ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

SITE SELECTION TECHNIQUE FOR WIND TURBINE POWER PLANTS UTILIZING GEOGRAPHICAL INFORMATION SYSTEMS (GIS) AND ANALYTICAL HIERARCHY PROCESS (AHP)

M.Sc. THESIS

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★FEN BİLİMLERİ ENSTİTÜSÜ

COĞRAFI BILGI SISTEMI (CBS) VE ANALİTİK HİYERARŞİ YÖNTEMİ (AHY) YARDIMIYLA RÜZGAR TÜRBİN SANTRALLERİ YER SEÇİMİ

YÜKSEK LİSANS TEZİ

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Tez Danışmanı: Doç.Dr. Deniz ARTAN İLTER

MAYIS 2016

Chingis AITZHANOV, a M.Sc. student of ITU **Graduate School of Science Engineering and Technology** student ID 501131116, successfully defended the thesis entitled **"SITE SELECTION TECHNIQUE FOR WIND TURBINE POWER PLANTS UTILIZING GEOGRAPHICAL INFORMATION SYSTEMS (GIS) AND ANALYTICAL HIERARCHY PROCESS (AHP)"**, which he prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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Date of Submission: 5 May 2016
Date of Defense: 7 June 2016

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ABBREVIATIONS

ACBK	: Association for the Conservation of Biodiversity of Kazakhstan
AHP	: Analytical Hierarchy Process
CFTPP	: Coal Fired Thermal Power Plant
ESRI	: Environmental Systems Research Institute
GEF	: Global Environment Facility
GIS	: Geographic Information System
IBA	: Important Birds Habitat
IREA	: International Renewable Energy Agency
KP	: Kyoto Protocol
RES	: Renewable Energy Source
SGE	: Samruk Green Energy
UNDP	: United Nations Development Program
UNFCCC	: United Nations Framework Convention on Climate Change
WTPP	: Wind Turbines Power Plant

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SUMMARY

Nowadays the future energy usage is increasing every year due to population growth around the globe. Anthropogenic influence on the planet leads to global warming owing to greenhouse gases emissions. In 1998 in Japan, Kyoto Protocol was adopted and stepped into force in 2005, obligating parties to reduce gas emission (UNFCCC, 2016). Subsequently, development of green energy sector is needed in order to provide sufficient amount of resources.

In the same time, construction sites of green energy plants and other sustainable projects have to be chosen very carefully in order to provide the maximum power gains. Therefore scientific base and research in certain green energy industries are necessary to provide the most objective approach.

The aim of the study is developing a site selection technique for wind turbine power plants utilizing Geographical Information Systems (GIS) and Analytical Hierarchy Process (AHP). Using the generic approach developed, the study then focuses on Akmola Region in the North Kazakhstan and explores the applicability of the model using GIS data layers available for the region.

First chapters discuss the relevance of the use of renewable energy sources (RES), followed by a discussion about RES in Kazakhstan, and the research approach adopted in this study. Next sections briefly explain about wind energy in general, how wind turbines power plants (WTPP) work and what kind of wind turbines are used currently worldwide. Later on the Geographic Information Systems (GIS) are introduced with specification of which types of analysis will be used in the thesis; also the sequence of analysis is presented. Further AHP technique is discussed focusing on the practical applications on the study area. In the last chapter, the data and results obtained by the implementation of both techniques, GIS and AHP, will be presented. The thesis concludes with the generic site selection technique proposed and its application in the Akmola Region of Kazakhstan as a validation.

ÖZET

Dünya çapındaki popülasyon artışı sebebiyle enerji kullanımı giderek artmaktadır. Gezegenin maruz kaldığı antropojenik etki, sera gazı emisyonunun da etkisiyle küresel ısınmaya yol açmaktadır. Japonya'da 1998 yılında kabul edilen ve 2005 yılında uygulanmaya başlanan Kyoto Protokolü taraf devletleri sera gazı emisyonunu azaltmaya zorlamıştır. Bunu takiben, yeterli miktarda kaynak sağlamak için yeşil enerji sektöründe gelişme kaydedilmesi gerekmektedir.

Aynı zamanda, azami enerji kazanımı elde etmek için yeşil enerji santrallerinin ve diğer sürdürülebilir projelerin inşaat alanlarının çok dikkatli seçilmesi gerekmektedir. Bu nedenle söz konusu yeşil enerji endüstrilerinde oluşturulacak bilimsel temel ve araştırmalar en tarafsız yaklaşımı elde etmek için gereklidir.

Çalışmanın amacı, rüzgar türbinli elektrik santralleri için Coğrafi Bilgi Sistemi (CBS) ve Analitik Hiyerarşi Yöntemi (AHY) kullanan bir yer seçim yöntemi geliştirmektir. Çalışma daha sonra, geliştirilen genel yaklaşımı kullanarak, Kuzey Kazakistan'daki Akmola bölgesine odaklanmakta ve alan için ulaşılabilir olan CBS veri katmanlarını kullanan modelin uygulanabilirliğini araştırmaktadır.

İlk bölümlerde yenilenebilir enerji kaynaklarının kullanımının önemi ele alınmaktadır, bunu da Kazakistandaki yenilenebilir enerji kaynakları ve bu çalışmaya uygun olarak araştırma yaklaşımı takip etmektedir. Genel olarak, Kazakistan'da elektrik üretimi daha çök doğal kömürün dev reservelerine dayanılır. Bu doğal kaynaklar genellikle Kazakistan'ın Orta bölgeleri, Karagandı ve Ekibastuz gibi şehirler etrafında bulunıyor. Ancak, büyük miktarlarıyla kömürden üretilen elektrik havanın yoğun kirlenmesine yol açar. Bu nedenle fabrikalarla çevrili bölgede insanların sağlık durumu bozulur. Bu hastanelerin tedavi için yıllık giderlerinin mali yükünü artırmıştır.

Bu tez çalışmasında açıklanan metadolojinin adaptasyonu Küzey Kazakistan'da bulunan Akmola bölgesinin seçilmesi için çeşitli nedenleri var. Birincisi, bölge

rüzgar enerjisi potansiyeli açısından daha önce değerlendirilmiş olan bölgelerden biridir. İkincisi, Yereymentau Rüzgar Türbinli Santral projesi bölgede son zamanlarda çalışmaya başlatıldı. Bu nedenle, çalışmanın sonuçlarını ve şu an işleyen santrali karşılaştırmayı daha uygun bir şekilde ypıldı. Yenilenebilen enerji kaynaklarına adanmış olan Astana EXPO 2017 dünya sergisi aynı bölgede bulunan başketintte düzenlenecektir.

Sonraki bölümlerde kısaca rüzgar enerjisi, rüzgar türbinli elektrik santrallerinin nasıl çalıştığı ve dünyada genel olarak hangi tipte rüzgar türbinlerinin kullanıldığı açıklanmaktadır. İnsanlar tarafından rüzgar enerjisini yüzyıllar önce kullanmaya başlamıştılar. Bir çok arkeolojik delilleri rüzgar enerjisini farklı şekillerde ve çeşitli amaçlarla kullanılabildiklerini gösteriyorlar. Yel değirmenlerinin ilk prototipleri genelde ahşaptan inşa ettiğine, su pompalama ve tahıl öğütme için kullanılıyormış olmasına rağmen, insanlar elektrik tüketimi için rüzgarı kullanmaya başlamadan önce binlerce yıl geçmiştir. 3. bölümünde rüzgar türbinlerinin elektrik üretim için çalışma prenseplerini, bir türbinin bileşenlerini açıklayarak, büyük bir rüzgar elektrik santralline nasıl toplandığını incelenir.

4. bölümünde rüzgar türbinli elektrik santraller için yer seçim kriterlerini anlatarak, yer değerlendirilmesi hakkında ayrıntılar verilir. Literatür analize göre alt kriteriler ana kriterler altında gruplandırıldı. Buna ek olark rüzgar santraliler için daha önce yapılan yer seçimi hakkında çalışmalarından ödenekler ve kabuller özetlenmiştir.

Daha sonra tezde kullanılacak analiz tiplerinin belirlenmesi ile Coğrafi Bilgi Sistemi (CBS) tanıtılmaktadır, aynı zamanda analiz dizisi de sunulmaktadır. Bu tez çalışmasında tüm analizleri yapmak için ArcGIS 10.2 yazılımı kullanılmıştır. Benzer yöntemleri göstererek CBS'yla yer seçim teknniklerini anlatarak farklı çalışmaların örnekleri sunulmuştur.

Ayrıca AHY yöntemi çalışma alanında pratik uygulamalara odaklanarak ele alınmaktadır. Gerekli ağırlıkları almak ve AHP analizi ArcGIS 10.2 yazılımıyla son değerlendirme yapmak için 4 uzman ile görüşme yapılmıştır. İki uzman rüzgar enerjisi alanında çalışan araştırmacıları ve rüzgar türbini endüstrisinde çalışan uzmanları sorgulayarak, ve onların ceveplarına göre tüm kriterleri arasında ikili karşılaştırma yapıldı.

Son bölümde her iki tekniğin, CBS ve AHY, uygulanması ile elde edilen veri ve sonuçlar sunulmaktadır. Tez, genel alan seçimi yönteminin önerilmesi ve Kazakistan'ın Akmola Bölgesindeki doğrulama amaçlı uygulaması ile sonuçlandırılmaktadır.

Sonuç bölümü işin sonunda elde edilen sonuçlarını özetlemektedir ve konunun daha geliştirilmesi için birkaç yol göstermektedir. Veri seti biraz daralmış olmasına rağmen, önerilen yöntemi ve sonuçlarının elde edilmesi genel gelişiminden engel olmadığını gösterilmemiş.

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1. INTRODUCTION

The Kazakhstan – Wind Power Market Development Initiative project began in December 2004 and concluded in June 2011. It has been financed by the Global Environment Facility (GEF) with a contribution of USD 2.55 million and implemented by the United Nations Development Program (UNDP) and the Government of Kazakhstan (Akker & Druz, 2011).

The development of wind energy in Kazakhstan is becoming a trend nowadays. After Kyoto Protocol was ratified by most developed countries around the globe, Kazakhstan took its initiative to support this trend. Development of this field is being actively financed and technically supported by the government. A massive construction of wind turbines power plant has been started in 2012 and reached 2 wind turbine plants with total capacity of 65MW (Table 1.1). Nevertheless the share of RES in Kazakhstan is presently around 0.5% it is awaited for it to reach 3% in 2020s (Marinushkin & Trofimov, 2012).

Table 1.1. Table outlines total amount of power plants currently constructed in Kazakhstan.

№	Name of The Station	Region	Power Capacity (MW)	Number of Wind Turbines
1	Yereymentau	Akmola	45	22
2	Kordai	Zhambyl	21	9
		TOTAL	65	31

Technically it is feasible to evolve a wind energy sector since major part of Kazakhstan is covered by steppes and deserts, blown along the year by winds. According to general global assessments approximately 18-20% of RES share is needed for sustainable development (Marinushkin & Trofimov, 2012).

UNDP wind program prepared for Kazakhstan is shown in the Figure 1.1. (Holttien, et al., 2011)

	Область Oblast	Местоположение Location	До 2015, МВт, MW	2024-2030, МВт, MW	Примечание Site information
1	Акмолинская область, Akmola oblact	Ерейментау Ereimentau	50	500	V-7.8 м/с, ВЛ (HVL) 110-220-500 КВ
2	Актюбинская область Aktobe oblast	Бадамша Badamsha	-	200	V-7 м/с, приб. ВЛ (HVL) 110-220-500 КВ
3	Алматинская область Almaty oblast	Шелек Shelek	50	300	V-7.8 м/с, ВЛ 220 КВ
4	Алматинская область Almaty oblast	Достык, Dostuk	-	250	V-9,7 м/с, ВЛ 110 КВ
5	Атырауская область Atyray oblast	Карабoтан, Karabotan	50	100	V-7,15 м/с, ВЛ 110 КВ
6	Кустанайская область Kostanay oblast	Аркалык Arkalyk	-	50	V-6,93 м/с, ВЛ 110 -220 КВ
7	Кустанайская область, Kostanay oblast	Боровское, Borovskoe	-	50	V-7 м/с приб, ВЛ 110 КВ
8	Кзыл-ординская Область Ksyl-orda oblast	Аральск Aralsk	-	50	V-7 м/с приб, ВЛ 110 КВ
9	Мангыстауская область Mangistau oblast	Ф-Шевченко, Fort - Shevchenko	50	50	V-7,83 м/с, ВЛ 110 КВ
10	Мангыстауская область Mangistau oblast	Курык, Kuryk	-	100	V-8 м/с прибл. ВЛ 110 КВ
11	Южно-Казахстанская область South Kazakhstan oblast	Чаян-Жузымдык Zhusumdyk	50	350	V-7,06 м/с, ВЛ 110 КВ
		Итого Total	**250**	**2000**	

Figure 1.1. Wind power scenarios for years 2015-2030 (UNDP)

The Figure 1.2 shows wind potential of Kazakhstan in general. As it can be

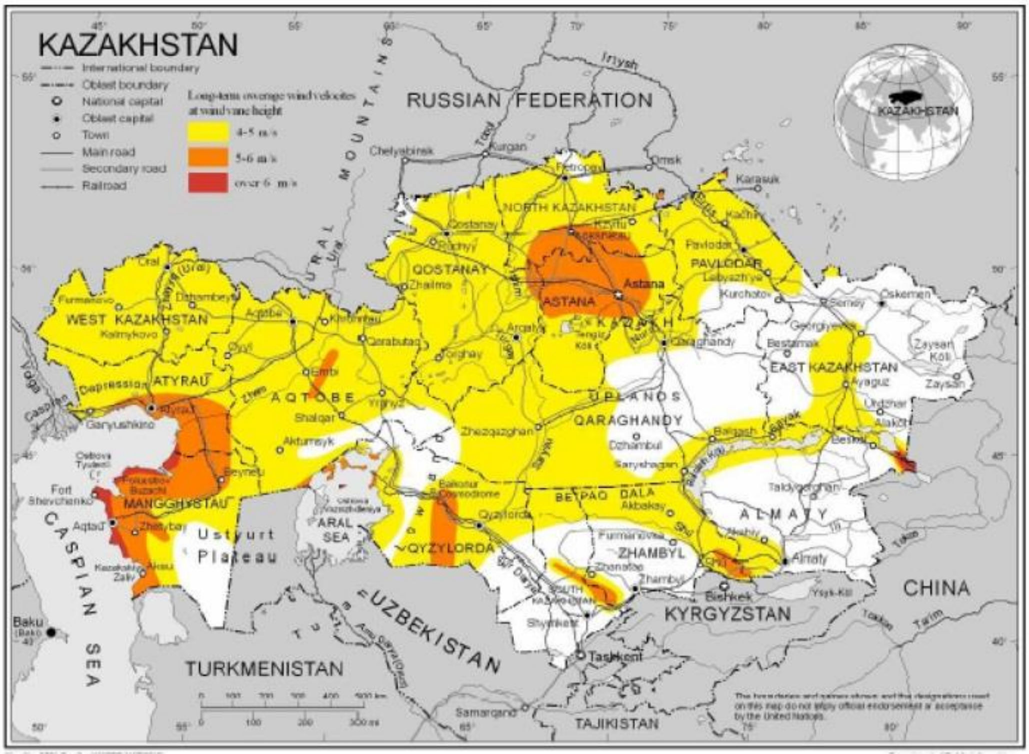

Figure 1.2. Wind potential of Kazakhstan

concluded from the map a big part of Kazakhstan has a great potential in term of wind energy. Vast and huge areas are blown by wind during each year and the average wind speed registered in Central Kazakhstan (dark orange zone) is 5-6 m/s.

1.1. Relevance of Study

Kyoto Protocol (KP) is an international agreement under United Nations Framework Convention on Climate Change (UNFCCC). This document obligates countries, signed to the protocol, to support actively the reduction of greenhouse gases emission, grounded on premise that global warming exists and immense CO_2 releases caused by it. In 1999 government of Kazakhstan issued law that obligated country to participate in KP. In 2009 Kyoto protocol was ratified in Kazakhstan (KPRK, 2011).

Traditionally Kazakhstan relies on huge reserves of natural coal that is currently being exploited for electricity generation. These natural resources of energy are satiated generally in Central Kazakhstan, around such cities as Karaganda and Ekibastus. However, massive production of electricity from coal leads to intensive contamination of air.

The Figure 1.3 below shows the share of emissions from different sources. The amount of emission coming from Coal Fired Thermal Power Plant (CFTPP) triggers various diseases in Kazakhstan such as malfunction of upper and lower respiratory tracts, acute asthma, an increase in the incidence of bronchitis and increase in cardiovascular diseases. According to Myrzakhmetova (2012) financial burden of local expenses for hospitals and treatments in Almaty, South of Kazakhstan, reach up to 26 550 million tenge (approximately $78 million) because of factors mentioned above. This fact highlights the importance and relevance of wind energy sector development in Kazakhstan (Myrzakhmetova, 2012).

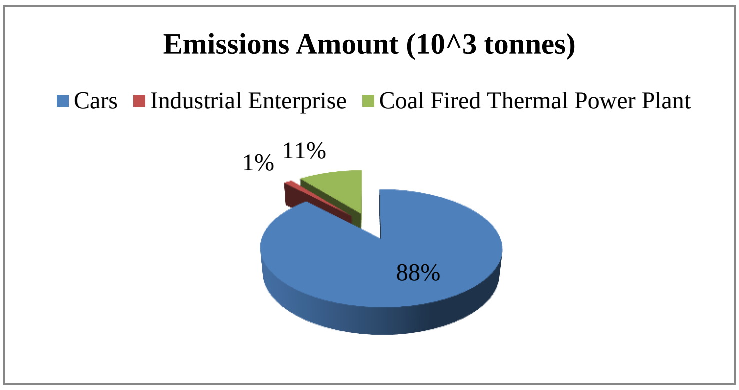

Figure 1.3. The share of emissions amount in Almaty, Kazakhstan

Respectively, many places in Kazakhstan rely on power being transported through extensive distances from power plant. Such transitions result in big losses of power. For rough comparison, in United Kingdom total power production is nearly 300 bn kWh/year, carried out on a transmission systems of 14 000 km, which makes 21 MWh/km of power density on the system. Whereas in Kazakhstan these numbers are 67 bn kWh/year and 24 000 km respectively, with outcome power density on a system of 2.8 MW/km. In other words there is a necessity of investments around 10 times more in infrastructure awaited in Kazakhstan to make it as sustainable as it is in UK (UNDP/GEF & Kazakhstan, 2006).

1.2. Purpose of Study

The main purpose of current research is to develop a Site Selection Technique for Wind Turbine Power Plants (WTPP) Utilizing Geographical Information Systems (GIS) and Analytical Hierarchy Process (AHP) and identify the most optimum location for a WTPP in Akmola Region, Kazakhstan, implying overlay and buffer zones analysis by ArcGIS software, and referring to weights of the selection criteria determined by the help of AHP technique. Each of these concepts will be discussed circumstantially in further chapters.

1.3. Area Selected for the Study (Akmola Region, Kazakhstan)

Area that will be considered in current research is Akmola Region that is situated in the north of Kazakhstan. There are several reasons why this region was chosen for current research:

- Akmola Region is one among others that was assessed before in terms of wind energy potential.
- There is one Wind Turbines Power Plant (WTPP) project is ongoing in this region. This project is initiated by Samruk Green Energy LLP (SGE), a governmental organization that was created in 2012 to develop wind energy sector in Kazakhstan. Yereymentau Wind Farm Project is situated in the south-east of Yereymentau Town, approximately 130 km east of the capital, Astana. It is expected that the project's capacity will be 50 MW (LLP, 2014).
- Astana the capital of Kazakhstan is situated in this region, hence it is currently one of the most rapidly growing and developing region in the country.

Moreover Astana EXPO 2017 worldwide exhibition dedicated to renewable sources of energy will be held in the city.

1.4. Methodology

1.4.1. Literature analysis

The methodology proposed in current study is similar to those that were applied for site selection of WTPP before. One of the first applications of GIS and weighted analysis for WTPP was introduced by Serwan R.J. Baban (Baban & Parry, 2000). In his work the survey was conducted to reveal the most suitable criteria for site selection. Further the assumptions were assigned for each criterion and according to these assumptions map layers were constructed in ArcGIS software. Finally overweighed analysis (see Chapter 5.3.4) was applied in order to get the most optimum areas for WTPP construction. Moreover, 2 scenarios were discussed at the end, (a) all the constraints have the same weight; (b) all the constraints are weighted by pairwise comparison.

In 2007 Adul Bennui applied GIS and Multi Criteria Decision Making (MCDMT) technique for optimum site selection of WTPP. AHP was used in order to compare all factors to each other and weight them. GIS Spatial analysis and 3D analysis were made based on suitability function. Tables of suitability range were made for each factor. Finally the suitable areas were divided into 5 rages from unsuitable to extremely suitable (Bennui, et al., 2007).

Nazil Yonca Aydin with Elcin Kentel and Sebnem Duzgun introduced GIS-environmental assessment of wind energy systems, considering a region in Western Turkey as area of study. Yet in their work Fuzzy Sets were applied in order to define the individual satisfaction degree for each of objective. And finally GIS was utilized in order to find the best location for wind turbines site (Aydin, et al., 2009). In the same year Leda-Ioanna Tegou, Heracles Polatidis and Dias A. Haralambopoulos applied similar combination of GIS and AHP in the island of Lesbos, Greece. A set of environmental, social, economic, and technical constrains were used in order to identify the potential sites for wind turbines. AHP was applied to estimate the criteria weights in order to establish their relative importance in site evaluation. As a result small percentage of area of Lesbos was found to be suitable for wind farm installation (Tegou, et al., 2010).

In 2011 Rob van Haaren and Vasilis Fthenakis evaluated an area in New York state with a similar approach. Their study was divided on 3 stages. 1st stage: excluding sites that are infeasible for wind turbines (land use and geological constrains); 2nd stage: identifying the best feasible sites based on the expected net present value (including, revenue from electricity, cost from access roads, power lines and land clearing); 3rd stage: assessment of ecological impacts on birds and their habitat. GIS and AHP were also applied in this work (Haaren & Fthenakis, 2011).

In 2014 T. Tsoutsos, I. Tsitoura, D. Kokologos and K. Kalaitzakis implemented methodology of evaluation and prioritizing for site selection of wind farms, aimed to support the spatial planning of the Crete Island. The basic tool used in this study is Specific plan for planning And Sustainable Development for Renewable energy applied on GIS and the parallel integration of a systematic and flexible method of multi-criteria analysis (Tsoutsos, et al., 2014).

D. Latinopoulos' and K. Kechagia's study was focused on selection of the most appropriate sites for wind-farm development projects as well and was introduced in 2015. Evaluation framework that is utilized is combined use of GIS and spatial multi-criteria decision analysis. Various technological, economic, social and environmental criteria were considered in order to define the appropriate sites and then evaluate them using Sustainability Index (SI) (Latinopoulos & Kechagia, 2015). In the same year, Kazim Baris Atici, Ahmet Bahadir Simsek, Aydin Ulucan and Mustafa Umur Tosun applied GIS and several stages of criteria evaluation in order to find the optimum sites for WTPP. First stage of the study was to eliminate unfeasible sites, based of several constraints and thresholds. Furthermore, the sites left were evaluated using MDCA: ELECTRE III, ELECTRE-TRI and SMAA-TRI in order to get a better approach and more precise results. This method aimed to get several alternative conclusions suitable for different stakeholders. In the section of results authors give a summary on relationship of the evaluation criteria with monetary variables (Atcic, et al., 2015).

In order to provide holistic approach, in the current study all selection criteria used in previous studies were determined. Through normative refinement method, the combination of those criteria was constructed and applied for the present study. Chapter 4.2 gives a detailed description of the criteria selection for this research.

For each sub-criterion specific acceptance was assigned. The process of assigning allowances is explained in Chapter 4.2. Further, these acceptances were utilized in order to construct buffer zones around features and limit the areas that are unfeasible for WTPP erection.

1.4.2. Obtaining data

After compiling the site selection criteria through literature review and determining the weights of the criteria through expert interviews using AHP, data related to the area selected for the study (Akmola Region, Kazakhstan) was obtained. In order to complete the analysis using the proposed technique in this thesis for the selected area, maps containing data relevant to each site selection criteria were required. For each sub-criterion a separate map layer was created, whether downloaded from open resources or drawn based of maps available online.

All maps that were available in raster extension are proposed in Appendix A.

The Chapter 5.3.1 explains what type of files were required and used for analysis utilizing ArcGIS 10.2 software. Since some maps were available only in .jpg, .png or .tiff extensions they were converted using Conversion Toolbox in ArcGIS (see Chapter 5.3.2). Conversion toolbox has a very wide range of functions. While ArcGIS is a complex system that allows multi-perspective analysis including various types of data, it is able to convert one type of data to another using conversion toolset. For the current study particularly, raster data was converted and analyzed so that it could be used in further examination.

Those map layers created from raster files such as .jpg or .png were drawn directly in ArcGIS 10.2 software as feature data extension. Chapter 5.4 describes the data obtaining process in more details.

1.4.3. Experts interviews and criteria weighting

In order to perform overlay analysis every criterion must have a certain weight in relevance to desirable outcome. All factors can be assigned to an equal weight or can be differentiated in terms of criteria importance. In order to assign weight to criteria in the current thesis AHP technique was applied. Moreover, the questionnaire was developed in order to obtain weights considering experts' opinions (Appendix B). Several experts were chosen from academic field of wind energy and from wind energy industries or business development in WTPPs.

AHP technique was chosen for this study among other MCDM tools due to several reasons:

- Consideration of many factors and sub-factors requires a certain hierarchy. AHP allows its users easily construct one, aggregating all sub-factors under a main factor.
- AHP technique is adjustable to any problem, which makes it one of the easiest methods for decision making process.
- AHP doesn't require complex calculations and allows obtaining results in short period of time.

Briefly, the hierarchy of all factors that influence on site selection for WTPP was structured and then, using the survey results (experts' opinion), weights were assigned for each criterion. Chapter 2 gives a general explanation of AHP methodology and how it can be used for any study.

1.4.4. Data analysis in ArcGIS 10.2

Finally in order to obtain location of the most suitable areas for site WTPPs a series of analysis were performed in ArcGIS 10.2 software. Figure 1.4 outlines the main steps of analysis that was made in GIS environment. Each of the methods used for all stages is revised in details in Chapter 5.3.

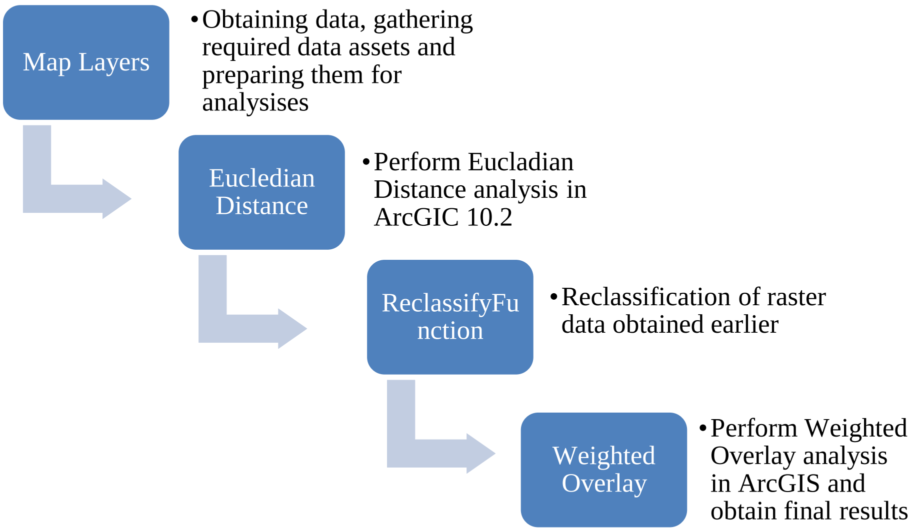

Figure 1.4. The general steps during analysis of map layers utilizing ArcGIS.

2. ANALYTICAL HIERARCHY PROCESS (AHP)

2.1. Introduction

Analytical Hierarchy Process is a multi-criteria decision-making (MCDM) tools that is commonly used when problems requires consideration of variety of criteria in order to obtain the most feasible and appropriate result of evaluation process. The usage of AHP is very wide and nowadays it is one of the most generally utilized decision making framework. AHP technique is a complex accountant of various criteria and sub-criteria assigning weights for each of them, yet it is comparatively easy to apply and use for different fields, particularly in management. I current research AHP is used to obtain necessary weight in order to evaluate each factor and sub-factor according to its importance and value for site selection.

2.2. Development of AHP

AHP takes its origin from 1970s when it was developed by Prof. Thomas L. Saaty, currently working at University of Pittsburg. Lately in 1980, 1988 and 1995 it was developed deeper allowing researches to use it in different fields of study. Being found a usage in business, government and social studies, defense, various engineering fields AHP has been applied for alternative selection, forecasting, resource allocation, balanced scorecard, public policy decisions, healthcare and many more others (Bhushan & Rai, 2004).

2.3. Principals

Briefly, AHP technique helps to structure complex problems, measurements, and synthesis of rankings. In the same time the structure can be easily edited and assigned to any decision making problem, providing basic mathematical tools to evaluate criteria. Even if criteria are given subjectively or verbally, they can be simply converted into numeric values (Bhushan & Rai, 2004).

Procedures for any decision making problem can be described in 6 classical steps that are listed below.

Table 2.1: General range of criterion evaluation for AHP.

Definition	Score
Equally important	**1**
Equally or slightly more important	2
Slightly more important	**3**
Slightly to much more important	4
Much more important	**5**
Much to far more important	6
Far more important	**7**
Far more important to extremely more important	8
Extremely more important	**9**

Step 1: Structuring decision problem (defining a goal, criteria and sub-criteria, alternatives). Figure 2.1 shows the example of hierarchy of main criteria (C_n) and sub-criteria that influence on general output and selection among different alternatives (L_n on Figure 5.1). Once the hierarchy is constructed, the relationships

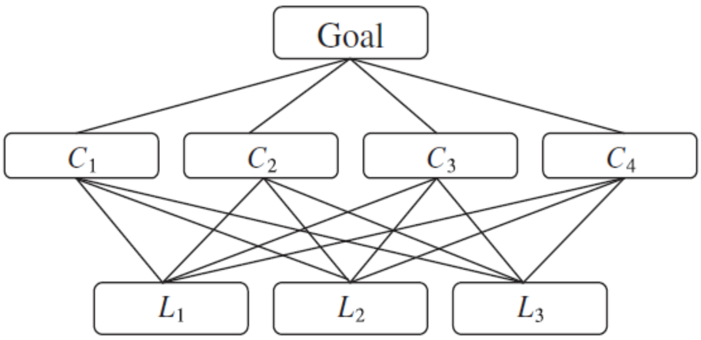

Figure 2.1. Example of hierarchy that must be structured from criteria and sub-criteria.

and impact between criteria and alternatives can be followed and observed easily.

Step 2 includes pairwise comparison, leading to development of judgmental matrix. Figure 2.2 shows the example of general view of pairwise comparison matrix that is usually build according to experts' opinions. Usually experts are given a questionnaire that represents each criterion in comparison to others. As a rule criteria can be evaluated according to classical range from 1 to 9 that is shown in Table 2.1.

Comparison of alternatives with respect to C_4.

	L_1	L_2	L_3	Local weights
L_1	1	3	9	0.692
L_2	1/3	1	3	0.231
L_3	1/9	1/3	1	0.077

Figure 2.2. Example of pairwise comparison matrix or judgmental matrix

Scores 1, 3, 5, 7, 9 are considered as the main evaluation levels, and scores 2, 4, 6, 8 can be also used in order to express the comparison more precisely.

One of outcome of this step will be the matrix $A = a_{ij}$, which is positive and reciprocal,

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & \vdots \\ \vdots & \vdots & \cdots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix}$$

where, for all $a_{ij} = 1/a_{ji}$, and for all i, j = 1, 2…, n (Harker, 1989).

Step 3 includes computing local weights by normalizing the judgmental matrix and checking the consistency of comparisons since the judgments are subjective. The consistency index (CI) must be calculated according to formula 2.3.1.

$$CI = \frac{\lambda_{max} - n}{n-1}; \tag{2.3.1}$$

where λ_{max}- the maximum of eigenvalue of the judgmental matrix, and n – matrix's order. To finalize the calculations the consistency ratio (CR) must be computed according to formula 2.3.2.

$$CR = CI/RI \tag{2.3.2}$$

where RI (random index) is being chosen from the Figure 2.3, that was calculated

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R.I.	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

Figure 2.3. Random inconsistency index (RI)

using generated random matrixes for each size of matrix *n*. (Harker, 1989)

Step 4, which is the final step of the process, is aggregation of all local weights, by multiplying them gradually moving from down of hierarchy till the beginning. Finally the global ratings can be calculated.

There are also three main concepts behind the AHP technique; they can be listed as follows (Bhushan & Rai, 2004):

- AHP is analytic – mathematical and logical reasoning for getting the decision. It assists in analyzing the main problem on logical basis and provides conversion of experts' subjective opinion into numeric value, which can be calculated through formulas and might be easily discussed and explained to others.
- AHP structures the problem as a hierarchy, which helps to understand problem and solve it by dividing it into small sub-problems, that is easy to deal with individually. Psychology studies suggest that human beings are able to keep in mind and compare only 7 ± 2 things at time. Thus, it is necessary to apply AHP in any problem that accounts large number of criteria and sub-criteria to deal with.
- AHP defines a process for decision – making. Being one of the most commonly used MCDMT, AHP also provides a methodology of solving a problem. Collaboration between experts' inputs, revision and learnings helps to reach collective decision.

2.4. Practical Applications

As it was said earlier, application of AHP has a big range starting from defense industry, being utilized in many engineering fields and many other management areas to find the optimum solution for various problems. In the same time AHP is actively applied and used in construction industry. The summary of all applications of AHP in construction management can be shown as follows:

- Strategic management

- Prioritization of critical success factors of the project
- Contracting/delivery method selection
- Contractor/Subcontractor selection
- Supplier selection
- Construction method selection
- Equipment selection
- Risk management
- Safety management
- Performance evaluation
- Improving productivity

The present study is concerned on optimum site selection for WTPP, and AHP is applied to assist a better approach to this problem. Since, one of the main steps of AHP is definition of weights for each factor and sub-factor, it is reasonable to employ this technique. Moreover, the site selection of WTPP is also includes the application of geographical information system (GIS), that will be discussed in next chapters.

3. WIND ENERGY

3.1. Introduction

Wind energy has been used by human beings over centuries ago. There are a lot of archeological evidences that show how wind energy could be used in different ways and various purposes. Historical and archeological records prove the fact that windmills were used by Babylonians, Chinese and Egyptians. Although the first prototypes of windmills were constructed mainly from wood and utilized for pumping water and grinding grain, thousands of years passed before people began to use wind to produce electricity.

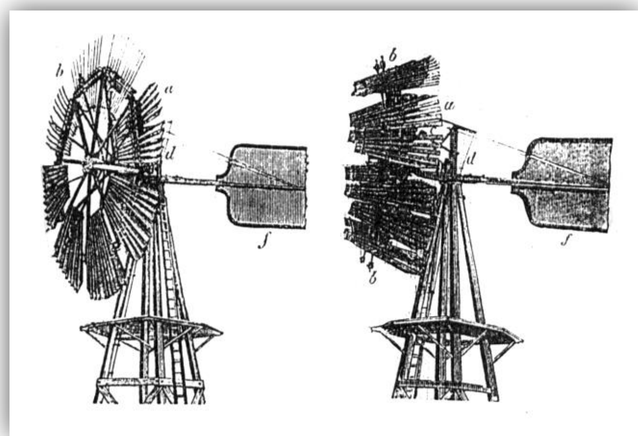

Figure 3.1. One of the earliest prototypes of windmills

In 1957, Daniel Holladay started making wind Machines that were self-regulating using paddle-shaped blades that pivoted, or feathered as wind speed increased. The eclipse windmill was introduced few years later and was the first to use a solid wheel assembly and a side vane to turn the rotor out of the wind as velocity increased (Clark, 2014). Figure 3.1 shows the prototypes that were commonly used at that time in USA.

All of these types of windmills erected before were just a predecessors to nowadays wind turbines that generate electricity taking the energy from natural and the cheapest resource on the planet. The same principal that was used to pump water from wells years before is used to power cities.

Figure 3.2. A small part of one of the biggest win turbines power plant in the world. Gansu Wind Farm Project, China.

The story of electricity generators powered by wind starts from Michael Faraday who presented the design of electrical motor at Royal Institution in 1821, and 10 years after discovered electrical induction. Within 10 years more Faraday invented dynamo, a simple mechanism that converts mechanical energy into electrical.

In 1887 professor of Glasgow and West Scotland Technical College at that times,

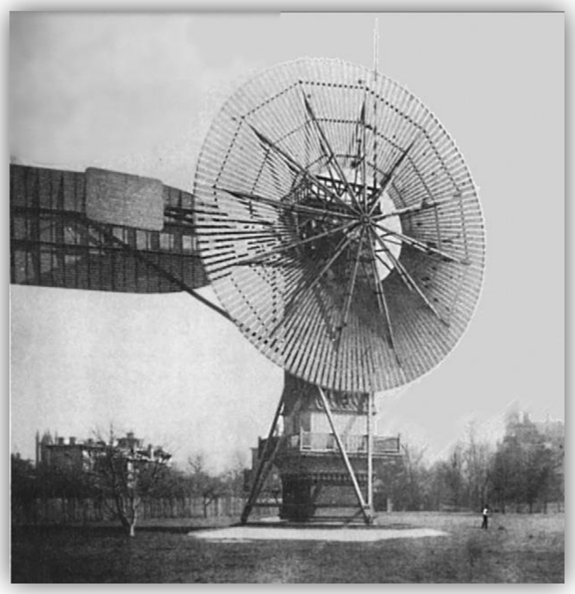

Figure 3.3. The wind electricity generator of Charles Brush. The wind turbine generator 17 m in diameter with 144 blades has been powering Brush's house for over 20 years.

named Prof. James Blyth came up with invention that might be considered as the first electrical power generator worked from wind (Swift-Hook, 2012). In the same time, Charles Brush first generated the power from wind in the same year as Blyth has made his invention. The house of Brush was the first one in Cleveland, Ohio powered by wind energy.

By the time technologies and forms of wind turbines were changing and, for example, in Europe several countries were experimenting with larger wind turbines that would generate electricity for connections to the electric grid (Clark, 2014). Nevertheless, these efforts were left behind for a while because of existence of low-cost petrol sources. However, oil crisis that had place in October 1973 triggered the need in renewable energy sources again, particularly for electricity production. Subsequently, governments in Europe and United States started investing into aerodynamics theories research and production of new technologies for wind turbines. In Europe that led to installation of nearly 8000 units by 1984, with a total capacity of 300 MW. Generally machines were three-bladed with a rotor diameter of

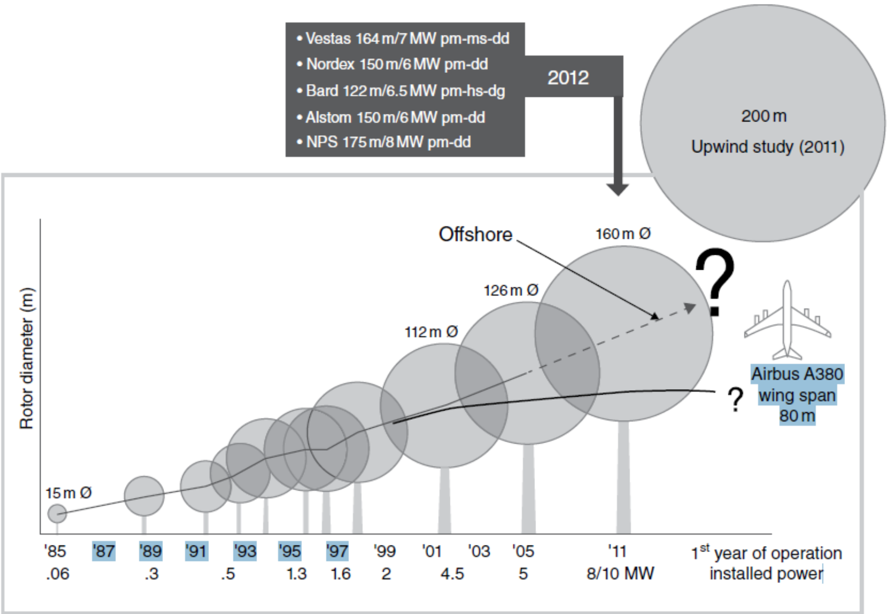

Figure 3.4. Representative turbine architectures from 1980s to 2011s **(Schaffarczyk, 2014)**

15 m and had a power rating of approximately 65kW. Whereas, US manufacturers were producing the turbines with a rotor diameter between 10 and 17 m. The Figure below shows the change in wind turbine dimensions over years.

Due to rapid technological development of new technologies, materials productions and performance improvement the capital cost for wind turbine installation was decreased dramatically over the las 30 years. It is also estimated that the cost might fall by 20-30% over the next decades (Lantz & Hand, 2012).

3.2. Wind Turbines

The general principals according to which wind turbines work is the utilizing kinetic energy and convert it to mechanical, electrical or heat energy. The power in the wind depends on the volume of air that passes through the rotor area perpendicular to the wind direction per unit of time. Theoretically this can be described by a simple formula:

$$P = \frac{1}{2} * \rho A V^3 \tag{3.3.1}$$

where P is the power in Watts, ρ is the air density in kilograms per cubic meter, A is area in square meters, and V is a wind speed in meters per second. However, the amount of power that can be extracted from wind is not the same as the amount of power gained. Experiments show that the maximum amount of energy that is extractable from wind is around 59.3% of energy available (Clark, 2014).

There two main types of wind turbines that have been used, horizontal axis wind turbines (HAWTs) and vertical axis wind turbines (VAWTs). All wins turbines commonly used nowadays can be assigned under these two categories, and HAWT are the most frequently chosen among them. The Figure 3.6 outlines general forms of both HAWT and VAWT.

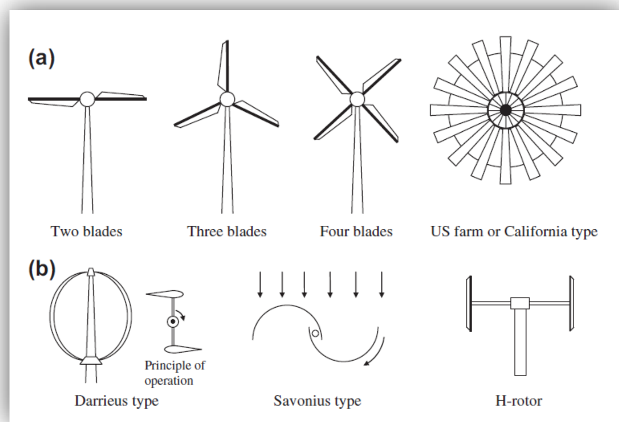

Figure 3.5. General types of wind turbines. (a) Horizontal Axis Wind Turbines and (b) Vertical Axis Wind Turbines.

There are also a single-bladed wind turbines, although they are not shown in Figure 3.6(a), this type of wind turbines has the lowest cost and weight, but in the same time, "must offset the counterweight". Even though, double-bladed turbines provide also the lowest cost, the disadvantage for both single- and double-bladed machines is "the high level of noise generated". Four-bladed wind turbines have a good balance of rotor; however they are not cost-efficient and heavier. Nowadays wind turbines used everywhere, three-bladed apparatuses, have a well-balanced ratio between cost, weight, noise level and energy-efficiency. The VAWTs, in comparison to HAWTs, has advantages due to possibility of placement of gear box and generator on the same level which makes them more accessible for maintenance (Figure 3.6(b)). In the same time, it doesn't matter which direction wind blows while utilizing VAWTs. Yet, the VAWTs are not as energy-efficient as HAWTs, because they cannot produce amount of energy that would be feasible enough (Kalogirou, 2014).

3.2.1. Wind Turbine Components

There are many types of wind turbines produced nowadays. All of them are differentiated by power yield, and subsequently sizes of their rotors and height of towers. Main parts of typical wind turbine include rotor, nacelle and tower (Figure 3.7).

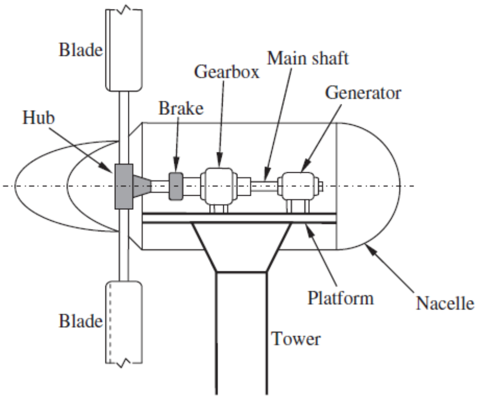

Figure 3.6. Schematic diagram of typical wind turbine components.

Rotor that consists of blades can vary in diameter. *Blades,* mounted on the *hub* are being powered by wind and turn around the *main shaft*. In the same time *gearbox* increases the rotation and passes the motion energy to *generator*. Both generator and gearbox are aligned on the same level and placed on a *platform*. Electricity that is produced by generator is being passed by cable along the tower to substation, and the energy transported to electricity grid.

3.3. Wind Turbine Power Plants

Wind farms or wind parks are known as number of wind turbines clustered together. Grid connection cost decrease sharply by combining several wind parks located in

Figure 3.7. Wind turbine power plant in Yereymentau province, Kazakhstan

the same area. Figure 3.8 represents the power plant that was erected recently around small city Yereymentau in Akmola Region, Kazakhstan.

Each wind turbine in any wind farm is usually placed as 5-10 rotor diameters from others to decrease the interference effects between them. This means that a wide are is normally needed for clustering many wind turbines into wind parks (Kalogirou, 2014).

3.4. Wind Energy Potential in Kazakhstan

Territories of Kazakhstan remarkably rich in wind resources. Vast areas have in average wind speed of 6 m/s and above during each year. The cost of energy in such places is usually about 5.5 – 6.5 cents/kWh. The availability of wind resources in Kazakhstan makes the country one of the most appropriate to develop wind energy sector.

The economics of wind power is related to wind speed. According to Renewable Energy Focus Handbook, if the wind speed would be doubled the energy outcome increases eight times. For instance, a 1.5 MW wind turbine located in a site with average wind speed 5.5 m/s can generate around 1000 MWh/year. While the wind speed is 8.5 m/s, energy yield raises up to 4500 MWh/year. Finally, if the wind speed is around 10.5 m/s annual outcome turns out to be 8000 MWh (Sørensen , et al., 2009).

In order to evaluate the wind speed in Kazakhstan observation points have been established since 1997 in order to register the wind speed in different regions of the country. Followed by development of Kazakhstan Wind Atlas Project initiated in 2007, the wind speed was visualized and shown on map of Kazakhstani territories. The atlas represents the distribution of wind speed on height of 80 m and the resolution of wind map of whole area of the country is 9 km (IRENA, 2013). The Figure shows the wind map of Kazakhstan.

4. SITE SELCTION FOR WIND TURBINE POWER PLANTS (WTPP)

4.1. Introduction

Site selection for any project is one the most essential parts among other procedures. One of the first and most complicated decisions that any construction manager can face during each project. The site selection decision is a long term decision what makes it hard to deal with. In the same time, the outcome of this decision will drastically influence on the project's outcome. During site selection procedures many factors must be taken into consideration. In many cases these factors must be technically, economically and environmentally feasible and reasonable.

As for site selection of wind turbines, it is probably more generally important to decide about location rather than which wind system to use because the performance of any well-designed wind power machine might be poor due to wind conditions. Many wind projects were not successful economically because of unfortunate site selection. For wind turbines power plant particularly not only physical location will a play a big role, but also the surroundings. Hence utility must be place at the proper height for turbulence reduction and good wind speed. Nevertheless, there are other additional criteria that must be considered while choosing appropriate location for wind turbine power plant. Next paragraphs will give deeper insights about these criteria.

Although wind energy progress is being actively supported by government financially and technically, there are no regulations and restrictions for WTPP and their placement.

4.2. Criteria for Wind Turbine Power Plant

Site selection is one of the first steps in construction projects. While for normal construction projects, as buildings, site selection is made more depending on economic factors (for example, placement of entertainment mall) and sites availability, the site selection for wind turbines includes many criteria. These criteria can be divided into main four groups: economic, environmental, planning, physical and technical criteria. Each of them include sub-criteria, such as availability of roads and electricity grid (economic criteria), placement on a certain distance from water bodies (lakes and rivers) and natural reserves (environmental criteria), placement on a certain distance from large cities and towns (safety and aesthetics criteria) . There are many researches were made for site selection of particular construction projects. For instance, the techniques that involve geographical information systems (GIS) are being widespread nowadays, due to possibility of performing complex analysis' of maps, visualizing any data that can be represented in spatial difference.

Utilizing GIS is a progressive method in decision making process. Nevertheless, to make this process more precise researchers employ some other multi-criteria decision making models (MCDM). For example, Bennui (Bennui, et al., 2007) used Analytical Hierarchy Process (AHP) in order to compare all factors to each other and weight them. Furthermore GIS Spatial analysis and 3D analysis were made based on suitability function, which was defined from weighted factors. Finally the suitable areas were divided into 5 rages from unsuitable to extremely suitable. Table 4-1 summarizes all criteria that were used by Bennui.

Table 4.1: Criteria that were used by **(Bennui, et al., 2007)**

Factors	Sub-factors	Acceptance
Amenities	Aiport area	Safety areas 3000 m
	Highway	Safety trips 500 m
Socioeconomic	Urban areas	Buffer zones within 2500 m
	Community zones	Buffer zones within 1000 m
	Important places	Buffer areas within 2000 m
	Touristic Places	Safety areas 1000 m around
Physical	Wind energy potential	
	Surface roughness	Areas elevation higher than 200 m above msl
	Elevation (slope)	< 15% slope
Environmental quality	River/canal	Reservation areas in 1st class watershed Nature safety zones within of 200 m from water bodies and main rivers

Haaren (Haaren & Fthenakis, 2011) excluded infeasible sites basing on several factors such as: visual intrusion and noise (urban areas), federal and Indian lands, safety and visual intrusion (roads), lakes, slope, foundation strength requirement (karst). Consequently, in his study economic evaluation was made based on factors such as: grid connection (price increases due to distance from electric grid connections); access roads (sufficiently wide roads are required); land clearing (cost depends on vegetation on site); wind resource. Table 4-2 summarizes all criteria that were used by Haaren. Aydin (Aydin, et al., 2009) made a very detailed work on fuzzy sets, determining the individual satisfaction degree for each of objectives. Than he utilized GIS in order to find the best location for wind turbines site. Table 4-3 summarizes all criteria that were used by Aydin.

Table 4.2: Criteria assigned by **(Haaren & Fthenakis, 2011)**

Factors	Sub-factors	Acceptance
Economic	Wind resources	-
	Electric line cost	-
	Electric integration cost	-
	Land cost	-
	Access road cost	-
Planning	Visual impact	Buffer zone from towns 1 km
	Safety Distances urban areas	(Federal lands)
	Noise	Buffer zone from cities 2 km
	Electromagnetic interference	(Federal lands)
		Buffer zone 3 km (Indian lands)
		Buffer zone from roads 0.5 km
	Parks	Exclusion
	Military	Exclusion
	Airports	Exclusion
	Prisons	Exclusion
Physical	Slope	<10% slope
	Altitude	-
	Karst (porous grounds and caves)	Exclusion
Ecological	Bird habitats/routs	Buffer zone from lakes 3 km
	Forest proximity	
	Lakes and rivers	Exclusion

Table 4.3: Criteria assigned by **(Aydin, et al., 2009)**

Factors	Sub-factors	Acceptance
	Safety and aesthetics for large city centers	2000 m away from large settlements [14]
	Safety and aesthetics for town centers	2000 m away from cities, urban centers Minimum 1000 m away from towns
	Safety and aesthetics for airports	2500 m away from airports
	Noise	500 m away from nearest habitat 400 m away from nearest habitat
	Natural reserves	1000 m away from areas of ecological value 400 m away from water bodies 250 m away from ecologically sensitive areas
	Birds habitat	At least 500 m away from wildlife conservation areas 300 m from nature reserves to reduce risk to birds

In the same time Tsoutsos in his study observed the current situation on environmental interests including areas of cultural heritage, areas of residential activities, networks of technical structure or zones and facilities of productive activities. Next step was to define the legally available areas, in other words exclude areas that are not feasible. The third stage was the evaluation of areas that are available. All criteria were concerned in terms of buffer zones and limited distances to specific areas such as, rivers and lakes, national parks, aesthetic forests, archeological sites, high voltage lines and others. Then the results were taken into account along with wind potential criterion (Tsoutsos, et al., 2014). Table 4-4 summarizes all criteria that were used by Tsoutsos.

Table 4.4: Criteria assigned by **(Tsoutsos, et al., 2014)**

Factors	Sub-factors	Acceptance
Areas of cultural heritage	World Heritage, archeological monuments and historical places of high importance	Min distance 3000 m
	No take zone (zone A) of the rest archeological sites	At least 500 m
	Cultural monuments, historical sites	At least 500 m
Areas of urban activities	Towns and settlements with population >2000 inhabitants	1000 m from the settlement boundaries
	Monasteries	Buffer zones 500 m
	Rest settlements	Buffer zones 500 m
	Traditional settlements	Buffer zones 1500 m
Environmental interest	Areas of absolute protection of the nature	Exclusion
	Centre of national forests, nature monuments, aesthetic forests	Exclusion
	Beaches	Exclusion
	Sites of Community Importance	Exclusion
	Special Protection Areas of bird habitat	Exclusion

Latinopoulos in his research started from exclusion of infeasible sites (study area boundaries, settlement areas, roads, slopes, natural sites, etc.) (Latinopoulos & Kechagia, 2015). Table 4.5 summarizes all criteria that were used by Latinopoulos. Tegou in his study considered eleven constraints and a binary GIS grid was created for each of the constraint assigned as 1 if they fall into consideration and 0 if not (Tegou, et al., 2010). Table 4.6 summarizes all criteria that were used by Tegou.

Table 4.5: Criteria assigned by **(Latinopoulos & Kechagia, 2015)**

Factors	Sub-factors	Acceptance
Areas of cultural heritage	Protected Landscapes	Buffer zone 1000 m
	Archeological sites	Buffer zone 1000 m
	Historical sites	Buffer zone 1000 m
Social	Urban Areas and traditional settlements	[Population > 2000 inhabitants]: 1000 m [Population < 2000 inhabitants]: 500 m [Traditional settlements]: 1500 m
	Tourism facilities (hotels/guesthouses)	1000 m Buffer zone
Physical	Wind speed	Areas where average wind speed is lower than 4.5 m/s
	Slope (no buffer)	>25%
Environmental and cost constraints	Land use restriction (no buffer) Artificial surfaces, industrial commercial and transport units; mine dump and construction sites; irrigated agricultural lands; wastelands.	Exclusion
Safety	Distance from roads	150 m Buffer zone
	Proximity to airports	3000 m buffer zone

Table 4.6: Criteria assigned by **(Tegou, et al., 2010)**

Factors	Sub-factors	Acceptance
Economic	Road network	>10 000 m
	Land value	
Technical	Slope angles	<30%
	Wind potential	-
Environmental,	Land of high productivity	-
and cultural issues,	NATURA 2000	-
	Water lands	-
	Petrified forest	-
	Settlements	Distances from settlements: Traditional <1500 m Significant <1000 m Other <500 m
	Archeological sites	<500 m
	Monasteries	<500 m

One of the earliest studies were made by Serwan M.J. Baban, he used the same methodology in 2000 considering 13 layers of different data aggregated into four groups (Baban & Parry, 2000). Table 4.7 summarizes all criteria that were used by Baban.

Table 4.7. Criteria assigned by **(Baban & Parry, 2000)**.

Factors	Sub-factors	Acceptance
Economic	Roads	<10 000 m
	National grid	<10 000 m
Planning	Large settlements	Buffer zone 2000 m
	Single Dwellings	Buffer Zone 500 m
	National Trust Property	Buffer zones 1000 m
Physical	Summits and large hills	Exclusion
	Slope angles	<10%
	Westerly orientated	
	Wind Speed	>5 m/s
	Woodland	Buffer zones 500 m
Environmental	Water bodies	Buffer zones 400 m
	Area of ecological value/special scientific interest	Buffer zones 1000 m
Historic/ Cultural resource	Historic sites	Buffer zones 1000 m

Atici in his study eliminated unfeasible sites, based of several constraints and thresholds. After that the sites left were evaluated using MDCA: ELECTRE III, ELECTRE-TRI and SMAA-TRI in order to get a better approach and more precise results. This method aimed to get several alternative conclusions suitable for different stakeholders (Atcic, et al., 2015). Table 4.8 summarizes all criteria that were used by Atici.

Table 4.8. Criteria assigned by **(Atcic, et al., 2015)**

Sub-factors	Acceptance
Distance to transmission lines	>250 m
Distance to roads	>500 m
Distance to railways	>500 m
Distance to airports	>5000 m
Distance to urban areas	>2000 m
Distance to fault lines	>200 m
Distance to mining sites	>100 m
Distance to radio and TV stations	>600 m
Capacity factor	>35
Elevation	<1500 m
Slope	<10%
Distance to lakes and rivers	>3000 m
Distance to protected areas	>2000 m

As it was mentioned before, Kazakhstan wind energy sector has just started evolving and there are no certain regulations for acceptances and restrictions of WTPP placement. Hence an investigation for each parameter is needed in order to choose suitable sub-criteria and main criteria for current research, which will be explained in following chapters.

Table 4.9 summarizes all criteria regarding studies mentioned earlier.

Table 4.9. Summary of all criteria used for site evaluation of WTPP

No	Sub-Factor	Bennui, 2007	Haaren, 2011	Aydin, 2009	Tsoutsos, 2014	Latinopoulos, 2015	Tegou, 2009	Baban, 2000	Atici, 2015
1	**Airport area**	3000 m	exclusion	2500 m	-	3000 m	-	-	>5000 m
2	**Highway**	500 m	500 m	-	-	150 m	>10 000 m (constraint)	<10 000 m (buffer zone)	>500 m
3	**Distance to railways**	-	-	-	-	-	-	-	>500 m
4	**Urban areas**	2500 m	2000 m	2000 m	1000 m	[Population > 2000 inhabitants]: 1000 m	<1500 m (traditional)	2000 m	>2000 m
5	**Community zones**	1000 m	1000 m	2000 m	-	[Population < 2000 inhabitants]: 500 m	<500 m	500 m	-
6	**Important places**	2000 m	3000 m (Indian lands)	500 m (nearest habitat)	500 m (nearest habitat)	exclusion	-	1000 m	-
7	**Touristic Places**	1000 m	-	-	-	1000 m	-	-	-
8	**Wind energy potential**	-	-	-	-	> 4.5 m/s	-	>5 m/s	-
9	**Surface roughness**	>200 m above msl	-	-	-	-	-	-	-
10	**Elevation (slope)**	< 15% slope	<10% slope	-	-	>25%	<30%	<10%	<1500 m (<10%)
11	**River/canal, waterbodies**	200 m	3000 m (lakes)	400 m	-	-	-	400 m	>3000 m
12	**Electric line cost**	-	-	-	-	-	-	<10 000 m (buffer zone)	>250 m
13	**Electric integration cost**	-	-	-	-	-	-	-	-
14	**Land cost**	-	-	-	-	-	-	-	-
15	**Access road cost**	-	-	-	-	-	-	-	-
16	**Parks, areas of ecological value/special scientific interest**	-	exclusion	1000 m	exclusion	-	-	1000 m	>2000 m
17	**Karst (porous grounds and caves)**	-	exclusion	-	-	-	-	-	-
18	**Bird habitats/routs**	-		500 m	exclusion	-	-	-	-
19	**World Heritage, archeological monuments and historical places of high importance**	-	-	-	3000 m	1000 m	-	1000 m	-
20	**Cultural monuments, historical sites**	-	-	-	500 m	1000 m	-	1000 m	-
21	**Summits and large hills**	-	-	-	-	-	-	exclusion	-
22	**Woodland**	-	-	-	-	-	-	500 m	-
23	**Distance to fault lines**	-	-	-	-	-	-	-	>200 m
24	**Distance to mining sites**	-	-	-	-	-	-	-	>100 m
25	**Distance to radio and TV stations**	-	-	-	-	-	-	-	>600 m

4.2.1. Economic criteria

There are two main economic criteria mentioned in majority of studies discussed in previous chapters, proximity to roads (highways) and proximity to electric lines (grid connection). According to International Renewable Energy Agency (IRENA) grid connection takes approximately 11% from capital cost (IRENA, 2012).

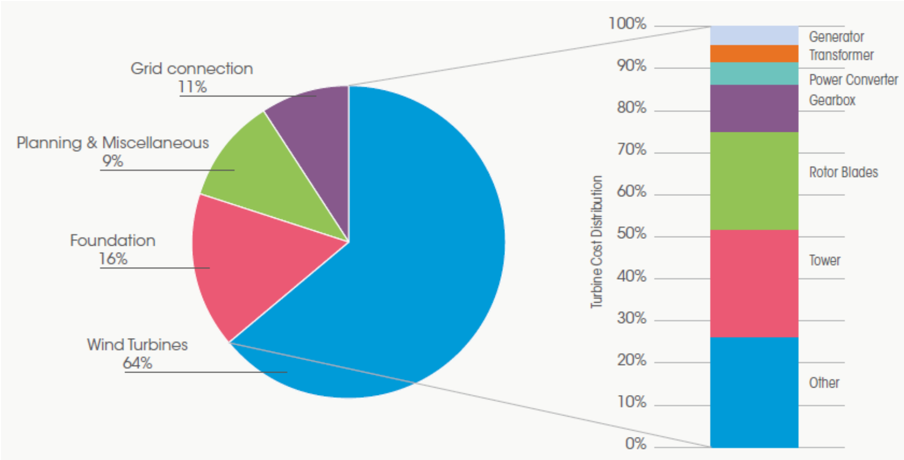

Figure 4.1. Capital cost breakdown for a typical onshore wind power system and turbine **(IRENA, 2012)**.

Proximity to electricity grid according to Baban (Table 4.9) should not excide 10 000 meters. In the same time there is no clear explanation about this assigned acceptance. On the other hand, Prof. V. G. Nikolayev has developed methodology that helps in placement of WTPP according to proximity to electricity grids and roads (Marinushkin & Trofimov, 2012). The Table 4.10 below shows the summary of these criteria proximity to WTPP. Depending on different types of wind turbine used in power plant, maximum allowance of its proximity can be assigned according to the table.

Table 4.10. Maximum allowance of wind turbines power plant with capacity 50mw from electric power lines and roads.

Maximum Allowance of WTPP	Types of Wind Turbines				
	Vestas V-80 2MW	**Siemens SWT 82 2.3 MW**	**Suzlon S-88 2.1 MW**	**Enercon E-82 2.05 MW**	**Furhlander FL 2500-91**
from electric power lines, km	29.5	30.1	26.4	32.4	31.2
from main roads, km	9.8	10	9.1	10.8	10.4

Land cost is one of other economic criteria that was mentioned in previous studies by Tegou (2009) and Haaren (2011). Land cost changes drastically from one geographic location to another, hence it will be different from values used by Haaren (2012) and

Tegou (2009) while appliying th technique on a region in Kazakhstan. However, the prices of land in Akmola region couldn't be found and thus were not applied in the current thesis.

4.2.2. Planning criteria

Most of planning criteria are coming out due to safety and aesthetics impact of noise and electromagnetic radiation perspectives. In order to provide a comfortable buffer zone avoiding disturbance of inhabitants criteria such as proximity to urban areas, community zones, important places, touristic places, areas of ecological value, world heritage, archeological and areas of historical values, cultural monuments and proximity to radio and TV stations should be considered and taken into account. Nevertheless it is always arguable how big the buffer zones for these criteria should be.

According to Table 4.9 the minimum and maximum acceptances assigned to sub-criteria "Airports", 2500 meters (Aydin, et al., 2009) and more than 5000 meters (Atcic, et al., 2015) respectively. There are two main sources revised by Aydin regarding acceptance for proximity to airports. One of them doesn't give a certain explanation of give allowance. Another one was traced till Baban's research (Baban & Parry, 2000). In the same time Aitici (Atcic, et al., 2015) doesn't give certain explanation about assigned acceptance.

According to report about noise impact from wind turbines prepared by noise group, distance from wind turbines should be increased regarding to number on turbines used (Turbines, 1996). Table 4.11 summarizes the data about wind farms acceptable proximity.

Table 4.11. Acceptable distance from nearest appropriate residence to wind farm.

Min Distance, feet	Max Distance, meters	Max Number of Turbines	Max Height (topographical), feet	Max Height (topographical), meters
2000.0	609.6	10.0	100.0	30.5
3000.0	914.4	25.0	125.0	38.1
4000.0	1219.2	50.0	150.0	45.7
5000.0	1524.0	110.0	175.0	53.3
6000.0	1828.8	200.0	200.0	61.0

Considering urban areas and areas Bennui (Bennui, et al., 2007) doesn't give a certain sources for acceptance assigned in his research. While Tsoutsos (Tsoutsos, et al., 2014) classifies allowances of proximity to urban areas according to population, referring to official document The Specific Plan for Spatial Planning and Sustainable Development for Renewable Energy (SPSPSD-RES), the regulations accepted in Greece. Finally, the world heritage areas, archeological monuments and places of historical value should be assigned to buffer zone no less than 3000 meters (Tsoutsos, et al., 2014). The same source of data was employed by Latinopoulos (Latinopoulos & Kechagia, 2015).

4.2.3. Physical and technical criteria

Among all physical and technical sub-criteria appropriate slope requirements takes a lot of arguments. "In many studies slopes greater than 10-20% are not candidates for wind turbine installation" (Baban & Parry, 2000; Haaren & Fthenakis, 2011). However, island of Crete, Greece, wind turbines are constructed on a land with slope of 30% (Tegou, et al., 2010).

Wind potential as one of other physical sub-criteria can be considered also as economic factor. Because the determination of wind potential or wind speed at any proposed wind turbine site is critical for estimation of the economic potential of the wind turbine (Clark, 2014). Therefore, required wind atlas was obtain for the current thesis study (Appendix A.3)

In order to optimize the price of WTPP, consideration of ground and soil properties is needed, taking into account that foundation of wind turbine is estimated to take 16% in capital cost (Figure 4.1). Consideration of surface roughness and porous grounds and caves (karst) was introduced by Bennui (2007) and Haaren (2011). "Since the foundations of wind turbines transfer the weight of the turbines to the ground, they must withstand great forces. Poor soil conditions can raise costs for the foundation type by 100% or more" (Haaren & Fthenakis, 2011).

Once the site evaluation is being done on seismically active zones, there is also a need of consideration of fault lines in area. This was proposed by Atici (2015): "Having one site closer to a fault line makes it riskier than the other in case of an earthquake".

4.2.4. Environmental criteria

Among environmental criteria water bodies (rivers, lakes), bird habitat and woodlands are assigned as sub-criteria. Although major part of Akmola region covered by steppes, there are a lot of ecosystems in the area. By Association for the Conservation of Biodiversity of Kazakhstan (ACBK) database of Important Birds Areas (IBA) and important ecosystems were created so that it would be easy to avoid any threatening facility for wild life in these areas and increase general awareness of citizens. Table 4.12 summarizes all possible environmentally important areas that appear in Akmola region, Kazakhstan.

Table 4.12. Summary of environmentally important area of Akmola region in Kazakhstan.

Code	Name	Location	Criteria							Conservation Status
			A1	**A2**	**A3**	**A4i**	**A4ii**	**A4iii**	**A4iv**	
KZ 049	Alekseyevskie steppe pine forests	Akmola region	+		+					Unprotected
KZ 051	Korgalzhin State Nature Reserve	Akmola region	+		+	+		+		Protected (State Nature Reserve)
KZ 052	Amangeldy	Akmola region	+		+	+				Unprotected
KZ 053	Zhumai-Maishukyr Lake System	Akmola region	+		+	+		+		Unprotected
KZ 054	Vicinity of Korgalzhyn village	Akmola region	+		+	+				Unprotected
KZ 055	Uhyalyshalkar Lake Group	Akmola region	+		+	+		+		Unprotected
KZ 056	Kumdykol-Zharlykol Lake Group	Akmola region	+		+	+		+		Unprotected
KZ 058	Tuzaschy and Karasor Lakes	Akmola region	+			+		+		Unprotected
KZ 083	Iskrinskie pine forests	Akmola region	+		+					Unprotected
KZ 084	Ereymentau mountains	Akmola region,Karaganda region	+		+					Protected (State Nature Reserve) Partially

4.2.5. Site selection criteria and allowances utilized for the study.

The Table 4.14 below represents the result of criteria selection for the current study.

Table 4.13 The result of Criteria selection for current study

No	No	Main Criteria	Sub-Criteria
1	1	Economic	**Highway**
	2		**Electric line cost**
	3		**Land cost**
2	4	Planning	**Distance to railways**
	5		**Airport area**
	6		**Urban areas**
	7		**Community zones**
	8		**Important places**
	9		**Touristic Places**
	10		**Parks, areas of ecological value/special scientific interest**
	11		**World Heritage, archeological monuments and historical places of high importance**
	12		**Cultural monuments, historical sites**
	13		**Distance to radio and TV stations**
3	14	Physical and Technical	**Wind energy potential**
	15		**Surface roughness**
	16		**Elevation (slope)**
	17		**Karst (porous grounds and caves)**
	18		**Distance to fault lines**
	19		**Distance to mining sites**
4	20	Environmental	**River/canal, waterbodies**
	21		**Bird habitats/routs**
	22		**Woodland**

In order to provide holistic approach, in the current study all selection criteria used in previous studies were determined. Through normative refinement method, the combination of those criteria was constructed and applied for the present study.

For each sub-criterion specific acceptance was assigned. Further, these acceptances were utilized in order to construct buffer zones around features and limit the areas that are unfeasible for WTPP erection. Table 4.15 outlines the acceptances and allowances for them that will be used in the current study.

Table 4.14. Summary of criteria and acceptances assigned for current study.

		Main Criteria		Sub-Criteria	Acceptance	Source
1	1	Economic	2	**Highway**	<10 000 m (buffer zone)	**Baban, 2000**
	2		12	**Electric line cost**	<10 000 m (buffer zone)	**Baban, 2000**
	3		14	**Land cost**		
2	4	Planning	3	**Distance to railways**	>500 m	**Atici, 2015**
	5		1	**Airport area**	>5000 m	**Atici, 2015**
	6		4	**Urban areas**	2500 m	**Bennui, 2007**
	7		5	**Community zones**	2000 m	**Aydin, 2009**
	8		6	**Important places**	3000 m (Indian lands)	**Haaren, 2011**
	9		7	**Touristic Places**	1000 m	**Latinopoulos, 2015**
	10		16	**Parks, areas of ecological value/special scientific interest**	>2000 m	**Atici, 2015**
	11		19	**World Heritage, archeological monuments and historical places of high importance**	3000 m	**Tsoutsos, 2014**
	12		20	**Cultural monuments, historical sites**	1000 m	**Latinopoulos, 2015**
	13		25	**Distance to radio and TV stations**	>600 m	**Atici, 2015**
3	14	Physical and Technical	8	**Wind energy potential**	>5 m/s	**Baban, 2000**
	15		9	**Surface roughness**	>200 m above msl	**Bennui, 2007**
	16		10	**Elevation (slope)**	<30%	**Tegou, 2009**
	17		17	**Karst (porous grounds and caves)**	exclusion	**Haaren, 2011**
	18		23	**Distance to fault lines**	>200 m	**Atici, 2015**
	19		24	**Distance to mining sites**	>100 m	**Atici, 2016**
4	20	Environmental	11	**River/canal, waterbodies**	>3000 m	**Atici, 2015**
	21		18	**Bird habitats/routs**	500 m	**Aydin, 2009**
	22		22	**Woodland**	500 m	**Baban, 2000**

5. GEOGRAPHIC INFORMATION SYSTEMS (GIS)

5.1. Introduction

People were using maps since ancient times for various purposes, for traveling from one city to another, for building these cities, for agriculture and water treatment and other. However, big volumes of paper maps were replaced when computers took a main place in scientific development and Geographical Information Systems were introduced to the world in early 1960s. At that time governments and university researches made a big effort in order to represent the earth's geography using computer databases, so that information could be displayed on computer and be easily printed at any moment. In 1970s several companies were established to develop and commercialize systems for smart mapping and analysis. Nowadays, one the biggest provider of systems for mapping tools is Environmental Systems Research Institute (ESRI) of Redlands, California.

A typical GIS's work based on three main principals. First, real-world feature on earth's surface that is related to any map coordinate system. Computer keeps records of grid coordinates to show where these features are, and shows their attributes to

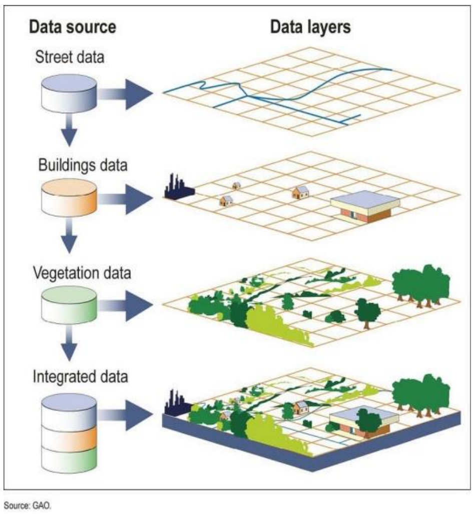

Figure 5.1. Simple example of dataset structure.

introduce what these features are. Second, map features can be displayed or printed in any form and combination of datasets using any map scale, which makes the digital maps more flexible and convenient to use rather than traditional paper maps. Thirds, there are many types of analysis that can be performed on the maps taking into account its features and coordinates (Korte, Fourth Edition, 1997).

In other words, GIS are systems that were designed to capture, store, manipulate, analyze, manage, and present all types of spatial, geographical or any other type of data. Those datasets can include:

- information about people, such as population, income, or education level;
- the location of streams, different kinds of vegetation, and different kinds of soil;
- sites of factories, farms, and schools, or storm drains, roads, and electric power lines.

In the same time this data can be aggregated into one information database or analyzed separately (Figure 5.1.).
For current study ArcGIS 10.2 was employed to perform all analyses.

5.2. GIS and Site Selection

GIS has a wide range of use, being exploited in different fields of study, including health statistics, agriculture, city planning, supply chain management and site

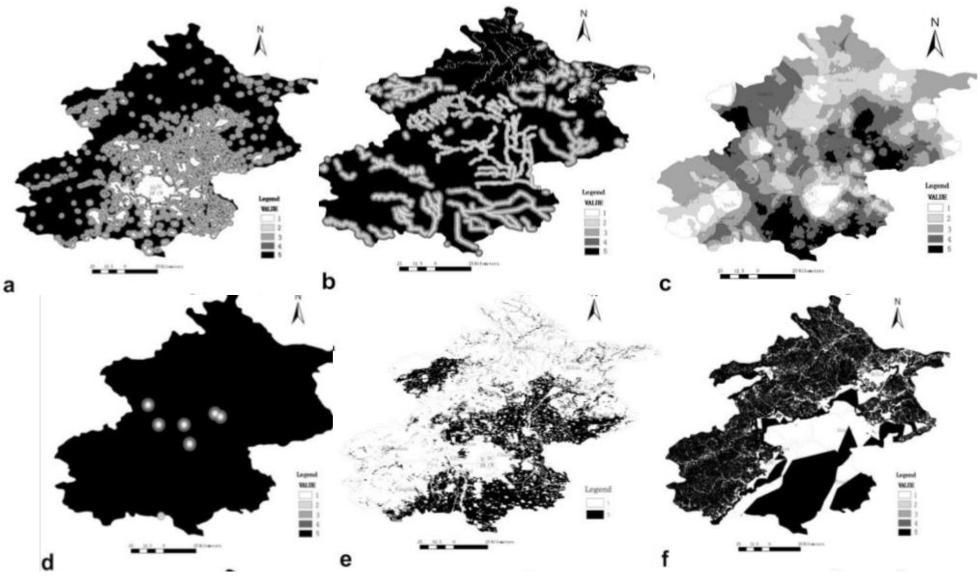

Figure 5.3. Layers of data that were used for optimum landfill site selection. (a) – residential areas; (b) – water bodies; (c) – ground waters; (d) – airports; (e) – land use; (f) - slope and land surface.

selection for various complicated construction projects.

Many researches applied GIS in their studies in order to select the most suitable site. For example Guiqin (Guiqina, et al., 2009) applied GIS for landfill site selection for solid wastes examined based on actual conditions of study area, Beijing, China. In

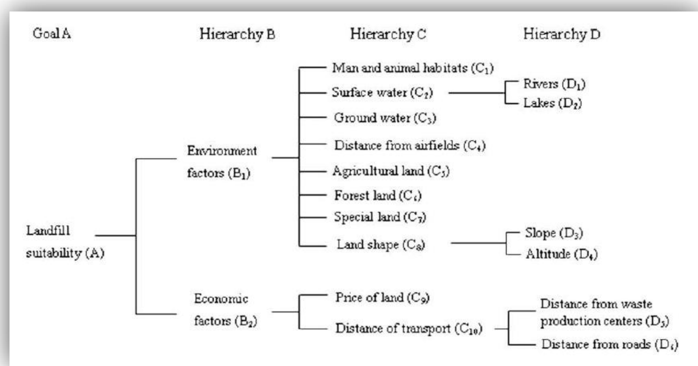

Figure 5.2. Hierarchy model for landfill site selection for solid waste.

that study economic factors were considered, criteria weights were calculated using the analytical hierarchy process (AHP), and the hierarchy model was structured in order to calculate the weights (Figure 5.2.). For each criterion a map layer with pointed buffer zones was created (Figure 5.3.). In the same time, for each criteria a range of suitability is provided, supposing that proximity to a specific feature varies from 1 to 5, the most and the least suitable location, respectively. Further, when each layer is assigned to a certain weight, all of them are being aggregated into one dataset (Figure 4.4.).

Similar methodology was applied for site selection of solar farm. The research was conducted in Karapinar Region, Konya, Turkey (Uyan, 2013). Taking into consideration several criteria such as, distance for residential area and roads, land use, slope, distance from transmission lines results were obtained by overlaying these criteria into one layer, including constrain areas that were excluded (Figure 5.4.)

In both cases displayed above, the outcome result is represented as map with differentiated territories according to land suitability, from unsuitable or low suitable (white area on Figure 4.4. and Figure 4.5., respectively), till the most suitable area colored as black on both figures.

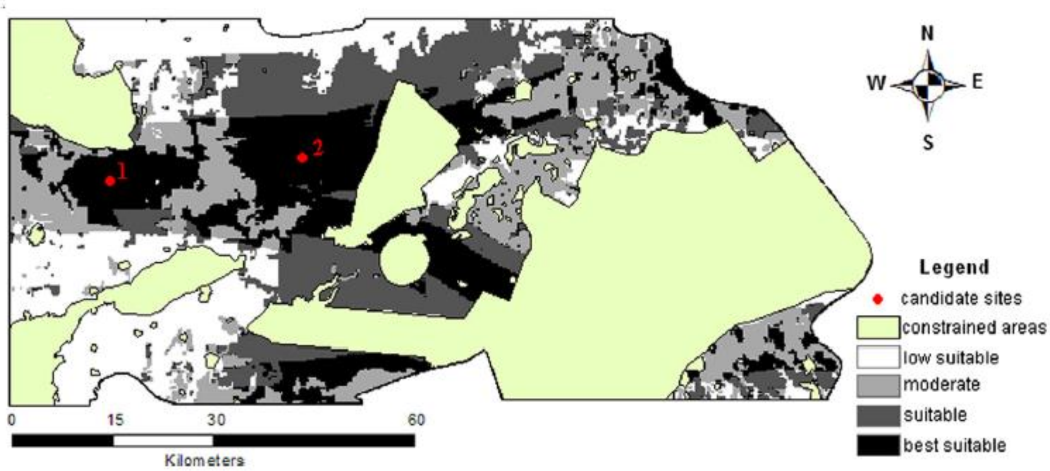

Figure 5.3. Map obtained from layers aggregated together according to weight values, with differentiated suitability index **(Uyan, 2013)**

In the same time, ArcGIS allows constructing a table from finalized map, automatically calculating the amount of area covered by each suitability index. For example, as a result Uyan in his research (Uyan, 2013) found out that 15.38%

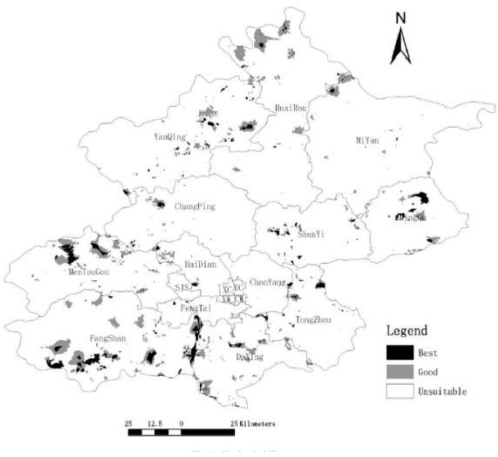

Figure 5.4. Map obtained from layers aggregated together according to weight values, with differentiated suitability index **(Guiqina, et al., 2009).**

(928.18km2) of the study area has low suitable, 14.38% (867.83km2) has moderate suitable, 15.98%(964.39km2) has suitable, 13.92%(840.07km2) has best suitable for solar farms area.

5.3. ArcGIS Methods

There is a certain amount of procedures necessary to deal with in order to obtain a

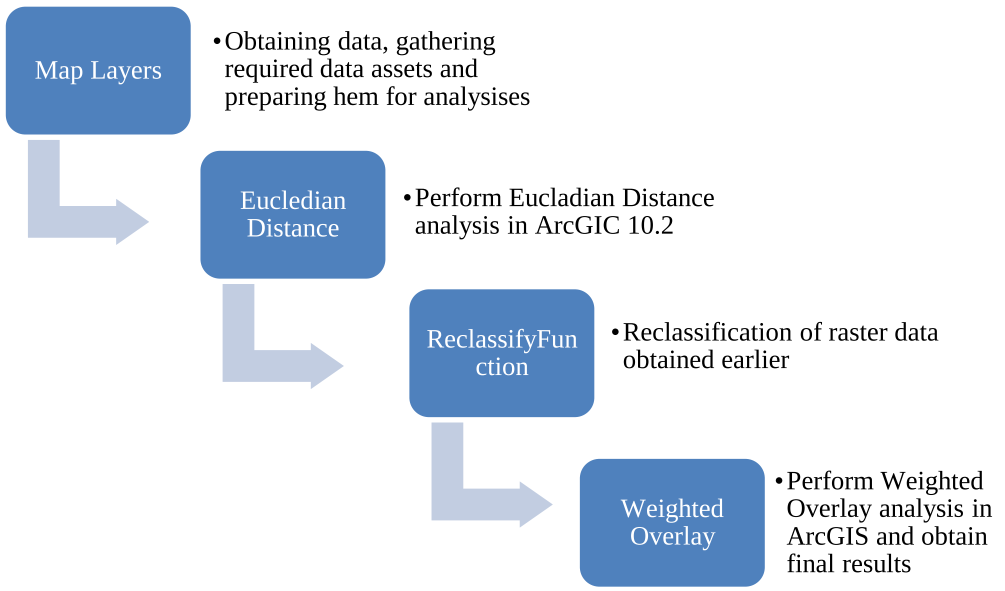

Figure 5.4. General scheme of the present study and steps of analysis procedures.

better result for the project. As it was mentioned in previous chapter, result for the most optimum areas for WTPP site is derived from layers of constraints and criteria. All of data must be processed through using different tools of ArcGIS software. The Figure 5.6 represents the general steps of analysis for current research.

5.3.1. Feature to raster

Data on any map can be expressed as a feature class. Geographic objects have an endless variety of shapes; they can be drawn as lines, polygons or points. For instance, polygons might represent lakes, countries, continents, something that has boundaries. Lines can represent lakes, roads, transmission lines, and points usually represent cities, villages, certain places, in other words something that is too small to be represented by polygon. Each feature might have a table constructed from data that feature represents (names of cities, villages, places for points, or area and perimeter for polygons) (Ormsby, et al., 2001). Moreover, each feature has its own location on a map that can be edited.

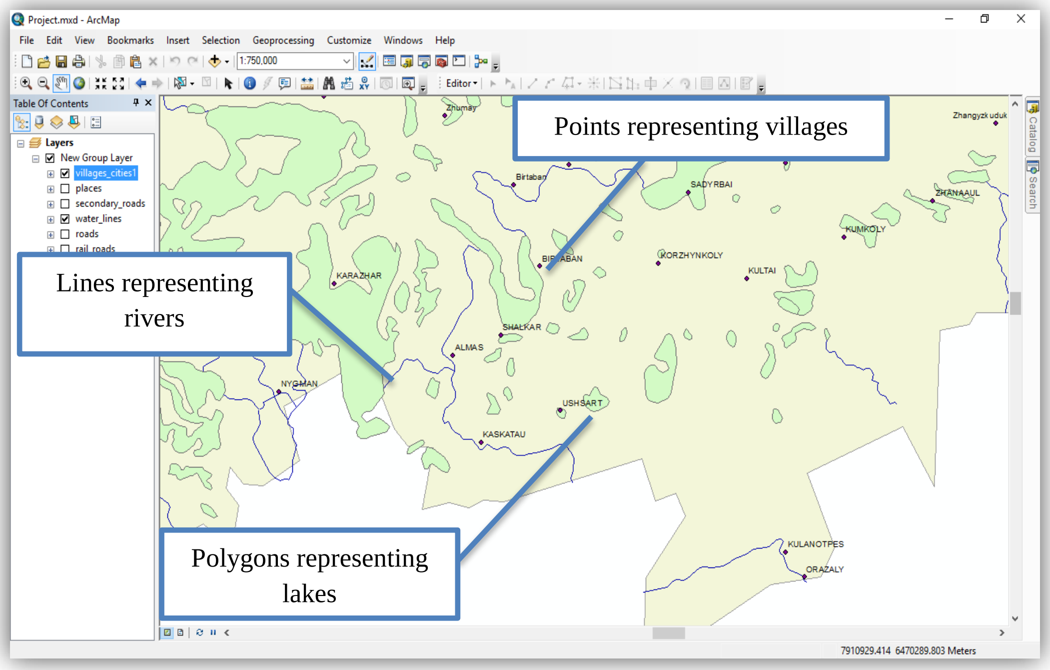

Figure 5.5. Examples of features in ArcGIS.

However, for some analysis performed in ArcGIS raster data was also required.

When some data is not available in open access it is also possible to create feature class data sets based on maps given in raster extensions. For instance, for the current

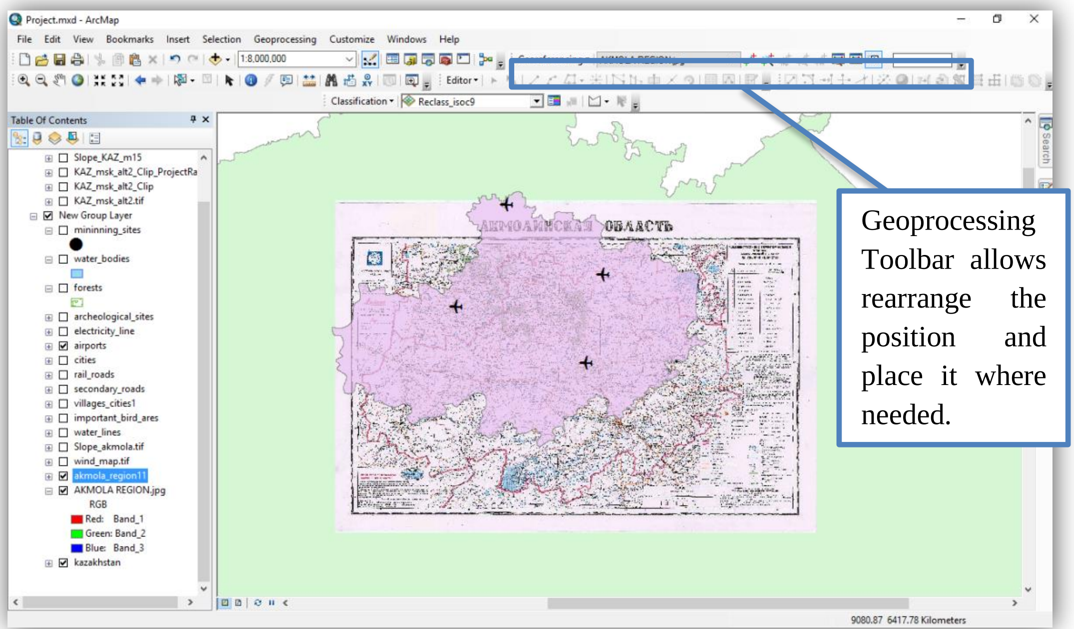

Figure 5.6. Example of pointing specific features in ArcGIS environment using map given in raster extension.

project map of airports in Akmola Region was not obtained, yet it was created as feature class (points) based on the map given in Appendix A. (Appendix A, Map of Akmola Region). Adding a raster layer into working environment and scaling or shifting it (Geoprocessing Toolbar) gives opportunity to point necessary features on the map and digitalize them (Figure 5.8).

In the same time it is possible to obtain data and point it out in ArcGIS environment using Google Earth.

5.3.2. Conversion toolbox

Since ArcGIS 10.2 is software that allows complex calculations and analysis for various types of data, Conversion Toolbox assists in formatting the files extensions from one to another. Among many kinds of data extensions are raster data (.jpg, .png, .tiff), tables (.xlsx), feature class (polygons, point, lines), each of them might consist of various sets of values, as it was mention a bit earlier.

5.3.3. Classification

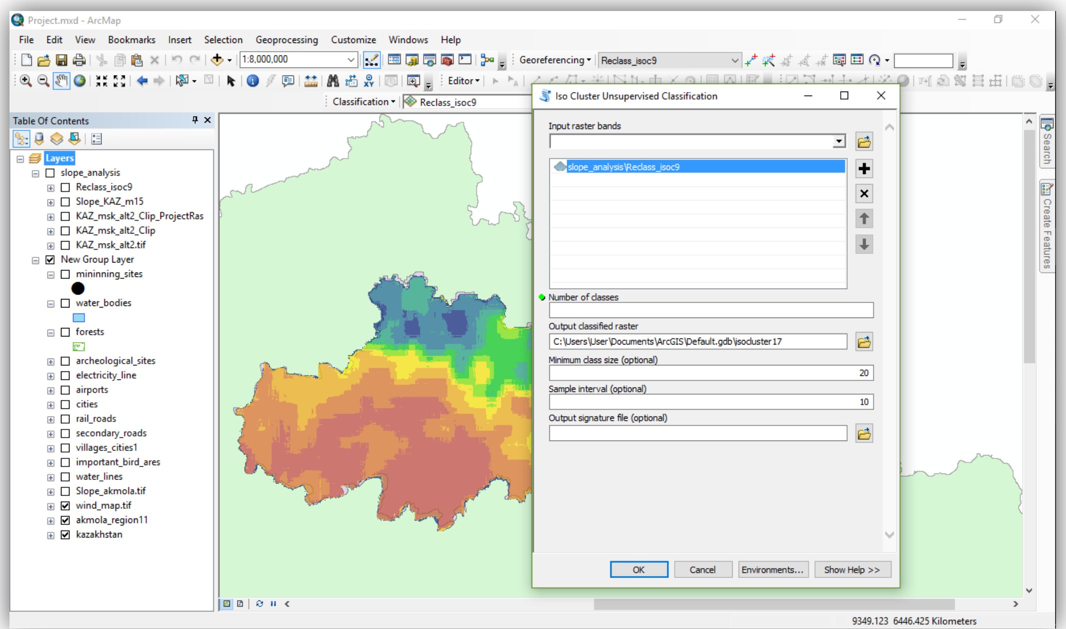

Figure 5.7. Raster data classification.

If the map was obtained in raster extension and in the same time it is divided visually on regions that are aiming to general valuation, ArcGIS allows classification of areas according to specific values. The Figure 5.9 shows the example from the present study when the raster data was classified. In this case wind atlas of Akmola region (Appendix A) was taken as an input file and classified raster map layer was obtained after analysis, which was used later on for further analysis.

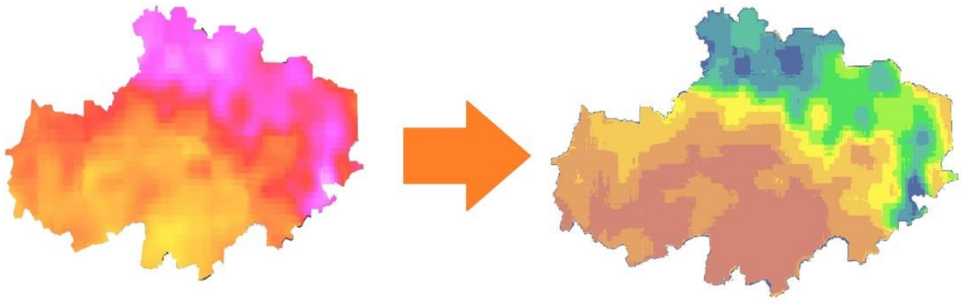

Figure 5.8. The output of Classification function in ArcGIS.

5.3.4. Euclidean distance

Such function of ArcGIS as Euclidian Distance allows users to visualize all points

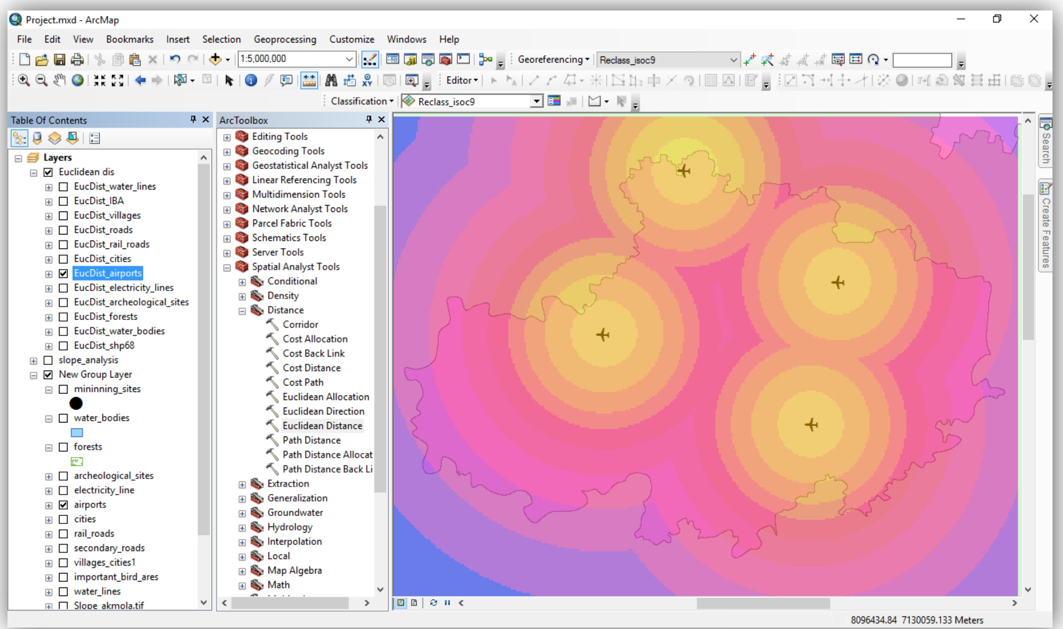

Figure 5.9. Typical example of Euclidian Distance's function output

that are place on a certain distance from specified feature (road, lake, city, electricity line). In other words in order to build and see buffer zones around particular object Euclidian Distance in the tool that is useful for this purpose (ESRI, 2015). Typical example of Euclidian Distance’s function output is shown on the Figure 5.9.

Furthermore, the values for buffer zones can be easily edited from properties of any map layer.

5.3.5. Reclassify

Before reclassifying data, classification of buffer zones should be applied in order to designate appropriate lengths and labels. Classification is available from layer properties. It can be done automatically dividing zones on equal intervals, defined intervals, natural breaks, standard deviation or manually. In the same time number of classes can be edited and changed. Figure 5.10 shows the dialog wind from which the classification can be revised.

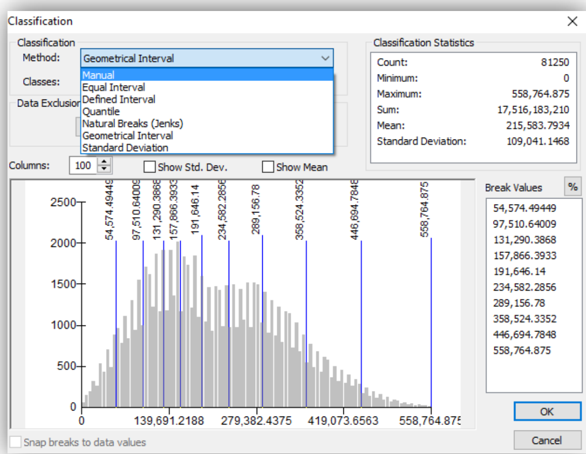

Figure 5.10. Classification methods.

In order to perform weighted overlay analysis reclassification of raster data is required. Reclassify function in toolbox of ArcGIS allows changing values when necessary to more appropriate (ESRI, 2015).

5.3.6. Weighted overlay

In general, during the performance of Weighted Overlay analysis, various raster assets are overlaid into one. Aggregation of these layers can be done utilizing weights obtained earlier or analysis can be process assuming that all layer are equally

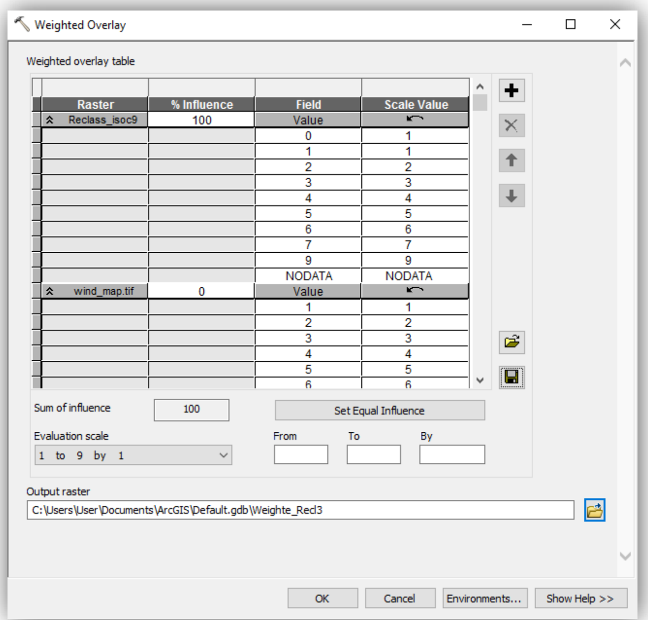

Figure 5.11. Dialog window of Weighted Overlay analysis.

weighted (ESRI, 2015). The Figure 5.11 displays the dialog window of Weighted Overlay function. It allows adding multiple numbers of layers from working environment and lets the user editing the weights of each layer from Influence graph given in percentages.

5.4. List of Map Layers Needed for Current Research

Unfortunately, due to insufficient data available in open access the amount of criteria used for this research was decreased. The final data set that was used for this thesis work is described in Chapter 6.1 (Table 5.1).

Table 5.1: **List of Map layers needed for current research**

No	Main Criteria	Sub-Criteria	Map needed
1	Economic	Highway	Map of road network
2		Electric line cost	Map of electricity grid
3		Land cost	Map of land use
4	Planning	Distance to railways	Map of railways network
5		Airport area	Map of airports in the region
6		Urban areas	Map of cities in the region
7		Community zones	Map of villages in the region
8		Important places	Map of other important places
9		Touristic Places	Map of touristic places
10		Parks, areas of ecological value/special scientific interest	Maps of places of scientific of ecological importance
11		World Heritage, archeological monuments and historical places of high importance	Map of archeological sites and historical places
12		Cultural monuments, historical sites	Map of cultural monuments
13		Distance to radio and TV stations	Map of radio and TV stations
14	Physical and Technical	Wind energy potential	Wind Atlas
15		Surface roughness	Map of surface roughness
16		Elevation (slope)	Topographical map
17		Karst (porous grounds and caves)	Map of karsts (porous grounds and caves)
18		Distance to fault lines	Map of fault lines
19		Distance to mining sites	Map of mining sites
20	Environmental	River/canal, waterbodies	Map of rivers and lakes
21		Bird habitats/routs	Map of IBA
22		Woodland	Map of forests

6. FINDINGS AND DISCUSSION

6.1. Results of the Research. Experts' Interviews and AHP.

As it was mentioned earlier in order to make the Overlay Analysis in ArcGIS each criteria needs a certain weight. These weights were obtained through questionnaires of experts who have an experience in construction of WTPP (marked as Practitioner 1 and 2) and who have general knowledge in WTPP site assessment and wind energy development (marked as Academic 1 and 2). The questionnaire samples are provided in Appendix B.2.

Practitioner 1 has 20 years' experience in the field. Practitioner 2 has 10. Academic 1 is an Associate Professor at Istanbul Technical University working in Renewable Energy Department of Energy Institute. Academic 2 is member of Rüzgar Enerjisi Araştırma Grubu. Both Practitioners 1 and 2 are working in wind energy industry as consultants and contractors. Whereas Academics 1 and 2 have publications and working on projects related directly to the field of study. Reference to questionnaire recipients and their answers that were used in the current work are given in Appendix B.1.

When all weights were derived from questionnaires and interviews, AHP analysis was applied in order to obtain final weights. Results obtained from each Expert were summarized in Tables 6.1 – 6.4 below.

Table 6.1. Results derived from questionnaire answers of Academic 1.

No of Criteria		Main Criteria	Local Weights	Sub-criteria	Local Weights	TOTAL WEIGHTS
1	1	Economical	0.584	Highway	0.077	0.045
	2			Electric line Cost	0.359	0.210
	3			Land Cost	0.564	0.329
2	4	Planning	0.120	Distance to railways	0.039	0.005
	5			Airport area	0.434	0.052
	6			Cities	0.234	0.028
	7			Towns and villages	0.087	0.011
	8			World Heritage, archeological monuments and historical places of high importance	0.091	0.011
	9			Distance to radio and TV stations	0.113	0.014
3	10	Physical and Technical	0.255	Wind energy potential	0.398	0.101
	11			Surface roughness	0.133	0.034
	12			Elevation (Slope)	0.154	0.039
	13			Karst (porous grounds and caves)	0.175	0.045
	14			Distance to fault lines	0.115	0.029
	15			Distance to mining sites	0.024	0.006
4	16	Environmental	0.041	River/canal, waterbodies	0.090	0.004
	17			Bird habitats/routs	0.767	0.032
	18			Woodland	0.143	0.006

Table 6.2. Results derived from questionnaire answers of Academic 2.

No of Criteria		Main Criteria	Local Weights	Sub-criteria	Local Weights	TOTAL WEIGHTS
1	1	Economical	0.627	Highway	0.192	0.121
	2			Electric line Cost	0.131	0.082
	3			Land Cost	0.677	0.424
2	4	Planning	0.186	Distance to railways	0.134	0.025
	5			Airport area	0.407	0.075
	6			Cities	0.199	0.037
	7			Towns and villages	0.121	0.022
	8			World Heritage, archeological monuments and historical places of high importance	0.056	0.010
	9			Distance to radio and TV stations	0.083	0.015
3	10	Physical and Technical	0.119	Wind energy potential	0.498	0.059
	11			Surface roughness	0.108	0.013
	12			Elevation (Slope)	0.062	0.007
	13			Karst (porous grounds and caves)	0.072	0.009
	14			Distance to fault lines	0.196	0.023
	15			Distance to mining sites	0.065	0.008
4	16	Environmental	0.069	River/canal, waterbodies	0.297	0.021
	17			Bird habitats/routs	0.164	0.011
	18			Woodland	0.539	0.037

Table 6.3. Results derived from questionnaire answers of Practitioner 1.

No of Criteria		Main Criteria	Local Weights	Sub-criteria	Local Weights	TOTAL WEIGHTS
1	1	Economical	0.589	Highway	0.098	0.058
	2			Electric line Cost	0.187	0.110
	3			Land Cost	0.715	0.421
2	4	Planning	0.228	Distance to railways	0.085	0.019
	5			Airport area	0.416	0.095
	6			Cities	0.205	0.047
	7			Towns and villages	0.141	0.032
	8			World Heritage, archeological monuments and historical places of high importance	0.049	0.011
	9			Distance to radio and TV stations	0.103	0.024
3	10	Physical and Technical	0.119	Wind energy potential	0.464	0.055
	11			Surface roughness	0.114	0.014
	12			Elevation (Slope)	0.064	0.008
	13			Karst (porous grounds and caves)	0.073	0.009
	14			Distance to fault lines	0.219	0.026
	15			Distance to mining sites	0.066	0.008
4	16	Environmental	0.063	River/canal, waterbodies	0.143	0.009
	17			Bird habitats/routs	0.571	0.036
	18			Woodland	0.286	0.018

Table 6.4. Results derived from questionnaire answers of Practitioner 2.

No of Criteria		Main Criteria	Local Weights	Sub-criteria	Local Weights	TOTAL WEIGHTS
1	1	Economical	0.617	Highway	0.093	0.058
	2			Electric line Cost	0.221	0.137
	3			Land Cost	0.685	0.423
2	4	Planning	0.208	Distance to railways	0.092	0.019
	5			Airport area	0.387	0.080
	6			Cities	0.220	0.046
	7			Towns and villages	0.150	0.031
	8			World Heritage, archeological monuments and historical places of high importance	0.045	0.009
	9			Distance to radio and TV stations	0.107	0.022
3	10	Physical and Technical	0.110	Wind energy potential	0.463	0.051
	11			Surface roughness	0.086	0.010
	12			Elevation (Slope)	0.061	0.007
	13			Karst (porous grounds and caves)	0.093	0.010
	14			Distance to fault lines	0.229	0.025
	15			Distance to mining sites	0.067	0.007
4	16	Environmental	0.065	River/canal, waterbodies	0.137	0.009
	17			Bird habitats/routs	0.239	0.016
	18			Woodland	0.623	0.040

Table 6.5 compares the weights between each expert's answers. It also helps so see how the weights can slightly differ between experts from academics and how different they are between academic and practitioner representatives.

Table 6.5. Comparison Of All Criteria Weights

		Academic 1			**Academic 2**			**Practitioner 1**			**Practitioner 2**		
		main	**sub**	**total**	**main**	**sub**	**total**	**main**	**sub**	**total**	**main**	**sub**	**total**
	1		0.077	**0.045**		0.192	**0.121**		0.098	**0.058**		0.093	**0.058**
1	2	0.584	0.359	**0.210**	0.627	0.131	**0.082**	0.589	0.187	**0.110**	0.617	0.221	**0.137**
	3		0.564	**0.329**		0.677	**0.424**		0.715	**0.421**		0.685	**0.423**
	4		0.039	**0.005**		0.134	**0.025**		0.085	**0.019**		0.092	**0.019**
	5		0.434	**0.052**		0.407	**0.075**		0.416	**0.095**		0.387	**0.080**
	6		0.234	**0.028**		0.199	**0.037**		0.205	**0.047**		0.220	**0.046**
2	7	0.120	0.087	**0.011**	0.186	0.121	**0.022**	0.228	0.141	**0.032**	0.208	0.150	**0.031**
	8		0.091	**0.011**		0.056	**0.010**		0.049	**0.011**		0.045	**0.009**
	9		0.113	**0.014**		0.083	**0.015**		0.103	**0.024**		0.107	**0.022**
	10		0.398	**0.101**		0.498	**0.059**		0.464	**0.055**		0.463	**0.051**
	11		0.133	**0.034**		0.108	**0.013**		0.114	**0.014**		0.086	**0.010**
	12		0.154	**0.039**		0.062	**0.007**		0.064	**0.008**		0.061	**0.007**
3	13	0.255	0.175	**0.045**	0.119	0.072	**0.009**	0.119	0.073	**0.009**	0.110	0.093	**0.010**
	14		0.115	**0.029**		0.196	**0.023**		0.219	**0.026**		0.229	**0.025**
	15		0.024	**0.006**		0.065	**0.008**		0.066	**0.008**		0.067	**0.007**
	16		0.090	**0.004**		0.297	**0.021**		0.143	**0.009**		0.137	**0.009**
4	17	0.041	0.767	**0.032**	0.069	0.164	**0.011**	0.063	0.571	**0.036**	0.065	0.239	**0.016**
	18		0.143	**0.006**		0.539	**0.037**		0.286	**0.018**		0.623	**0.040**
SUM		**1.000**	**4.000**	**1.000**	**1.000**	**4.000**	**1.000**	**1.000**	**4.000**	**1.000**	**1.000**	**4.000**	**1.000**

It can be noticed from the table above that weights for main criteria derived from academicians are similar, whereas a slight difference in local sub-criteria leads to slightly different total weight. Analogically, the results derived from both Practitioners 1 and 2 are similar for weights of main criteria and quite different for total criteria. In order to show the difference in results and how experts' opinion (in this case opinion of academicians against opinion of practitioners) can influence on the results, another table was prepared. Average values of each criterion were calculated separately for academicians and practitioners (Table 6.6).

Table 6.6. Average values of each criterion for Academics' and Practitioners' opinion.

No		Average for Academics			Average for Practitioners		
		main	sub	total	main	sub	total
1	1	0.605	0.121	0.073	0.603	0.096	0.058
	2		0.217	0.131		0.203	0.123
	3		0.618	0.374		0.700	0.422
2	4	0.149	0.073	0.011	0.218	0.088	0.019
	5		0.420	0.063		0.402	0.087
	6		0.216	0.032		0.212	0.046
	7		0.103	0.015		0.145	0.032
	8		0.072	0.011		0.047	0.010
	9		0.097	0.014		0.105	0.023
3	10	0.174	0.445	0.077	0.115	0.463	0.053
	11		0.120	0.021		0.099	0.011
	12		0.098	0.017		0.062	0.007
	13		0.112	0.019		0.082	0.009
	14		0.150	0.026		0.224	0.026
	15		0.040	0.007		0.067	0.008
4	16	0.053	0.164	0.009	0.064	0.140	0.009
	17		0.354	0.019		0.370	0.024
	18		0.278	0.015		0.422	0.027

The table above shows a good example of criteria weighting between different stakeholders. Although the main criteria are weighted similarly the weights for sub-criteria differ, which leads to different outcome scenarios. These outcomes are influenced by background of two representatives, in present case, academicians and practitioners. In similar way, during site selection for WTPP several parties are included in the process.

Table shows the total average weights between all parties, in current case between practitioners and academicians. Geometric mean was calculated in order to gain final average weights.

Further the weights from Table 6.6 will be used in Overlay Analysis in ArcGIS software.

Table 6.7. Total Average values of each criterion for all parties.

No		TOTAL Average		
		main	sub	total
1	1	0.604	0.108	0.065
	2		0.210	0.127
	3		0.658	0.397
2	4	0.180	0.080	0.014
	5		0.411	0.074
	6		0.214	0.039
	7		0.122	0.022
	8		0.058	0.010
	9		0.101	0.018
3	10	0.141	0.454	0.064
	11		0.109	0.015
	12		0.078	0.011
	13		0.096	0.014
	14		0.184	0.026
	15		0.051	0.007
4	16	0.059	0.151	0.009
	17		0.362	0.021
	18		0.342	0.020

Table 6.7 shows the final weights that will be also used for Overlay Analysis further. These averages were calculated as geometric mean taking into account experts' opinion.

6.2. Site Selection Technique for WTPP Utilizing GIS and AHP

Figure 6.1 outlines the main steps for the current study. Once the hierarchy of criteria for WTPP site selection is created and all the factors are weighted according to experts' opinion, data set can be constructed and analyzed using ArcGIS software.

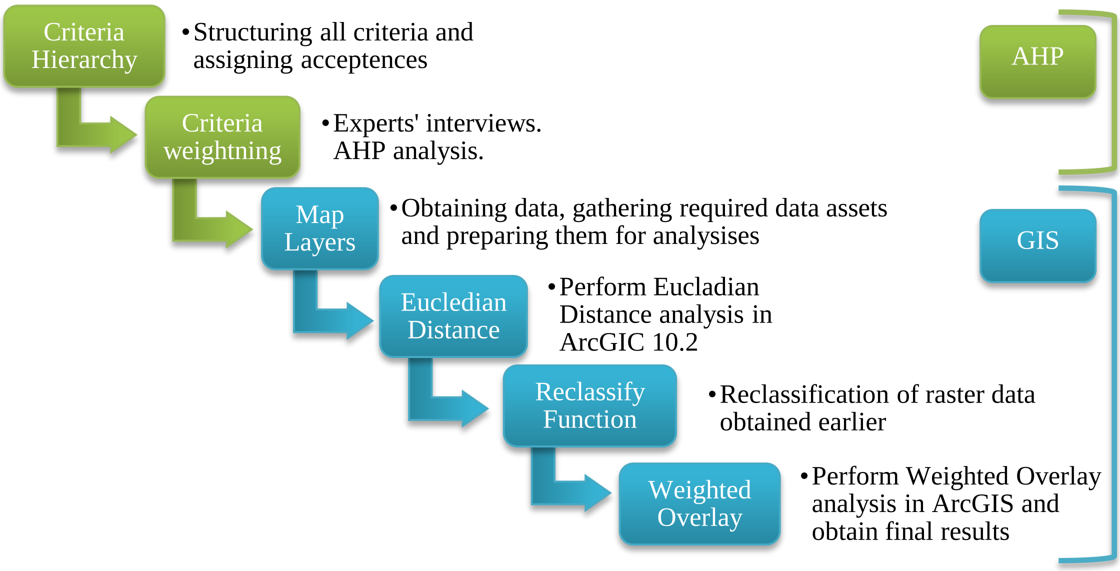

Figure 6.1. General scheme of the present study and steps of analysis procedures.

Earlier, in Chapter 4 site selection criteria and their allowances were discussed, and Table 6.8 outlines all acceptances assigned for each factor.

The methodology is applicable in any region. Nevertheless, some acceptances and allowances can differ from one country to another, while other acceptances are general and can be assigned to any region. For example, while assigning allowances for economic criteria, consideration of local prices and expenses must be taken into account due to differences in local prices of land cost, electricity line extension and organization of required road connections. Yet the proximity to railroads, airports, cities, TV and radio stations, archeological monuments and historical places can be the same regardless local restrictions, because these criteria are based on general influence of wind turbines on surrounding environment. In the same, allowances for physical and technical criteria can also vary due to local prices of wind turbine's foundation erection, while other acceptances for technical criteria, wind energy potential for example, can stay the same everywhere, being more related to properties of certain wind turbine type that is selected regardless geolocation.

Table 6.8. Summary of criteria and allowances assigned for the current study.

No	No	Main Criteria	Sub-Criteria	Acceptance	Source
1	1	Economic	Distance to Roads	<10 000 m (buffer zone)	*Baban, 2000*
	2		Distances to Electric line	<10 000 m (buffer zone)	*Baban, 2000*
	3		Land cost		
2	4	Planning	Distance to railways	>500 m	*Atici, 2015*
	5		Distances to Airport area	>5000 m	*Atici, 2015*
	6		Distances to Cities	2500 m	*Bennui, 2007*
	7		Distances to Villages and towns	2000 m	*Aydin, 2009*
	8		World Heritage, archeological monuments and historical places of high importance	3000 m	*Tsoutsos, 2014*
	9		Distance to radio and TV stations	>600 m	*Atici, 2015*
3	10	Physical and Technical	Wind energy potential	>5 m/s	*Baban, 2000*
	11		Surface roughness	>200 m above msl	*Bennui, 2007*
	12		Elevation (slope)	<30%	*Tegou, 2009*
	13		Karst (porous grounds and caves)	exclusion	*Haaren, 2011*
	14		Distance to fault lines	>200 m	*Atici, 2015*
	15		Distance to mining sites	>100 m	*Atici, 2016*
4	16	Environmental	Distances to River/canal, waterbodies	>3000 m	*Atici, 2015*
	17		Distances to Bird habitats/routs	500 m	*Aydin, 2009*
	18		Distances to Woodland	500 m	*Baban, 2000*

6.3. Application to Akmola Region

As it was discussed in Chapter 5, geographical information systems or GIS is a complex structure that captures, stores, allows manipulating, analyzing and managing all types of spatial and geographical data. In the current thesis ArcGIS 10.2 software was utilized to create datasets, manage map data, and perform certain analysis with created data set.

6.3.1. Data Layers

In order to provide a validation of technique developed for site selection of WTPP, discussed methodology is applied in Akmola region situated in North Kazakhstan.

Table 6.9 outlines map layers regarding all site selection criteria chosen for the current study. These maps are required in order to follow developed model of site selection for WTPP.

Table 6.9. List data layers used in current study.

No	Map needed	Maps Availability	Source
1	Map of road network	Available	http://www.diva-gis.org/gdata
2	Map of electricity grid	Created	Geographic Map Akmola Region. Appendix A
3	Map of land use	Not available	-
4	Map of railways network	Available	http://www.diva-gis.org/gdata
5	Map of airports in the region	Created	created using Google Earth Maps
6	Map of cities in the region	Created	Geographic Map of Akmola Region. Appendix A
7	Map of villages in the region	Available	http://www.diva-gis.org/gdata
8	Maps of places of scientific of ecological importance	Considered the same as IBA territories	http://database.acbk.kz
9	Map of archeological sites and historical places	Created	Archeological map of Kazakhstan. Appendix A
10	Map of radio and TV stations	Not Available	-
11	Wind Atlas	Created	http://www.atlas.windenergy.kz/
12	Map of surface roughness	Not Available	-
13	Topographical map	Available	http://www.diva-gis.org/gdata
14	Map of karsts (porous grounds and caves)	Not Available	-
15	Map of fault lines	Not Available	-
16	Map of mining sites	Created	Map of Heavy Industries of Kazakhstan. Appendix A
17	Map of rivers and lakes	Available	http://www.diva-gis.org/gdata
18	Map of IBA	Created	http://database.acbk.kz
19	Map of forests	Created	Geographic Map of Akmola Region. Appendix A

Final dataset for present study looks as listed in the Table 6.10. Some map layers are not available in free access. Nevertheless, other layers were created in ArcGIS 10.2 software environment using maps shown in Appendix A. Therefore the number of criteria used for the present study was decreased.

Table 6.10. Final map layers asset used in current study.

No	Map needed	Maps Availability	Source
1	Map of road network	Available	http://www.diva-gis.org/gdata
2	Map of electricity grid	Created	Geographic Map Akmola Region. Appendix A
3	Map of railways network	Available	http://www.diva-gis.org/gdata
4	Map of airports in the region	Created	created using Google Earth Maps
5	Map of cities in the region	Created	Geographic Map of Akmola Region. Appendix A
6	Map of villages in the region	Available	http://www.diva-gis.org/gdata
7	Map of cultural monuments	Created	Archeological map of Kazakhstan. Appendix A
8	Wind Atlas	Created	http://www.atlas.windenergy.kz/
9	Topographical map	Available	http://www.diva-gis.org/gdata
10	Map of mining sites	Created	Map of Heavy Industries of Kazakhstan. Appendix A
11	Map of rivers and lakes	Available	http://www.diva-gis.org/gdata
12	Map of IBA	Created	http://database.acbk.kz
13	Map of forests	Created	Geographic Map of Akmola Region. Appendix A

Table 6.11. Final list of data layers and their allowances.

No	No	Main Criteria	Sub-Criteria	Acceptance	Source of Allowances
1	1	Economic	Distance to Roads	<10 000 m (buffer zone)	*Baban, 2000*
	2		Distances to Electric line	<10 000 m (buffer zone)	*Baban, 2000*
2	4	Planning	Distance to railways	>500 m	*Atici, 2015*
	5		Distances to Airport area	>5000 m	*Atici, 2015*
	6		Distances to Cities	2500 m	*Bennui, 2007*
	7		Distances to Villages and towns	2000 m	*Aydin, 2009*
	8		World Heritage, archeological monuments and historical places of high importance	3000 m	*Tsoutsos, 2014*
3	9	Physical and Technical	Wind energy potential	>5 m/s	*Baban, 2000*
	10		Elevation (slope)	<30%	*Tegou, 2009*
	11		Distance to mining sites	>100 m	*Atici, 2016*
4	12	Environmental	Distances to River/canal, waterbodies	>3000 m	*Atici, 2015*
	13		Distances to Bird habitats/routs	500 m	*Aydin, 2009*
	14		Distances to Woodland	500 m	*Baban, 2000*

For each sub-criterion specific acceptance was assigned. The process of allowances selection is explained in details in Chapter 4.2. The acceptances listed in Table 6.11 were utilized in order to construct buffer zones around features and limit the areas that are unfeasible for WTPP erection.

6.3.2. Buffer Zones and Acceptances.

As it was mentioned in Chapter 5.3.4 in order to construct a buffer zone around a certain feature on a map Euclidean Distance analysis must be made for each map layer of all criteria. Meanwhile, acceptances and allowances given in Table 6.10 are not sufficient to construct proper buffer zones in a way that distinguish the areas of each criterion according to the importance (in this case marked as 1- areas with the least suitability, and 5 – the most suitable areas). Tables 6.12 – 6.14 below show how allowances were assigned for each sub-factor that influence on site selection for WTPP. Ares that are within the acceptable zones were marked with Suitability Index of 0, and subsequently these areas were excluded from the analysis.

Table 6.12. Assigning suitability index to all criteria.

	IBA Territories	
Suitability Index		m
0	Not applicable (buffer zones)	0-500
1	Less suitable	500-1000
2	Suitable	1000-1500
3	Moderately suitable	1500-2000
4	Highly suitable	2000-2500
5	Extremely suitable	>2500
	Rivers (Water Lines)	
Suitability Index		m
0	Not applicable (buffer zones)	0-3000
1	Less suitable	3000-6000
2	Suitable	6000-9000
3	Moderately suitable	9000-12000
4	Highly suitable	12000-15000
5	Extremely suitable	>15000

Table 6.13. Assigning suitability index to all criteria.

	Railroads	
Suitability Index		m
0	Not applicable (buffer zones)	0-500
1	Less suitable	500-1000
2	Suitable	1000-1500
3	Moderately suitable	1500-2000
4	Highly suitable	2000-2500
5	Extremely suitable	>2500
	Cities	
Suitability Index		m
0	Not applicable (buffer zones)	0-2500
1	Less suitable	2500-5000
2	Suitable	5000-7500
3	Moderately suitable	7500-10000
4	Highly suitable	10000-12500
5	Extremely suitable	>12500
	Villages and towns	
Suitability Index		m
0	Not applicable (buffer zones)	0-2000
1	Less suitable	2000-4000
2	Suitable	4000-6000
3	Moderately suitable	6000-8000
4	Highly suitable	8000-10000
5	Extremely suitable	>10000
	Mining Sites	
Suitability Index		m
0	Not applicable (buffer zones)	0-100
1	Less suitable	100-200
2	Suitable	200-300
3	Moderately suitable	300-400
4	Highly suitable	400-500
5	Extremely suitable	>500
	Airports	
Suitability Index		m
0	Not applicable (buffer zones)	0-5000
1	Less suitable	5000-10000
2	Suitable	10000-15000
3	Moderately suitable	15000-20000
4	Highly suitable	20000-25000
5	Extremely suitable	>25000

Table 6.14. Assigning suitability index to all criteria.

	Archeological and Historical Sites	
Suitability Index		m
0	Not applicable (buffer zones)	0-3000
1	Less suitable	3000-6000
2	Suitable	6000-9000
3	Moderately suitable	9000-12000
4	Highly suitable	12000-15000
5	Extremely suitable	>15000
	Woodlands	
Suitability Index		m
0	Not applicable (buffer zones)	0-500
1	Less suitable	500-1000
2	Suitable	1000-1500
3	Moderately suitable	1500-2000
4	Highly suitable	2000-2500
5	Extremely suitable	>2500
	Lakes (Water Bodies)	
Suitability Index		m
0	Not applicable (buffer zones)	0-3000
1	Less suitable	3000-6000
2	Suitable	6000-9000
3	Moderately suitable	9000-12000
4	Highly suitable	12000-15000
5	Extremely suitable	>15000
	Roads	
Suitability Index		m
0	Not applicable (buffer zones)	0-500
5	Extremely suitable	500-2000
4	Highly suitable	2000-4000
3	Moderately suitable	4000-6000
2	Suitable	6000-8000
1	Less suitable	8000-10000
	Electricity Lines	
Suitability Index		m
0	Not applicable (buffer zones)	0-500
5	Extremely suitable	500-2000
4	Highly suitable	2000-4000
3	Moderately suitable	4000-6000
2	Suitable	6000-8000
1	Less suitable	8000-10000

For economic criteria such as proximity to roads and electricity lines, suitability index was assigned in opposite way. In other words areas that are closer to roads and electricity lines are more feasible, because the construction of additional roads and electricity line extension will cost more when the distance between these factors and WTPP increases.

Figures 6.2 and 6.3 below show the results of Euclidean Distance analysis that was performed in ArcGIS 10.2 software. Buffer zones were colored in a different way and assigned the suitability indexes that are listed in Table 6.11.

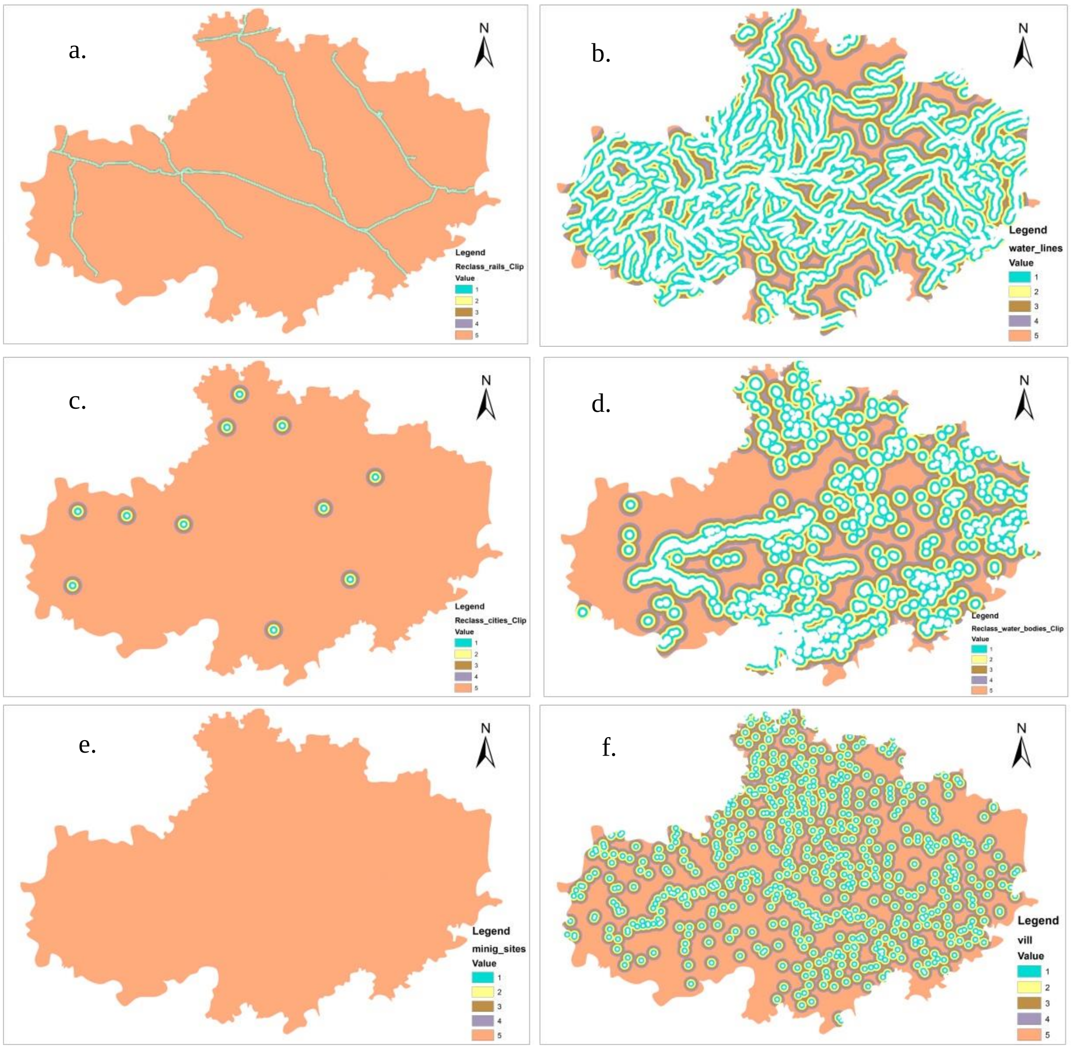

Figure 6.2. Euclidean Distance analysis for proximity to railways (a), rivers (b), cities (c), lakes (d), mining sites (e), villages and towns (f) criteria.

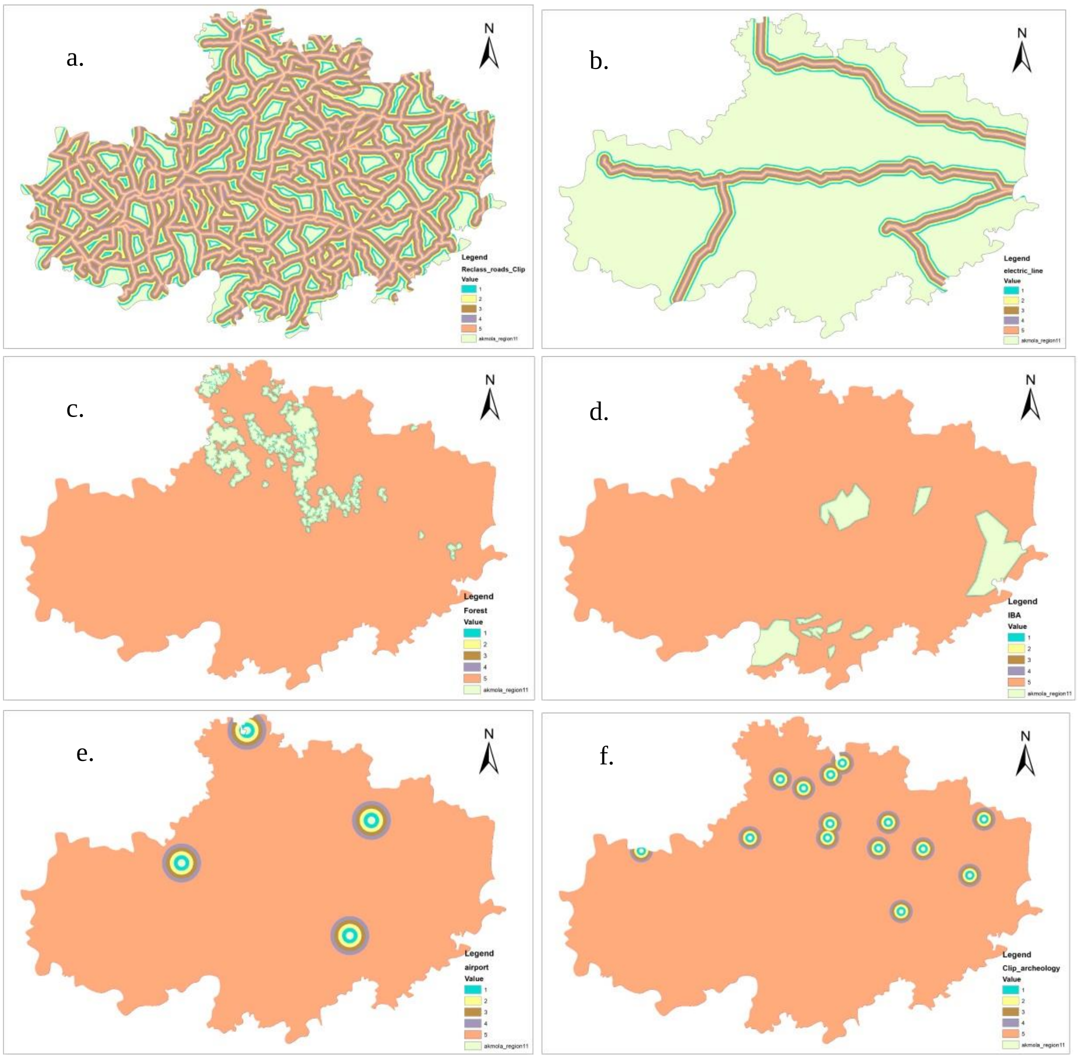

Figure 6.4. Euclidean Distance analysis for proximity to roads (a), electricity line (b), woodland (c), IBA (d), airports (e), archeological and historical sites (f).

Map layer that represents the wind speed didn't need Euclidean Distance analysis and Figure 6.4 shows the final wind map layer that was used further in Weighted Overlay analysis.

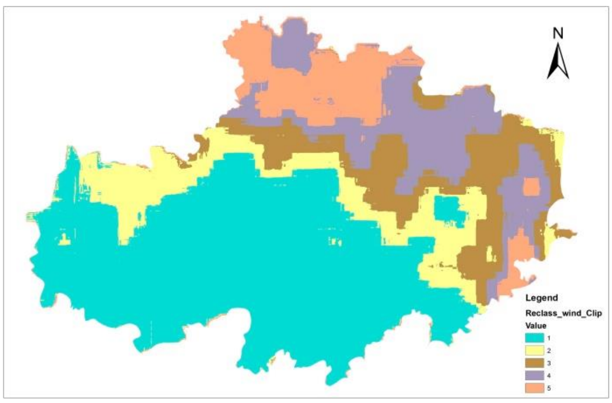

Figure 6.3. Wind map layer

Table 6.15 below show how suitability index was assigned for wind map layer.

Table 6.15. Assigning suitability index to wind speed criteria.

Wind speed		
Suitability Index		m/s
1	Less suitable	6.5
1	Less suitable	6.7
2	Suitable	7
3	Moderately suitable	7.5
3	Moderately suitable	7.7
4	Highly suitable	8
4	Highly suitable	8.1
5	Extremely suitable	8.3
5	Extremely suitable	8.5

6.3.3. Overlay analysis.

Finally, when all layers are assigned to a certain allowance and acceptance and buffer zones are represented as map layers as well, Weighted Overlay analysis can be performed.

During site selection for WTPP many parties influence the outcome. In order to show the difference several scenarios are presents in present chapter. Scenario 1: weights are assigned according to interview answers of 2 academicians. Scenario 2: weights are assigned according to interview answers of 2 practitioners. Scenario 3: weights are assigned equally to all criteria. Scenario 4: weights are assigned according to parties' opinions. The weights for Scenario 4 were assigned as geometric mean shown in previous chapter.

Figure 6.5 shows the results of Weighted Overlay analysis performed in ArcGIS 10.2, when the weights were assigned according to interviews and questionnaires of 2 representatives, who have numerous publications and research works on Wind Energy field of study. The pattern is depicted along the electricity line which had the most influential among other criteria.

Figure 6.6 shows the results of Weighted Overlay analysis performed in ArcGIS 10.2, when the weights were assigned according to interviews and questionnaires of

2 practitioners, who has a work experience from 10 to 20 years in Wind Energy Industry, working as consultants and contractors.

Figure 6.7 shows the results of Weighted overlay analysis performed in ArcGIS 10.2 when all criteria were weighted equally.

Table 6.16, 6.17, 6.18 outline the areas of each suitability index obtained after overlay analysis for Scenario 1, Scenario 2 and Scenario 3 respectively.

Table 6.16. The areas obtained after Scenario 1.

Suitability Index	Number of Cells	Total Area, m2	Total Area, km2
2	49	27 021 647.1	27.022
3	8 026	4 426 035 505.0	4 426.036
4	10 710	5 906 160 012.3	5 906.160
5	490	270 216 471.2	270.216

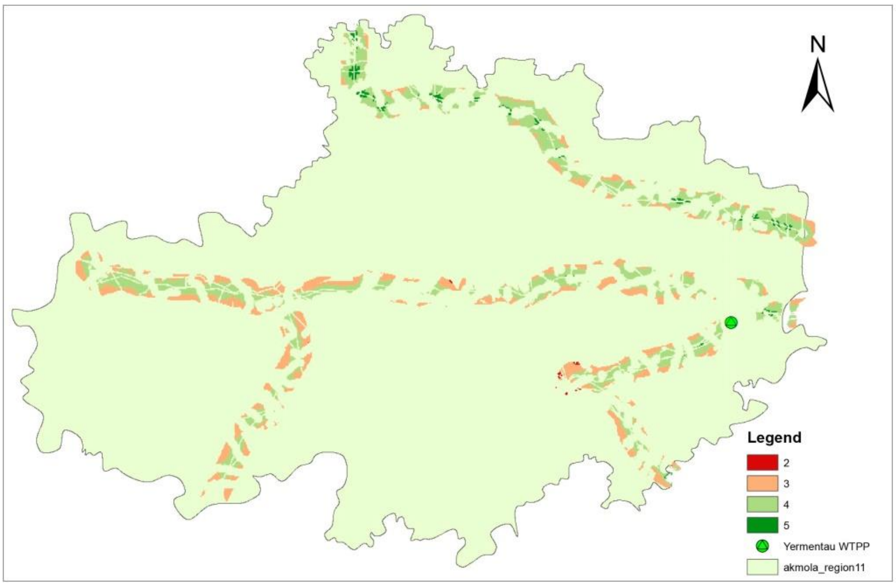

Figure 6.5. Results of Scenario 1. Weights are obtained from interview and questionnaire answers of 2 academic representatives.

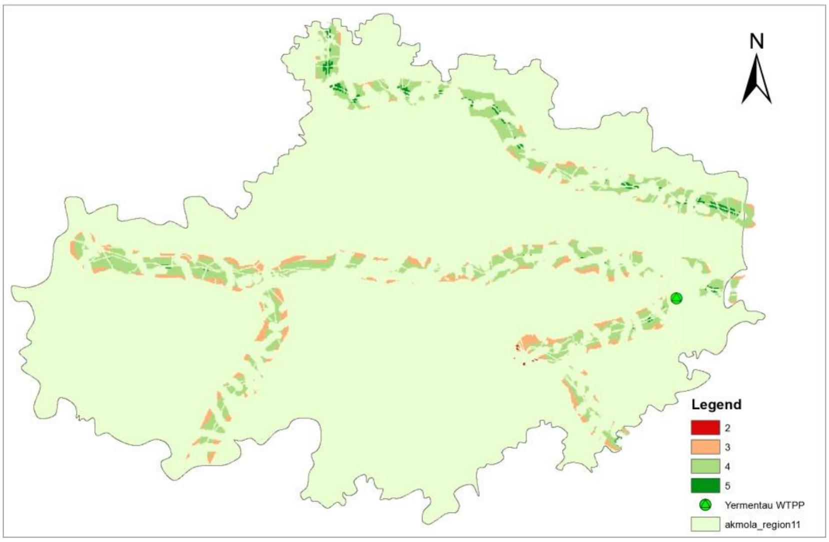

Figure 6.6. Results of Scenario 2. Weights are obtained from interview and questionnaire answers of 2 practitioners

Table 6.17. The areas obtained after Scenario 2.

Suitability Index	Number of Cells	Total Area, m2	Total Area, km2
2	21	11 580 705.9	11.581
3	4 780	2 635 989 249.2	2 635.989
4	13 792	7 605 766 469.7	7 605.766
5	682	376 097 210.9	376.097

Table 6.18. The areas obtained after Scenario 3.

Suitability Index	Number of Cells	Total Area, m2	Total Area, km2
3	351	193 563 227.3	193.563
4	18 707	10 316 203 114.0	10 316.203
5	217	119 667 294.4	119.667

Table 6.19. The areas obtained after Scenario 4.

Suitability Index	Number of Cells	Total Area, m2	Total Area, km2
2	11	6066084.0	6.066
3	5937	3274030998.4	3274.031
4	12682	6993643443.2	6993.643
5	645	355693110.0	355.693

Figure 6.7 represents the result of Scenario 4, when all weights were calculated using geometric mean as it was mentioned earlier.

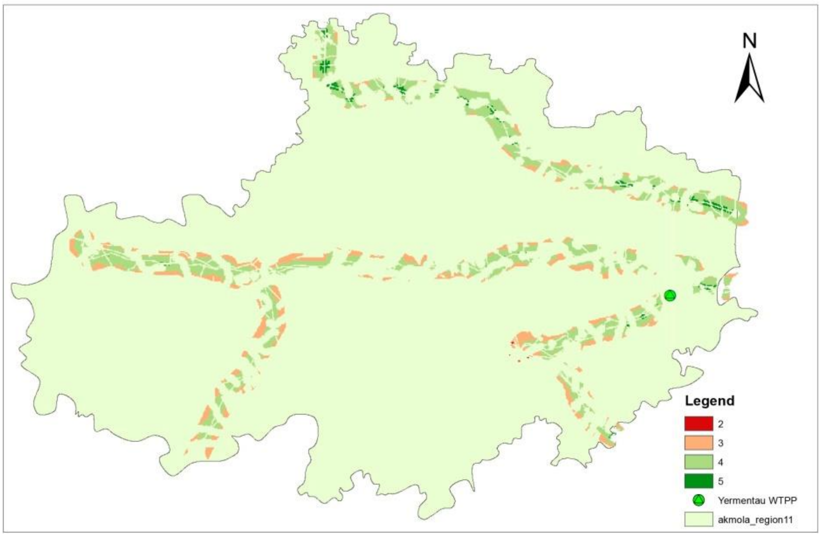

Figure 6.8. Results of Scenario 4. All parties' opinion is accounted.

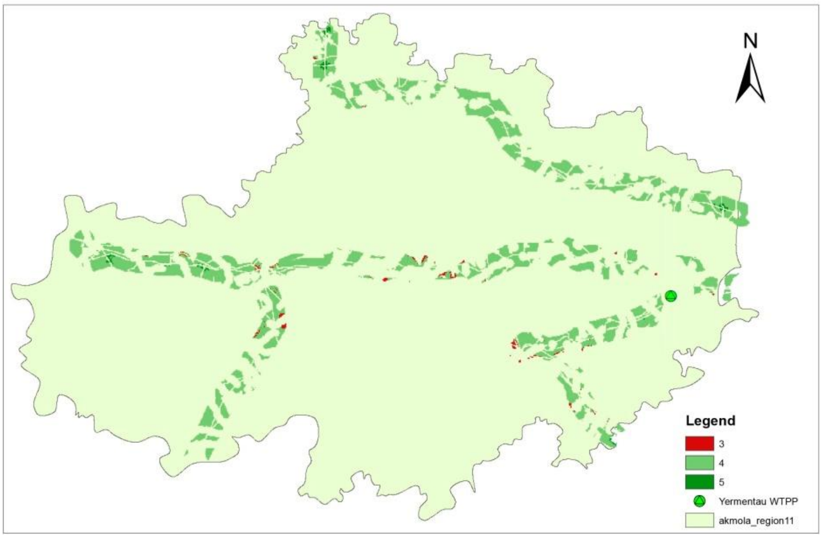

Figure 6.7. Results of Scenario 3. All criteria are weighted equally.

6.3.4. Discussion

In order to show the how stakeholders' opinion can influence on analysis results three scenarios were considered. Scenario 1: criteria are weighted according to opinion of academicians; Scenario 2: criteria are weighted according to opinion of practitioners; Scenario 3: criteria are weighted equally. Under each scenario various allocations of weights were performed. Table 6.18 shows the difference in numeric values between outcomes of these three scenarios.

Table 6.20. Comparison of three different scenarios.

Suitability Index		Total Area, km2			
		Scenario 1	Scenario 2	Scenario 3	Scenario 4
1	Less suitable	-	-	-	
2	Suitable	14.3	6.6	-	6.1
3	Moderately suitable	4 242.9	2 490.9	186.9	3274.0
4	Highly suitable	6 077.6	7 723.7	10 329.4	6993.6
5	Extremely suitable	298.8	412.4	117.4	355.7

It is obvious that Scenario 3 is completely unrealistic, yet it was made in order to show a contrast in results. The highest value for the areas with suitability index marked "Highly suitable" is for Scenario 2, which is 7 723,7 km2. It show be noticed that all unfeasible sites for WTPP were excluded automatically as it was mentioned earlier (marked as 0 for suitability index, Tables 11, 12, 13).

Visually all scenarios are very similar to each other. It happened due to criterion of "proximity to electric lines", which excludes all areas further than 10 000 m (Baban & Parry, 2000). However, in case of Scenario 3 most of area is appeared to be Highly Suitable, whereas for Scenario 1 and 2 it is more distributed between extremely Suitable, Highly Suitable and Moderately Suitable.

Concurrently, Figures 6.5 – 6.8 also show the placement of Yereymentau WTPP. According to obtained results the location chosen for this project was not feasible enough due to several reasons, although the wind atlas shows a very good wind potential in that area (Figure 6.3). The area around the Yereymentau project is considered as one of the IBAs (important bird areas), Figure 6.4, (d). There are also number of rivers and lakes passed through that area, which forces to exclude these areas.

As a result, any areas within the borders of zones marked as 4 – Highly Suitable and 5 – Extremely Suitable might be the best candidates for WTPP sites. Yet the consideration of different wind turbines technologies should be considered, because all suitable areas are scattered between zones with different average wind speed.

During the literature analysis phase several works related to site selection of WTPP were examined. Each of methodologies mentioned by scientists varies slightly in application of Analytical Hierarchy Process and usage of Geographical Information System. For instance, Rob van Haaren (2011) divided all analysis into three stages: exclusion of unfeasible sites; identification of the most suitable sites (these were based more on economic factors); environmental assessment and ecological impact on birds and their habitat. Atici (2015) proposed in his work a more complex model of site selection that also included several stages. First, unfeasible sites were eliminated from the map. Then 3-phases of Multi Criteria Decision Analysis were performed to rank and sort the areas via the identified evaluation criteria.

7. CONCLUSION

Last decades the question of global warming forces humanity to rethink about energy usage everywhere. Extensive utilization of natural resources, such as gas, coal and petroleum that are limited, leads scientists and engineers to collaborate in order to find better resolutions for energy usage. One of the simplest solutions for the problem is to obtain energy from renewable resources. Wind energy is among them. Being available everywhere it doesn't affect environment as much as extraction of petroleum.

The aim of the study was to develop a site selection technique for wind turbine power plants utilizing Geographical Information Systems (GIS) and Analytical Hierarchy Process (AHP). Using the generic approach developed the study then was focused on Akmola Region in the North Kazakhstan, as a practical validation of discussed methodology. The region was chosen due to several factors. Being assessed before in terms of wing energy, 45MW WTPP with 22 wind turbines was constructed in the region. Moreover, the capital Astana that is situated in the region is going to hold the international exhibition EXPO 2017.

In order to get a better approach to the problem of site selection for wind turbine power plants, several researches completed before in different areas around the globe, were revised. During site evaluation for WTPP various criteria must be considered. All criteria that were mentioned by authors of examined papers were combined and selected for the current thesis work. Moreover, the acceptances and allowances were assigned to each criterion according to literature review and using normative refinement method.

Further, it was discovered that Analytic Hierarchy Process is one of the most commonly used decision making tools that is easy to use. At the same time AHP tool can be applied to any problem, when there is a need of evaluation in numeric values. Combined earlier, all criteria and sub-criteria were analyzed using AHP method.

Through interviews and questionnaires of 2 academicians and 2 practitioners weights for each criterion were obtained and used in further analyses.

One of the stumbling blocks for any research is data set organization and data obtaining. For the current research data set is consisted from map layers for each criterion, since the proposed methodology includes usage of Geographical Information Systems. Some of the map layers was downloaded and others were created in GIS environment due to insufficient availability of data online free of charge. Because of this reason some of criteria were omitted and their amount decreased from 18 to 14. Hopefully, this did not influence on the research process radically. The final data set was constructed and there are 14 sub-criteria and 14 map layers that were used in further analysis. Once the data set was structured, series of analysis were performed in ArcGIS 10.2 software. The methodology proposed in the present study is assumed to be more practically applicable and user-friendly. A Weighted Overlay analysis that was performed in ArcGIS software, allowed assigning weights for each criterion considering acceptances and allowances from one hand and all restricted and unfeasible areas from the other.

Finally the results were obtained. While in every project many parties are being involved, this can generally influence on the outcome. Three scenarios were suggested in order to compare the results. For Scenario 1 criterial were weighted according to weights obtained from academicians, for Scenario 2 – from practitioners, and for Scenario 3 – all criteria were weighted equally. It was found that visually all three scenarios repeat the pattern of electric line. In the same time, the major part of area was distributed between Extremely Suitable, Highly Suitable and Moderately Suitable index for Scenario 1 and 2. Similar picture can be observed from Scenario 4, when all the experts' opinion was taken into account, while numeric values for this scenario slightly vary. Nevertheless, all scenarios show the same result of the wrong placement for Yereymentau WTPP site selection. It might occur due to considerations of wind potential criterion as the main one, omitting all the others.

Analytic Hierarchy Process used for the current research allowed assigning weights in a very short period of time. Although, all calculations were made without usage of special software, the results of AHP analysis were obtained quickly. In the same time

ArcGIS 10.2 being one of the commonly used GIS soft wares allowed increase the speed of the work, by letting to weight all map layers and exclude unfeasible areas during the analysis.

The current methodology and results obtained at the end could be improved by upgrading the data set, if it was constructed by experts in cartography. Furthermore, the availability of map layers for each criterion would increase the quality of the approach suggested in the present work. In addition, a deeper research might be conducted in the future on economic evaluation. In other words, more precise calculations are required to predict how the capital cost of WTPP changing according to proximity to electricity lines and roads. However, the sensitivity of these calculations will vary according to local prices of electricity line and road connection extension.

Generally, site selection for WTPP plant can consume a lot of time, while all parties, being sometimes separated from each other physically. Agreement on certain decisions can also take some time. However, the availability of map data for each criterion that can be assessed according to experts' opinion of different parties using AHP analysis, and then utilization of GIS analyses can save plenty of time.

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APPENDICIES

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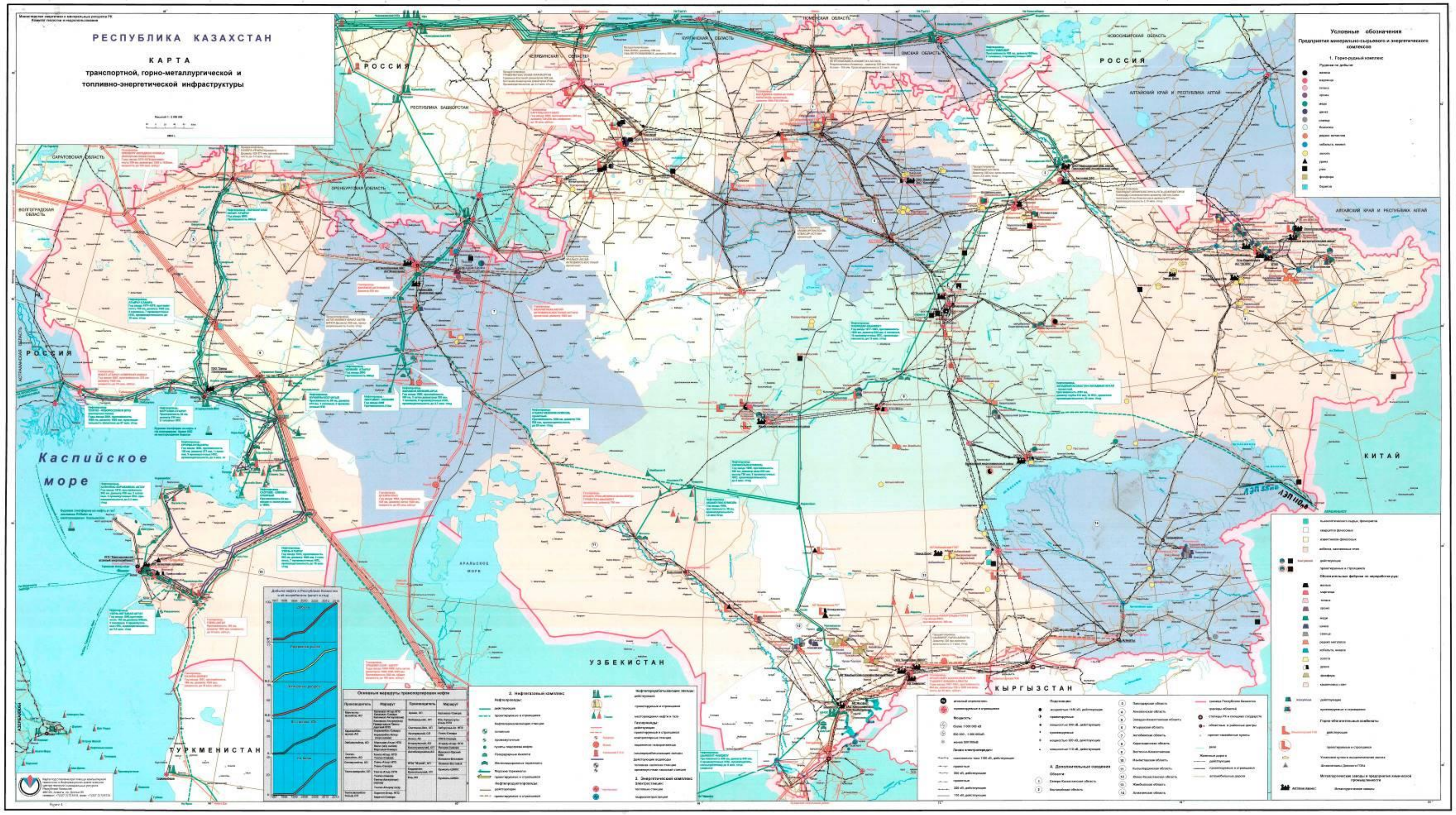
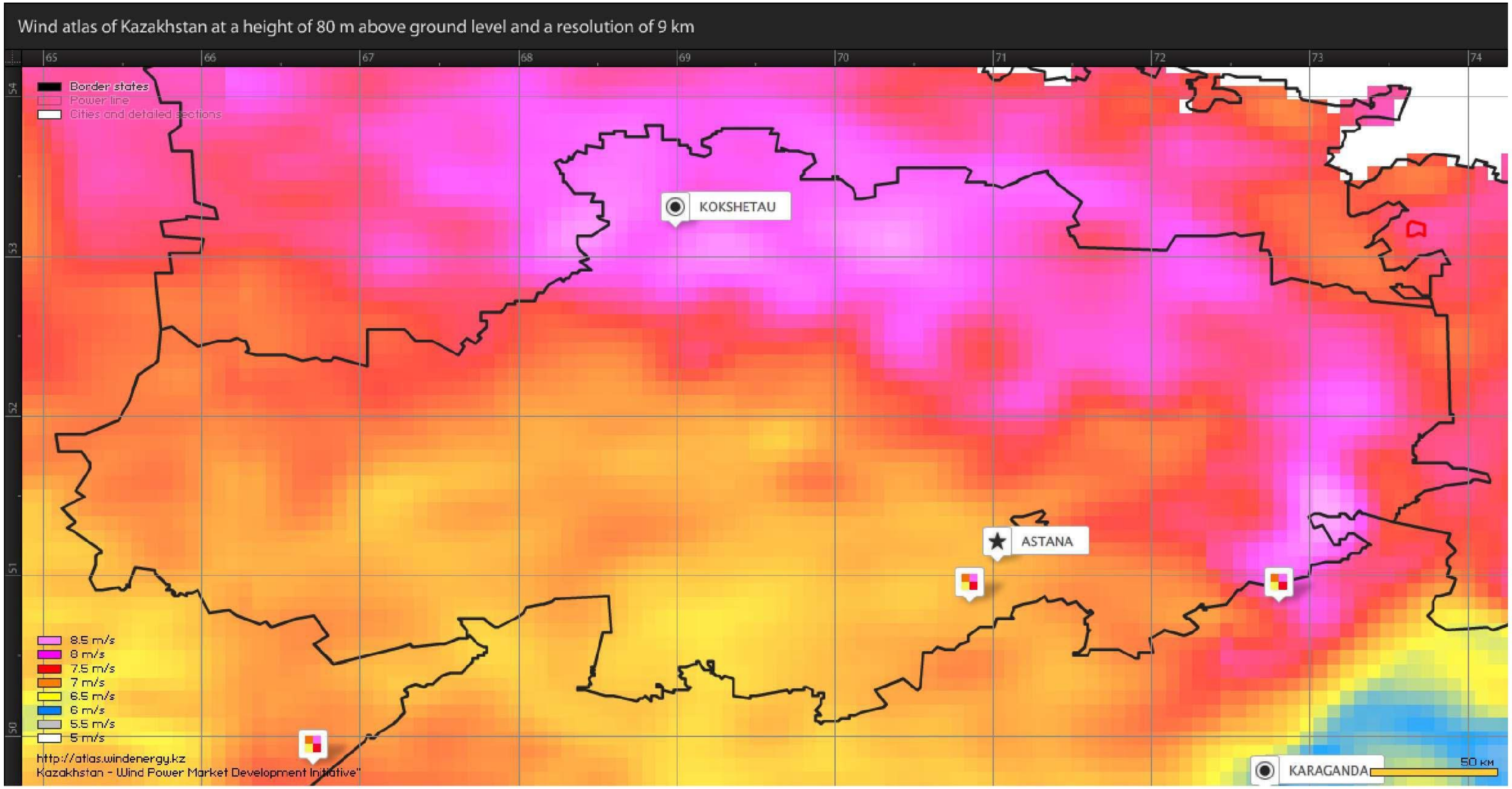
APPENDIX A.1: Map of Akmola Region

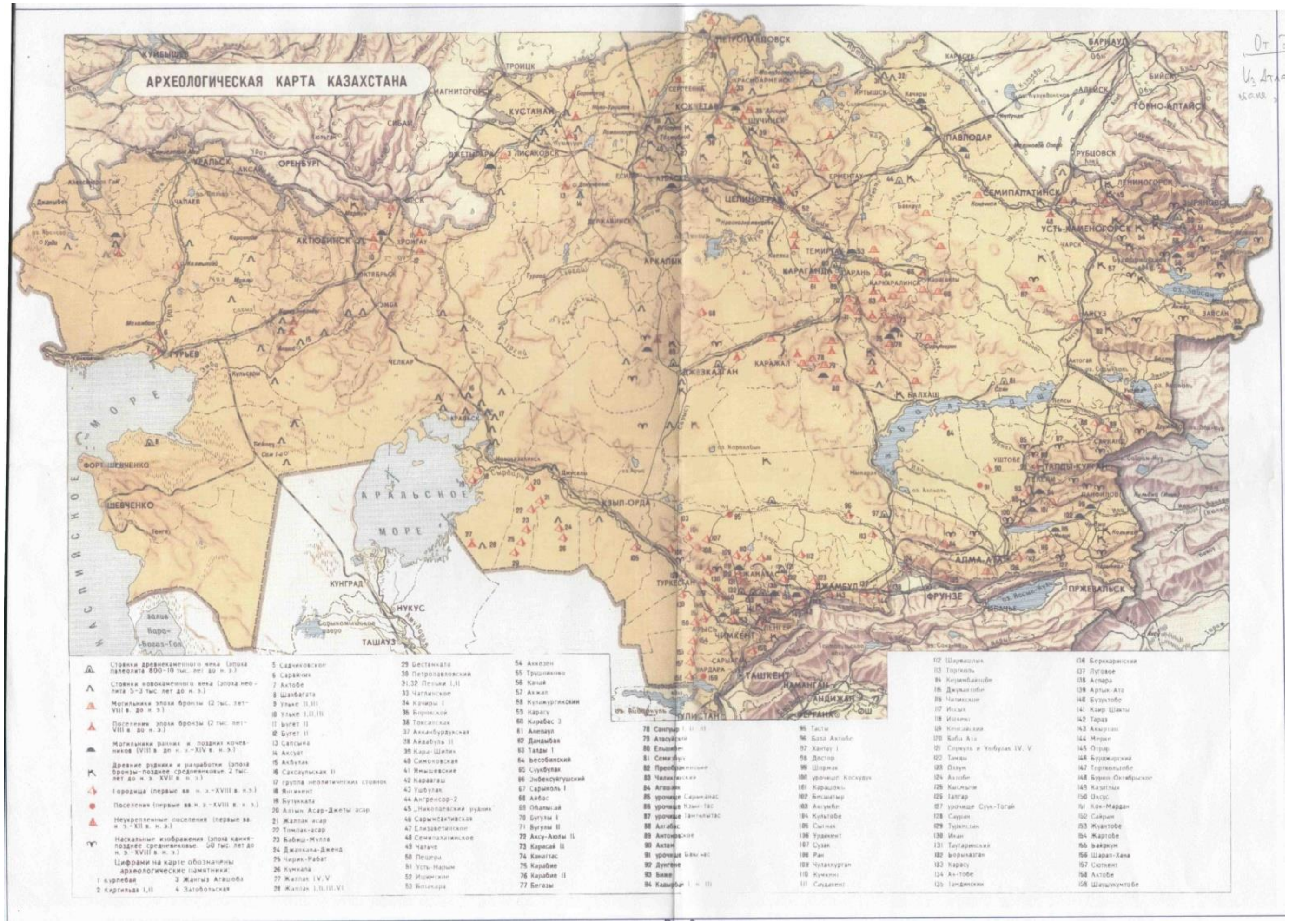
APPENDIX A.2: Map of Heavy Industries in Kazakhstan



APPENDIX A.3: Wind Map of Akmola Region



APPENDIX A.4: Archeological Map of Kazakhstan



APPENDIX B.1: Experts’ Reference and Criteria Weighting. AHP Calculations.

Practitioner 1:

Following questionnaire was filled by an expert, marked as Practitioner 1. The expert has in average 20 years of experience in Wind Energy Industry as consultant and contractor. The Answers were used in order to weight all criteria.

Which of factors below are more important?

Definition	Score
Equally important	**1**
Slightly more important	**3**
Much more important	**5**
Far more important	**7**
Extremely more important	**9**

Note: scores 1, 3, 5, 7, 9 are considered as the main evaluation levels, and scores 2, 4, 6, 8 can be also used in order to express the comparison more precisely.

	Main Factors																	
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Economical							x											Planning
Economical					x													Physical and Technical
Economical		x																Environmental
Planning											x							Economical
Planning								x										Physical and Technical
Planning						x												Environmental
Physical and Technical														x				Economical
Physical and Technical										x								Planning
Physical and Technical								x										Environmental
Environmental																x		Economical
Environmental												x						Planning
Environmental										x								Physical and Technical

Which of sub-factors below are more important when influence on capital cost is considered?

Definition	Score
Equally important	**1**
Slightly more important	**3**
Much more important	**5**
Far more important	**7**
Extremely more important	**9**

Note: scores 1, 3, 5, 7, 9 are considered as the main evaluation levels, and scores 2, 4, 6, 8 can be also used in order to express the comparison more precisely.

	Economical Sub-factors																	
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Highway										x								Electric line cost
Highway															x			Land cost
Electric line cost								x										Highway
Electric line cost												x						Land cost
Land cost			x															Highway
Land cost						x												Electric line cost

Questionnaire was prepared for thesis study ‘Site Selection Technique for Wind Turbines Power Plants Utilizing Geographical Information Systems (GIS) and Analytical Hierarchy Process (AHP)’, May 2016.

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APPENDIX B.1. Experts’ Reference and Criteria Weighting. Practitioner 1

Which of sub-factors below are more important when site selection for WTP is made according to general planning criteria?

Definition	Score
Equally important	**1**
Slightly more important	**3**
Much more important	**5**
Far more important	**7**
Extremely more important	**9**

Note: scores 1, 3, 5, 7, 9 are considered as the main evaluation levels, and scores 2, 4, 6, 8 can be also used in order to express the comparison more precisely.

	Planning Sub-factors																	
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Distance to railways												x						Airports area
Distance to railways										x								Cities
Distance to railways									x									Towns, villages
Distance to railways								x										World Heritage, archeological monuments and historical places of high importance
Distance to railways									x									Distance to radio and TV stations
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Airport area						x												Distance to railways
Airport area								x										Cities
Airport area						x												Towns and villages
Airport area			x															World Heritage, archeological monuments and historical places of high importance
Airport area					x													Distance to radio and TV stations
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Cities								x										Distance to railways
Cities										x								Airports area
Cities								x										Towns and villages
Cities						x												World Heritage, archeological monuments and historical places of high importance
Cities								x										Distance to radio and TV stations
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Towns and villages									x									Distance to railways
Towns and villages												x						Airports area
Towns and villages											x							Cities
Towns and villages							x											World Heritage, archeological monuments and historical places of high importance
Towns and villages								x										Distance to radio and TV stations
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
World Heritage, archeological monuments and historical places of high importance										x								Distance to railways
World Heritage, archeological monuments and historical places of high importance															x			Airports area
World Heritage, archeological monuments and historical places of high importance												x						Cities

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World Heritage, archeological monuments and historical places of high importance										x								Towns and villages
World Heritage, archeological monuments and historical places of high importance										x								Distance to radio and TV stations
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Distance to radio and TV stations									x									Distance to railways
Distance to radio and TV stations												x						Airports area
Distance to radio and TV stations											x							Cities
Distance to radio and TV stations										x								Towns and villages
Distance to radio and TV stations								x										World Heritage, archeological monuments and historical places of high importance

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APPENDIX B.1. Experts' Reference and Criteria Weighting. Practitioner 1

Which of sub-factors below are more important when site selection of WTP is considered according to physical characteristics of landscape and technical characteristics of wind turbine?

Definition	Score
Equally important	**1**
Slightly more important	**3**
Much more important	**5**
Far more important	**7**
Extremely more important	**9**

Note: scores 1, 3, 5, 7, 9 are considered as the main evaluation levels, and scores 2, 4, 6, 8 can be also used in order to express the comparison more precisely.

	Physical and Technical Sub-factors																	
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Wind energy potential					x													Surface roughness
Wind energy potential			x															Elevation (slope)
Wind energy potential					x													Karst (porous grounds and caves)
Wind energy potential							x											Distance to fault lines
Wind energy potential			x															Distance to mining sites
Surface roughness													x					Wind energy potential
Surface roughness								x										Elevation (slope)
Surface roughness									x									Karst (porous grounds and caves)
Surface roughness										x								Distance to fault lines
Surface roughness								x										Distance to mining sites
Elevation (slope)															x			Wind energy potential
Elevation (slope)										x								Surface roughness
Elevation (slope)										x								Karst (porous grounds and caves)
Elevation (slope)												x						Distance to fault lines
Elevation (slope)								x										Distance to mining sites
Karst (porous grounds and caves)													x					Wind energy potential
Karst (porous grounds and caves)									x									Surface roughness
Karst (porous grounds and caves)								x										Elevation (slope)
Karst (porous grounds and caves)											x							Distance to fault lines
Karst (porous grounds and caves)										x								Distance to mining sites
Distance to fault lines											x							Wind energy potential
Distance to fault lines								x										Surface roughness
Distance to fault lines						x												Elevation (slope)
Distance to fault lines							x											Karst (porous grounds and caves)
Distance to fault lines					x													Distance to mining sites
Distance to mining sites															x			Wind energy potential
Distance to mining sites											x							Surface roughness
Distance to mining sites										x								Elevation (slope)
Distance to mining sites										x								Karst (porous grounds and caves)
Distance to mining sites													x					Distance to fault lines

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APPENDIX B.1. Experts' Reference and Criteria Weighting. Practitioner 1

Which of sub-factors below are more important when site selection of WTP is considered according to environmental sub-factors?

Definition	Score
Equally important	**1**
Slightly more important	**3**
Much more important	**5**
Far more important	**7**
Extremely more important	**9**

Note: scores 1, 3, 5, 7, 9 are considered as the main evaluation levels, and scores 2, 4, 6, 8 can be also used in order to express the comparison more precisely.

	Environmental Sub-factors																	
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
River/canal, waterbodies												x						Bird habitats/routs
River/canal, waterbodies										x								Woodland
Bird habitats/routs						x												River/canal, waterbodies
Bird habitats/routs								x										Woodland
Woodland								x										River/canal, waterbodies
Woodland										x								Bird habitats/routs

Questionnaire was prepared for thesis study 'Site Selection Technique for Wind Turbines Power Plants Utilizing Geographical Information Systems (GIS) and Analytical Hierarchy Process (AHP)', May 2016.

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APPENDIX B.1. AHP Calculations

Practitioner 1:

Main Criteria:

1. Pair-wise comparison matrix is constructed.

	ECO	**PLN**	**PHS/TECH**	**ENV**
Economical`	1.000	3.000	5.000	8.000
Planning	0.333	1.000	2.000	4.000
Physical and Technical	0.200	0.500	1.000	2.000
Environmental	0.125	0.250	0.500	1.000
	1.658	**4.750**	**8.500**	**15.000**

2. Normalized matrix

	ECO	**PLN**	**PHS/TECH**	**ENV**	**SUM**	$\boldsymbol{\varpi}$
ECO	0.603	0.632	0.588	0.533	2.356	0.589041
PLN	0.201	0.211	0.235	0.267	0.913	0.228373
PHS/TECH	0.121	0.105	0.118	0.133	0.477	0.119212
ENV	0.075	0.053	0.059	0.067	0.253	0.063375

3. Matrix $\lambda = A * \varpi$

$$\lambda = A * \varpi = \begin{bmatrix} 1.000 & 3.000 & 5.000 & 8.000 \\ 0.333 & 1.000 & 2.000 & 4.000 \\ 0.200 & 0.500 & 1.000 & 2.000 \\ 0.125 & 0.250 & 0.500 & 1.000 \end{bmatrix} * \begin{bmatrix} 0.589 \\ 0.228 \\ 0.119 \\ 0.0633 \end{bmatrix} = \begin{bmatrix} 2.377 \\ 0.917 \\ 0.478 \\ 0.478 \end{bmatrix}$$

4. Consistency ratio check

$$\lambda'_n = \lambda_n / \varpi_n$$

$$\lambda' = \begin{bmatrix} 4.036 \\ 4.014 \\ 4.009 \\ 4.003 \end{bmatrix}$$

$$\lambda'_{max} = \frac{\sum \lambda'}{n} = 4.016$$

$$CI = \frac{\lambda_{max} - n}{n-1} = 0.005$$

$RI = 0.9$ (see Figure 2.3)

$$CR = \frac{CI}{RI} = 0.006 < 0.10$$

Economic Sub-Criteria:

1. Pair-wise comparison matrix is constructed.

	HGW	ELC	LC
Highway	1.000	0.500	0.143
Electric line Cost	2.000	1.000	0.250
Land Cost	7.000	4.000	1.000
	10.000	**5.500**	**1.393**

2. Normalized matrix

	HGW	ELC	LC	SUM	ϖ
HGW	0.100	0.091	0.103	0.293	0.098
ELC	0.200	0.182	0.179	0.561	0.187
LC	0.700	0.727	0.718	2.145	0.715

3. Matrix $\lambda = A * \varpi$

$$\lambda = A * \varpi = \begin{bmatrix} 1.000 & 0.500 & 0.143 \\ 2.000 & 1.000 & 0.250 \\ 7.000 & 4.000 & 1.000 \end{bmatrix} * \begin{bmatrix} 0.098 \\ 0.187 \\ 0.715 \end{bmatrix} = \begin{bmatrix} 0.294 \\ 0.562 \\ 2.148 \end{bmatrix}$$

4. Consistency ratio check

$$\lambda'_n = \lambda_n / \varpi_n$$

$$\lambda' = \begin{bmatrix} 3.001 \\ 3.001 \\ 3.004 \end{bmatrix}$$

$$\lambda'_{max} = \frac{\sum \lambda'}{n} = 3.002$$

$$CI = \frac{\lambda_{max} - n}{n - 1} = 0.001$$

$RI = 0.58$ (see Figure 2.3)

$$CR = \frac{CI}{RI} = 0.0017 < 0.10$$

Planning Sub-Criteria:

1. Pair-wise comparison matrix is constructed.

	RLW	ARP	CT	VLL	ARCH	RD/TV
Distance to railways	1.000	0.250	0.500	0.500	2.000	0.500
Airport area	4.000	1.000	2.000	4.000	7.000	5.000
Cities	2.000	0.500	1.000	2.000	4.000	2.000
Towns and villages	2.000	0.250	0.500	1.000	3.000	2.000
World Heritage, archeological monuments and historical places of high importance	0.500	0.143	0.250	0.333	1.000	0.500
Distance to radio and TV stations	2.000	0.200	0.500	0.500	2.000	1.000
	11.50	**2.34**	**4.75**	**8.33**	**19.00**	**11.00**

1. Normalized matrix

	RLW	ARP	CT	VLL	ARCH	RD/TV	SUM	ϖ
RLW	0.087	0.107	0.105	0.060	0.105	0.045	0.510	0.085
ARP	0.348	0.427	0.421	0.480	0.368	0.455	2.499	0.416
CT	0.174	0.213	0.211	0.240	0.211	0.182	1.230	0.205
VLL	0.174	0.107	0.105	0.120	0.158	0.182	0.846	0.141
ARCH	0.043	0.061	0.053	0.040	0.053	0.045	0.295	0.049
RD/TV	0.174	0.085	0.105	0.060	0.105	0.091	0.621	0.103

2. Matrix $\lambda = A * \varpi$

$$\lambda = A * \varpi = \begin{bmatrix} 1.000 & 0.500 & 0.500 & 0.500 & 2.000 & 0.500 \\ 4.000 & 1.000 & 2.000 & 4.000 & 7.000 & 5.000 \\ 2.000 & 0.500 & 1.000 & 2.000 & 4.000 & 2.000 \\ 2.000 & 0.250 & 0.500 & 1.000 & 3.000 & 2.000 \\ 0.500 & 0.143 & 0.250 & 0.333 & 1.000 & 0.500 \\ 2.000 & 0.200 & 0.500 & 0.500 & 2.000 & 1.000 \end{bmatrix} * \begin{bmatrix} 0.085 \\ 0.416 \\ 0.205 \\ 0.141 \\ 0.049 \\ 0.103 \end{bmatrix} = \begin{bmatrix} 0.512 \\ 2.592 \\ 1.269 \\ 0.872 \\ 0.301 \\ 0.628 \end{bmatrix}$$

3. Consistency ratio check

$$\lambda'_n = \lambda_n / \varpi_n$$

$$\lambda' = \begin{bmatrix} 6.030 \\ 6.223 \\ 6.188 \\ 6.187 \\ 6.121 \\ 6.070 \end{bmatrix}$$

$$\lambda'_{max} = 6.136$$

$$CI = \frac{\lambda_{max} - n}{n - 1} = 0.0273$$

$$RI = 1.24 \text{ (see Figure 2.3)}$$

$$CR = \frac{CI}{RI} = 0.022 < 0.10$$

Physical and Technical Sub-Criteria:

1. Pair-wise comparison matrix is constructed.

	WE	SR	ELV	KRS	DFL	DMS
Wind energy potential	1.000	5.000	7.000	5.000	3.000	7.000
Surface roughness	0.200	1.000	2.000	2.000	0.500	2.000
Elevation (Slope)	0.143	0.500	1.000	0.500	0.250	2.000
Karst (porous grounds and caves)	0.200	0.500	2.000	1.000	0.333	0.500
Distance to fault lines	0.333	2.000	4.000	3.000	1.000	5.000
Distance to mining sites	0.143	0.500	0.500	2.000	0.200	1.000
	2.02	**9.50**	**16.50**	**13.50**	**5.28**	**17.50**

2. Normalized matrix

	WE	SR	ELV	KRS	DFL	DMS	SUM	ϖ
WE	0.495	0.526	0.424	0.370	0.568	0.400	0.510	0.085
SR	0.099	0.105	0.121	0.148	0.095	0.114	2.499	0.416
ELV	0.071	0.053	0.061	0.037	0.047	0.114	1.230	0.205
KRS	0.099	0.053	0.121	0.074	0.063	0.029	0.846	0.141
DFL	0.165	0.211	0.242	0.222	0.189	0.286	0.295	0.049
DMS	0.071	0.053	0.030	0.148	0.038	0.057	0.621	0.103

3. Matrix $\lambda = A * \varpi$

$$\lambda = A * \varpi = \begin{bmatrix} 1.000 & 5.000 & 7.000 & 5.000 & 3.000 & 7.000 \\ 0.200 & 1.000 & 2.000 & 2.000 & 0.500 & 2.000 \\ 0.143 & 0.500 & 1.000 & 0.500 & 0.250 & 2.000 \\ 0.200 & 0.500 & 2.000 & 1.000 & 0.333 & 0.500 \\ 0.333 & 2.000 & 4.000 & 3.000 & 1.000 & 5.000 \\ 0.143 & 0.500 & 0.500 & 2.000 & 0.200 & 1.000 \end{bmatrix} * \begin{bmatrix} 0.085 \\ 0.416 \\ 0.205 \\ 0.141 \\ 0.049 \\ 0.103 \end{bmatrix} = \begin{bmatrix} 2.965 \\ 0.722 \\ 0.411 \\ 0.456 \\ 1.407 \\ 0.411 \end{bmatrix}$$

4. Consistency ratio check

$$\lambda'_n = \lambda_n / \varpi_n$$

$$\lambda' = \begin{bmatrix} 6.391 \\ 6.348 \\ 6.438 \\ 6.244 \\ 6.416 \\ 6.218 \end{bmatrix}$$

$$\lambda'_{max} = 6.343$$

$$CI = \frac{\lambda_{max} - n}{n - 1} = 0.0685$$

$RI = 1.24$ (see Figure 2.3)

$$CR = \frac{CI}{RI} = 0.0553 < 0.10$$

Environmental Sub-Criteria:

1. Pair-wise comparison matrix is constructed.

	WB	BH	WDL
River/canal, waterbodies	1.000	0.250	0.500
Bird habitats/routs	4.000	1.000	2.000
Woodland	2.000	0.500	1.000
	7.00	**1.75**	**3.50**

2. Normalized matrix

	WB	BH	WDL	SUM	ϖ
WB	0.143	0.143	0.143	0.429	0.143
BH	0.571	0.571	0.571	1.714	0.571
WDL	0.286	0.286	0.286	0.857	0.286

3. Matrix $\lambda = A * \varpi$

$$\lambda = A * \varpi = \begin{bmatrix} 1.000 & 0.250 & 0.500 \\ 4.000 & 1.000 & 2.000 \\ 2.000 & 0.500 & 1.000 \end{bmatrix} * \begin{bmatrix} 0.143 \\ 0.571 \\ 0.286 \end{bmatrix} = \begin{bmatrix} 0.429 \\ 1.714 \\ 0.857 \end{bmatrix}$$

4. Consistency ratio check

$$\lambda'_n = \lambda_n / \varpi_n$$

$$\lambda' = \begin{bmatrix} 3.000 \\ 3.000 \\ 3.000 \end{bmatrix}$$

$$\lambda'_{max} = \frac{\sum \lambda'}{n} = 3.000$$

$$CI = \frac{\lambda_{max} - n}{n - 1} = 0.000$$

$RI = 0.58$ (see Figure 2.3)

$$CR = \frac{CI}{RI} = 0.000 < 0.10$$

APPENDIX B.1. Experts' Reference and Criteria Weighting.

Practitioner 2

Following questionnaire was filled by an expert, marked as Practitioner 2. The expert has in average 10 years of experience in Wind Energy Industry as consultant and contractor. The Answers were used in order to weight all criteria.

Which of factors below are more important?

Definition	Score
Equally important	**1**
Slightly more important	**3**
Much more important	**5**
Far more important	**7**
Extremely more important	**9**

Note: scores 1, 3, 5, 7, 9 are considered as the main evaluation levels, and scores 2, 4, 6, 8 can be also used in order to express the comparison more precisely.

	Main Factors																	
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Economical						x												Planning
Economical				x														Physical and Technical
Economical			x															Environmental
Planning												x						Economical
Planning								x										Physical and Technical
Planning						x												Environmental
Physical and Technical														x				Economical
Physical and Technical										x								Planning
Physical and Technical								x										Environmental
Environmental															x			Economical
Environmental												x						Planning
Environmental										x								Physical and Technical

Which of sub-factors below are more important when influence on capital cost is considered?

Definition	Score
Equally important	**1**
Slightly more important	**3**
Much more important	**5**
Far more important	**7**
Extremely more important	**9**

Note: scores 1, 3, 5, 7, 9 are considered as the main evaluation levels, and scores 2, 4, 6, 8 can be also used in order to express the comparison more precisely.

	Economical Sub-factors																	
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Highway											x							Electric line cost
Highway														x				Land cost
Electric line cost							x											Highway
Electric line cost												x						Land cost
Land cost				x														Highway
Land cost						x												Electric line cost

Questionnaire was prepared for thesis study 'Site Selection Technique for Wind Turbines Power Plants Utilizing Geographical Information Systems (GIS) and Analytical Hierarchy Process (AHP)', May 2016.

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APPENDIX B.1. Experts' Reference and Criteria Weighting. Practitioner 2

Which of sub-factors below are more important when site selection for WTP is made according to general planning criteria?

Definition	Score
Equally important	**1**
Slightly more important	**3**
Much more important	**5**
Far more important	**7**
Extremely more important	**9**

Note: scores 1, 3, 5, 7, 9 are considered as the main evaluation levels, and scores 2, 4, 6, 8 can be also used in order to express the comparison more precisely.

	Planning Sub-factors																	
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Distance to railways											x							Airports area
Distance to railways											x							Cities
Distance to railways									x									Towns, villages
Distance to railways							x											World Heritage, archeological monuments and historical places of high importance
Distance to railways									x									Distance to radio and TV stations
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Airport area							x											Distance to railways
Airport area								x										Cities
Airport area						x												Towns and villages
Airport area			x															World Heritage, archeological monuments and historical places of high importance
Airport area						x												Distance to radio and TV stations
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Cities							x											Distance to railways
Cities											x							Airports area
Cities								x										Towns and villages
Cities						x												World Heritage, archeological monuments and historical places of high importance
Cities								x										Distance to radio and TV stations
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Towns and villages									x									Distance to railways
Towns and villages												x						Airports area
Towns and villages											x							Cities
Towns and villages						x												World Heritage, archeological monuments and historical places of high importance
Towns and villages								x										Distance to radio and TV stations
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
World Heritage, archeological monuments and historical places of high importance											x							Distance to railways
World Heritage, archeological monuments and historical places of high importance															x			Airports area
World Heritage, archeological monuments and historical places of high importance												x						Cities

Questionnaire was prepared for thesis study 'Site Selection Technique for Wind Turbines Power Plants Utilizing Geographical Information Systems (GIS) and Analytical Hierarchy Process (AHP)', May 2016.

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APPENDIX B.1. Experts’ Reference and Criteria Weighting. Practitioner 2

World Heritage, archeological monuments and historical places of high importance										x								Towns and villages
World Heritage, archeological monuments and historical places of high importance										x								Distance to radio and TV stations
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Distance to radio and TV stations									x									Distance to railways
Distance to radio and TV stations												x						Airports area
Distance to radio and TV stations												x						Cities
Distance to radio and TV stations										x								Towns and villages
Distance to radio and TV stations								x										World Heritage, archeological monuments and historical places of high importance

Questionnaire was prepared for thesis study ‘Site Selection Technique for Wind Turbines Power Plants Utilizing Geographical Information Systems (GIS) and Analytical Hierarchy Process (AHP)’, May 2016.

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APPENDIX B.1. Experts’ Reference and Criteria Weighting. Practitioner 2

Which of sub-factors below are more important when site selection of WTP is considered according to physical characteristics of landscape and technical characteristics of wind turbine?

Definition	Score
Equally important	**1**
Slightly more important	**3**
Much more important	**5**
Far more important	**7**
Extremely more important	**9**

Note: scores 1, 3, 5, 7, 9 are considered as the main evaluation levels, and scores 2, 4, 6, 8 can be also used in order to express the comparison more precisely.

	Physical and Technical Sub-factors																	
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Wind energy potential					x													Surface roughness
Wind energy potential		x																Elevation (slope)
Wind energy potential					x													Karst (porous grounds and caves)
Wind energy potential							x											Distance to fault lines
Wind energy potential			x															Distance to mining sites
Surface roughness													x					Wind energy potential
Surface roughness								x										Elevation (slope)
Surface roughness									x									Karst (porous grounds and caves)
Surface roughness											x							Distance to fault lines
Surface roughness								x										Distance to mining sites
Elevation (slope)																x		Wind energy potential
Elevation (slope)											x							Surface roughness
Elevation (slope)										x								Karst (porous grounds and caves)
Elevation (slope)												x						Distance to fault lines
Elevation (slope)								x										Distance to mining sites
Karst (porous grounds and caves)													x					Wind energy potential
Karst (porous grounds and caves)									x									Surface roughness
Karst (porous grounds and caves)								x										Elevation (slope)
Karst (porous grounds and caves)											x							Distance to fault lines
Karst (porous grounds and caves)										x								Distance to mining sites
Distance to fault lines											x							Wind energy potential
Distance to fault lines							x											Surface roughness
Distance to fault lines					x													Elevation (slope)
Distance to fault lines							x											Karst (porous grounds and caves)
Distance to fault lines					x													Distance to mining sites
Distance to mining sites															x			Wind energy potential
Distance to mining sites											x							Surface roughness
Distance to mining sites										x								Elevation (slope)
Distance to mining sites										x								Karst (porous grounds and caves)
Distance to mining sites													x					Distance to fault lines

Questionnaire was prepared for thesis study ‘Site Selection Technique for Wind Turbines Power Plants Utilizing Geographical Information Systems (GIS) and Analytical Hierarchy Process (AHP)’, May 2016.

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APPENDIX B.1. Experts' Reference and Criteria Weighting. Practitioner 2

Which of sub-factors below are more important when site selection of WTP is considered according to environmental sub-factors?

Definition	Score
Equally important	**1**
Slightly more important	**3**
Much more important	**5**
Far more important	**7**
Extremely more important	**9**

Note: scores 1, 3, 5, 7, 9 are considered as the main evaluation levels, and scores 2, 4, 6, 8 can be also used in order to express the comparison more precisely.

	Environmental Sub-factors																	
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
River/canal, waterbodies										x								Bird habitats/routs
River/canal, waterbodies												x						Woodland
Bird habitats/routs								x										River/canal, waterbodies
Bird habitats/routs											x							Woodland
Woodland						x												River/canal, waterbodies
Woodland										x								Bird habitats/routs

Questionnaire was prepared for thesis study 'Site Selection Technique for Wind Turbines Power Plants Utilizing Geographical Information Systems (GIS) and Analytical Hierarchy Process (AHP)', May 2016.

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APPENDIX B.1. AHP Calculations

Practitioner 2:

Main Criteria:

1. Pair-wise comparison matrix is constructed.

	ECO	PLN	PHS/TECH	ENV
Economical`	1.00	4.00	6.00	7.00
Planning	0.25	1.00	2.00	4.00
Physical and Technical	0.17	0.50	1.00	2.00
Environmental	0.14	0.25	0.50	1.00
	1.56	**5.75**	**9.50**	**14.00**

2. Normalized matrix

	ECO	PLN	PHS/TECH	ENV	SUM	$\boldsymbol{\varpi}$
ECO	0.641	0.696	0.632	0.500	2.468	0.617
PLN	0.160	0.174	0.211	0.286	0.830	0.208
PHS/TECH	0.107	0.087	0.105	0.143	0.442	0.110
ENV	0.092	0.043	0.053	0.071	0.259	0.065

3. Matrix $\lambda = A * \varpi$

$$\lambda = A * \varpi = \begin{bmatrix} 1.000 & 4.000 & 6.000 & 7.000 \\ 0.250 & 1.000 & 2.000 & 4.000 \\ 0.170 & 0.500 & 1.000 & 2.000 \\ 0.140 & 0.250 & 0.500 & 1.000 \end{bmatrix} * \begin{bmatrix} 0.617 \\ 0.208 \\ 0.110 \\ 0.065 \end{bmatrix} = \begin{bmatrix} 2.564 \\ 0.842 \\ 0.447 \\ 0.260 \end{bmatrix}$$

4. Consistency ratio check

$$\lambda'_n = \lambda_n / \varpi_n$$

$$\lambda' = \begin{bmatrix} 4.155 \\ 4.056 \\ 4.043 \\ 4.015 \end{bmatrix}$$

$$\lambda'_{max} = \frac{\sum \lambda'}{n} = 4.0671$$

$$CI = \frac{\lambda_{max} - n}{n - 1} = 0.0224$$

$RI = 0.9$ (see Figure 2.3)

$$CR = \frac{CI}{RI} = 0.0248 < 0.10$$

Economic Sub-Criteria:

5. Pair-wise comparison matrix is constructed.

	HGW	ELC	LC
Highway	1.000	0.333	0.167
Electric line Cost	3.000	1.000	0.250
Land Cost	6.000	4.000	1.000
	10.000	**5.333**	**1.417**

6. Normalized matrix

	HGW	ELC	LC	SUM	ϖ
HGW	0.100	0.063	0.118	0.280	0.093
ELC	0.300	0.188	0.176	0.664	0.221
LC	0.600	0.750	0.706	2.056	0.685

7. Matrix $\lambda = A * \varpi$

$$\lambda = A * \varpi = \begin{bmatrix} 1.000 & 0.333 & 0.167 \\ 3.000 & 1.000 & 0.250 \\ 6.000 & 4.000 & 1.000 \end{bmatrix} * \begin{bmatrix} 0.093 \\ 0.221 \\ 0.685 \end{bmatrix} = \begin{bmatrix} 0.281 \\ 0.673 \\ 2.131 \end{bmatrix}$$

8. Consistency ratio check

$$\lambda'_n = \lambda_n / \varpi_n$$

$$\lambda' = \begin{bmatrix} 3.013 \\ 3.040 \\ 3.109 \end{bmatrix}$$

$$\lambda'_{max} = \frac{\sum \lambda'}{n} = 3.054$$

$$CI = \frac{\lambda_{max} - n}{n - 1} = 0.027$$

$RI = 0.58$ (see Figure 2.3)

$$CR = \frac{CI}{RI} = 0.0467 < 0.10$$

Planning Sub-Criteria:

2. Pair-wise comparison matrix is constructed.

	RLW	ARP	CT	VLL	ARCH	RD/TV
Distance to railways	1.000	0.333	0.333	0.500	3.000	0.500
Airport area	3.000	1.000	2.000	4.000	7.000	4.000
Cities	3.000	0.500	1.000	2.000	4.000	2.000
Towns and villages	2.000	0.250	0.500	1.000	4.000	2.000
World Heritage, archeological monuments and historical places of high importance	0.333	0.143	0.250	0.250	1.000	0.500
Distance to radio and TV stations	2.000	0.250	0.500	0.500	2.000	1.000
	11.33	**2.48**	**4.58**	**8.25**	**21.00**	**10.00**

4. Normalized matrix

	RLW	ARP	CT	VLL	ARCH	RD/TV	SUM	ϖ
RLW	0.088	0.135	0.073	0.061	0.143	0.050	0.549	0.092
ARP	0.265	0.404	0.436	0.485	0.333	0.400	2.323	0.387
CT	0.265	0.202	0.218	0.242	0.190	0.200	1.318	0.219
VLL	0.176	0.101	0.109	0.121	0.190	0.200	0.898	0.149
ARCH	0.029	0.058	0.055	0.030	0.048	0.050	0.270	0.045
RD/TV	0.176	0.101	0.109	0.061	0.095	0.100	0.642	0.107

5. Matrix $\lambda = A * \varpi$

$$\lambda = A * \varpi = \begin{bmatrix} 1.000 & 0.333 & 0.333 & 0.500 & 3.000 & 0.500 \\ 3.000 & 1.000 & 2.000 & 4.000 & 7.000 & 4.000 \\ 3.000 & 0.500 & 1.000 & 2.000 & 4.000 & 2.000 \\ 2.000 & 0.250 & 0.500 & 1.000 & 4.000 & 2.000 \\ 0.333 & 0.143 & 0.250 & 0.250 & 1.000 & 0.500 \\ 2.000 & 0.250 & 0.500 & 0.500 & 2.000 & 1.000 \end{bmatrix} * \begin{bmatrix} 0.092 \\ 0.387 \\ 0.219 \\ 0.149 \\ 0.045 \\ 0.107 \end{bmatrix} = \begin{bmatrix} 0.557 \\ 2.442 \\ 1.381 \\ 0.933 \\ 0.277 \\ 0.661 \end{bmatrix}$$

6. Consistency ratio check

$$\lambda'_n = \lambda_n / \varpi_n$$

$$\lambda' = \begin{bmatrix} 6.086 \\ 6.308 \\ 6.288 \\ 6.233 \\ 6.157 \\ 6.178 \end{bmatrix}$$

$$\lambda'_{max} = 6.2084$$

$$CI = \frac{\lambda_{max} - n}{n - 1} = 0.0417$$

$$RI = 1.24 \text{ (see Figure 2.3)}$$

$$CR = \frac{CI}{RI} = 0.0336 < 0.10$$

Physical and Technical Sub-Criteria:

1. Pair-wise comparison matrix is constructed.

	WE	SR	ELV	KRS	DFL	DMS
Wind energy potential	1.000	5.000	8.000	5.000	3.000	7.000
Surface roughness	0.200	1.000	2.000	0.500	0.333	2.000
Elevation (Slope)	0.125	0.500	1.000	0.500	0.250	2.000
Karst (porous grounds and caves)	0.200	2.000	2.000	1.000	0.333	0.500
Distance to fault lines	0.333	3.000	4.000	3.000	1.000	5.000
Distance to mining sites	0.143	0.500	0.500	2.000	0.200	1.000
	2.00	**12.00**	**17.50**	**12.00**	**5.12**	**17.50**

2. Normalized matrix

	WE	SR	ELV	KRS	DFL	DMS	SUM	ϖ
WE	0.500	0.417	0.457	0.417	0.586	0.400	2.776	0.463
SR	0.100	0.083	0.114	0.042	0.065	0.114	0.519	0.086
ELV	0.062	0.042	0.057	0.042	0.049	0.114	0.366	0.061
KRS	0.100	0.167	0.114	0.083	0.065	0.029	0.558	0.093
DFL	0.167	0.250	0.229	0.250	0.195	0.286	1.376	0.229
DMS	0.071	0.042	0.029	0.167	0.039	0.057	0.405	0.067

3. Matrix $\lambda = A * \varpi$

$$\lambda = A * \varpi = \begin{bmatrix} 1.000 & 5.000 & 8.000 & 5.000 & 3.000 & 7.000 \\ 0.200 & 1.000 & 2.000 & 0.500 & 0.333 & 2.000 \\ 0.125 & 0.500 & 1.000 & 0.500 & 0.250 & 2.000 \\ 0.200 & 2.000 & 2.000 & 1.000 & 0.333 & 0.500 \\ 0.333 & 3.000 & 4.000 & 3.000 & 1.000 & 5.000 \\ 0.143 & 0.500 & 0.500 & 2.000 & 0.200 & 1.000 \end{bmatrix} * \begin{bmatrix} 0.463 \\ 0.086 \\ 0.061 \\ 0.093 \\ 0.229 \\ 0.067 \end{bmatrix} = \begin{bmatrix} 3.008 \\ 0.559 \\ 0.401 \\ 0.591 \\ 1.503 \\ 0.439 \end{bmatrix}$$

4. Consistency ratio check

$$\lambda'_n = \lambda_n / \varpi_n$$

$$\lambda' = \begin{bmatrix} 6.501 \\ 6.465 \\ 6.568 \\ 6.351 \\ 6.553 \\ 6.513 \end{bmatrix}$$

$$\lambda'_{max} = 6.4918$$

$$CI = \frac{\lambda_{max} - n}{n - 1} = 0.0984$$

$RI = 1.24$ (see Figure 2.3)

$$CR = \frac{CI}{RI} = 0.0794 < 0.10$$

Environmental Sub-Criteria:

1. Pair-wise comparison matrix is constructed.

	WB	**BH**	**WDL**
River/canal, waterbodies	1.000	0.500	0.250
Bird habitats/routs	2.000	1.000	0.333
Woodland	4.000	3.000	1.000
	7.00	**4.50**	**1.58**

2. Normalized matrix

	WB	**BH**	**WDL**	**SUM**	**ϖ**
WB	0.143	0.111	0.158	0.412	0.137
BH	0.286	0.222	0.211	0.718	0.239
WDL	0.571	0.667	0.632	1.870	0.623

3. Matrix $\lambda = A * \varpi$

$$\lambda = A * \varpi = \begin{bmatrix} 1.000 & 0.500 & 0.250 \\ 2.000 & 1.000 & 0.333 \\ 4.000 & 3.000 & 1.000 \end{bmatrix} * \begin{bmatrix} 0.137 \\ 0.239 \\ 0.623 \end{bmatrix} = \begin{bmatrix} 0.413 \\ 0.722 \\ 1.891 \end{bmatrix}$$

4. Consistency ratio check

$$\lambda'_n = \lambda_n / \varpi_n$$

$$\lambda' = \begin{bmatrix} 3.007 \\ 3.014 \\ 3.034 \end{bmatrix}$$

$$\lambda'_{max} = \frac{\sum \lambda'}{n} = 3.0183$$

$$CI = \frac{\lambda_{max} - n}{n - 1} = 0.0092$$

$RI = 0.58$ (see Figure 2.3)

$$CR = \frac{CI}{RI} = 0.0158 < 0.10$$

APPENDIX B.1. Experts’ Reference and Criteria Weighting.

Academic 1

Following questionnaire was filled by an expert, marked as Academic 1. The expert has numerous publications in Wind Energy field of study and working on projects directly related to the field. Academic 1 is an Associate Professor at Istanbul Technical University working in Renewable Energy Department of Energy Institute. The Answers were used in order to weight all criteria.

Which of factors below are more important?

Definition	Score
Equally important	**1**
Slightly more important	**3**
Much more important	**5**
Far more important	**7**
Extremely more important	**9**

Note: scores 1, 3, 5, 7, 9 are considered as the main evaluation levels, and scores 2, 4, 6, 8 can be also used in order to express the comparison more precisely.

	Main Factors																	
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Economical			x															Planning
Economical			x				A											Physical and Technical
Economical	x																	Environmental
Planning															x			Economical
Planning											x							Physical and Technical
Planning					x													Environmental
Physical and Technical											A				x			Economical
Physical and Technical							x											Planning
Physical and Technical			x															Environmental
Environmental																	x	Economical
Environmental													x					Planning
Environmental															x			Physical and Technical

Which of sub-factors below are more important when influence on capital cost is considered?

Definition	Score
Equally important	**1**
Slightly more important	**3**
Much more important	**5**
Far more important	**7**
Extremely more important	**9**

Note: scores 1, 3, 5, 7, 9 are considered as the main evaluation levels, and scores 2, 4, 6, 8 can be also used in order to express the comparison more precisely.

	Economical Sub-factors																	
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Highway														X				Electric line cost
Highway														x				Land cost
Electric line cost				x														Highway
Electric line cost										x								Land cost
Land cost				x														Highway
Land cost								x										Electric line cost

Questionnaire was prepared for thesis study ‘Site Selection Technique for Wind Turbines Power Plants Utilizing Geographical Information Systems (GIS) and Analytical Hierarchy Process (AHP)’, May 2016.

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APPENDIX B.1. Experts' Reference and Criteria Weighting. Academic 1

Which of sub-factors below are more important when site selection for WTP is made according to general planning criteria?

Definition	Score
Equally important	**1**
Slightly more important	**3**
Much more important	**5**
Far more important	**7**
Extremely more important	**9**

Note: scores 1, 3, 5, 7, 9 are considered as the main evaluation levels, and scores 2, 4, 6, 8 can be also used in order to express the comparison more precisely.

	Planning Sub-factors																	
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Distance to railways														X				Airports area
Distance to railways														X				Cities
Distance to railways										X								Towns, villages
Distance to railways											X							World Heritage, archeological monuments and historical places of high importance
Distance to railways														X				Distance to radio and TV stations
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Airport area				x														Distance to railways
Airport area							x											Cities
Airport area					x													Towns and villages
Airport area					x													World Heritage, archeological monuments and historical places of high importance
Airport area				x														Distance to radio and TV stations
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Cities				x														Distance to railways
Cities											x							Airports area
Cities							x											Towns and villages
Cities						x												World Heritage, archeological monuments and historical places of high importance
Cities							x											Distance to radio and TV stations
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Towns and villages								x										Distance to railways
Towns and villages													x					Airports area
Towns and villages											x							Cities
Towns and villages								x										World Heritage, archeological monuments and historical places of high importance
Towns and villages										x								Distance to radio and TV stations
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
World Heritage, archeological monuments and historical places of high importance							x											Distance to railways
World Heritage, archeological monuments and historical places of high importance													x					Airports area
World Heritage, archeological monuments and historical places of high importance												x						Cities

Questionnaire was prepared for thesis study 'Site Selection Technique for Wind Turbines Power Plants Utilizing Geographical Information Systems (GIS) and Analytical Hierarchy Process (AHP)', May 2016.

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APPENDIX B.1. Experts’ Reference and Criteria Weighting. Academic 1

World Heritage, archeological monuments and historical places of high importance										x								Towns and villages
World Heritage, archeological monuments and historical places of high importance								x										Distance to radio and TV stations
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Distance to radio and TV stations				x														Distance to railways
Distance to radio and TV stations														x				Airports area
Distance to radio and TV stations											x							Cities
Distance to radio and TV stations								x										Towns and villages
Distance to radio and TV stations										x								World Heritage, archeological monuments and historical places of high importance

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APPENDIX B.1. Experts' Reference and Criteria Weighting. Academic 1

Which of sub-factors below are more important when site selection of WTP is considered according to physical characteristics of landscape and technical characteristics of wind turbine?

Definition	Score
Equally important	**1**
Slightly more important	**3**
Much more important	**5**
Far more important	**7**
Extremely more important	**9**

Note: scores 1, 3, 5, 7, 9 are considered as the main evaluation levels, and scores 2, 4, 6, 8 can be also used in order to express the comparison more precisely.

	Physical and Technical Sub-factors																	
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Wind energy potential						x												Surface roughness
Wind energy potential							x											Elevation (slope)
Wind energy potential					x													Karst (porous grounds and caves)
Wind energy potential							x											Distance to fault lines
Wind energy potential		x																Distance to mining sites
Surface roughness															x			Wind energy potential
Surface roughness								x										Elevation (slope)
Surface roughness										x								Karst (porous grounds and caves)
Surface roughness										x								Distance to fault lines
Surface roughness	x																	Distance to mining sites
Elevation (slope)													x					Wind energy potential
Elevation (slope)										x								Surface roughness
Elevation (slope)										x								Karst (porous grounds and caves)
Elevation (slope)								x										Distance to fault lines
Elevation (slope)	x																	Distance to mining sites
Karst (porous grounds and caves)															x			Wind energy potential
Karst (porous grounds and caves)								x										Surface roughness
Karst (porous grounds and caves)								x										Elevation (slope)
Karst (porous grounds and caves)							x											Distance to fault lines
Karst (porous grounds and caves)			x															Distance to mining sites
Distance to fault lines															x			Wind energy potential
Distance to fault lines								x										Surface roughness
Distance to fault lines											x							Elevation (slope)
Distance to fault lines											x							Karst (porous grounds and caves)
Distance to fault lines					x													Distance to mining sites
Distance to mining sites																	x	Wind energy potential
Distance to mining sites																	x	Surface roughness
Distance to mining sites																	x	Elevation (slope)
Distance to mining sites																	x	Karst (porous grounds and caves)
Distance to mining sites													x					Distance to fault lines

Questionnaire was prepared for thesis study 'Site Selection Technique for Wind Turbines Power Plants Utilizing Geographical Information Systems (GIS) and Analytical Hierarchy Process (AHP)', May 2016.

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APPENDIX B.1. Experts' Reference and Criteria Weighting. Academic 1

Which of sub-factors below are more important when site selection of WTP is considered according to environmental sub-factors?

Definition	Score
Equally important	**1**
Slightly more important	**3**
Much more important	**5**
Far more important	**7**
Extremely more important	**9**

Note: scores 1, 3, 5, 7, 9 are considered as the main evaluation levels, and scores 2, 4, 6, 8 can be also used in order to express the comparison more precisely.

	Environmental Sub-factors																	
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
River/canal, waterbodies															x			Bird habitats/routs
River/canal, waterbodies										x								Woodland
Bird habitats/routs			x															River/canal, waterbodies
Bird habitats/routs			x															Woodland
Woodland								x										River/canal, waterbodies
Woodland															x			Bird habitats/routs

Questionnaire was prepared for thesis study 'Site Selection Technique for Wind Turbines Power Plants Utilizing Geographical Information Systems (GIS) and Analytical Hierarchy Process (AHP)', May 2016.

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APPENDIX B.1. AHP Calculations

Academic 1:

Main Criteria:

1. Pair-wise comparison matrix is constructed.

	ECO	PLN	PHS/TECH	ENV
Economical`	1.00	7.00	3.00	9.00
Planning	0.14	1.00	0.33	5.00
Physical and Technical	0.33	3.00	1.00	7.00
Environmental	0.11	0.20	0.14	1.00
	1.59	**11.20**	**4.48**	**22.00**

2. Normalized matrix

	ECO	PLN	PHS/TECH	ENV	SUM	ϖ
ECO	0.630	0.625	0.670	0.409	2.334	0.584
PLN	0.090	0.089	0.074	0.227	0.481	0.120
PHS/TECH	0.210	0.268	0.223	0.318	1.019	0.255
ENV	0.070	0.018	0.032	0.045	0.165	0.041

3. Matrix $\lambda = A * \varpi$

$$\lambda = A * \varpi = \begin{bmatrix} 1.000 & 7.000 & 3.000 & 9.000 \\ 0.143 & 1.000 & 0.333 & 5.000 \\ 0.333 & 3.000 & 1.000 & 7.000 \\ 0.111 & 0.200 & 0.143 & 1.000 \end{bmatrix} * \begin{bmatrix} 0.584 \\ 0.120 \\ 0.255 \\ 0.041 \end{bmatrix} = \begin{bmatrix} 2.562 \\ 0.495 \\ 1.099 \\ 0.167 \end{bmatrix}$$

4. Consistency ratio check

$$\lambda'_n = \lambda_n / \varpi_n$$

$$\lambda' = \begin{bmatrix} 4.390 \\ 4.117 \\ 4.313 \\ 4.033 \end{bmatrix}$$

$$\lambda'_{max} = \frac{\sum \lambda'}{n} = 4.213$$

$$CI = \frac{\lambda_{max} - n}{n - 1} = 0.071$$

$RI = 0.9$ (see Figure 2.3)

$$CR = \frac{CI}{RI} = 0.079 < 0.10$$

Economic Sub-Criteria:

1. Pair-wise comparison matrix is constructed.

	HGW	ELC	LC
Highway	1.00	0.17	0.17
Electric line Cost	6.00	1.00	0.50
Land Cost	6.00	2.00	1.00
	13.00	**3.17**	**1.67**

2. Normalized matrix

	HGW	ELC	LC	SUM	$\boldsymbol{\varpi}$
HGW	0.077	0.053	0.100	0.230	0.077
ELC	0.462	0.316	0.300	1.077	0.359
LC	0.462	0.632	0.600	1.693	0.564

3. Matrix $\lambda = A * \varpi$

$$\lambda = A * \varpi = \begin{bmatrix} 1.000 & 0.167 & 0.167 \\ 6.000 & 1.000 & 0.500 \\ 6.000 & 2.000 & 1.000 \end{bmatrix} * \begin{bmatrix} 0.077 \\ 0.359 \\ 0.564 \end{bmatrix} = \begin{bmatrix} 0.230 \\ 1.100 \\ 1.742 \end{bmatrix}$$

4. Consistency ratio check

$$\lambda'_n = \lambda_n / \varpi_n$$

$$\lambda' = \begin{bmatrix} 3.011 \\ 3.064 \\ 3.086 \end{bmatrix}$$

$$\lambda'_{max} = \frac{\sum \lambda'}{n} = 3.054$$

$$CI = \frac{\lambda_{max} - n}{n - 1} = 0.027$$

$RI = 0.58$ (see Figure 2.3)

$$CR = \frac{CI}{RI} = 0.0465 < 0.10$$

Planning Sub-Criteria:

1. Pair-wise comparison matrix is constructed.

	RLW	ARP	CT	VLL	ARCH	RD/TV
Distance to railways	1.000	0.167	0.167	0.500	0.333	0.167
Airport area	6.000	1.000	3.000	5.000	5.000	6.000
Cities	6.000	0.333	1.000	3.000	4.000	3.000
Towns and villages	2.000	0.200	0.333	1.000	2.000	0.500
World Heritage, archeological monuments and historical places of high importance	3.000	0.200	0.250	0.500	1.000	2.000
Distance to radio and TV stations	6.000	0.167	0.333	2.000	0.500	1.000
	24.00	**2.07**	**5.08**	**12.00**	**12.83**	**12.67**

7. Normalized matrix

	RLW	ARP	CT	VLL	ARCH	RD/TV	SUM	ϖ
RLW	0.042	0.081	0.033	0.042	0.026	0.013	0.236	0.039
ARP	0.250	0.484	0.590	0.417	0.390	0.474	2.604	0.434
CT	0.250	0.161	0.197	0.250	0.312	0.237	1.407	0.234
VLL	0.083	0.097	0.066	0.083	0.156	0.039	0.524	0.087
ARCH	0.125	0.097	0.049	0.042	0.078	0.158	0.548	0.091
RD/TV	0.250	0.081	0.066	0.167	0.039	0.079	0.681	0.113

8. Matrix $\lambda = A * \varpi$

$$\lambda = A * \varpi = \begin{bmatrix} 1.000 & 0.167 & 0.167 & 0.500 & 0.333 & 0.167 \\ 6.000 & 1.000 & 3.000 & 5.000 & 5.000 & 6.000 \\ 6.000 & 0.333 & 1.000 & 3.000 & 4.000 & 3.000 \\ 2.000 & 0.200 & 0.333 & 1.000 & 2.000 & 0.500 \\ 3.000 & 0.200 & 0.250 & 0.500 & 1.000 & 2.000 \\ 6.000 & 0.167 & 0.333 & 2.000 & 0.500 & 1.000 \end{bmatrix} * \begin{bmatrix} 0.039 \\ 0.434 \\ 0.234 \\ 0.087 \\ 0.091 \\ 0.113 \end{bmatrix} = \begin{bmatrix} 0.244 \\ 2.948 \\ 1.583 \\ 0.571 \\ 0.625 \\ 0.720 \end{bmatrix}$$

9. Consistency ratio check

$$\lambda'_n = \lambda_n / \varpi_n$$

$$\lambda' = \begin{bmatrix} 6.201 \\ 6.792 \\ 6.753 \\ 6.528 \\ 6.842 \\ 6.348 \end{bmatrix}$$

$$\lambda'_{max} = 6.578$$

$$CI = \frac{\lambda_{max} - n}{n - 1} = 0.1155$$

$$RI = 1.24 \text{ (see Figure 2.3)}$$

$$CR = \frac{CI}{RI} = 0.0932 < 0.10$$

Physical and Technical Sub-Criteria:

1. Pair-wise comparison matrix is constructed.

	WE	SR	ELV	KRS	DFL	DMS
Wind energy potential	1.000	3.000	3.000	3.000	3.000	8.000
Surface roughness	0.333	1.000	2.000	0.500	0.500	9.000
Elevation (Slope)	0.333	0.500	1.000	0.500	3.000	9.000
Karst (porous grounds and caves)	0.333	2.000	2.000	1.000	2.000	7.000
Distance to fault lines	0.333	2.000	0.333	0.500	1.000	5.000
Distance to mining sites	0.125	0.111	0.111	0.143	0.200	1.000
	2.46	**8.61**	**8.44**	**5.64**	**9.70**	**39.00**

2. Normalized matrix

	WE	SR	ELV	KRS	DFL	DMS	SUM	ϖ
WE	0.407	0.348	0.355	0.532	0.309	0.205	2.156	0.359
SR	0.136	0.116	0.237	0.089	0.052	0.231	0.859	0.143
ELV	0.136	0.058	0.118	0.089	0.309	0.231	0.941	0.157
KRS	0.136	0.232	0.237	0.177	0.206	0.179	1.168	0.195
DFL	0.136	0.232	0.039	0.089	0.103	0.128	0.727	0.121
DMS	0.051	0.013	0.013	0.025	0.021	0.026	0.148	0.025

3. Matrix $\lambda = A * \varpi$

$$\lambda = A * \varpi = \begin{bmatrix} 1.000 & 3.000 & 3.000 & 3.000 & 3.000 & 8.000 \\ 0.333 & 1.000 & 2.000 & 0.500 & 0.500 & 9.000 \\ 0.333 & 0.500 & 1.000 & 0.500 & 3.000 & 9.000 \\ 0.333 & 2.000 & 2.000 & 1.000 & 2.000 & 7.000 \\ 0.333 & 2.000 & 0.333 & 0.500 & 1.000 & 5.000 \\ 0.125 & 0.111 & 0.111 & 0.143 & 0.200 & 1.000 \end{bmatrix} * \begin{bmatrix} 0.359 \\ 0.143 \\ 0.157 \\ 0.195 \\ 0.121 \\ 0.025 \end{bmatrix} = \begin{bmatrix} 2.405 \\ 0.957 \\ 1.032 \\ 1.330 \\ 0.801 \\ 0.155 \end{bmatrix}$$

4. Consistency ratio check

$$\lambda'_n = \lambda_n / \varpi_n$$

$$\lambda' = \begin{bmatrix} 6.691 \\ 6.683 \\ 6.581 \\ 6.835 \\ 6.607 \\ 6.265 \end{bmatrix}$$

$$\lambda'_{max} = 6.610$$

$$CI = \frac{\lambda_{max} - n}{n - 1} = 0.122$$

$RI = 1.24$ (see Figure 2.3)

$$CR = \frac{CI}{RI} = 0.098 < 0.10$$

Environmental Sub-Criteria:

1. Pair-wise comparison matrix is constructed.

	WB	**BH**	**WDL**
River/canal, waterbodies	1.000	0.143	0.500
Bird habitats/routs	7.000	1.000	7.000
Woodland	2.000	0.143	1.000
	10.00	**1.29**	**8.50**

2. Normalized matrix

	WB	**BH**	**WDL**	**SUM**	$\boldsymbol{\varpi}$
WB	0.100	0.111	0.059	0.270	0.090
BH	0.700	0.778	0.824	2.301	0.767
WDL	0.200	0.111	0.118	0.429	0.143

3. Matrix $\lambda = A * \varpi$

$$\lambda = A * \varpi = \begin{bmatrix} 1.000 & 0.143 & 0.500 \\ 7.000 & 1.000 & 7.000 \\ 2.000 & 0.143 & 1.000 \end{bmatrix} * \begin{bmatrix} 0.090 \\ 0.767 \\ 0.143 \end{bmatrix} = \begin{bmatrix} 0.271 \\ 2.397 \\ 0.432 \end{bmatrix}$$

4. Consistency ratio check

$$\lambda'_n = \lambda_n / \varpi_n$$

$$\lambda' = \begin{bmatrix} 3.012 \\ 3.125 \\ 3.026 \end{bmatrix}$$

$$\lambda'_{max} = \frac{\sum \lambda'}{n} = 3.054$$

$$CI = \frac{\lambda_{max} - n}{n - 1} = 0.027$$

$RI = 0.58$ (see Figure 2.3)

$$CR = \frac{CI}{RI} = 0.047 < 0.10$$

APPENDIX B.1. Experts' Reference and Criteria Weighting.

Academic 2

Following questionnaire was filled by an expert, marked as Academic 2. The expert has numerous publications in Wind Energy field of study and working on projects directly related to the field. Academic 2 is member of Rüzgar Enerjisi Araştırma Grubu. The Answers were used in order to weight all criteria.

Which of factors below are more important?

Definition	Score
Equally important	1
Slightly more important	3
Much more important	5
Far more important	7
Extremely more important	9

Note: scores 1, 3, 5, 7, 9 are considered as the main evaluation levels, and scores 2, 4, 6, 8 can be also used in order to express the comparison more precisely.

	Main Factors																	
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Economical					x													Planning
Economical					x		A											Physical and Technical
Economical			x															Environmental
Planning													x					Economical
Planning								x										Physical and Technical
Planning							x											Environmental
Physical and Technical													x					Economical
Physical and Technical										x								Planning
Physical and Technical								x										Environmental
Environmental															x			Economical
Environmental													x					Planning
Environmental											x							Physical and Technical

Which of sub-factors below are more important when influence on capital cost is considered?

Definition	Score
Equally important	1
Slightly more important	3
Much more important	5
Far more important	7
Extremely more important	9

Note: scores 1, 3, 5, 7, 9 are considered as the main evaluation levels, and scores 2, 4, 6, 8 can be also used in order to express the comparison more precisely.

	Economical Sub-factors																	
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Highway									x									Electric line cost
Highway															x			Land cost
Electric line cost									x									Highway
Electric line cost												x						Land cost
Land cost		x																Highway
Land cost						x												Electric line cost

Questionnaire was prepared for thesis study 'Site Selection Technique for Wind Turbines Power Plants Utilizing Geographical Information Systems (GIS) and Analytical Hierarchy Process (AHP)', May 2016.

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APPENDIX B.1. Experts' Reference and Criteria Weighting. Academic 2

Which of sub-factors below are more important when site selection for WTP is made according to general planning criteria?

Definition	Score
Equally important	**1**
Slightly more important	**3**
Much more important	**5**
Far more important	**7**
Extremely more important	**9**

Note: scores 1, 3, 5, 7, 9 are considered as the main evaluation levels, and scores 2, 4, 6, 8 can be also used in order to express the comparison more precisely.

	Planning Sub-factors																	
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Distance to railways												x						Airports area
Distance to railways												x						Cities
Distance to railways								x										Towns, villages
Distance to railways								x										World Heritage, archeological monuments and historical places of high importance
Distance to railways								x										Distance to radio and TV stations
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Airport area						x												Distance to railways
Airport area									x									Cities
Airport area						x												Towns and villages
Airport area			x															World Heritage, archeological monuments and historical places of high importance
Airport area						x												Distance to radio and TV stations
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Cities								x										Distance to railways
Cities												x						Airports area
Cities								x										Towns and villages
Cities							x											World Heritage, archeological monuments and historical places of high importance
Cities								x										Distance to radio and TV stations
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Towns and villages										x								Distance to railways
Towns and villages												x						Airports area
Towns and villages											x							Cities
Towns and villages								x										World Heritage, archeological monuments and historical places of high importance
Towns and villages							x											Distance to radio and TV stations
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
World Heritage, archeological monuments and historical places of high importance											x							Distance to railways
World Heritage, archeological monuments and historical places of high importance														x				Airports area
World Heritage, archeological monuments and historical places of high importance												x						Cities

Questionnaire was prepared for thesis study 'Site Selection Technique for Wind Turbines Power Plants Utilizing Geographical Information Systems (GIS) and Analytical Hierarchy Process (AHP)', May 2016.

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APPENDIX B.1. Experts' Reference and Criteria Weighting. Academic 2

World Heritage, archeological monuments and historical places of high importance											x							Towns and villages
World Heritage, archeological monuments and historical places of high importance										x								Distance to radio and TV stations
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Distance to radio and TV stations											x							Distance to railways
Distance to radio and TV stations												x						Airports area
Distance to radio and TV stations										x								Cities
Distance to radio and TV stations										x								Towns and villages
Distance to radio and TV stations							x											World Heritage, archeological monuments and historical places of high importance

Questionnaire was prepared for thesis study 'Site Selection Technique for Wind Turbines Power Plants Utilizing Geographical Information Systems (GIS) and Analytical Hierarchy Process (AHP)', May 2016.

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APPENDIX B.1. Experts' Reference and Criteria Weighting. Academic 2

Which of sub-factors below are more important when site selection of WTP is considered according to physical characteristics of landscape and technical characteristics of wind turbine?

Definition	Score
Equally important	**1**
Slightly more important	**3**
Much more important	**5**
Far more important	**7**
Extremely more important	**9**

Note: scores 1, 3, 5, 7, 9 are considered as the main evaluation levels, and scores 2, 4, 6, 8 can be also used in order to express the comparison more precisely.

	Physical and Technical Sub-factors																	
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Wind energy potential				x														Surface roughness
Wind energy potential			x															Elevation (slope)
Wind energy potential					x													Karst (porous grounds and caves)
Wind energy potential						x												Distance to fault lines
Wind energy potential		x																Distance to mining sites
Surface roughness														x				Wind energy potential
Surface roughness								x										Elevation (slope)
Surface roughness								x										Karst (porous grounds and caves)
Surface roughness										x								Distance to fault lines
Surface roughness								x										Distance to mining sites
Elevation (slope)															x			Wind energy potential
Elevation (slope)								x										Surface roughness
Elevation (slope)										x								Karst (porous grounds and caves)
Elevation (slope)													x					Distance to fault lines
Elevation (slope)								x										Distance to mining sites
Karst (porous grounds and caves)													x					Wind energy potential
Karst (porous grounds and caves)									x									Surface roughness
Karst (porous grounds and caves)								x										Elevation (slope)
Karst (porous grounds and caves)												x						Distance to fault lines
Karst (porous grounds and caves)										x								Distance to mining sites
Distance to fault lines												x						Wind energy potential
Distance to fault lines								x										Surface roughness
Distance to fault lines						x												Elevation (slope)
Distance to fault lines							x											Karst (porous grounds and caves)
Distance to fault lines						x												Distance to mining sites
Distance to mining sites																x		Wind energy potential
Distance to mining sites												x						Surface roughness
Distance to mining sites											x							Elevation (slope)
Distance to mining sites											x							Karst (porous grounds and caves)
Distance to mining sites														x				Distance to fault lines

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APPENDIX B.1. Experts' Reference and Criteria Weighting. Academic 2

Which of sub-factors below are more important when site selection of WTP is considered according to environmental sub-factors?

Definition	Score
Equally important	**1**
Slightly more important	**3**
Much more important	**5**
Far more important	**7**
Extremely more important	**9**

Note: scores 1, 3, 5, 7, 9 are considered as the main evaluation levels, and scores 2, 4, 6, 8 can be also used in order to express the comparison more precisely.

	Environmental Sub-factors																	
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
River/canal, waterbodies									x									Bird habitats/routs
River/canal, waterbodies										x								Woodland
Bird habitats/routs									x									River/canal, waterbodies
Bird habitats/routs												x						Woodland
Woodland								x										River/canal, waterbodies
Woodland							x											Bird habitats/routs

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APPENDIX B.1. AHP Calculations

Academic 2:

Main Criteria:

1. Pair-wise comparison matrix is constructed.

	ECO	**PLN**	**PHS/TECH**	**ENV**
Economical`	1.00	5.00	5.00	7.00
Planning	0.20	1.00	2.00	3.00
Physical and Technical	0.20	0.50	1.00	2.00
Environmental	0.14	0.33	0.50	1.00
	1.54	**6.83**	**8.50**	**13.00**

2. Normalized matrix

	ECO	**PLN**	**PHS/TECH**	**ENV**	**SUM**	$\boldsymbol{\varpi}$
ECO	0.648	0.732	0.588	0.538	2.507	0.627
PLN	0.130	0.146	0.235	0.231	0.742	0.186
PHS/TECH	0.130	0.073	0.118	0.154	0.474	0.119
ENV	0.093	0.049	0.059	0.077	0.277	0.069

3. Matrix $\lambda = A * \varpi$

$$\lambda = A * \varpi = \begin{bmatrix} 1.000 & 5.000 & 5.000 & 7.000 \\ 0.200 & 1.000 & 2.000 & 3.000 \\ 0.200 & 0.500 & 1.000 & 2.000 \\ 0.143 & 0.333 & 0.500 & 1.000 \end{bmatrix} * \begin{bmatrix} 0.627 \\ 0.186 \\ 0.119 \\ 0.069 \end{bmatrix} = \begin{bmatrix} 2.632 \\ 0.756 \\ 0.475 \\ 0.280 \end{bmatrix}$$

4. Consistency ratio check

$$\lambda'_n = \lambda_n / \varpi_n$$

$$\lambda' = \begin{bmatrix} 4.200 \\ 4.074 \\ 4.008 \\ 4.040 \end{bmatrix}$$

$$\lambda'_{max} = \frac{\sum \lambda'}{n} = 4.0807$$

$$CI = \frac{\lambda_{max} - n}{n - 1} = 0.0269$$

$RI = 0.9$ (see Figure 2.3)

$$CR = \frac{CI}{RI} = 0.0299 < 0.10$$

Economic Sub-Criteria:

1. Pair-wise comparison matrix is constructed.

	HGW	ELC	LC
Highway	1.000	2.000	0.200
Electric line Cost	0.500	1.000	0.250
Land Cost	5.000	4.000	1.000
	6.500	**7.000**	**1.450**

2. Normalized matrix

	HGW	ELC	LC	SUM	ϖ
HGW	0.154	0.286	0.138	0.577	0.192
ELC	0.077	0.143	0.172	0.392	0.131
LC	0.769	0.571	0.690	2.030	0.677

3. Matrix $\lambda = A * \varpi$

$$\lambda = A * \varpi = \begin{bmatrix} 1.000 & 2.000 & 0.200 \\ 0.500 & 1.000 & 0.250 \\ 5.000 & 4.000 & 1.000 \end{bmatrix} * \begin{bmatrix} 0.192 \\ 0.131 \\ 0.677 \end{bmatrix} = \begin{bmatrix} 0.589 \\ 0.396 \\ 2.162 \end{bmatrix}$$

4. Consistency ratio check

$$\lambda'_n = \lambda_n / \varpi_n$$

$$\lambda' = \begin{bmatrix} 3.061 \\ 3.030 \\ 3.195 \end{bmatrix}$$

$$\lambda'_{max} = \frac{\sum \lambda'}{n} = 3.096$$

$$CI = \frac{\lambda_{max} - n}{n - 1} = 0.048$$

$RI = 0.58$ (see Figure 2.3)

$$CR = \frac{CI}{RI} = 0.0824 < 0.10$$

Planning Sub-Criteria:

1. Pair-wise comparison matrix is constructed.

	RLW	ARP	CT	VLL	ARCH	RD/TV
Distance to railways	1.000	0.250	0.500	2.000	2.000	2.000
Airport area	4.000	1.000	2.000	4.000	7.000	4.000
Cities	2.000	0.500	1.000	2.000	3.000	2.000
Towns and villages	0.500	0.250	0.500	1.000	2.000	3.000
World Heritage, archeological monuments and historical places of high importance	0.500	0.143	0.333	0.500	1.000	0.500
Distance to radio and TV stations	0.500	0.250	0.500	0.333	2.000	1.000
	8.50	**2.39**	**4.83**	**9.83**	**17.00**	**12.50**

2. Normalized matrix

	RLW	ARP	CT	VLL	ARCH	RD/TV	SUM	ϖ
RLW	0.118	0.104	0.103	0.203	0.118	0.160	0.807	0.134
ARP	0.471	0.418	0.414	0.407	0.412	0.320	2.441	0.407
CT	0.235	0.209	0.207	0.203	0.176	0.160	1.191	0.199
VLL	0.059	0.104	0.103	0.102	0.118	0.240	0.726	0.121
ARCH	0.059	0.060	0.069	0.051	0.059	0.040	0.337	0.056
RD/TV	0.059	0.104	0.103	0.034	0.118	0.080	0.498	0.083

3. Matrix $\lambda = A * \varpi$

$$\lambda = A * \varpi = \begin{bmatrix} 1.000 & 0.250 & 0.500 & 2.000 & 2.000 & 2.000 \\ 4.000 & 1.000 & 2.000 & 4.000 & 7.000 & 4.000 \\ 2.000 & 0.250 & 1.000 & 2.000 & 3.000 & 2.000 \\ 0.500 & 0.250 & 0.500 & 1.000 & 2.000 & 3.000 \\ 0.500 & 0.143 & 0.333 & 0.500 & 1.000 & 0.500 \\ 0.500 & 0.250 & 0.500 & 0.333 & 2.000 & 1.000 \end{bmatrix} * \begin{bmatrix} 0.134 \\ 0.407 \\ 0.199 \\ 0.121 \\ 0.056 \\ 0.083 \end{bmatrix} = \begin{bmatrix} 0.856 \\ 0.551 \\ 1.247 \\ 0.751 \\ 0.350 \\ 0.504 \end{bmatrix}$$

4. Consistency ratio check

$$\lambda'_n = \lambda_n / \varpi_n$$

$$\lambda' = \begin{bmatrix} 6.367 \\ 6.271 \\ 6.285 \\ 6.204 \\ 6.224 \\ 6.068 \end{bmatrix}$$

$$\lambda'_{max} = 6.2363$$

$$CI = \frac{\lambda_{max} - n}{n - 1} = 0.0473$$

$$RI = 1.24 \text{ (see Figure 2.3)}$$

$$CR = \frac{CI}{RI} = 0.0381 < 0.10$$

Physical and Technical Sub-Criteria:

1. Pair-wise comparison matrix is constructed.

	WE	SR	ELV	KRS	DFL	DMS
Wind energy potential	1.000	6.000	7.000	5.000	4.000	8.000
Surface roughness	0.167	1.000	2.000	2.000	0.500	2.000
Elevation (Slope)	0.143	0.500	1.000	0.500	0.250	2.000
Karst (porous grounds and caves)	0.200	0.500	2.000	1.000	0.333	0.500
Distance to fault lines	0.250	2.000	4.000	3.000	1.000	4.000
Distance to mining sites	0.125	0.500	0.500	2.000	0.250	1.000
	1.88	**10.50**	**16.50**	**13.50**	**6.33**	**17.50**

2. Normalized matrix

	WE	SR	ELV	KRS	DFL	DMS	SUM	ϖ
WE	0.531	0.571	0.424	0.370	0.632	0.457	2.985	0.498
SR	0.088	0.095	0.121	0.148	0.079	0.114	0.646	0.108
ELV	0.076	0.048	0.061	0.037	0.039	0.114	0.375	0.062
KRS	0.106	0.048	0.121	0.074	0.053	0.029	0.430	0.072
DFL	0.133	0.190	0.242	0.222	0.158	0.229	1.174	0.196
DMS	0.066	0.048	0.030	0.148	0.039	0.057	0.389	0.065

3. Matrix $\lambda = A * \varpi$

$$\lambda = A * \varpi = \begin{bmatrix} 1.000 & 6.000 & 7.000 & 5.000 & 4.000 & 8.000 \\ 0.167 & 1.000 & 2.000 & 2.000 & 0.500 & 2.000 \\ 0.143 & 0.500 & 1.000 & 0.500 & 0.250 & 2.000 \\ 0.200 & 0.500 & 2.000 & 1.000 & 0.333 & 0.500 \\ 0.250 & 2.000 & 4.000 & 3.000 & 1.000 & 4.000 \\ 0.125 & 0.500 & 0.500 & 2.000 & 0.250 & 1.000 \end{bmatrix} * \begin{bmatrix} 0.498 \\ 0.108 \\ 0.062 \\ 0.072 \\ 0.196 \\ 0.065 \end{bmatrix} = \begin{bmatrix} 3.241 \\ 0.687 \\ 0.402 \\ 0.448 \\ 1.260 \\ 0.404 \end{bmatrix}$$

4. Consistency ratio check

$$\lambda'_n = \lambda_n / \varpi_n$$

$$\lambda' = \begin{bmatrix} 6.514 \\ 6.374 \\ 6.433 \\ 6.243 \\ 6.437 \\ 6.238 \end{bmatrix}$$

$$\lambda'_{max} = 6.3732$$

$$CI = \frac{\lambda_{max} - n}{n - 1} = 0.0746$$

$RI = 1.24$ (see Figure 2.3)

$$CR = \frac{CI}{RI} = 0.0602 < 0.10$$

Environmental Sub-Criteria:

5. Pair-wise comparison matrix is constructed.

	WB	BH	WDL
River/canal, waterbodies	1.000	2.000	0.500
Bird habitats/routs	0.500	1.000	0.333
Woodland	2.000	3.000	1.000
	3.50	**6.00**	**1.83**

6. Normalized matrix

	WB	BH	WDL	SUM	ϖ
WB	0.286	0.333	0.273	0.892	0.297
BH	0.143	0.167	0.182	0.491	0.164
WDL	0.571	0.500	0.545	1.617	0.539

7. Matrix $\lambda = A * \varpi$

$$\lambda = A * \varpi = \begin{bmatrix} 1.000 & 2.000 & 0.500 \\ 0.500 & 1.000 & 0.333 \\ 2.000 & 3.000 & 1.000 \end{bmatrix} * \begin{bmatrix} 0.297 \\ 0.164 \\ 0.539 \end{bmatrix} = \begin{bmatrix} 0.894 \\ 0.492 \\ 1.625 \end{bmatrix}$$

8. Consistency ratio check

$$\lambda'_n = \lambda_n / \varpi_n$$

$$\lambda' = \begin{bmatrix} 3.008 \\ 3.004 \\ 3.015 \end{bmatrix}$$

$$\lambda'_{max} = \frac{\sum \lambda'}{n} = 3.0092$$

$$CI = \frac{\lambda_{max} - n}{n - 1} = 0.0046$$

$RI = 0.58$ (see Figure 2.3)

$$CR = \frac{CI}{RI} = 0.0079 < 0.10$$

APPENDIX B.2: Questionnaires' Samples

Evaluation Method

On the following pages you will be asked to evaluate factors and sub-factors of the most suitable site selection for wind turbine plants (WTP). Evaluation process consists of pairwise comparison of all main factors and sub-factors that must be considered during site selection for WTP. Furthermore , to simplify the process of explanation scale from 1 to 9 was utilized in order to show the importance of one factors over others. Scores assigned are explained below.

Score Ratings and Interpretation.

Definition	Score
Equally important	**1**
Equally or slightly more important	2
Slightly more important	**3**
Slightly to much more important	4
Much more important	**5**
Much to far more important	6
Far more important	**7**
Far more important to extremely more important	8
Extremely more important	**9**

Note: scores 1, 3, 5, 7, 9 are considered as the main evaluation levels, and scores 2, 4, 6, 8 can be also used in order to express the comparison more precisely.

Evaluation Samples:

Which of factors mentioned below affects the site selection for WTP more? If you think that "Electric Line Cost" sub-factor is equally important that "Highways (roads)" from economical perspective, 1 should be assigned for this question. In other words, if proximity to electricity lines might influence on capital cost in the same way as proximity to highways and roads, then 1 is the right answer.

	Economical Sub-factors																	
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Electric line cost									x									Highway

In contrast, if you consider "Touristic places" far more important than "Cities", then 7 must be assigned.

	Planning Subfactors																	
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Touristic Places			x															Cities

Questionnaire was prepared for thesis study 'Site Selection Technique for Wind Turbines Power Plants Utilizing Geographical Information Systems (GIS) and Analytical Hierarchy Process (AHP)', May 2016.

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APPENDIX B.2: Questionnaires' Samples

Which of factors below are more important?

Definition	Score
Equally important	**1**
Slightly more important	**3**
Much more important	**5**
Far more important	**7**
Extremely more important	**9**

Note: scores 1, 3, 5, 7, 9 are considered as the main evaluation levels, and scores 2, 4, 6, 8 can be also used in order to express the comparison more precisely.

	Main Factors																	
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Economical																		Planning
Economical																		Physical and Technical
Economical																		Environmental
Planning																		Economical
Planning																		Physical and Technical
Planning																		Environmental
Physical and Technical																		Economical
Physical and Technical																		Planning
Physical and Technical																		Environmental
Environmental																		Economical
Environmental																		Planning
Environmental																		Physical and Technical

Which of sub-factors below are more important when influence on capital cost is considered?

Definition	Score
Equally important	**1**
Slightly more important	**3**
Much more important	**5**
Far more important	**7**
Extremely more important	**9**

Note: scores 1, 3, 5, 7, 9 are considered as the main evaluation levels, and scores 2, 4, 6, 8 can be also used in order to express the comparison more precisely.

	Economical Sub-factors																	
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Highway																		Electric line cost
Highway																		Land cost
Electric line cost																		Highway
Electric line cost																		Land cost
Land cost																		Highway
Land cost																		Electric line cost

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APPENDIX B.2: Questionnaires' Samples

Which of sub-factors below are more important when site selection for WTP is made according to general planning criteria?

Definition	Score
Equally important	1
Slightly more important	3
Much more important	5
Far more important	7
Extremely more important	9

Note: scores 1, 3, 5, 7, 9 are considered as the main evaluation levels, and scores 2, 4, 6, 8 can be also used in order to express the comparison more precisely.

	Planning Sub-factors																	
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Distance to railways																		Airports area
Distance to railways																		Cities
Distance to railways																		Towns, villages
Distance to railways																		World Heritage, archeological monuments and historical places of high importance
Distance to railways																		Distance to radio and TV stations
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Airport area																		Distance to railways
Airport area																		Cities
Airport area																		Towns and villages
Airport area																		World Heritage, archeological monuments and historical places of high importance
Airport area																		Distance to radio and TV stations
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Cities																		Distance to railways
Cities																		Airports area
Cities																		Towns and villages
Cities																		World Heritage, archeological monuments and historical places of high importance
Cities																		Distance to radio and TV stations
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Towns and villages																		Distance to railways
Towns and villages																		Airports area
Towns and villages																		Cities
Towns and villages																		World Heritage, archeological monuments and historical places of high importance
Towns and villages																		Distance to radio and TV stations
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
World Heritage, archeological monuments and historical places of high importance																		Distance to railways
World Heritage, archeological monuments and historical places of high importance																		Airports area
World Heritage, archeological monuments and historical places of high importance																		Cities

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	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
World Heritage, archeological monuments and historical places of high importance																		Towns and villages
World Heritage, archeological monuments and historical places of high importance																		Distance to radio and TV stations
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Distance to radio and TV stations																		Distance to railways
Distance to radio and TV stations																		Airports area
Distance to radio and TV stations																		Cities
Distance to radio and TV stations																		Towns and villages
Distance to radio and TV stations																		World Heritage, archeological monuments and historical places of high importance

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APPENDIX B.2: Questionnaires' Samples

Which of sub-factors below are more important when site selection of WTP is considered according to physical characteristics of landscape and technical characteristics of wind turbine?

Definition	Score
Equally important	**1**
Slightly more important	**3**
Much more important	**5**
Far more important	**7**
Extremely more important	**9**

Note: scores 1, 3, 5, 7, 9 are considered as the main evaluation levels, and scores 2, 4, 6, 8 can be also used in order to express the comparison more precisely.

	Physical and Technical Sub-factors																	
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Wind energy potential																		Surface roughness
Wind energy potential																		Elevation (slope)
Wind energy potential																		Karst (porous grounds and caves)
Wind energy potential																		Distance to fault lines
Wind energy potential																		Distance to mining sites
Surface roughness																		Wind energy potential
Surface roughness																		Elevation (slope)
Surface roughness																		Karst (porous grounds and caves)
Surface roughness																		Distance to fault lines
Surface roughness																		Distance to mining sites
Elevation (slope)																		Wind energy potential
Elevation (slope)																		Surface roughness
Elevation (slope)																		Karst (porous grounds and caves)
Elevation (slope)																		Distance to fault lines
Elevation (slope)																		Distance to mining sites
Karst (porous grounds and caves)																		Wind energy potential
Karst (porous grounds and caves)																		Surface roughness
Karst (porous grounds and caves)																		Elevation (slope)
Karst (porous grounds and caves)																		Distance to fault lines
Karst (porous grounds and caves)																		Distance to mining sites
Distance to fault lines																		Wind energy potential
Distance to fault lines																		Surface roughness
Distance to fault lines																		Elevation (slope)
Distance to fault lines																		Karst (porous grounds and caves)
Distance to fault lines																		Distance to mining sites
Distance to mining sites																		Wind energy potential
Distance to mining sites																		Surface roughness
Distance to mining sites																		Elevation (slope)
Distance to mining sites																		Karst (porous grounds and caves)
Distance to mining sites																		Distance to fault lines

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APPENDIX B.2: Questionnaires' Samples

Which of sub-factors below are more important when site selection of WTP is considered according to environmental sub-factors?

Definition	Score
Equally important	**1**
Slightly more important	**3**
Much more important	**5**
Far more important	**7**
Extremely more important	**9**

Note: scores 1, 3, 5, 7, 9 are considered as the main evaluation levels, and scores 2, 4, 6, 8 can be also used in order to express the comparison more precisely.

	Environmental Sub-factors																	
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
River/canal, waterbodies																		Bird habitats/routs
River/canal, waterbodies																		Woodland
Bird habitats/routs																		River/canal, waterbodies
Bird habitats/routs																		Woodland
Woodland																		River/canal, waterbodies
Woodland																		Bird habitats/routs

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