the increase in global temperature below 2°C. In order to achieve the target, some plans and policies concerning energy, industrial processes and products use, agriculture, land-use change and forestry, and waste sectors were determined. The tasks regarding energy for 2030 encompass;

- Increasing capacity of production of electricity from solar power to 10 GW
- Increasing capacity of production of electricity from wind power to 16 GW
- Tapping the full hydroelectric potential
- Commissioning of a nuclear power plant
- Reducing electricity transmission and distribution losses to 15 percent

[3] http://www.eea.europa.eu/data-and-maps/data/clc-2006-vector-data-version-3#tab-gis-data

- Rehabilitation of public electricity generation power plants

- Establishment of micro-generation, co-generation systems and production on site at electricity production

The Turkish Statistical Institute (TurkStat) is the responsible agency for compiling the National Greenhouse Gases (GHG) Inventory. The Emission Inventory includes direct GHGs as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), F gases. The main contributor for greenhouse effect is CO_2 and it accounts for 82% of the total effect for Turkey. It is followed by CH_4 (12%), N_2O (%5) and F gases (1%)[101]. Figure 20 demostrates greenhouse gas emission rates by sectors in Turkey for the years 1990-2014. The inventory revealed that the overall GHG emissions changed from 207.8 to 467.6 million tonnes of carbon dioxide equivalent (CO_2-eq) between the years 1990 and 2014 [101]. This represents an increase of 125 % above 1990 levels. As it is shown that the highest portion of total GHG emissions was originated from energy sector caused from fossil fuel combustion with 72.53%. The energy sector was followed by the industrial processes with 13.43%, the agriculture activities with 10.59% and the waste with 3.45%.

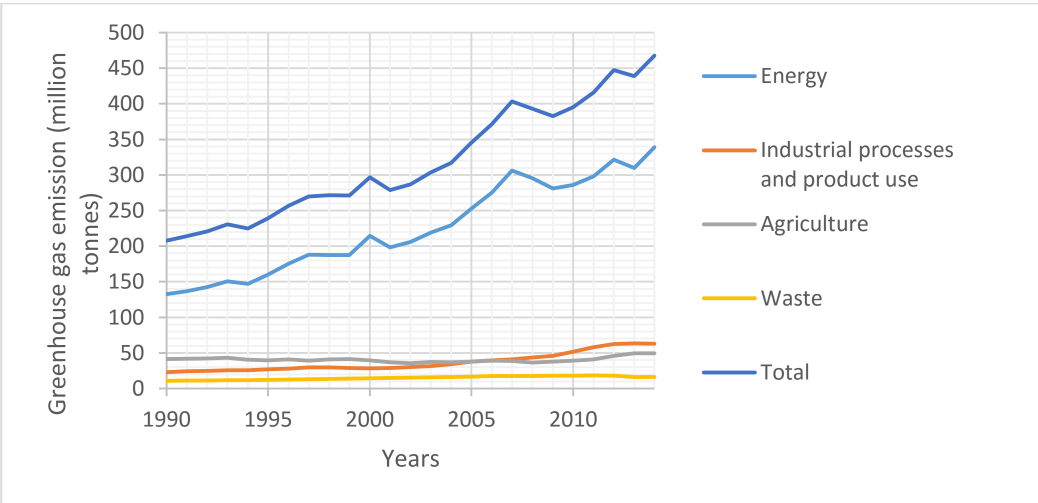

Figure 20. Greenhouse gas emissions by sectors (CO_2 equivalent)

All energy sources contribute to anthropogenic climate change by emitted GHGs. Although wind energy is accepted as clean energy sources, it has a negative impact on the environment during manufacturing, utilization and recycling stages. Life cycle assessment (LCA) is an analysis to evaluate the environmental impacts of wind turbines during their whole life cycle from cradle-to-grave period. LCA of wind turbines deals with the stages from extracting raw materials to it's decommission. Raadal et al. [102] carried out a comprehensive overview of GHG emissions from wind turbines based on 63 LCAs published between 1990 and 2010. The study revealed that larger turbines have lower life-cycle GHG emissions than smaller turbines (Figure 21). The results show that GHG emissions are varying with turbine sizes from 4.6 g to 55.4 g CO_2-equivalents per kWh. The mean value of environmental impacts decreases from 45.0 to 10.4 g CO_2-equivalents per kWh as the turbine size increases.

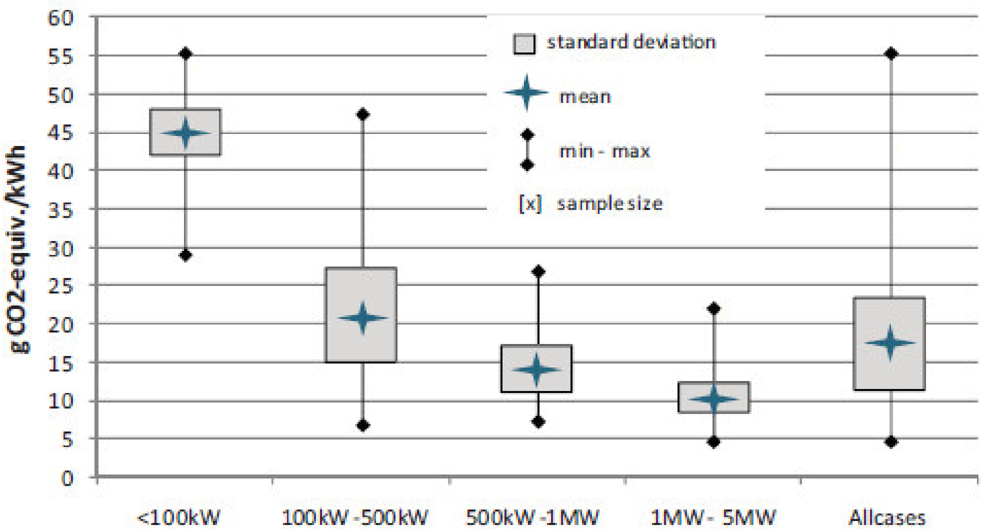

Figure 21. Life cycle GHG emissions from wind power based on turbine size [102]

The GHG emissions of wind power plant per kWh is much lower than conventional sources such as coal fired, oil fired, and natural gas fired power plants (Table 13). The oil-fired generation of electricity is positioned between the natural gas and coal-fired power plant whereas the coal-fired power station has the biggest environmental impact. To conclude, wind power plants is the most environmentally-friendly pathway for electricity generation and can significantly reduce the greenhouse effect with respect to traditional fossil electricity generation technologies. This parameter does not constitute factor for evaluation in this study, since there is no parameter which is varying with regions.

Table 13. Life Cycle GHG emissions of wind and fossil fuel sources [103]

Energy source	**Minimum** (grams GHG CO_2e/KWh)	**Maximum** (grams GHG CO_2e/KWh)
Wind turbine	14.5	28.5
Coal-fired power plant	950	1250
Natural gas-fired power plant	360	575
Oil-fired power plant	700	800

4.3.4.19. Important Bird Areas

Although environmental impacts of wind turbines are considered to be relatively lower than those caused by traditional energy sources, adverse impacts on wildlife populations, especially birds and their habitats, have been identified as a main ecological drawback to wind energy [104]. Report prepared by BirdLife International on behalf of the Bern Convention categorizes potential impacts of wind power plant on birds as [105];

- Collision with the moving turbine blades, with the turbine tower or associated infrastructure such as overhead powerlines, or the wake behind the rotors causing injury, leading to direct mortality.
- Disturbance displacement from around the turbines or exclusion from the whole wind farm. Reduced breeding productivity or reduced survival may result if birds are displaced from preferred habitat and are unable to find suitable alternatives. Disturbance may be caused by the presence of the turbines, and/or by maintenance vehicles/vessels and people, as well as during the construction of wind farms.
- Barriers to movement disrupting ecological links between feeding, wintering, breeding and moulting areas and extended flights around wind clusters, leading to increasing energy demand potentially reducing fitness. Large individual wind farms, or the cumulative effect of multiple wind farms, are the main concerns.
- Change to or loss of habitat due to wind turbines and associated infrastructure.

The risk of bird mortality is still poorly quantified, since bird deaths by wind turbines has not been corrected because of scavenger removal and collisions with other human-made structures [106]. Nevertheless, collision rates per turbine worldwide has been estimated between 0 and 40 collision fatalities per turbine per year (Table 14) [106].

Besides that, wind farms causes less damage to overall bird mortality than other human-made structures. The predicted avian mortality percentages caused from wind farm and building, power lines or even traffic etc. are demonstrated in Figure 22 [107].

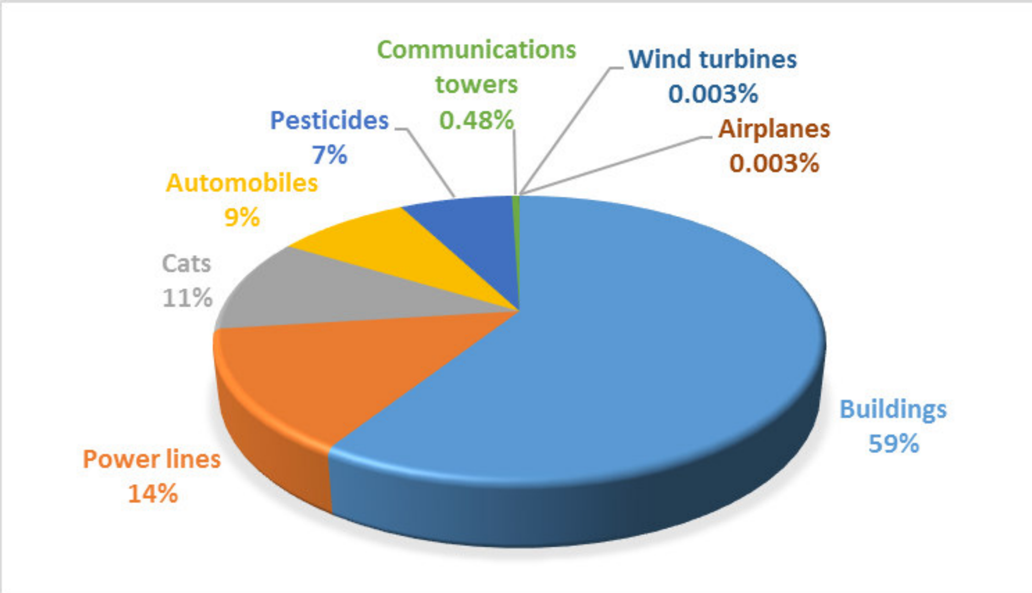

Figure 22. Predicted annual avian mortality percentages

The main bird groups at risk of collision are large raptors and other large soaring species, as well as some migrating birds [108]. Soaring birds use kinetic energy available in convective updraughts to gain altitude and glide to another location. It has been argued [109, 110] that soaring birds can detect the presence of the turbines. De Lucas et al. [110] supported that 71.2% of soaring birds changed their flight direction when detecting the turbines at the top of the mountain and turbines of different size do not represent a significant problem for bird populations. Besides flight strategy, the resident birds are more prone to collision and only a few of birds on migratory flights are actually crushed to turbines [111, 112], because of the fact that resident birds generally use the wind farms area several times while a migrant bird crosses it just once.

Two legal instruments have importance for the conservation of birds and habitats within Europe; The Birds Directives (79/409/EEC) and Habitats Directives (92/43/EEC). These directives were designed to conserve endangered and valuable species and habitats [105]. The aim of Birds Directive is to maintain and restore the populations of naturally occurring wild bird species present in the EU at a level which will ensure their survival over the long term. On the other hands, the Habitats Directive does not cover every species of plant and animal in Europe. Instead, it focuses on some species other than birds which are so rare and threatened that they need protection in order to ensure their long-term survival within the EU. Special Protection Areas (SPAs) arise from the Birds Directive and Special Area of Conservation (SAC) arise from the Habitats Directive are known as Natura 2000 which comprises substantial EU countries.

Table 14. Bird collision mortality caused by wind turbines [106]

Bird mortality: /turbine/year	**Location and time**	**Reference**
24 birds	East dam, Zeebrugge (2001-2002)	[113]
35 birds	Boudewijn canal, Brugge (2001-2002)	[113]
18 birds	Schelle (2002)	[113]
0.27 birds	Straits of Gibraltar (1993/12-1994/12)	[114]
0.03 birds	Tarifa, Spain (1994/7 to 1995/9)	[110]
0.186 vultures	Tarifa, Cadiz, Spain (2006-2007)	[115]
0.145 vultures	Tarifa, Cadiz, Spain (2008-2009)	[115]
3.59 birds	Nine Canyon Wind Power Project (2002/9-2003/8)	[116]
1.33 birds	Tarifa, Andalusia, Spain (2005-2008)	[117]

The Convention on the Conservation of Migratory Species of Wild Animals (CMS) and the Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention) are international conventions in order to develop guidance on how to tackle issues relating to wind energy and nature conservation and impact assessment. Resolution 7.5 on Wind Turbines and Migratory Species was adopted by the 7th meeting of the Conference of Parties (2002) to identify areas where migratory species are vulnerable to wind turbines and where wind turbines should be evaluated to protect migratory species [105]. Although Turkey is a non-party on Convention on the Conservation of Migratory Species of Wild Animals (CMS), some species listed in Bonn Convention are existing in Turkey. In a similar manner, report prepared by BirdLife International on behalf of the Bern Convention provided the basis for minimizing adverse effects of wind power generation on wildlife.

This study tried to develop recommendation for unconstructed wind farm projects by focusing on the effect on soaring birds listed Table 15. A database of bird and biodiversity compiled by Doğa Derneği[4] which is the partner of BirdLife International in Turkey provides some information regarding critical soaring bird habitats. Important Bird Areas, having internationally significance for migrating, wintering or breeding bird, designated under the Birds Directive to form the basis of the Special Protection Area network. The species listed Table 15 are protected by either the The Birds Directives or Bern Convention or Bonn Convention. Authoritative siting distances for regarding bird habitat have not been determined. Doğa Derneği, however, has carried out a literature survey to estimate the soaring-birds habitat and to protect them from harm. While habitat zone of 20 species among all soaring-birds have been known, the remaining has not been studied yet (Table 15). It was assumed that 0.1 km buffer zone around these limits are applicable for this study.

4.3.4.20. Visual Impact

Public perception against the visual impact is more distinctive than other environmental concerns, therefore their acceptance is the primary barrier to any new development. Their reaction against wind farms has always been mixed; although the conducted surveys demonstrate that public generally promote wind power, the same people also complain about visual impact. A national survey in the UK revealed that 81% of that people support for wind power [118]. Additionally, society's acceptance in Denmark, Germany, and Sweden are generally supportive [119]. Although many people hold supportive attitudes towards the installation of wind power, they oppose it because the planning of wind farm installation is close to where they live. The phenomenon of NIMBYism (Not In My Backyard) may cause the the difficulties, for instance, 85% of proposed wind farm projects in the Czech Republic have been cancelled due to their visual impacts [120]. The reasoning behind the theory is selfish motives and maximizing their own individual utility [121]. The point they ignored is that if all people think in the same way with them, no doubt that wind power will not be developed anywhere. Tegou et al.

[4] KusBank veritabanı, Erciyes Üniversitesi, Doğa Derneği: Royal Society for the Protection of Birds and BirdLife International. www.kusbank.org.

[122] stated that the term of NIMBY sendrome sometimes replaces with the new term BANANA (Build Absolutely Nothing Anywhere Near Anything) sendrome. Such people do not support wind energy in any circumstances.

Table 15. Soaring-birds species

	Common name	Buffer (km)		Common name	Buffer (km)
1	Black Kite	1	**21**	Barbary Falcon	N.A.
2	Black Stork	1	**22**	Black-winged Kite	N.A.
3	Bonelli's Eagle	10	**23**	Booted Eagle	N.A.
4	Cinereous Vulture	50	**24**	Common Buzzard	N.A.
5	Egyptian Vulture	10	**25**	Common Kestrel	N.A.
6	Griffon Vulture	25	**26**	Eleonora's Falcon	N.A.
7	European Honey Buzzard	5	**27**	Eurasian Hobby	N.A.
8	Golden Eagle	6	**28**	Eurasian Sparrowhawk	N.A.
9	Imperial Eagle	10	**29**	Greater Spotted Eagle	N.A.
10	Lesser Kestrel	1	**30**	Lammergeier	N.A.
11	Lesser Spotted Eagle	3	**31**	Lanner Falcon	N.A.
12	Northern Harrier	1	**32**	Levant Sparrowhawk	N.A.
13	Montagu's Harrier	5	**33**	Long-legged Buzzard	N.A.
14	Northern Goshawk	0.5	**34**	Merlin	N.A.
15	Osprey	2	**35**	Oriental Honey-buzzard	N.A.
16	Peregrine Falcon	2	**36**	Pallid Harrier	N.A.
17	Red Kite	3	**37**	Rough-legged Hawk	N.A.
18	Western Marsh Harrier	0.5	**38**	Red-footed Falcon	N.A.
19	White Stork	1	**39**	Short-toed Snake-eagle	N.A.
20	White-tailed Eagle	5	**40**	Saker Falcon	N.A.
			41	Steppe Eagle	N.A.
			42	Yellow-billed Stork	N.A.

Visual impact of wind turbines depends on many physical attributes: the characteristics of the WTs themselves (height, number, colour, rotor diameter and moving blades), landscape qualities, distance from the observer and many other factors. Several studies have pointed out that smaller wind farms are more positively perceived in comparison with larger-scale developments, since wind turbines are getting larger and larger (Figure 23) and their dominance on landscapes is proportional with their size [123].

Visual impact was handled for this study according to visual impact zones of wind turbines which was defined by Abromas et al. [124]. Theoretical classification of these zones were corroborated by conducted survey and intervals of zones were defined as the listed in Table 16. According to classification, wind turbines usually dominate in the landscape at a distance of 0 km – 3 km, they become accents at a distance of 4 km – 7 km, subdominants at a distance of 8 km – 10 km and background elements at a distance of >10 km.

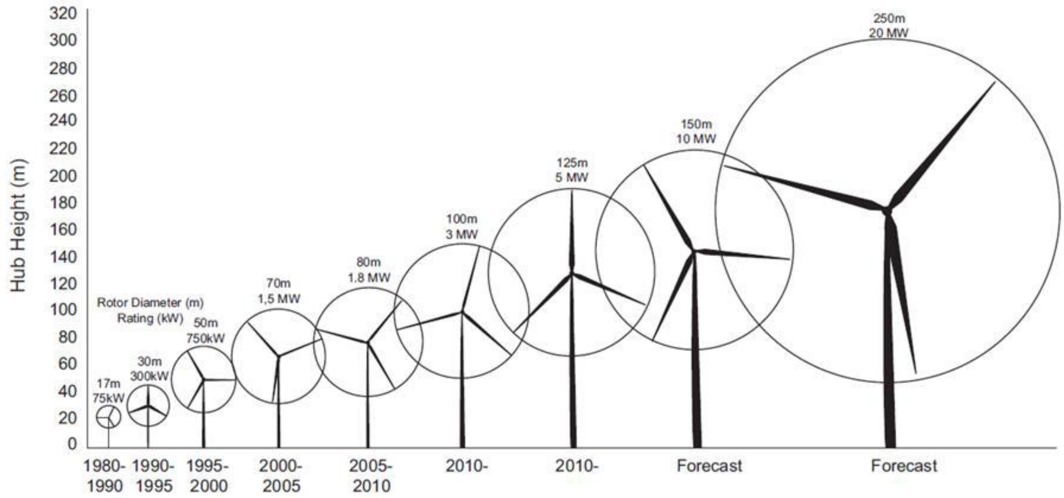

Figure 23. Growth in size of commercial wind turbines [123]

4.3.4.21. Noise

Exposure to noise of wind turbines for a short duration does not cause much of a distraction. However, if duration is a whole day, it can be annoying, especially if wind turbines are densely placed.

Wind turbines generate noise as aerodynamic noise and mechanical noise [106]. Aerodynamic noise, being functions of the blade's aerodynamic design and the wind velocity, is caused from rotation of blades. A strong wind on a big turbine is obviously noisier. On the other hands, mechanical noise, produced by the moving electro-mechanical parts of the machine, does not change with the turbine dimensions.

Noise is quantifiable on the decibels (dB) scale and summation of the mechanical and the aerodynamic noises. "Sound power" and "sound pressure" are two distinct characteristics of sound both share the same unit of measure, the decibel. Sound power (L_w) is the acoustical energy emitted by the sound source, and is not affected by the environment and distances. On the other hand; sound pressure (Lp) is sound what our ears hear and influenced by the strength of the source, the surroundings and the distance from the source to the receiver [125].

This section describes the existing noise level around the project areas and identifies the distances needed to provide the upper sound limit values for night-time hours criteria in regulation of Assessment and Management of Environmental Noise [126].

Table 16. Theoretical classification of visual impact zones of wind turbines [124]

Distance to the wind farm (km)	**Visual impact degree**
0-1	Wind turbines **dominate** because of their large scale, movement of blades, close proximity and the number of them.
1-3	Wind turbines **generally dominate** in a landscape. The impact is more significant due to the proximity, visual parameter of wind turbines, which dominate in landscape.
3-5	Wind turbines are clearly seen, and their impact is average. Also, with the distance their domination decreases. The blade movement is seen.Though wind turbines are seen, they are not totally dominating when being observed from the observation point (with enough level of visibility). They become landscape **accents.**
5-7	Wind turbines are seen but do not stand out clearly from the overall picture. The blade movement is seen when visibility is good and average. They become landscape **accents.**
7-10	Wind turbines are less clear, and, visually, their size is decreased, but movement can be noticed (level of **subdominants**).
10-13	The visual impact is weak, and the movement can be noticed on a bright day – wind turbines get among all the common elements (**background elements**).
13-16	Wind turbines become indistinct, with slight impact on the remote landscape.The movement of blades can be seen, but with greater distance they become **background elements**.
16-20	Wind turbines and movement of blades can be seen on a bright day but their visual **impact is insignificant**.
>20	**No impact or it is insignificant**. Visibility is influenced by weather conditions, wind turbine visual parameters (rotor diameter, hub height), the local terrain, single trees and forest arrays.

The worst case scenario for noise level of wind farms contains simultaneously running wind turbines and gives Equivalent Noise Level. The calculated noise from whole turbines is given by the following formula [127] ;

$$Leq = 10 * log \sum_{i=1}^{n} 10^{(Lw(i)/10)} \qquad (4.\ 8)$$

where; Leq is equivalent continuous noise level (dB), Lw(i) is sound power level of a source (dB), n is number of noise sources.

Frequency, measured in Hertz (Hz), is the number of cycles completed per second by a vibrating object. Narrow band, 1/3-octave band and octave band are three of the most common filters in acoustics [128]. The term of one octave denotes the frequency ratio of lower limiting frequency and the upper limiting frequency which is the the boundary of the band. An octave is frequency ratio of 2:1. The frequency ratio of lower boundary frequency and the upper boundary frequency is 1/2 [128].

Which means:

$$f_l = f_c / 2^{1/2} \qquad (4.\ 9)$$

$$f_u = f_c * 2^{1/2} \qquad (4.\ 10)$$

and the center frequency is the geometric mean value :

$$f_c = \sqrt{f_l * f_u} \qquad (4.\ 11)$$

Calculation is done at each 500 Hz increment from 500 Hz through 4000 Hz based on one octave band center frequencies which follows ISO standard [128]. The distribution of the sound level in each octave band (500-1000-2000-4000 Hz) is calculated by below equation;

$$Lw = 10 * log \sum_{i=1}^{n} 10^{\left(\frac{Lw(i)}{10}\right)} \qquad (4.\ 12)$$

$$Lw(i) = 10 * log \sum_{i=1}^{n} \frac{(10^{\left(\frac{Lw}{10}\right)})}{4} \qquad (4.\ 13)$$

As distance from a wind farm site increases, the noise level decreases as a result of the spreading out of the sound energy. Noise levels in different distances from the turbines are calculated by this formula (Rau & Wooten, 1980);

$$Lp(i) = Leq + 10 * log \frac{Q}{4*\pi*r^2} \tag{4. 14}$$

where, Lp(i) is sound pressure level (dB), Q is reduction factor depending on whether flat or hilly terrain (2 is taken as a medium level terrain), R is distances from sources (m).

Additionally, reduction in the sound pressure level due to exposure the atmosphere should be considered. The air absorption (Aair) increases with increasing frequency and calculated by the following expression [127] :

$$Aair = (7.4 * 10^{-8}) * (\frac{f^2 * r}{\phi}) \tag{4. 15}$$

where, Φ is relative humidity of air (%70), f is frequency of the transmitted sound.

The total sound produced by multiple wind turbines is calculated by subtracted air absorption from the sound pressure level [127];

$$Lp = Lp - Aatm \tag{4. 16}$$

There are several weighting curves to modify the measured sound pressure level. The correspond A-weighting value correlates in general better with the main effects of noise [128] (Table 17). Therefore, A-weighting values are used in order to obtain more accurate sound level.

To keep sound levels at an appropriate level, government set an upper limit dBA value that can be heard at the closest settlements. Operating sound produced from wind turbines are classified as same as industrial sources in Turkey and must remains below the limit value set out in the Regulation on Assessment and Management of Environmental Noise [126]. According to siting area of wind turbines and hours of the day, the required environmental sound limits are changing. For instances, 50 dBA should be provided by developer in the densely-populated educational, cultural and healthcare fields and camping areas in night-time hours (Table 18). The sound power levels of a present day wind turbine are in the 98–104 dB range, which result in an exposure of about 33–40 dB for a person living 500 m away [123].

Table 17. The response of standard A-weighting filter in frequency bands [128]

Frequency (Hz)	A-weighted (dB)
500	-3.2
1000	0
2000	1.2
4000	1

Table 18. Environmental sound limit values for industrial plants [126]

Fields	L_{day}(dB)	$L_{evening}$(dB)	L_{night}(dB)
The densely-populated educational, cultural and healthcare fields and camping areas	60	55	50
The densely-populated residential areas	65	60	55
The densely-populated workplaces	68	63	58
Facility in the Organized Industrial Zones	70	65	60

To obtain the average distance of wind farm to meet the sound limit values specified in the Regulation [126], the upper sound limit values for all licensed wind turbines in Turkey [129] were taken as 50 dB and the required distances for each farm were calculated. The sample calculations are included in Appendix D. Results showed that average of the distances (580 m) is already within a distance of 1000 m which is buffer zone from the urban area is according the Legislation of the General Directorate of Renewable Energy.

4.3.2. Exclusion of Infeasible Sites

Exclusion zone is unsuitable zone for wind turbine installation based on factual reasons and legal regulations. In some cases, buffer zones are also taken into account to define the minimum distance around those areas. In this step, all sites that fail to satisfy even one constraint factor are excluded from further investigation. The GIS software package used in the exclusion procedure is ArcMap developed by the Environmental Systems Research Institute (ESRI). A final constraint map illustrates technically infeasible sites for the development of wind energy in the Turkey. Table 19 provides an overview of the constraints and buffer zones.

4.3.3. Criteria Evaluation

After the technically feasible sites were assessed, economically viable sites were obtained in this section using the pair-wise comparisons of the evaluation criteria. The evaluation criteria chosen are presented in Table 19. The relevant priorities for the pair-wise comparisons were provided by a study group comprised of 2 academicians, 1 manager of a company, 1 project engineer and 2 graduate students. The criteria evaluation was performed by dividing the study area into regular grids with certain size and each of these grids was considered as a potential location for installation of wind turbines.

Maximum value of wind power, roads density and grid capacities are more preferable for a place, therefore their maximum score were scored with the highest value (Table 19). On the other hands, the factors of land cost, frozen period and cost for forested terrain were assigned with maximum score for their minimum values.

4.3.4. Environmental Impacts Evaluation

Animals are affected by the loss of their habitat as a result of removing vegetation to construct power plants. It has been estimated that approximately 1.23 ha of vegetation is removed per turbine, then road and grid infrastructure should add up habitat loss from the turbine footprints [130]. Although actual habitat loss changes based on local circumstances, the predicted habitat loss for Turkey based on this average loss per turbine and the number of turbines locating in Turkey according to [129], was approximately 2063 ha. Besides that, habitats in the vicinity of wind farms are not preferred by birds for foraging, nesting, and roosting during their construction activities and operation since the turbines themselves or something associated with the turbines were disturbing and thus displacing birds [130].

During the developments in wind energy sector in Turkey, some problems were observed in implementation. For example, first wind farm in Çeşme did not have any requirement about Environmental Impact Assessment and developers were not aware of habitat loss, noise and the other adverse impact of wind farm. Environmental Impact Assessment (EIA) Regulation in Turkey was issued for wind energy power plants in 2003 and underwent four major revisions due to problems in implementation. Projects which are scope in this by-law were listed in two categories; while first one is the list of projects to which environmental impact assessment shall be applied, second one is the list of the projects to which selection and elimination criteria to be applied.

2003- Capacity of wind farms were not defined and wind farms were categorized only in the scope of Selection and Elimination Projects.

2008- Capacity for classification were identified and wind power plants having more than 10 MW installed capacity were involved in the scope of Selection and Elimination Projects.

2013- Mandatory assessment was applied for wind farms having 20 or more turbines anymore, while wind farms having between 5 and 20 Turbines were under Selection and Election Process.

2014- Assesment is compulsory for the wind power plant over 50 MW, whereas wind power plants with 10 to 50 MW installed capacity are involved in the scope of Selection and Elimination Projects.

The EIA includes project description, project area, environmental and socioeconomic impacts of project and environmental management plan during construction, operation, closure and decommissioning phases. Although comprehensive studies should be conducted for the EIA, this study aim to provide preliminary environmental impact assessments for wind power plants.

After pre-elimination of infeasible sites and sorting of available sites, technically feasible sites were also evaluated in terms of environmental aspect in order to eliminate potentially problematic sites. The primary environmental issues were classified as forest, agricultural area, important bird areas, noise and visual impact evaluation (Table 19).

Table 19. Exclusion Parameters, Evaluation Criteria and Environmental Impact Constraints

Exclusion Parameters		
	Constraints	Buffer zone (m)
1	Electromagnetic interference	5000
2	Airports	3000
3	Fault lines	150
4	Urban areas	1000
5	Protected areas[1]	0
Evaluation Criteria		
	Factors	Type (Min/Max)
1	Wind Power	Max
2	Frozen Period	Min
3	Land Cost	Min
4	Roads	Max
5	Forest	Min
6	Grid Capacities	Max
7	Terrain Complexity	Min
Environmental Impact Constraints		
1	Forest	
2	Agricultural Area	
3	Visual Impact	
4	Noise	
5	Bird Habitats	

[1]Protected areas including; National Park, Natural Reserve Areas, Natural Monuments, Nature Park, Wildlife Protection and Development Areas, Special Protection Areas, Biosphere Reserve

4.4. Usage of the Outputs

To make a decision in an organised way, three steps (exclusion of infeasible sites, criteria evaluation and environmental impacts evaluation) were performed. However, it should be noted that although exclusion of infeasible sites and criteria evaluation were combined to remove unpermitted sites and to rank the remaining sites with respect to their preferabilities, environmental impacts evaluation were not linked with suitability map. Therefore, the decision makers, firstly, should select the three or four best places according to their preferences based on pairwise comparison results. The next stage is to evaluate these sites in environmental aspects. The reason behind inconnected stages is that all decision makers do not think in the same way. While some are interested with visual impact and establish wind farms away from residential places to minimize impact, the other may evaluate visual impact as unnecessary criteria for site selection.

For instances, if you chose 3 optimum location from suitability map and one of the place was locating in forested terrain, you have to chose one of the places among the others. Or if all were located in forested terrain, you should identify how much area are covered by forests. On the other hands, decision makers may not take any notice of visual impact and decision can be made quickly.

CHAPTER 5

RESULTS

The data analysis was performed following the step-wise processing algorithm described in Chapter 4.3. In the first step, unsuitable areas to wind energy has been collected, merged and dissolved (Chapter 4.3.2.). In second step, selected criteria (Chapter 3.3.3.) were scaled and used in calculation of coefficients to the final decision making atlas. Finally, all results were filtered through environmental impact step and a decision making tool was finalized. In this chapter, all mentioned steps were explained in detail. The data-processing analysis was performed using ArcGIS 10.3.1, SAGA GIS software as well as the GDAL GIS library.

5.1. Infeasible Areas

After obtaining and formatting the raw data, intermediate constraint layers, which were obtained from government agencies, web-based dataset and voluntary agency sources, were created by adding appropriate buffers. The constraint criteria were defined for this study as;

- 5 km buffer zones from radars
- 3 km buffer zones from airports
- 150 m buffer zones from fault lines
- 1 km buffer zones from urban areas
- Protected areas

The aim of this stage was to remove unsuitable areas from the analysis based on the criteria and their associated buffers. A vector database which was created in order to define the exclusion zone were subtracted from the borders of Turkey including the maps of urban areas, protected area, airports, fault lines and electromagnetic interference. Since, the total territory of Turkey is about 78 million hectares, approximately 11% of the country is covered by urban area, 6% by airports, 4% by protected area, 0.6% by faults line, and 0.2% by radars (Table 20). The excluded and available areas for installing wind turbines in Turkey are depicted in Figure 26. It is evident from the map that 22% of that area will not be viable to erect wind farms; this corresponds to a total of 17 million ha. The remaining area constitutes 78 % of the total area. Therefore, the majority of the study area is considered suitable for wind energy development at this stage.

Table 20. Covered area of infeasible sites

Type of Lands	**Covered Area (ha)**	**Covered area (%)**
Urban areas	8385637.9	11
Airports	4687576.8	6
Protected Area	3113020.0	4
Fault lines	475745.9	0.6
Electromagnetic interference	124053.0	0.2
Total	**16786033.7**	**22**

5.2. Criteria Evaluation

The most significant step of multi-criteria decision making was assigning the weight of each criterion according to the decision makers' preferences for obtaining the best alternatives from a finite set of possible solution choices. Since there is lack of knowledge regarding ruggedness index, weight of this parameter was assigned by only one person from the study group to avoid wrong decision. For the other parameters, geometric mean of decision makers' preferences were used. After that, every factor was multiplied with these weighted criterion values and final solution were ranked based on minimum and maximum values for the remaining area after exclusion of infeasible area.

Firstly, data of each layer were converted from vector format to a raster format, and resampled to 0.008333° cell sizes (around 700 x 900 m) to obtain raw data of all criteria in grid format. After the conversions were succeeded for each file, the maps were scaled using a graduated scale from value of 0 to 100 based on their maximum and minimum values by subtracting between the actual value of raster cell and local minimum value, and then divided by the differences of maximum and minimum values. The suitable areas for wind turbines were repeated for two different class to estimate suitability atlas of two generic wind turbines representing at the 50 and 100 m hub heights classes. While higher criterion values were preferred for wind power, roads density and grid capacities, the factors of land cost, frozen period and cost for forested terrain were assigned with maximum score for their minimum values. The forested terrains included a special consideration. Although these areas were classified according to their fees and the regions having lowest prices represented high preferability, the treeless area were scored with highest score because of the study trying not to cut any forests and also aimed to keep. The raw data and scaled distribution of the criteria are illustrated in Figure 27-34.

On the other hands, the relative importances of each layers were assigned by the study group. In order to obtain priority vector of all the criteria, the n^{th} root value method was applied by multiplying all of the criteria values together and taking the n^{th} root, in this case n = 7. Dividing the each row to summation of n^{th} root column gave us priority vector. The priority vector of each factor for this study are given in Table 21. Since CR is the mostly used to evaluate acceptability of judgements and being lower than 10% represent consistent matrix, the results of this study can be evaluated as consistent (λ_{max}= 7.7713, CI=0.1286, CR=0.0974).

Table 21. Pairwise matrix for group decision, nth root values and priority vectors of criteria

	Power	**Frozen Period**	**Land Cost**	**Roads**	**Forest**	**Grid Capacity**	**Terrain Complexity**	**nth root**	**Priority Vector**
Power	1.00	1.31	2.17	1.31	0.88	1.85	4.00	1.58	0.21
Frozen Period	0.76	1.00	1.94	1.48	0.87	1.68	0.50	1.07	0.14
Land Cost	0.46	0.52	1.00	0.91	0.37	1.25	0.25	0.59	0.08
Roads	0.76	0.67	1.10	1.00	0.73	1.53	0.33	0.80	0.11
Forest	1.13	1.15	2.69	1.37	1.00	0.93	2.00	1.37	0.18
Grid Capacity	0.54	0.60	0.80	0.65	1.08	2.00	0.50	0.78	0.10
Terrain Complexity	0.3	2	4	3	0.5	2	1	1.3	0.2

As a final step, the overall scores were calculated by multiplying weighs and standardized criteria and summed to obtain overall suitability index. As the regulation regarding airports were changed during the study, two different suitability maps with new and old regulation were developed to illustrate the suitability levels within the feasible sites (Figure 35-36). Then, the resultant map obtained by multipliying the priority vector with scored value for each criteria was divided into four equal sized classes according to result score. It was seen that differentiation in suitability maps between the two generic turbines is so insignificant that, the study used second generic turbine (2.1 MW) for the remaining calculations (Figure 24). The classes having higher score represents the better class and named as low suitable, moderate suitable, high suitable, extremely suitable.

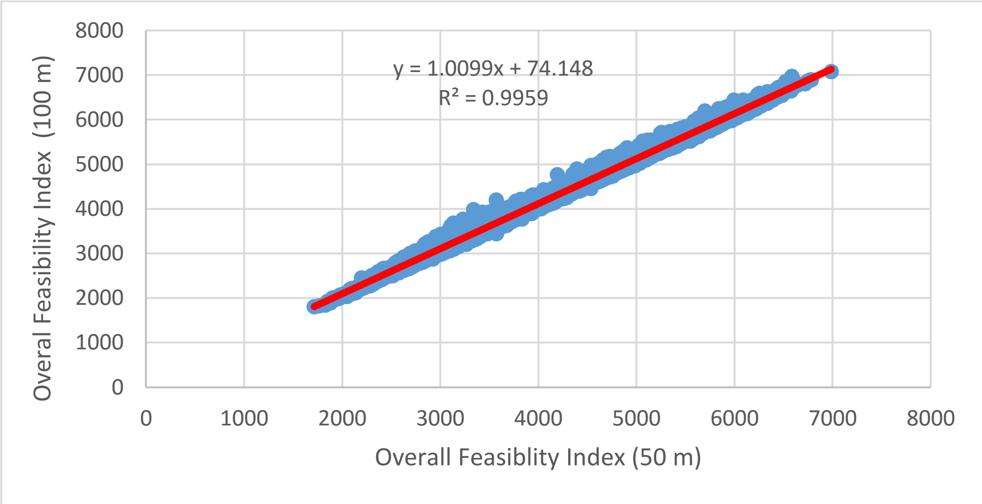

Figure 24. Overall Feasibility Index for two generic wind turbines

Figure 25 shows distribution of suitability classes at 100 m hub heights over Turkey. It was observed that the majority of the area (%34) are covered by the high suitability classes, followed by the extremely suitable area (%33). The reason of that is Turkey has flat terrains, low frozen periods, low land costs and moderate wind power. The results also prove that Turkey is a rich country in terms of wind energy potential. Therefore, this makes possible to achieve 2023 targets. The area of "low suitable" lands represents 28% of the feasible area and occupies 21.5 million ha area. The variety is also observed from the resultant map, this is because of the exclusion of infeasible sites. This demonstrate the highly selective decision making was carried out in this study.

5.3. Environmental Impacts Evaluation

As the final stage, preliminary environmental impact assessments for wind power plants was tried to carry out. To do this, the most environmentally friendly approach were followed during project development stage. Forest, agricultural area, bird habitats, noise

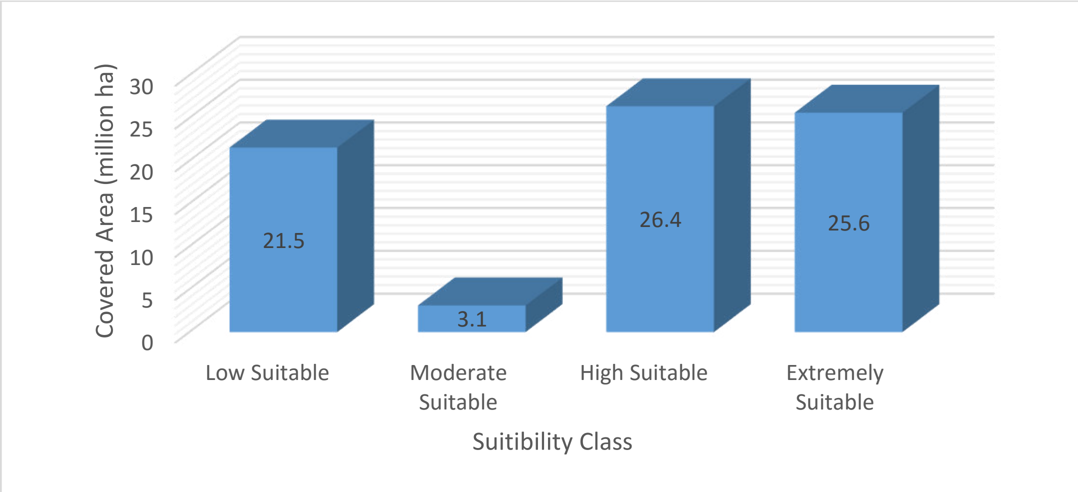

Figure 25. Suitability classes and their areas

and visual impact have been accounted for environmental constraints and tried to protect environmentals from the wind power plan installation.

Since 20 km distance from wind turbine eliminates visual impact on human completely, 20 km buffer zones from urban area were calculated. It was seen that it occupies 75 million ha of Turkey. It showed impossibility of the issue (Figure 37). Besides, as wind turbines become landscape accents 5 km away from the urban area, that distances from the urban area were considered as acceptable. It covers 43 million ha area (Figure 38). However visual impact is not usually taken into consideration by developer and only a distance of 1000 m which is buffer zone from the urban area according the General Directorate of Renewable Energy (dated 22/05/2009) are protected from wind farm installation. Urban areas and 1 km buffer zone covers 8 million ha of total boundary. Any mechanism on permitting license does not control comprehensive study regarding existence of important birds' areas that causes opposition in the courts after construction of wind farms. To avoid this, important bird areas were protected in this study. The variations on suitable areas in terms of bird's habitat for different time intervals were indicated (Figure 39). Figure 39.a. and 39.b. demonstrates that 54.8% of our study area was predicted to be unsuitable for wind energy development as soaring birds' habitat. Furthermore, while important bird areas collected from 2011-2015 and 2013-2015 were taken into consideration, it covers 32.2 % and 20.6 % of country, respectively (Figure 39.c and 39.d). Since the getting license for wind farm takes nearly five years, it was thought that including the only sightings reported from 2011 through 2015 was be applicable for this study.

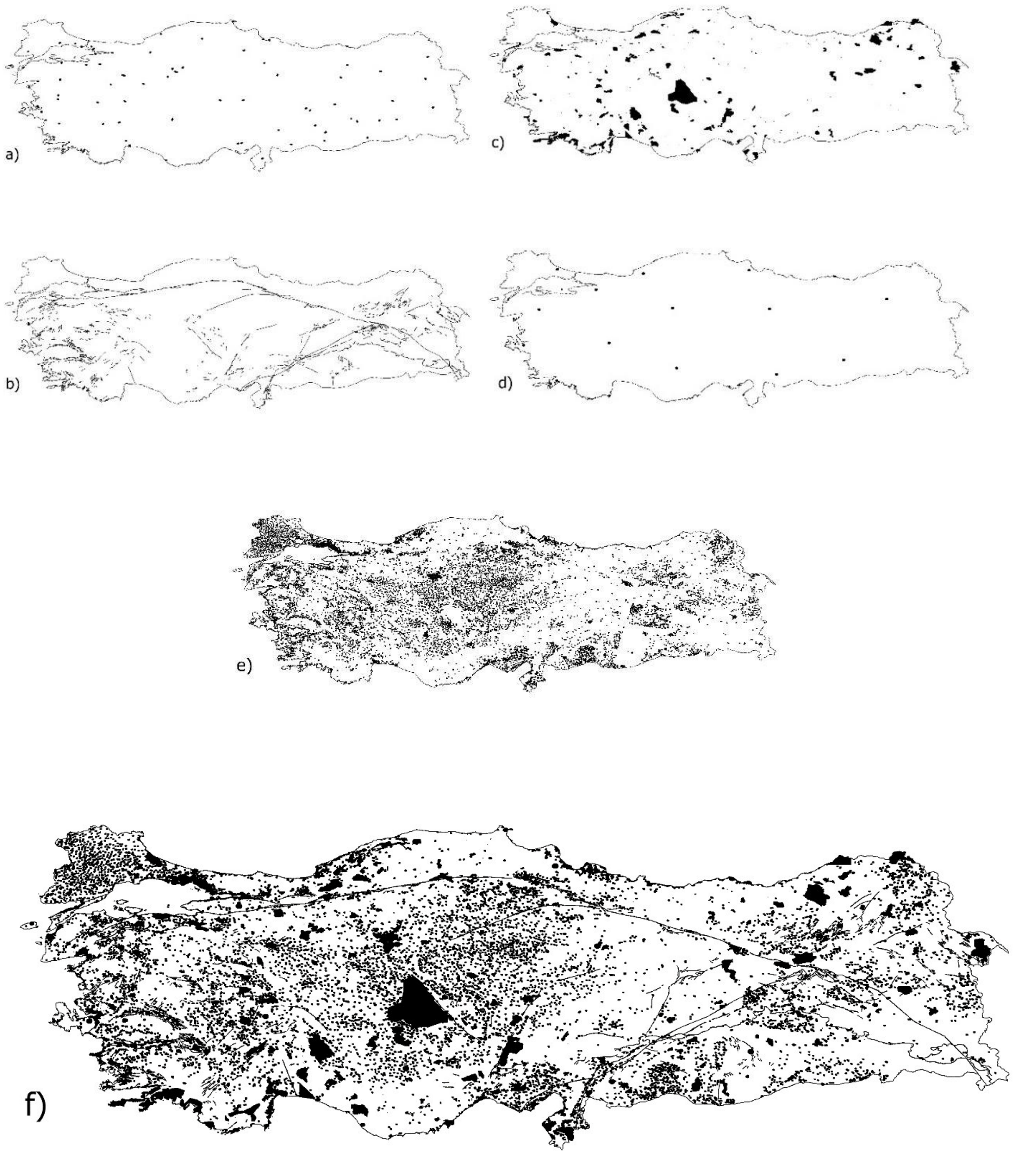

Figure 26. Excluded zone of a) airport b) fault lines c) protected area d) radar e) urban and f) the total excluded area

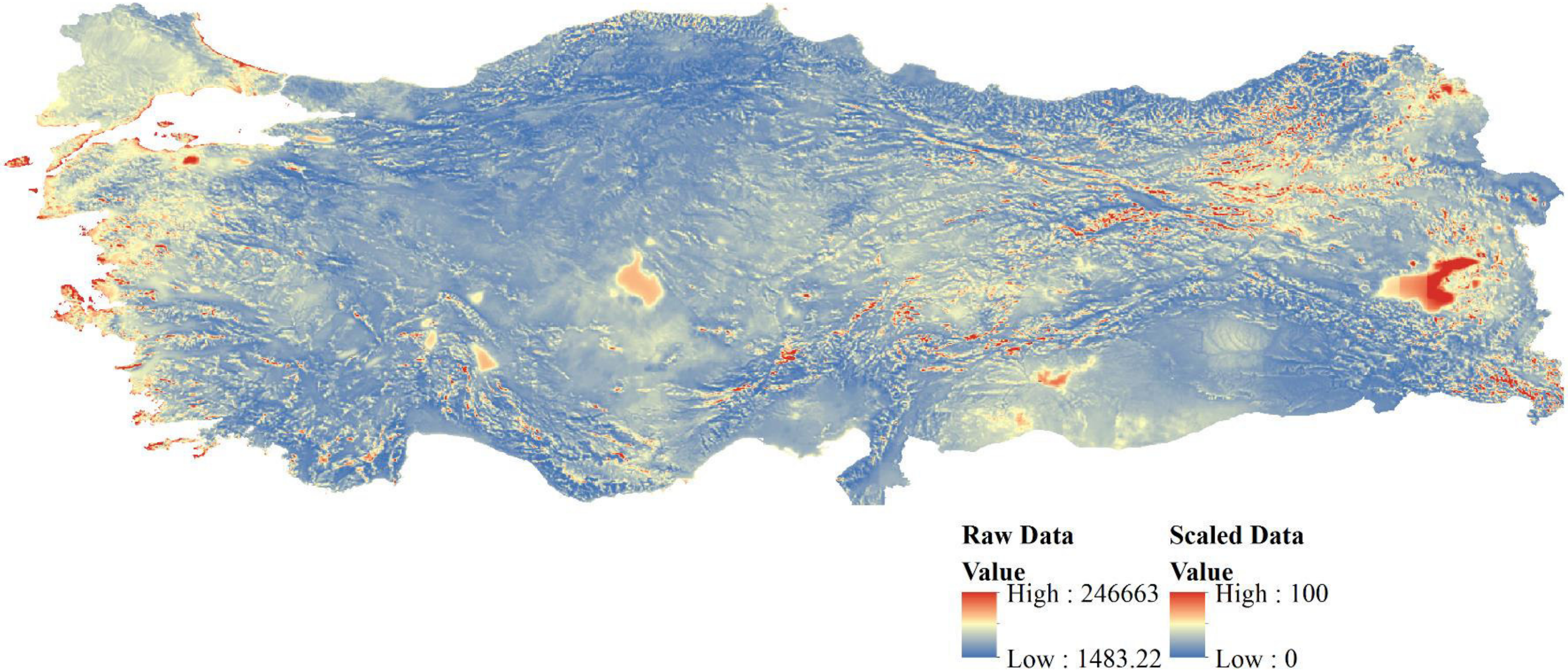

Figure 27. Wind power for first generic wind turbine (50 m)

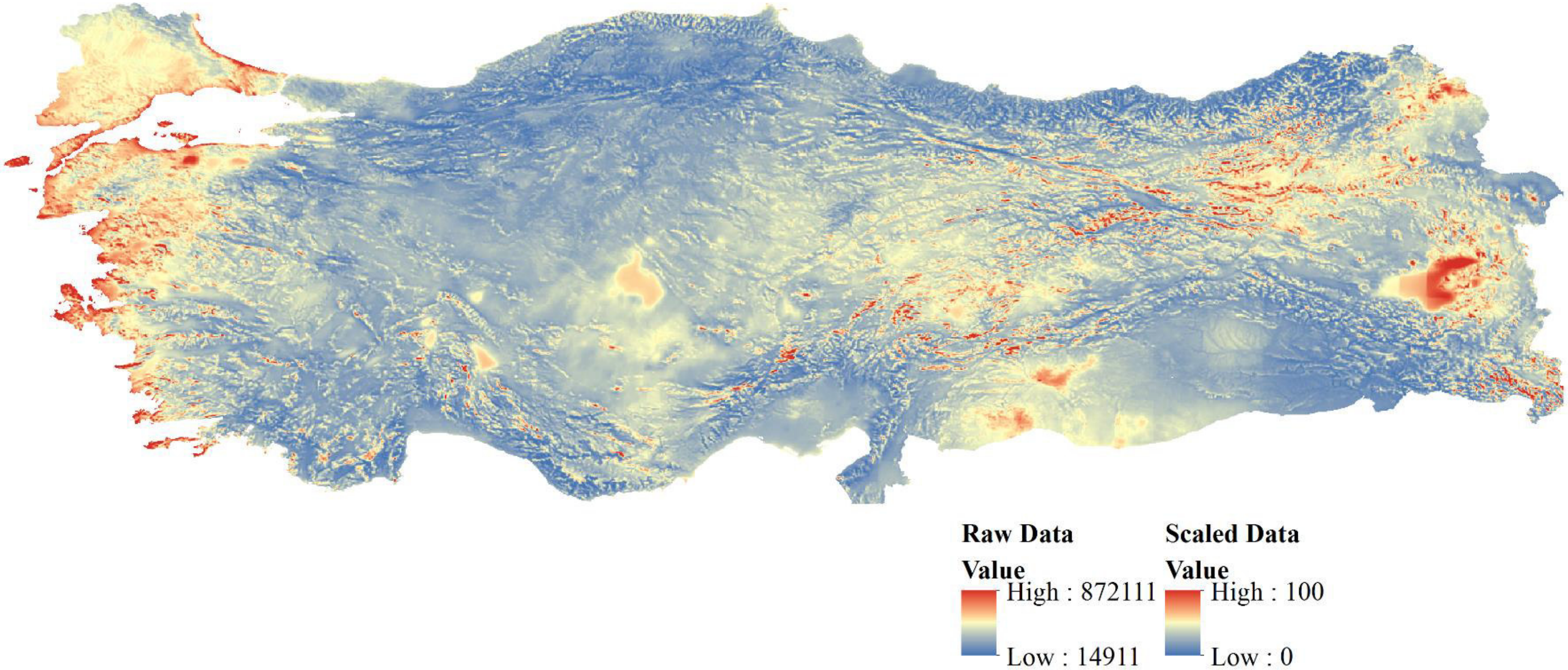

Figure 28. Wind power for second generic wind turbine (100 m)

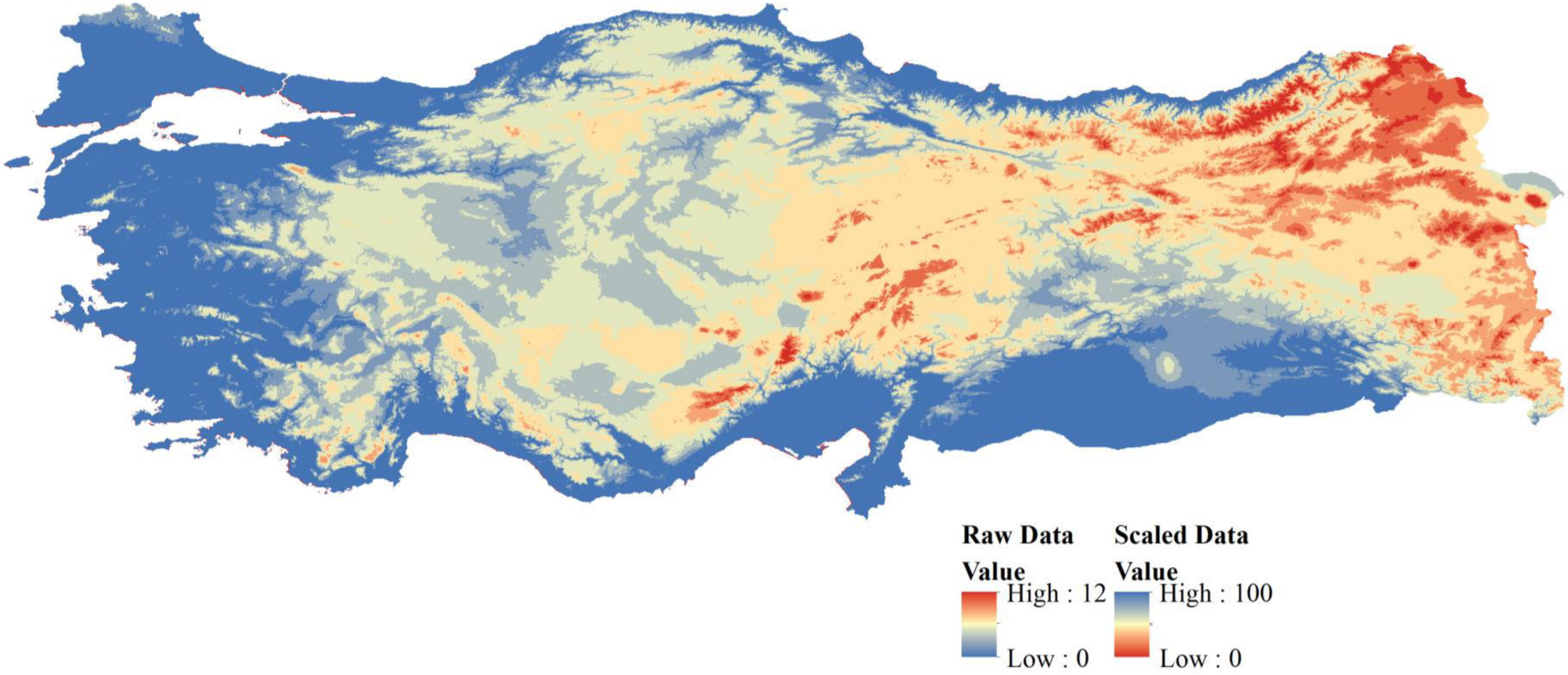

Figure 29. Frozen Periods

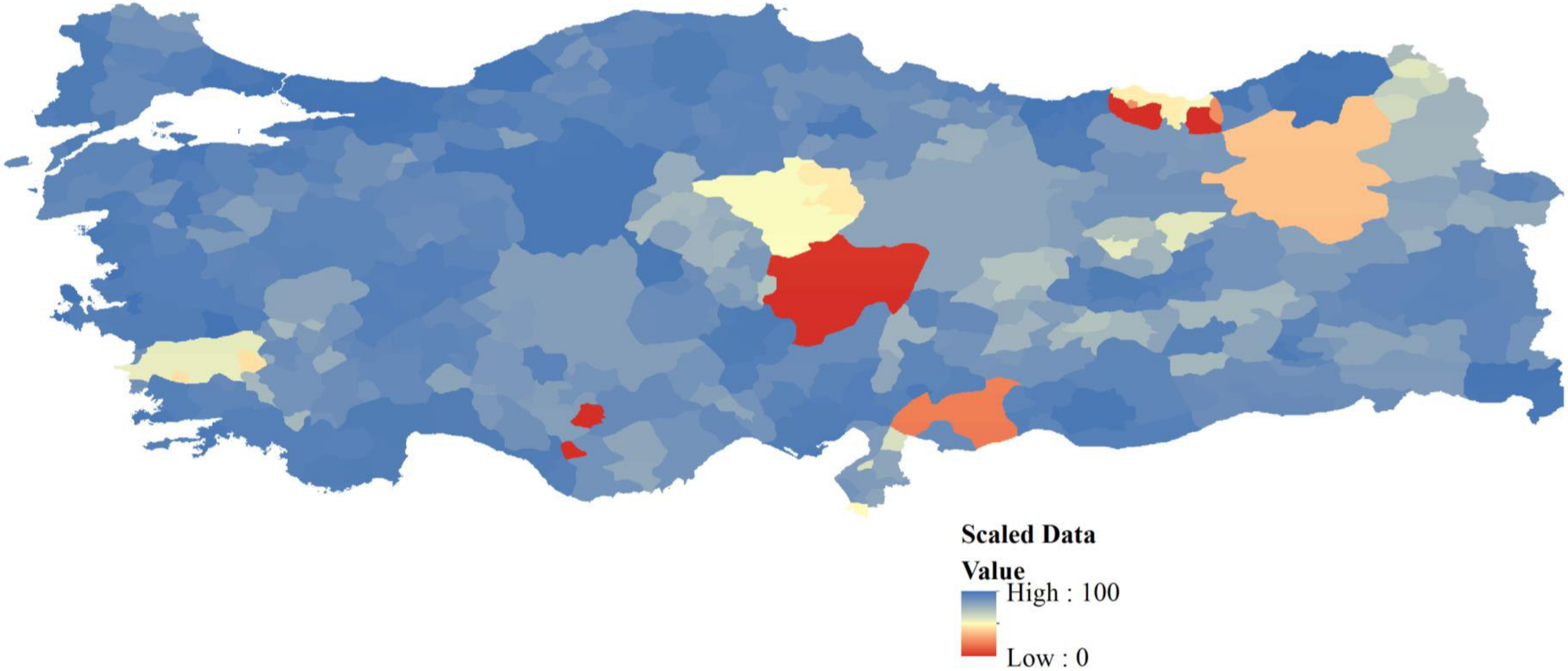

Figure 30. Land costs

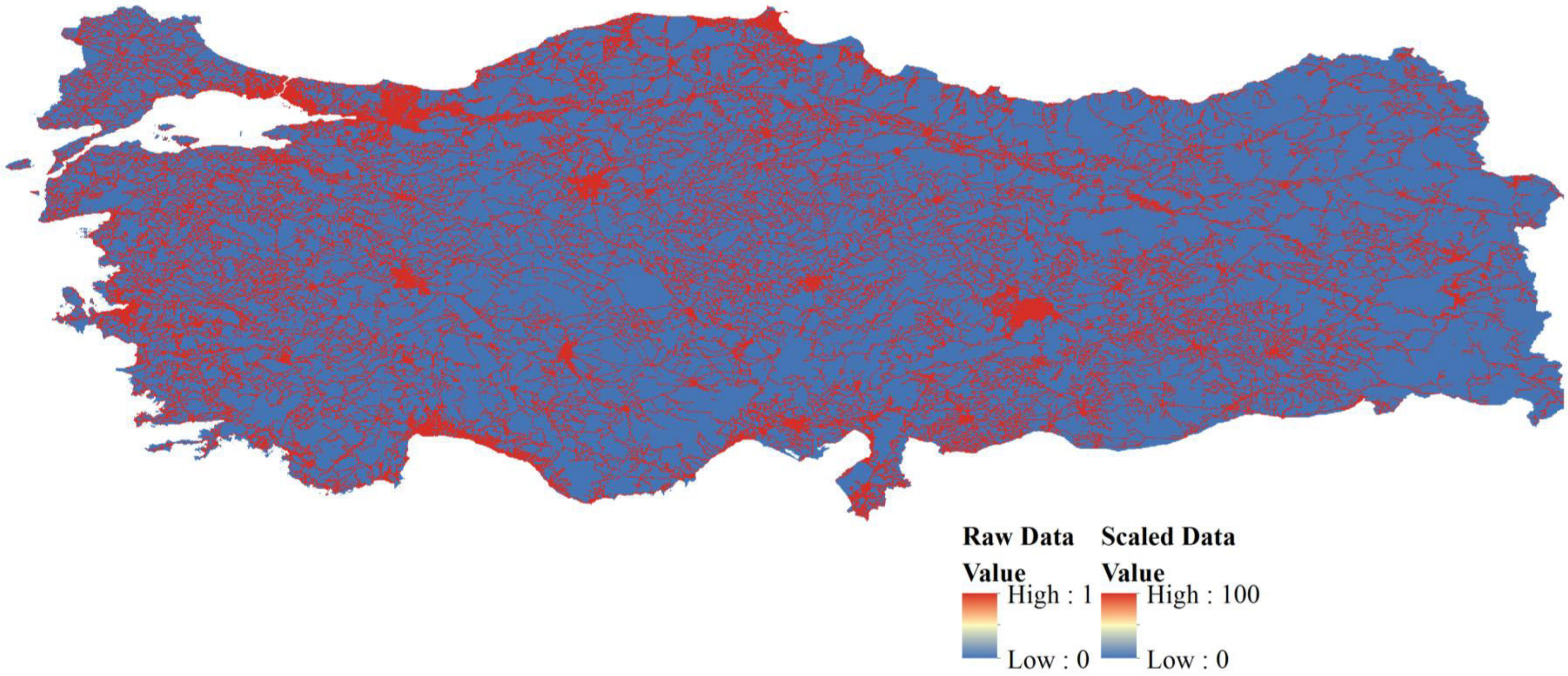

Figure 31. Roads

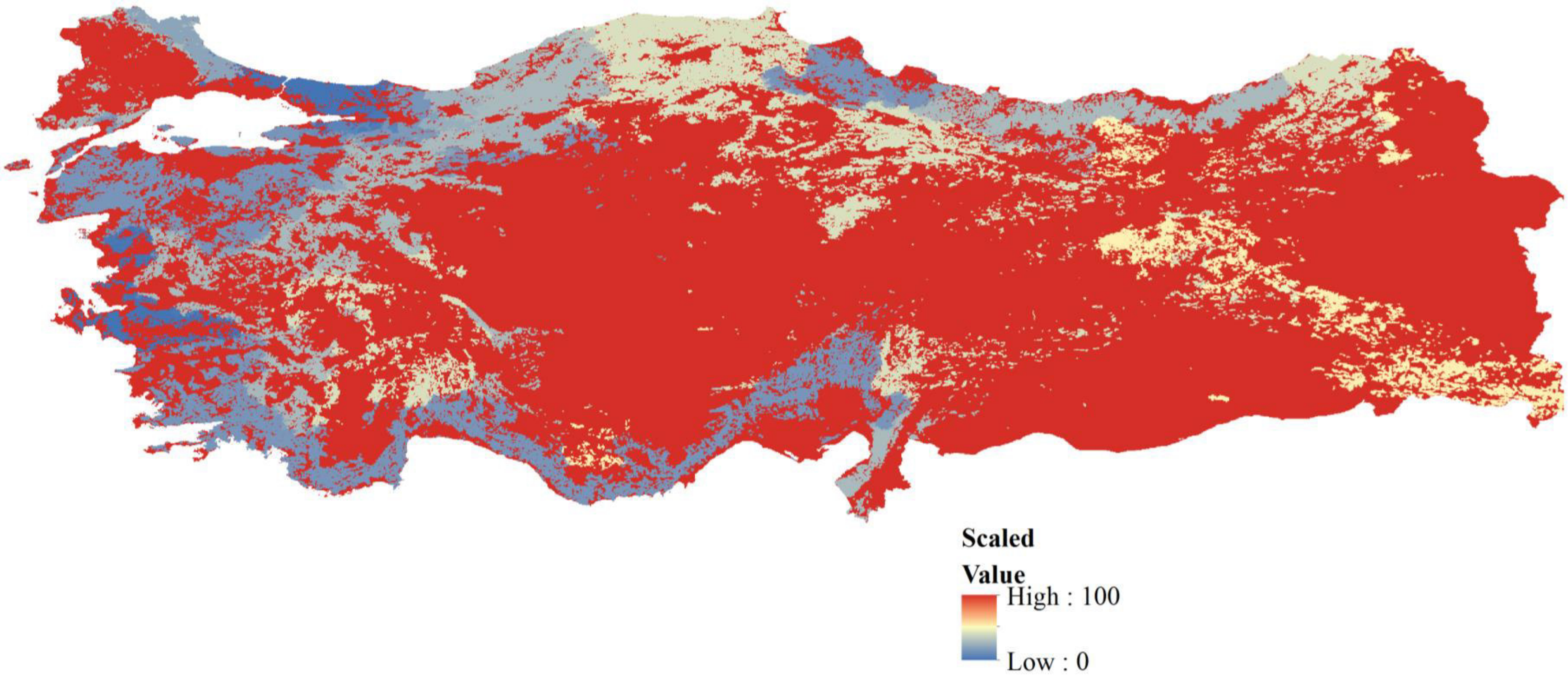

Figure 32. Forests

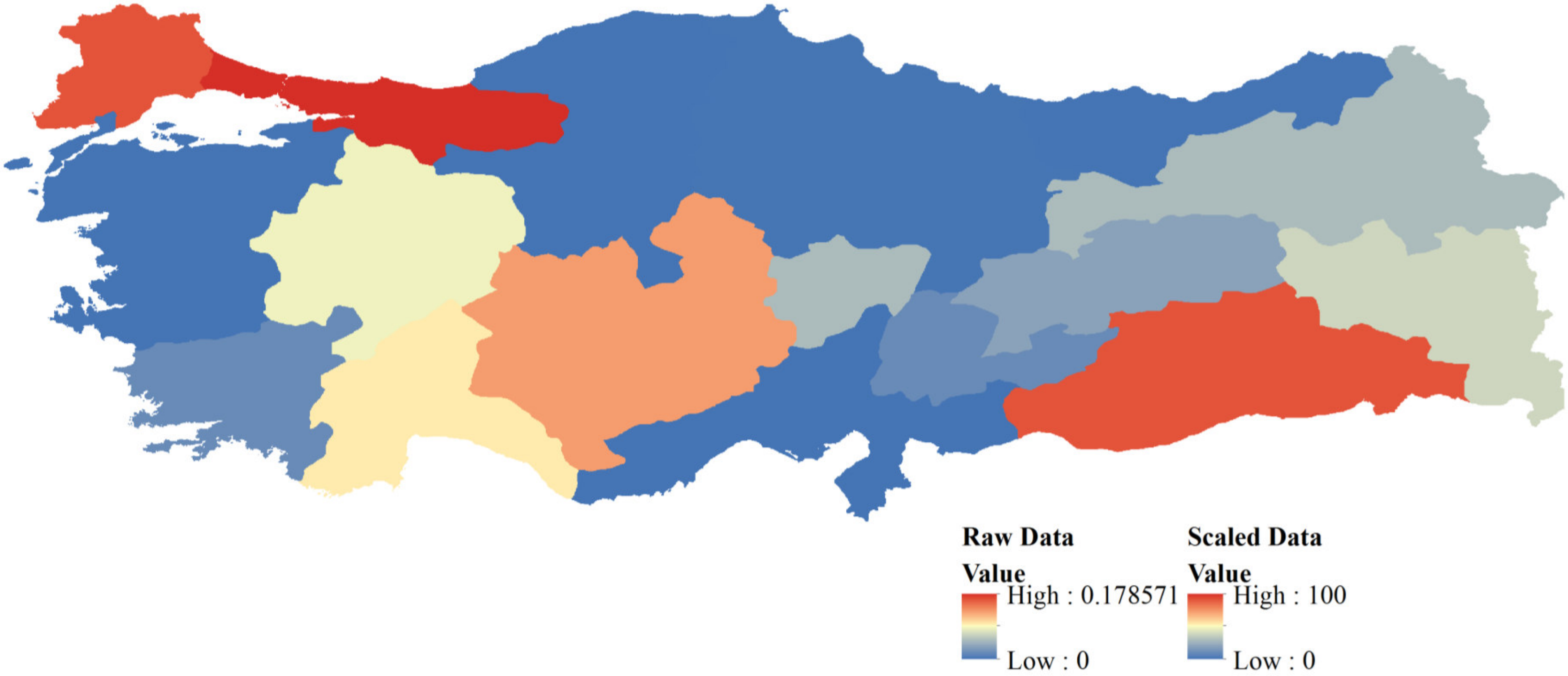

Figure 33. Grid Capacity

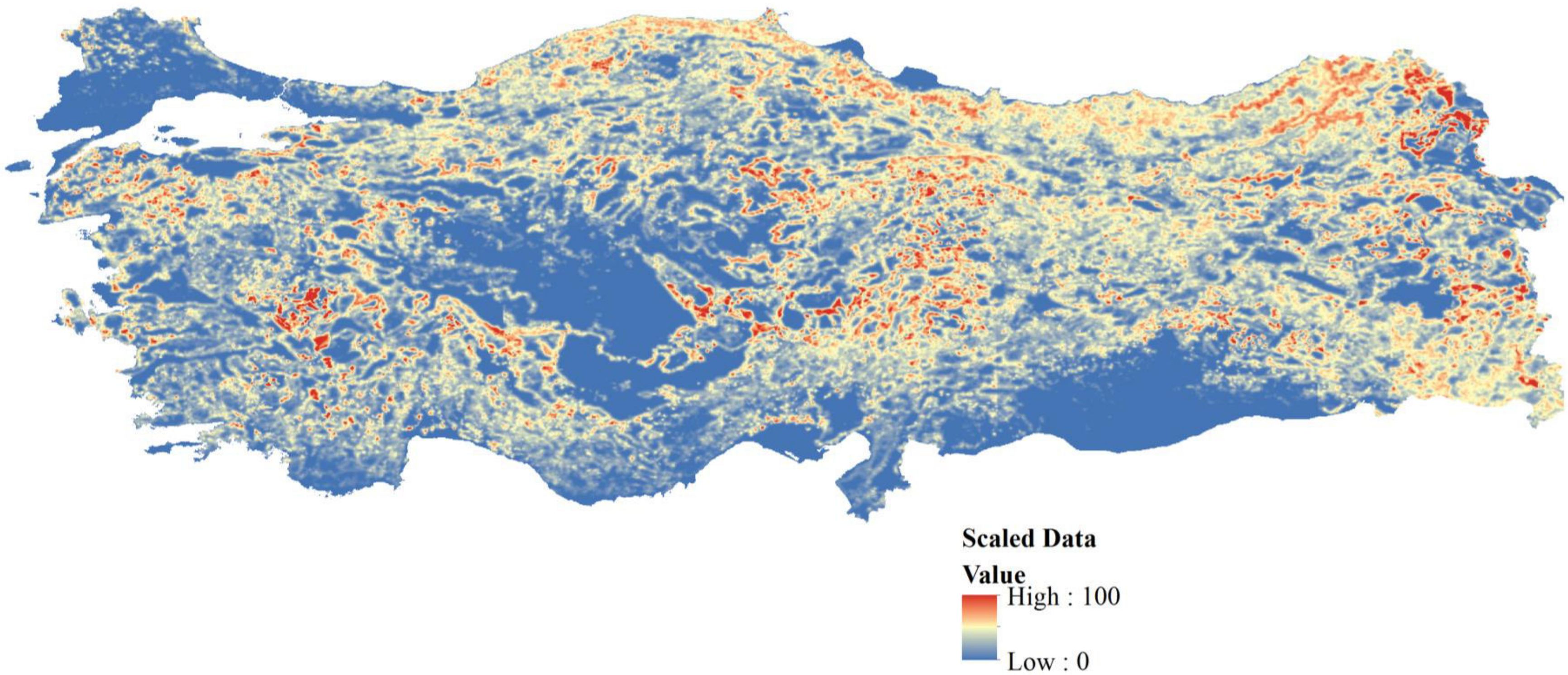

Figure 34. Terrain Complexity

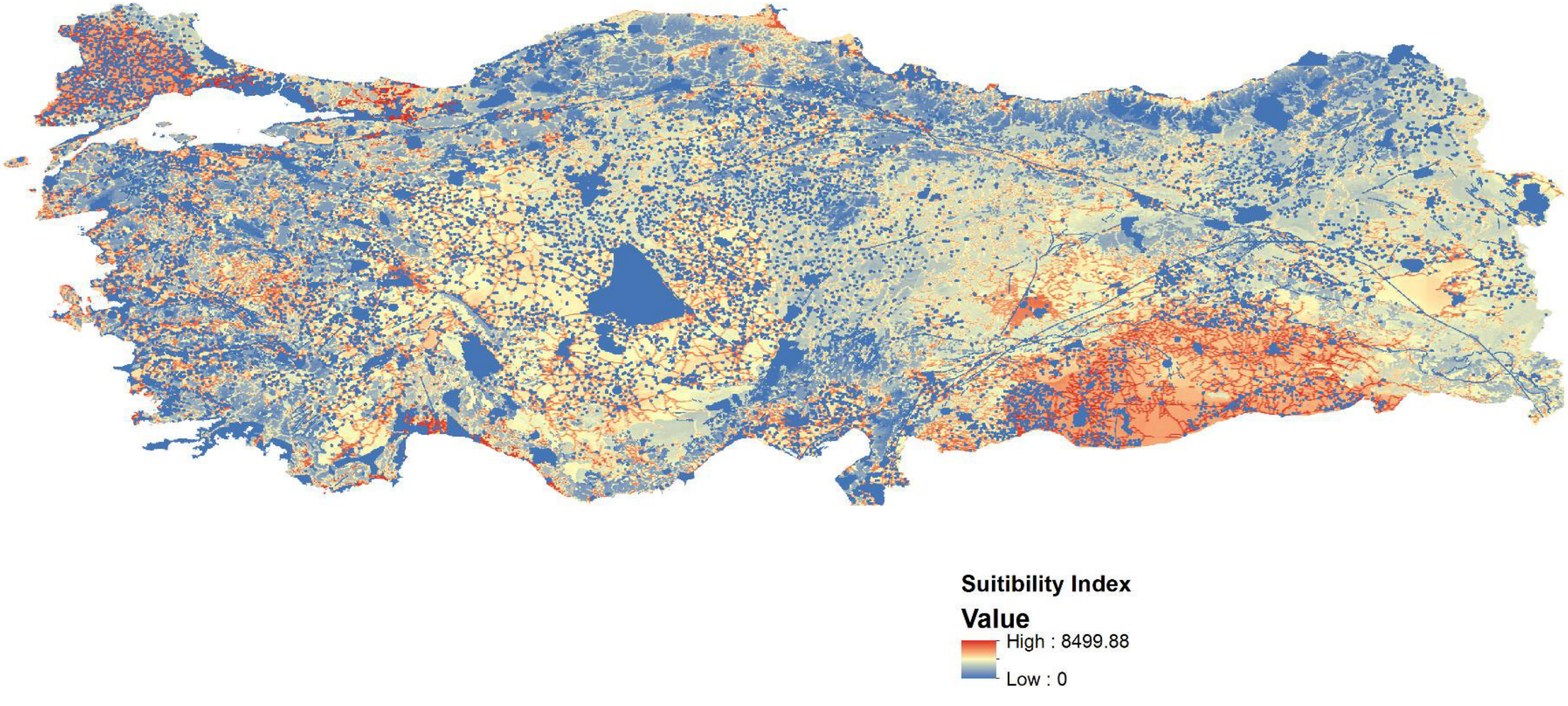

Figure 35. Suitability index with old airport regulation

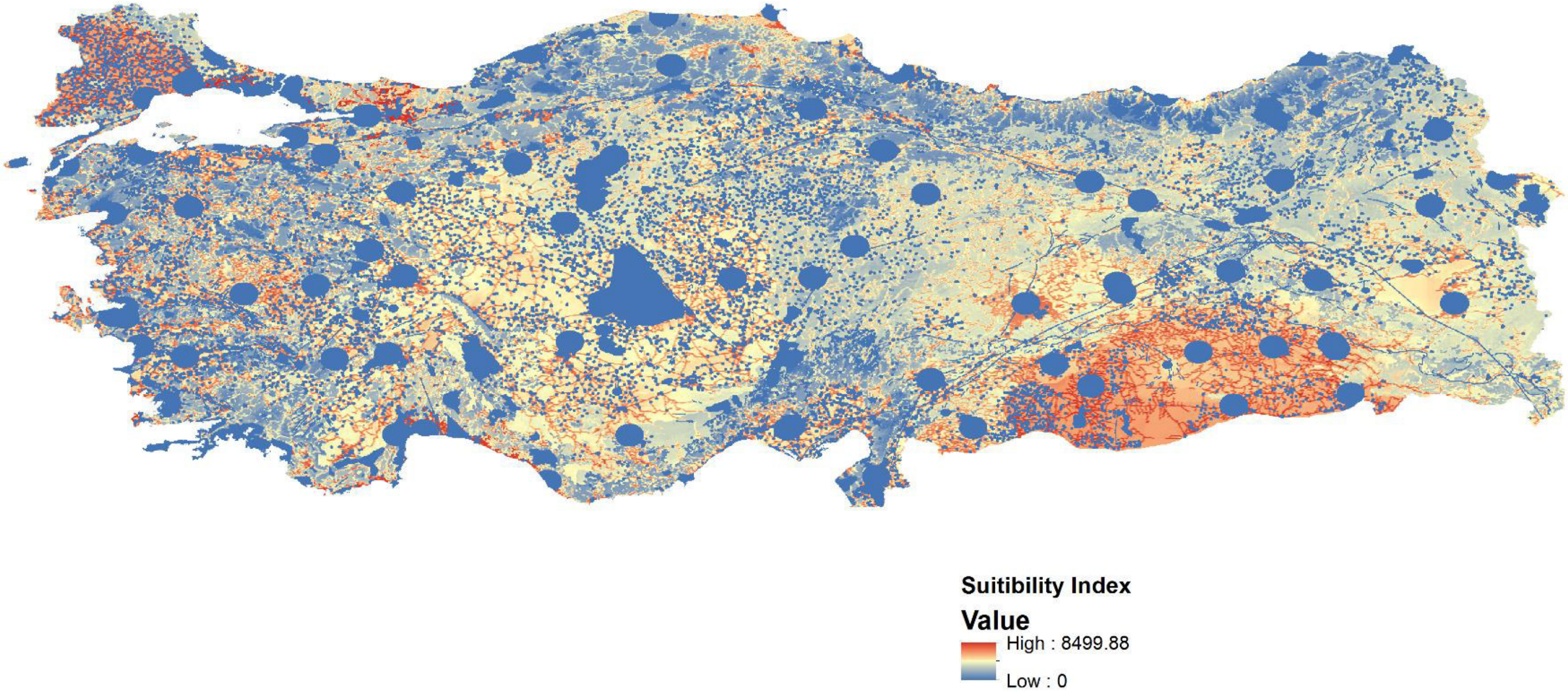

Figure 36. Suitability index with updated airport regulation

Aditionally, noise does not constitute any constraint for further evaluation, since government already provides keeping the sound level of wind turbine under operation in appropriate level by the Regulation (129) and wind turbine developers have enough technology to meet the sound limit values.

As environmentally friendly approach were followed in this part of study, agricultural land and forest are protected, although there is no obligatory for wind farms to be outside forested terrain.

To conclude, the resultant map of infeasible areas in terms of environmental aspect were created by using forest, agricultural area, bird habitat and visual impact (Figure 40) and the occupied area were calculated as 57.6 million hectar.

Figure 37. 20 km buffer zone around urban area to avoid visual impact

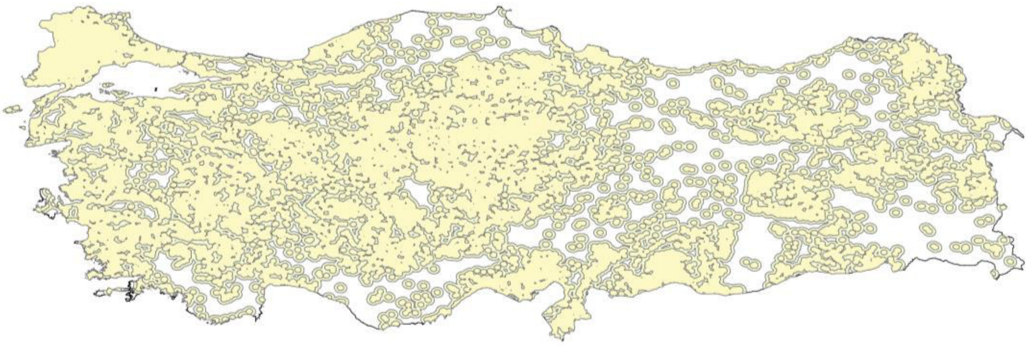

Figure 38. 5 km buffer zone around urban area to avoid visual impact

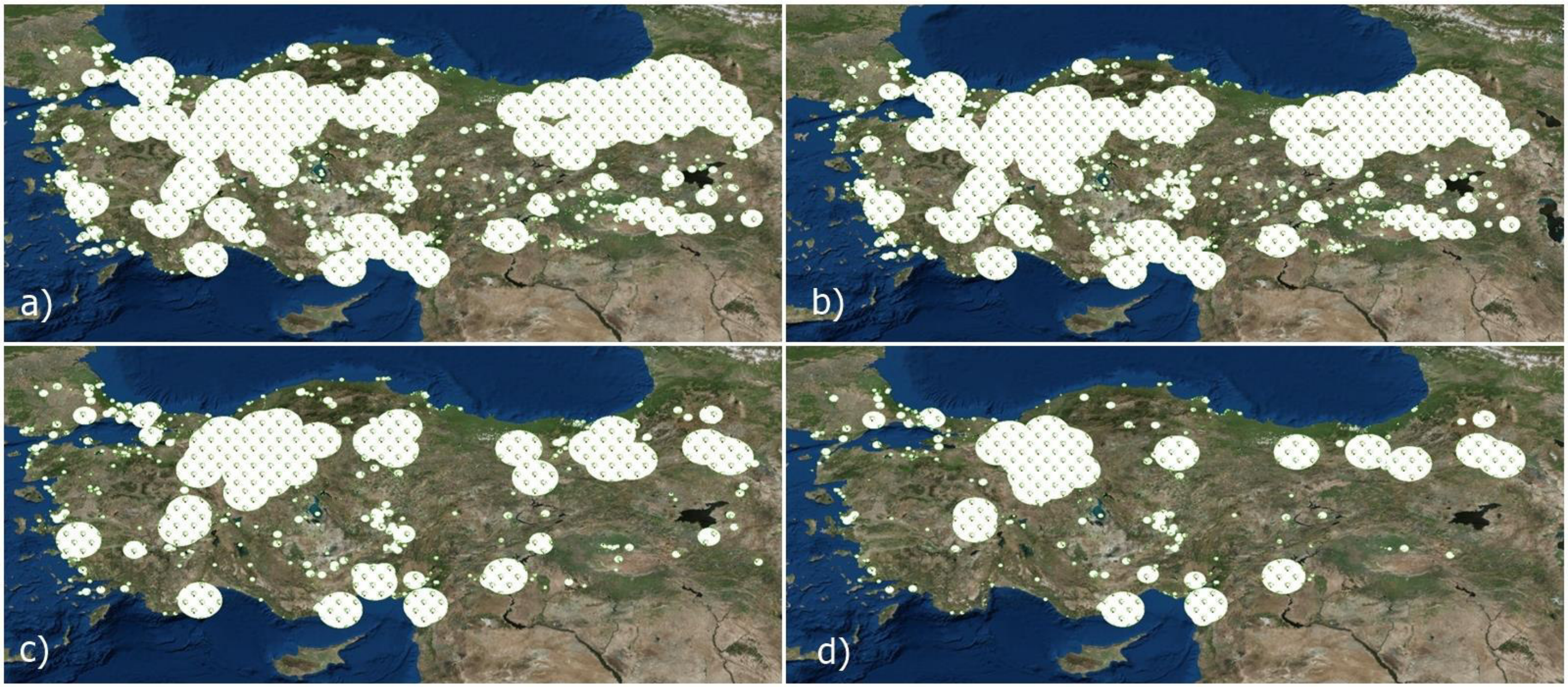

Figure 39. Important bird areas from a) 1931, b) 1971, c) 2011 and d) 2013 to 2015

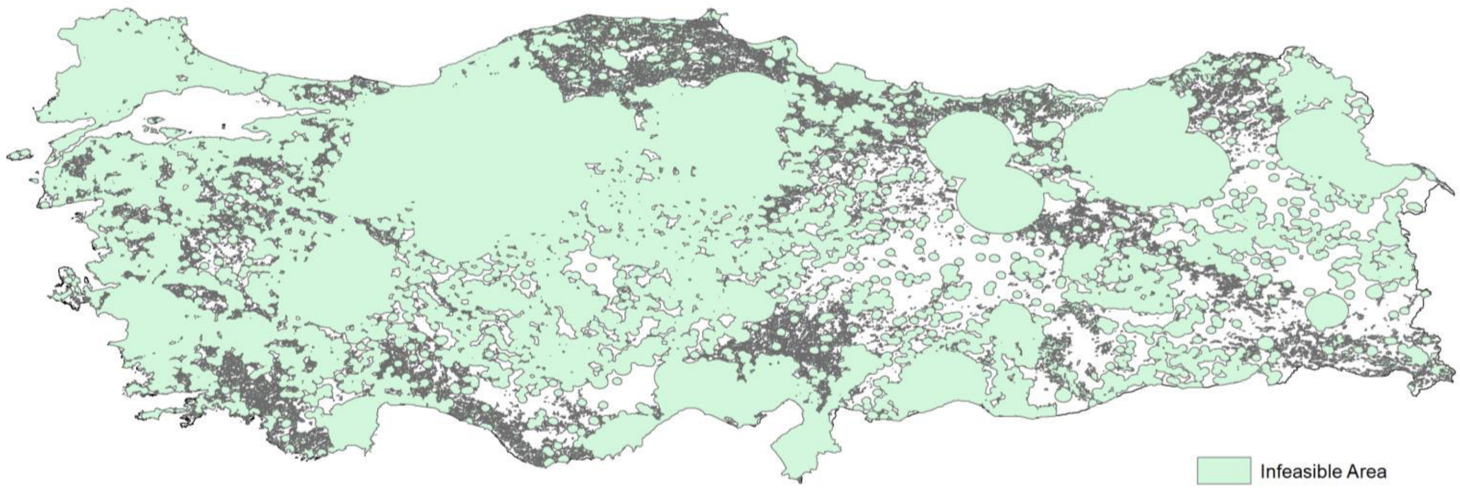

Figure 40. Infeasible areas in terms of environmental aspect

CHAPTER 6

DISCUSSIONS

The main output of this study is GIS based MCDM models which can provide effective decision support tool for evaluating wind farm sites. This study collected economical, technical, administrative, social and environmental objectives associated with site selection of wind farms. The criteria identification was carried out depending on national legislations and literature research and then a set of criteria was obtained.

Inclusion of further criteria in the site suitability analysis was also considered for this study, such as location of protection forests, world heritage sites, natural sites, military districts, bats habitat and bird migration routes. However, these were not accessible, due to the fact that;

i) The relevant authority of protection forests and world heritage sites did not share the spatial information,
ii) The location of natural sites will be opened to public at the end of 2016
iii) Giving information about the military district is forbidden.
iv) Bats are not listed as priority protection list on global scale

One of the limitation of the study was that non-avaibility of the most recent version of CORINE dataset (CLC2012) for whole Turkey when this project was conducted. CLC2006 dataset has been used as a source of forested terrains, urban area, airports and agricultural lands despite not being up-to-date information. Besides that, although fees for forested terrain are varying with the density of forests, CORINE dataset does not make possible to separate forested terrain based on density of forests. Even a location having no trees on it, was evaluated same score with a much denser forested terrain.

Another limitation of the study is that the buffer zone around river/lakes is not clear. Aydin et al. [7] and Van Haaren et al. [17] have taken the distance from water bodies as 400 m with reference to the study of Baban et al. [10]. Baban et al. [10] gathered guidelines from 60 local authorities in the UK by means of a survey and determined a representative distance of 400 m to water bodies. However, it has not proved by any scientific research, yet. On the other hand, Bennui et al. [11] and Phuangpornpitak et al. [131] excluded the zone of 200 m from water bodies and main rivers without any explanation. Turkish legislation of wetland protection also causes some conflicts, since wind power plants investments even over 10 MW installed capacity are allowed by permission. Due to the uncertainities regarding lakes, this study were not taken into consideration as a parameter.

Despite these limitations, the study successed in developing a tool for site selection modelling in Turkey.

In previous MCDM studies [9, 18], wind speed has been considered as the main criteria for the power. However, the power is also related with air density and the capacity of wind turbines. Therefore, this study tried to move one step further than wind speed, and combine the wind speed with the calculated air density, capacity factor and swept area. As a final step, power output by using two types of generic wind turbines were created. As explained in Chapter 4.3.1.1, these generic wind turbines have been selected from the most of the turbine has been used until now in Turkey and in the world. The capacity factor for the first generic turbine (900 kW) and second ones (2.1 MW) were calculated as 22% and 31%, respectively. So it was thought that it is better way of calculating the available power in the country.

Additionally, none of the study we have reviewed was taken care of operation in cold temperatures. However, all the people carried out survey for this study and the authors of this study reported that cold is significantly important in energy production from wind turbines and difficulties will arise when installing them in cold locations [132]. These countries have tried to create blade heating systems. Since if wind turbine was not working for 5 to 7 months or spending the energy produced to warm up itself, the production would be much less and sometimes even the half of the expected generation such that it is not worth to invest in high wind areas. The results proved that none of existing wind farms are located below the value of 50 on scaled data of frozen period and majority of them takes place on the best places according to the map of frozen period. However, in the future, wind farms will move towards higher places where being below zero is problem. For instances, Borusan EnBW installed Mut Wind Energy Power Plant which is located in Gökçetaş and Medreselik Villages in Mersin has 52.8 MW installed capacity and height is within 1600-1693 meters. Since the wind energy is moving to that section of country, this study has put temperature into decision making criteria contrary to the other studies.

It was revealed that the priority weight of forest was low in the previous MCDM studies. However, it was considered for this study that it has higher values in Turkey due to the fact that forested terrain should be protected. This study aimed at protecting forests even those areas categorized as forest but with no trees left. Although an 85 percent discount is applied to lease forested terrain for 10 years to the power plants, investors have to pay fee for 20 years. That means it is extra expense for the wind energy production in Turkey. Therefore, the forested terrain was included in this study and assigned with higher importance weight due to this reason.

Since the methodology was constructed as updatable by the changing regulations, the changing in regulations can be integrated into the developed tool. This study, firstly, carried out decision making analysis based on the old legislation regarding airport to protect flight security [53], wind farms should not be constructed in the first 3000 m zone from departure end of taking-off and landing. After the suitability maps and all the results were obtained, EMRA announced the new buffer zone as 2 km and 15 km and coordinates of aeronautical stations and navigational aids on 12th of May, 2016. Therefore, it was considered that the old regulation will be more logical to compare the suitability of the existing wind farms, whereas the decision maker should use the new map to determine new wind power plant locations.

The results of site priority map were compared to the locations of existing wind farms in Turkey to validate the compatibility of the existing wind farms with the suitable areas. However, as it is mentioned before, this comparison was not included environmental criteria. According to the results, it has been identified as 14 wind farms are located in extremely suitable areas according to the classification of this study, whereas the majority of them are placed on moderate and highly suitable areas. Finally, there are two commercial wind farms on low suitability areas. This result can be evaluated such that there are probably something which are important according to project developer and not included this study. For instances, existing wind farms can be constructed by giving more importance to make new roads than forested terrains. Therefore, we might not notice such points by limited conducted surveys.

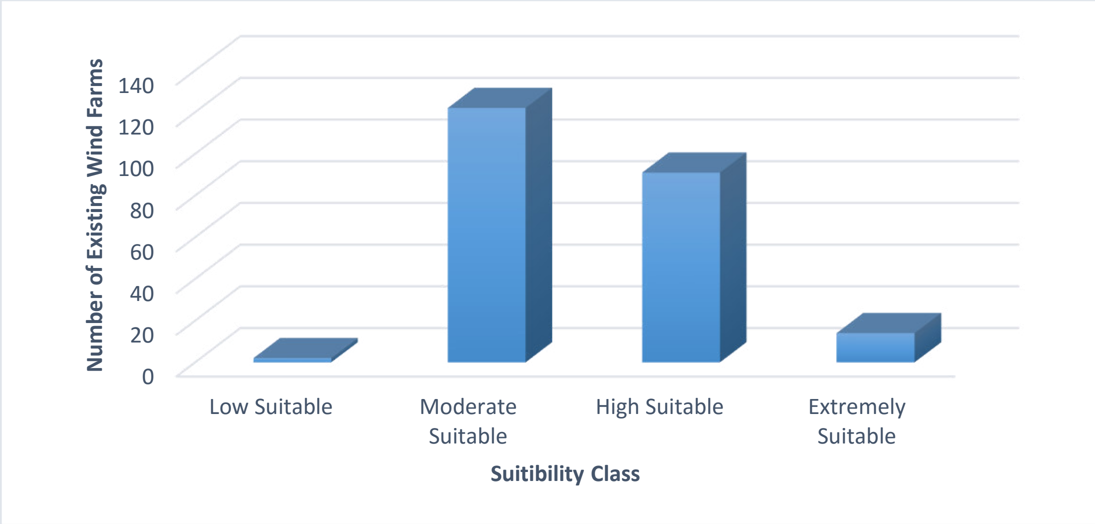

Figure 41. Number of existing wind farms within the overall suitability classification

With respect to environmental aspects, it should not be forgotten that the number of wind farms has been increasing dramatically to meet the kind of targets, hence wind farms would occupy more than 2063 ha, and it would cause more habitat loss for wildlife in the future. To avoid this, it is vital that governments and wind energy sector should work together in partnership to provide a single web-based resource to inform future research and project development.

CHAPTER 7

CONCLUSION

The market needs were defined in the problem statement of this study as to the need for a planning tool to shorten the planning process, and a visualized suitability map for wind energy installation based on the current regulations and scientific studies. This study created a combination of GIS and MCDM analysis tools by using AHP. The GIS models provides to create a dataset for the analysis and demonstrate the suitability of particular areas for wind farms, whereas the AHP method was applied for assessment of the pairwise importance of criteria on determining suitability of wind farm location.

The first research objective of this study was 'to collect the current regulations together and to create a GIS database'. This objective was accomplished by gathering the related regulation regarding wind power plant installation which were published on Turkish Republic Official Journals. The second objective was 'to exclude infeasible site from the map depending on the government laws or regulations'. This objective was achieved using current regulations by GIS tool. The third objective of this study was 'to derive the relative importance of each criterion through the series of pairwise comparisons by a study group'. The study group and use of GIS-based MCDA siting approach provided an effective way to visualize the results. The final target was 'to set environmental evaluation criteria and to give a preliminary environmental impact assessment'. This target was succeeded by making literature review and gathering related criteria together.

Following specific conclusion can also be done based on the study results:

- Final spatial analysis of the environmental impact areas shows that the most suitable areas left to install wind farms are mostly at high altitude regions. That means, if the developers would like to stay away from environmental impact issues, they would move on developing wind farms at high altitude regions in next decade.
- Another possibility to expand wind power capacity and lower the impact on environment is to re-build already available wind farms with higher capacity wind turbines. Results show that most of the active wind farms are using high capacity

areas. Replacing these turbines with bigger turbines in next decades can improve the energy production significantly without creating impact on the environment.

- Although the forested and urban areas are excluded in this study to find the locations with lowest environmental impact that does not mean that some wind farms will be erected near or close by these locations. In such cases, the wind turbines will be affected from the high turbulence generated by the forests or urban areas. Therefore, forest and complex terrain modelling for site assessment should be studied and improved by the Turkish developers in order to make the final micro siting.

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APPENDIX A

TOOLS USED IN THIS STUDY

ArcGIS

ArcGIS[5], released by Environmental Systems Research Institute (ESRI) in 1999, is a GIS tool to create maps, perform spatial analysis, manage geographic data, and share results. The study was conducted using ArcGIS 10.3.1 for Desktop software (realesed in May 2015).

SAGA-GIS

System of Automatic Geoscientific Analyses (SAGA)[6] is a GIS tool which can be used with graphical user interface or batch processing mode and first created by Dept. of Physical Geography, Göttingen University Germany and moved to Dept. of Physical Geography at University of Hamburg in 2007.

Other

Also some other GIS tools are used to perform batch processing of several single or combination of maps. At this state most usefull tool was to employe well-known Geospatial Data Abstraction Library (GDAL) which is an open source library and toolbox[7].

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[5] https://www.arcgis.com/features/index.html
[6] http://www.saga-gis.com
[7] http://www.gdal.org

APPENDIX B

COST ACCOUNTING OF GENERIC WIND TURBINES

First Generic Wind Turbine (0.9 MW)

Expected lifetime=20 years

Turbine rated power=0.9 MW

Total Turbine cost=1.000.000 $/MW[68]

1.000.000 $/MW x 0.9 MW = $900.000

O&M Cost=1.000.000 $ /MW [40]

1.000.000 $/MW x 0.9 MW=$900.000

Total expenditure

= Total Turbine cost + O&M Cost over expected lifetime

=900.000 $+ 900.000 $= $ 1.800.000 = 5.400.000 TL

= 1.350.000 TL (equity capital=%25) + 4.050.000 TL (bank loans=%75)

Interest rate = 4.050.000 TL x 0.42 = 1.701.000 TL

Money needed= 5.400.000 TL + 1.701.000 TL =7.101.000 TL

Income

Capacity factor= 22 percent = 0.22 [49]

Energy produced in a year = 900 kW x 365 day/year x 24 h/day x 0.22 = 1.734.480 kWh/year

When tower and blades produces in Turkey;

Price of electricity = 0,087 $ /kWh [61]

=0,087 $ /kWh X 3 TL/$ = 0,261 TL / kWh

Gross yearly income from electric sale

= 1.734.480 kWh/year x 0,261 TL / kWh = 452.699,28 TL/year

Income over lifetime = 452.699,28 TL/year x 20 year

= 9.053.985,6 TL

Net Income over lifetime

= Income over lifetime - Bank Loans with interest rate

= 9.053.985,6 TL - 7.101.000 TL = 1.952.985,6 TL

= 83.411.856 TL /20 year= 97.649,28 TL

Second Generic Wind Turbine (2.1 MW)

Expected lifetime=20 years

Turbine rated power= 2.1 MW

Total Turbine cost=1.000.000 $ /MW [68]

1.000.000 $/MW x 2.1 MW=2.100.000 $

O&M Cost=1.000.000$/MW [40]

1.000.000 $/MW x 2.1 MW=2.100.000 $

Total expenditure

= Total Turbine cost + O&M Cost over expected lifetime

= 2.100.000 $+ 2.100.000 $= 4.200.000 $=12.600.000 TL

= 3.150.000 TL (equity capital=%25) + 9.450.000 TL (bank loans=%75)

Interest rate = 9.450.000 TL x 0.42 = 3.969.000 TL

Money needed= 12.600.000 TL + 3.969.000 TL =16.569.000 TL

<u>Income</u>

Capacity factor= 31 percent = 0.31 [49]

Energy produced in a year = 2100 kW x 365 day/year x 24 h/day x 0.31 = 5.702.760 kWh/year

When tower and blades produces in Turkey;

Price of electricity = 0,087 $ /kWh [61]

=0,087 $ /kWh X 3 TL/$ = 0,261 TL / kWh

Gross yearly income from electric sale

= 5.702.760 kWh/year x 0,261 TL / kWh = 1.488.420,36 TL/year

Income over lifetime = 1.488.420,36 TL/year x 20 year = 29.768.407,2 TL

<u>Net Income over lifetime</u>

Net Income

=Income over lifetime - Bank Loans with interest rate

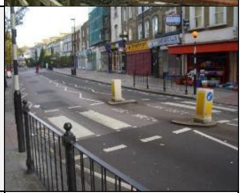
= 29.768.407,2 TL - 16.569.000 TL = 13.199.407 TL

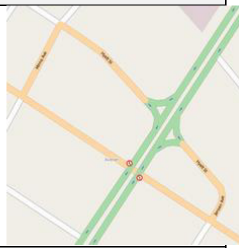
Net Income Annually=13.199.407 TL /20 year= 659.970,36 TL

APPENDIX C

ROAD TYPES SELECTED FOR THE STUDY

(The table was taken by courtesy of OpenStreetMap)

Type	Brief Information	Photo
Construction	For roads under construction.	
Crossing	Pedestrians can cross a street here; e.g., zebra crossing	
Motorway	A restricted access major divided highway, normally with 2 or more running lanes plus emergency hard shoulder. Equivalent to the Freeway, Autobahn, etc..	
Motorway-link	The link roads (sliproads/ramps) leading to/from a motorway from/to a motorway or lower class highway. Normally with the same motorway restrictions.	
Planned/ Proposed	A value of the proposed highway value.	
Primary	Often link larger towns	
Primary-link	The link roads (sliproads/ramps) leading to/from a primary road from/to a primary road or lower class highway.	
Residental	Roads which serve as an access to housing, without function of connecting settlements. Often lined with housing.	
Rest Area	Place where drivers can leave the road to rest, but not refuel.	
Road	This is intended as a temporary tag to mark a road until it has been properly surveyed. Once it has	

	been surveyed, the classification should be updated to the appropriate value.	
Secondary-link	The link roads (sliproads/ramps) leading to/from a secondary road from/to a secondary road or lower class highway.	
Services	A service station to get food and eat something, often found at motorways	
Tertiary	Often link smaller towns and villages	
Tertiary-link	The link roads (sliproads/ramps) leading to/from a tertiary road from/to a tertiary road or lower class highway.	
Trunk	Need not necessarily be a divided highway	
Trunk-link	The link roads (sliproads/ramps) leading to/from a trunk road from/to a trunk road or lower class highway.	
Unclassified	Minor roads of a lower classification than tertiary, but which serve a purpose other than access to properties. Often link villages and hamlets.	

APPENDIX D

NOISE CALCULATION

The wind turbines in the operating phase will generate noise depending on their own turbine properties. The sample calculation was carried out on one of the licensed wind power plant and information of the plant is given in below;

- Installed Capacity (MWm); 31.5
- Manufacturer of Turbine; SUZLON
- Model of Turbine; S88
- Capacity of Turbine (MW); 2.1
- Number of Turbine; 15
- Standard Sound Power Level (dB); 110

The noise level is based upon the sound power level of turbine models specified by the manufacturers. In terms of SUZLON S88 2.1 MW machine, an overall sound power level is 110 dB. Sound level of the wind farm in operating period is calculated as 121 dB, when 15 turbines are running simultaneously.

$$Leq = 10 * log \sum_{i=1}^{n} 10^{(Lw(i)/10)} \qquad \text{(A. 1)}$$

$$\mathrm{Leq} = 10 * \log \sum_{i=1}^{15} 10^{\left(\frac{110}{10}\right)} = 121 \text{ dB}$$

The distribution of the calculated sound level in four octave bands is the same with each other as it is seen in Table 4.20.

$$\mathrm{Lw(i)} = 10 * \log \sum_{\mathrm{i}=1}^{\mathrm{n}} \frac{(10^{\left(\frac{\mathrm{Lw}}{10}\right)})}{4} \qquad \text{(A. 2)}$$

$$\mathrm{Lw(i)} = 10 * \log \sum_{i=1}^{15} \frac{(10^{\left(\frac{121}{10}\right)})}{4} = 115.74 \; dBA$$

Table A. 1. Sound level in octave bands

	Sound Power Level (dB)				
Noise Source	**Total**	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**
Turbine	121.76	115.74	115.74	115.74	115.74

To obtain spreading out of the sound energy with distances from a wind farm site, variables were replaced into formula. As it can seen from the formula, sound level is changing with the distance from the source to receiver. It is expected that sound level for 50 m away will be 73.78 dB.

For distance 50 m;

$$\mathrm{Lpi} = \mathrm{Leq} + 10 * \log \frac{\mathrm{Q}}{4*\pi*\mathrm{r}^\wedge 2} \tag{A. 3}$$

$$\mathrm{Lpi} = 121 + 10 * \log \frac{2}{4 * \pi * 50^\wedge 2} = 73.78 \text{ dBA}$$

The same calculation is repeated to find the relationship between sound level and distance by replacing 50 m with variable distances. As it is expected, the noise level decreases with increasing distances from source to receiver.

Table A. 2. Sound propagation with distances

	Sound Power Level (dB)				
Noise Source	**Distance (m)**	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**
Turbine	50	73.78	73.78	73.78	73.78
	100	67.76	67.76	67.76	67.76
	200	61.74	61.74	61.74	61.74
	250	59.80	59.80	59.80	59.80
	400	55.72	55.72	55.72	55.72
	500	53.78	53.78	53.78	53.78
	750	50.26	50.26	50.26	50.26
	1000	47.76	47.76	47.76	47.76
	1250	45.82	45.82	45.82	45.82
	1500	44.24	44.24	44.24	44.24
	1750	42.90	42.90	42.90	42.90
	2500	39.80	39.80	39.80	39.80

Due to working in open environment, there would be a reduction in noise caused by atmospheric absorption. However, in order to calculate the most pessimistic approach, it is assumed that there will not any reduction at sound pressure level due to atmospheric absorption. Therefore, the calculation for all wind farms in operation is done up to below formula.

Calculation for air absorption in 500 Hz and 50 m away from the source was found as 0.01 dB.

$$\mathrm{Aatm} = (7.4 * 10^{-8}) * (\frac{\mathrm{f}^2 * \mathrm{r}}{\phi}) \quad \text{(A. 4)}$$

$$Aatm = (7.4 * 10^{-8}) * \left(\frac{500^2 * 50}{70}\right) = 0.01\ dB$$

Calculation was continued with subtracting air absorption from sound pressure level.

For 500 Hz, 50 m;

$$\mathrm{Lp} = \mathrm{Lp} - \mathrm{Aatm} \quad \text{(A. 5)}$$

$$Lp = 73.78 - 0.01 = 73.77\ dB$$

The same calculations are repeated by replacing 50 m with variable distances and 500 Hz with other octave bands.

A-weighting values of the corresponding frequencies were added to modify the measured sound pressure level;

<u>50 m;</u>

For 500 Hz; $Lp = 73.77 + (-3.2) = 70.57\ dB$

For 1000 Hz; $Lp = 73.73 + 0.0 = 73.73\ dB$

For 2000 Hz; $Lp = 73.73 + 1.2 = 74.77\ dB$

For 4000 Hz; $Lp = 72.94 + 1.0 = 7$

To sum up, although the energy across the whole frequency range is reduced, higher frequencies are reduced more than lower frequencies with the distances.

Table A. 3. The noise level that the air absorption was removed

	Sound Power Level (dB)				
Noise Source	Distance (m)	500 Hz	1000 Hz	2000 Hz	4000 Hz
Turbine	50	73.77	73.73	73.57	72.94
	100	67.73	67.66	67.34	66.07
	200	61.69	61.53	60.89	58.36
	250	59.74	59.54	58.74	55.57
	400	55.61	55.30	54.03	48.95
	500	53.65	53.25	51.67	45.32
	750	50.06	49.47	47.09	37.57
	1000	47.50	46.70	43.53	30.85
	1250	45.49	44.50	40.54	24.68
	1500	43.84	42.65	37.90	18.87
	1750	42.44	41.05	35.50	13.30
	2500	39.14	37.16	29.23	-2.48

Table A. 4. The ultimate noise level modified by A-weighting values

	Sound Power Level (dB)				
Noise Source	**Distance (m)**	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**
Turbine	50	70.57	73.73	74.77	73.94
	100	64.53	67.66	68.54	67.07
	200	58.49	61.53	62.09	59.36
	250	56.54	59.54	59.94	56.57
	400	52.41	55.30	55.23	49.95
	500	50.45	53.25	52.87	46.32
	750	46.86	49.47	48.29	38.57
	1000	44.30	46.70	44.73	31.85
	1250	42.29	44.50	41.74	25.68
	1500	40.64	42.65	39.10	19.87
	1750	39.24	41.05	36.70	14.30
	2500	35.94	37.16	30.43	-1.48

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