LOCATION THEORY BASED WIND ENERGY SYSTEM PLANNING

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ABSTRACT

Wind Energy is the one of the fastest growing renewable energy in the last two decades. Besides having the most rapid growth, wind energy has become a big part of the energy consumed globally. However, some of the key factors for a successful wind power project can be overlooked at times, leading to the failure of such projects and posing negative effects on its contribution. This project studies the key parameters that are crucial in the process of selecting potential location for optimal success in wind power planning at its initial stage. The aim is to build a model that can be generally applied during wind power planning. A multi-criteria decision making tool: Analytic Hierarchy Process (AHP) is implemented using Saaty scale ranging from 1-9 to form pairwise comparisons and evaluate the weightage of each criteria. The result shows the priorities of the parameters and their significance, indicating the order of which they should be carried out during planning process.

ABSTRACK

Tenaga angin adalah salah satu tenaga boleh diperbaharui yang pesat membangun sejak dua dekad yang lepas. Selain daripada pembangunan yang pesat, tenaga angin juga menjadi satu bahagian yang penting dalam penggunaan tenaga dunia. Namun demikian, terdapat faktor-faktor penting yang boleh menjayakan projek tenaga angin sering diabaikan, mengakibatkan kegagalan projek dan mendatangkan kesan negatif dalam sumbangannya. Projek ini mengkaji parameter yang penting dalam memilih lokasi yang berpotensi untuk kejayaan optimum dalam perancangan peringkat awal. Tujuan projek adalah membina satu model yang boleh digunakan secara umum semasa membuat perancangan projek tenaga angin. Satu kaedah membuat keputusan pelbagai kriteria (multi-criteria decision making tool): *Analytic Hierarchy Process (AHP)* dengan scala Saaty (Saaty scale) berjulat 1-9 digunnakan untuk membentuk bandingan berpasangan (pairwise comparisons) dan menilai pemberat setiap kriteria. Keputusan kajian menunjukkan susunan tertib parameter yang akan diambilkira semasa proses perancangan dijalankan mengikut keutamaan dan kepenting parameter tersebut.

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LIST OF SYMBOLS AND ABBREVIATIONS

v_o	-	Initial velocity
v	-	Velocity
h_o	-	Initial height
h	-	Height
α	-	Roughness coefficient
z_o	-	Surface roughness length
P_d	-	Power density
P	-	Air density
P	-	Surface pressure
R	-	Specific gas content
T_o	-	Initial temperature
T	-	Temperature
∑	-	Summation
MSL	-	Mean sea level
AHP	-	Analytic hierarchy process
WPF	-	Wind probability density Function
WDP	-	Wind power density

CHAPTER 1

INTRODUCTION

1.1 Wind Energy Today

The push towards carbon emission free energy impacted significantly on production of renewable energy. Availability of wind as a free unlimited resource created high interest in the field which encourages research and development in the industry. The reason that wind power has growth in such tremendous pace among renewable energy is because wind technology has evolved significantly in the last two decades. Generation of electricity from wind has seen potential to reduce environmental impacts caused by hydrocarbon fuels. It is forecasted that wind power are able to reduce electricity prices due to its low marginal cost, phasing out more expensive power alternatives in the market (EWEA, 2010).

In 1997, Japan initiated the Kyoto Protocol after growing concerns of the effects from environment pollution. The aim of the protocol is to raise awareness of global warming issues and to reduce the emission of green house gases. By year 2010, the protocol was signed up by 191states (countries). Under the Kyoto protocol, countries are obligated to reduce and manage their green house gases according to ratified targets. Taking effects are the renewable energy policies established in countries setting wind energy production targets in short term and long term development. The European Union with a history of twenty years in wind industry has set a 20% wind energy production of total energy production by 2020 (EWEA, 2010). American Wind Energy Association calls for 25% of electricity to be produced from wind energy by 2025 (Saidur et al., 2010). From there, electricity generated by wind energy in the United States has been almost none in the 1980 to more than 11MW in 2006 (NAP, 2007). China has set 15% of wind energy production by 2020 (NDRC, 2007). This has become the solid push that has fueled the rapid renewable energy development in the past decade.

The development of wind energy surpasses all other renewable sector as one of the world's biggest renewable energy output (Figure. 1.1). Furthermore, wind energy has chosen to be the focus of renewable energy development in the next few decades.

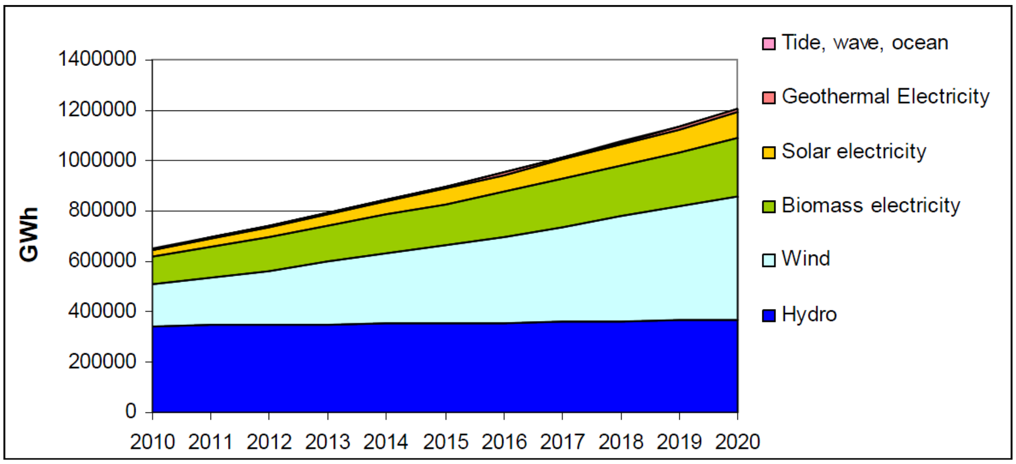

Figure 1.1: EU development of renewable energy in electricity (COM, 2011)

Although there has been vast development in this field, wind energy has yet to develop to its full potential. The improvement in technology has allowed wind farm projects to see positive effects on electricity generation. But due to the short history of wind energy, wind projects have been more or less in the experimental stage.

We are still vulnerable to the nature processes and face problems in the reliability of wind energy. Wind does not always come as fast or blows from the same direction all year long. Neither does it provide sufficient available energy output to be harnessed wherever it blows. It is because of this unique and complex characteristic of wind, all aspects concerning this field are still in developmental process. This project focused on the assessing the important parameters in the process of selecting potential site for optimal success in wind power planning at its initial stage.

In general, wind farm development can be divided into a few stages (Wizelius, 2007 & Burton, 2001):

1. Survey and initial site selection
2. Feasibility study
3. Preparation and Submission of planning application
4. Construction
5. Operation
6. Decommissioning

Survey and initial site selection is the foremost step in wind farm development. It concludes whether a location is suitable for wind energy development and also marks the starting point of wind energy project. Usually wind data are collected to produce an approximate indication of the wind energy output to confirm the potential site (Wizelius, 2007). Studies revealed that a minimum of one year wind data is required to effectively forecast the wind characteristic of a location (Jafarian, Soroudi.& Ehsan, 2008).

Usually, initial assessment also comprises of environmental considerations. After the assessment of a potential site, developer should be able to know:

- Distributions of hourly mean wind speeds and directions.
- The mean wind speed versus time pattern
- Mean air density, seasonal mean temperatures
- Terrain and surface roughness characteristics in the neighborhood
- Surrounding structures, and resident proximity
- Noise and visual impact
- Grid infrastructure and availability to site

1.1 Problem Statement

Current wind farm projects take substantial amount of time to realise that commonly lead to years before a wind turbine is erected. This is mainly contributed by the fact that all potential locations within the proposed area have to be analysed very carefully, given a large numbers of factors. The full individual studies of these locations are the reason behind the long planning duration. Each analysis of the relevant factors are evaluated and agreed upon before any decision is finalized. This is practiced for all wind farm projects. However, some of the key factors for a successful wind farm project can be overlooked at times, leading to the failure of such projects (Liao, Jochem, Zhang & Farid, 2010). It is best desired if a planning model is presented so that the planning process can be shorten as it will save cost and provide efficient energy sooner while still giving stress to important factors that should not be overlooked or neglected.

With the growing population of wind farms around the globe, potential locations for wind development are decreasing every year. Added with safety reasons, political and environmental issues, wind development policies are written with restrictions for wind farm development. Due to this, the theoretical potential of the exploitable wind energy are reduced drastically with the limited coastal, land and sea area, not to mention future development that might hinder wind farm progress. It is in the best interest that each investment in wind farm development will contribute to an efficient green energy as a worthy return. All of these goes down to the best suited wind farm site selection.

To date, no considerate number of models has been designed to cover the overall requirement of a wind farm planning. Majority of the models mainly focus on feasibility of wind energy penetration and wind characteristic pairing with wind turbine generators. All of these are only partial considerations of what should actually be included into a wind farm site selection progress. The development of such model allows fluent planning in wind farm project.

1.2 Objectives of the thesis

This project is directed towards creating a model aiming to prioritise the key parameters in assessing a wind site during initial planning stage. The objectives of this project are;

- To magnify the parameters which are of significant importance
- Identify and classify relevant parameters – key parameter recognition and simplification
- Develop a criteria success model using multi-decision making model

1.3 Thesis Outline

This thesis consists of 6 chapters. The current chapter mainly presents the background, the objectives and significance of this study. It also provides the general development of wind farm and its benefiting contribution towards electricity production globally.

Chapter 2 consists of current methods used to assess the feasibility of a wind farm location. This includes all studies that are of relevance in the potential wind resources assessment.

Chapter 3 will detail about Multi-Criteria Decision Making: Analytic Hierarchy Process (AHP). As this study implemented AHP in the process to produce the final result, procedures and method will be discussed here. Usage of AHP is very wide covering, hence, their numerous applications are also discussed here.

Chapter 4 discussed the methodology that is used for this study. It details the process that has actually been carried out for the short listing of parameters and the steps taken to build the AHP model for this study.

Chapter 5 details the analysis and result of the study. Each chosen parameter is assessed individually and related detailed calculation is executed to see their impact on energy production of a wind farm. Pair-wise comparison and the results are also discussed in this section.

Chapter 6 discusses and concludes the findings of this thesis, and reviews parameters of future development.

CHAPTER 2

WIND ENERGY

2.1 Wind Energy Development

Wind energy created a new trend for renewable energy three decades ago. The harnessing of wind energy dated back as far as a few centuries ago, with the creation of windmill. However, the true development of the wind technology didn't happen until the 1970's. This is partially contributed by the awareness of earth's diminishing natural resources and political pressure to find other inexhaustible alternatives. The situation peaked when the world was hit with the oil crisis in 1973 and the price of oil rocketed overnight globally. Severity of the condition was push further when the issues of pollution and over exploitation of the earth resources arise.

Being one of the world most successful renewable energy, the installations of wind farm around the globe is going at an astonishing rate. Large amount of money is being invested into research to develop better turbines in hopes that the energy can be efficiently produced and harvested in the most cost-efficient ways. Generation of electricity from wind has seen potential to reduce environmental impacts caused by hydrocarbon fuels. The growth of wind technology in the past two decades has evolved to a point where it can compete with conventional forms of power generations at good wind location. Furthermore, it is forecasted that wind power are able to reduce electricity prices due to its low marginal cost, phasing out more expensive power alternatives in the market (EWEA, 2009). Although much of the attention in wind energy production is given to the turbine technology, it is actually the location of the installation itself which will give the best return for the technology given.

Size of wind farms have become increasingly large; growing from single unit installations to hundreds of wind turbine generators units for a single wind farms. The capacity started from tens of kilowatts to the current largest onshore installation of few hundred megawatts. Such installation covers a vast area up to hundreds of square kilometers. The current largest onshore wind farm is Roscoe Wind Farm in United States at an installed capacity at 781.5MW with an area of 400km^2.

Europe has the longest history in wind power development and also holds the biggest share in wind energy at 53% (2009) globally. Although Denmark is the earliest country to harvest wind energy and incorporate it into their national grid, United States is currently holding the highest installed capacity globally. Electricity generated by wind energy in the 1980 has been almost none to more than 11MW in 2006 (National Research Council, 2007). The development of wind energy has surpasses all other renewable sector as one of the world's biggest renewable energy output. The slow development of wind projects seen in Denmark in the past few years is due to the saturated level of land usage. Good wind locations have already been occupied by previous wind energy projects and older wind turbines can only be put out of commissioning upon reaching contracted period.

In such case, new turbines with better technology and higher efficiency are put in place at the same location upon decommissioning of older turbines for better energy harvest. Such plan seemed good as good wind site will always be harvested for energy with increased efficiency. However, wind development can only see positive effects when it is installed at large capacity. With the increasing demand in electricity, such installations put wind energy development at a flat line. Lowering the cost of wind energy requires mass production of wind turbines to boost the market and this is achievable through large wind energy projects (Wizelius, 2006). Such trend can be seen from the current development of wind farm. By stating that, good location is crucial to expand wind energy harvest as much as possible. Exploitations of all potential sites are being carried out to enable optimum harnessing of wind energy and this requires proper planning even at an early stage.

2.2 Wind Policy Development

Generally, development of all new technology and implementation requires the public support. This also similarly applies to installation of renewable wind energy in a country. After signing the Kyoto Protocol, policies and regulations are individually planned and formed to promote research and development of the energy. Many aspects are to be considered for the success of a wind project: technical and non-technical. The non-technical part involves environmental issues, population's concern and among all government policy restriction where as the technical part includes the wind turbine generator, and the entire electrical system requirement to support the wind project.

Loring's (2006) stated there is high level of general support for the development of wind energy. Still, in the process of determining new wind project applications, local authorities have to balance the needs and views of the local public with the broader national targets and guidance for renewable energy. In another study, Hindmarsh (2010) found that wind energy faced difficulty to develop in Australia due to lack of community engagement. This is mainly caused by social conflict surrounding wind farm location. Past experience shows that social acceptance is crucial for the successful development of wind energy. Social research has been widely carried out globally and was found to focus on three main points (EWEA, 2009);

1. Assessment of the levels of public support for wind energy
2. Identification of and understanding the social response at the local level
3. Analysis of the key issues involved in social acceptance by key stakeholders and policy makers

Hindmarsh's work proved that negative attitudes towards wind energy leads authority towards stricter regulation indirectly obstruct the progress of wind energy development at some places. Typically, policy making process involved the general public consultation from the beginning and the involvement continues until the commissioning stage of a wind farm. Policy developed typically categorised the type of land acceptable for wind energy development, limiting the shadow flicker and noise from wind turbine generator, benefits of the community from the project, feed-in tariffs and et cetera.

2.3 Wind Resource Assessment

Throughout the years, numerous methods have been proposed and implemented to seek suitable wind site. Usually several years of wind data for a site is required but it is often expensive to collect such long term data and difficult for remote location. Analysis of recorded wind speed data has provided aid in estimating wind potential at site. Various methods have evolved and improved by researchers. In all, Weibull Probability Density Function (WPF) used to represent the cubic mean cube root of wind speed gives reliable estimation of wind power potential (Stannard & Bumby, 2006).

Doddamani and Jangamshetti (2008) used WPF in their study to match the potential location with most suitable wind turbine generator to find the best returns in terms of economy index. The success of a wind farm relates to how much energy is produced at a site, hence the parameters that they used in their study is important. Mainly focusing on the economic index, they utilised wind data gathered at site to produce the WPF to match with the capacity ratings and power curve of the wind turbine generator. The main focus here is only on the wind data manipulation: how they assess the energy produce and how the best match location-wind turbine is found.

Jafarian, Soroudi and Ehsan (2008) studied the effect of different environmental parameters on annual produced electrical energy by wind turbine. Hourly wind speed and wind turbine are simulated to produce annual power production. The wind speed data created here was also represented using WPF. In the study, one parameter is changed after a complete simulation and the effect of the changed parameter is studied carefully. Among the parameters included that are relevance for this study is; wind speed annual average, altitude above sea level, wind speed monthly averages variance in one year. Of the simulated results, electrical power produced has a linear pattern with respect to altitude above sea level. This means that altitude above sea level which affects the air density have importance effects on power produced by wind turbine.

Rehman, Halawani and Mohandes (2003) conducted another study to assess the wind power at twenty locations in the Kingdon of Saudi Arabia. Hourly wind speed data for period of 5.5 to 13 years were collected for all 20 locations in this study. This included mean, maximum, minimum values of wind speed, wind direction, relative humidity and even cloud type. From the data, WPF curves were developed to analyse energy yield and wind turbine ratings were used to calculate annual energy yield with WPF curves. The cost of installation is also included as part of the study. Wind duration analysis is concluded as an important aspect to be considered while selecting a site for developing wind farm.

Rehman (2004) studied the unadjusted energy, gross energy specific yield and capacity factor to present energy output of a wind farm. Meteorological measurements for a period of 14 yrs were used for five locations at height of 10m. The study uses two different methods in combination with energy production curve of wind turbine to predict energy output for the locations. The site specific mean wind speed temperature and surface pressure are used as input in the methods. Gross energy and energy delivered to the distribution grid is calculated and taken into analysis. The study focused on the economic feasibility of the location according to the parameters studied and thus determined the suitable location,

From a different study, wind shear coefficients and its effect on energy production are analysed (Rehman & Al-Abbadi, 2005). Wind data for duration of three years were used in this study and the study focused primarily on the effects of wind shear factors on the energy production with contributing element such as air density values, measured air temperatures, and surface pressure. Geological and meteorological date were collected for different heights and analysed in the study to determine if there is any difference in the energy output. The study concluded that air density is an important parameter for wind power density calculation.

Rehman et al (2007) determined the wind energy potential for a remote village in Saudi Arabia using wind measurements. In their study, wind speeds were recorded at 20, 30 and 40m above ground level (AGL). Other meteorological parameters such as ambient temperature, pressure, relative humidity and global solar radiation were measured at 2m AGL. From the data, seasonal variation of wind speed and mean wind power density were tabulated. It is stated that wind speed increase with height, and wind shear coefficient at site is not constant and varied with season affecting energy production. Other parameter that directly affects the energy production estimates is the air density.

In another study, Rehman, Ahmad and Al-Hadhrami (2010) conducted a study on developing and assessing a wind farm at a location in Saudi Arabia with more complete coverage. Wind farm is usually remotely located from development except for urban wind energy. The assessment of the proposed wind farm includes consideration of type of land surface, area required for the installation of wind turbines, wind turbine model selections, micro-sitting of wind turbines, noise contours of the wind turbines, wind power generated based on wind data collected, investment cost and also energy production and maintenance cost. The result of the study justified the location proposed in the study is feasible. Based on the point of high annual wind speed, the location is decided optimum for wind energy harnessing.

Gualtieri and Secci (2010) presented a work that studied the terrain effect on wind power production. The study used wind data of 6 years observation at two different heights in southern Italy. Parameters analysed included wind shear coefficients and roughness length. In the process, the European land classification has been employed to investigate the land use influence on studied parameters. Furthermore, temperatures and pressure surface measurements were used to compute specific air density and monthly variations. Wind resources have been analysed using WPF for energy yield. Comparisons were performed to assess the discrepancy of output at different heights. It is stated that detailed topography and land use at surroundings area are deemed to be necessary and important.

The analysis of terrain effect for selection of proper location for installment of wind power plants is carried out in 2010 by Ambia et al. Wind speed data at eight different sites were collected from the Meteorological Department of Bangladesh and were analysed at different height to select best possible season of the year proposing to utilise wind turbine effectively. Here, wind speed data were collected over a year and standard wind speed deviation were used to calculate wind speed at different height to eliminate low wind locations. The terrain effect of each the location is also analysed and they concluded that flat terrain is most desirable to increase energy yield for a wind farm.

Murakami, Mochida and Kato (2003) developed a local area wind prediction system for selecting suitable site for the wind turbines projects. The model aimed to provide an accurate prediction of the wind energy distribution for the installation of wind turbine at hilly or mountainous areas. Appropriate selection of suitable land is the focal point in this study. Meteorological conditions, wind tunnel tests, field observation, regional wind distributions, local area wind distribution were all the parameters collected to predict wind energy output. Data were analysed by computer simulation program developed in the study.

El-Shimy (2009) designed a model for optimal site matching of wind turbine generators based on a case study in Egypt. The model he proposed utilised an improved formulation for the capacity factor estimated based on WPF and an accurate model of wind turbine generator output power curves. For each candidate site, optimal wind turbine generators were determined by turbine performance index maximization and optimal output power curves. His model included the constraints of turbine heights considering the turbine impact on environmental issue. It focused mainly on the suitability of the wind energy at a specific site to a wind turbine generator. Parameters such as wind shear coefficient, long term wind speed data and wind turbine characteristics are crucial in the study.

Similarly, Hu and Cheng (2004) came up with performance evaluation of pairing between sites and current wind turbines generator on the market. The method used six parameters to evaluate the matching between turbine models and site characteristics. It estimated the energy output performance of the pairing and used the index as scale of suitability. WPF model of wind distribution, including shape and scale parameter, turbine cut-in speed, rated speed, cut-off speed and nominal power output were the parameters considered. Average power output of turbine-site pair is the obtained to determine the selection of location.

Another method for selecting suitable location for wind farm is developed based on decision support system (Ignacio et al, 2007). Implemented on Geographic Information Systems (GIS), different criterion maps were created based on attributes by groups of different interest: economic group interest on investment return and environmental group on environmental impact. Factors of each group's interest were analysed: wind energy resources, electricity cost, terrain slope, prohibited area, visual impact, sound impact etc. The classical Saaty matrix was applied to the factors provided by each group where criteria weights and aggregation of criteria are given on preference order. The developed maps were cross referenced to provide the best suited location with optimal tolerance from each group's decision.

Again in 2008, a GIS based wind farm site selection method also is proposed by Bazzi and Fares in Lebanon. The design parameters consisted of wind data, urban areas, type of turbines used and feasible distance between wind turbines. Energy users are requested to defined the preferred areas and generated computer software is used to analyse the data.. Cost analysis is also computed by the program once all areas are defined.

A multi-criteria decision making model on strategic selection of wind farms was developed by Lee, Chen and He (2008). The concept of the model is based on Analytic Hierarchy Process by Saaty TL 'Fundamentals of analytic network process-multiple networks with Benefits, Opportunity, Costs and Risks' and it approaches the feasibility of the wind project by considering benefits, cost, opportunity and risks. Benefits refer to the wind availability and site advantage. Costs accounts wind turbine, connection and foundation. Risks include concept conflict, technical risks and uncertainty of future land development. Opportunity includes financial schemes, policy support etc. The scale or weigh in the model is divided into five levels which were predetermined and preference were provided by a dedicated team specially formed for the project planning consisting of experts from different sector. The design of the model provides a good platform for this project.

Azadeh, Ghaderi and Nasrollahi (2003) presented an integrated approach for location of wind plants by using Data Envelopment Analysis (DEA). This approach incorporated environmental circumstances and geographical location related to wind intensity. Different factors affecting the suitability of wind farm location is considered concurrently for optimum location identification. It introduced the most relevant parameter for wind plants: wind speed, quality of proper geological areas, quantity of proper topographical area, distance of power distribution network and cost of wind devices. Values of parameters were provided by the meteorological organization of Iran. The study included considerations of rural region and determined that distance from power distribution grid is a vital factor for a location. Result of the DEA model showed that wind speed is the most important parameter.

Mostafaeipou (2010) studied the feasibility of harnessing wind energy in the province of Yazd in Iran. Analysis was based upon wind speed data that is collected for duration of 13 years from 11 stations to assess wind potential at sites. The parameters studied included hourly measured wind speed data at 10m, 20 and 40m: using Power Law to extrapolate 10m height data to determine wind data at heights 20m and 40m. Also included in the analysis are the wind direction and roughness values for different cities. The study focused mainly on the availability of adequate wind speed to determine the suitability of a site.

In a similar study, wind persistence is studied to determine best site for a wind farm (Cancino-Solorzano, Gutierrez-Trashorras, & Xiberta-Bernat., 2010). Property of wind, specifically mean duration of wind speed within a defined interval for a location, is the crucial parameter here. Wind speed data comprised of wind speed records of every 10min at the height of 10m for duration of five years in five locations. Roughness length and height were taken as part of the analysis to determine the result.

Wind energy potential at four locations in Ethiopia was assessed by Bekele and Palm (2010) to determine their feasibility. Data were compiled from different sources and analysed using computer software tool. Wind speeds are recorded 5 times daily for duration of four years. Results are based upon monthly average wind speed, WPF, wind speed cumulative density function and wind speed duration curve that is computed. Determination of potential site is indicated by wind speed profile created by the data.

Ucar and Balo (2009) developed a method to evaluate wind energy potential at a location using wind speed data. Wind characteristics were studied based on the data collected in six years for six locations in Turkey. Data were recorded at height of 10m and 30m AGL. Surface roughness, wind direction and height AGL were included as part of the considerations in the study. Using the tabulated data, WPF curve is created and annual energy output were calculated. Evaluation on best location was selected based on the highest energy production in combination with predetermined wind turbine model.

Furthermore in 2010, another study is conducted to assess the wind power potential for turbine installation in coastal areas of Turkey. Ucar and Balo used the wind direction, mean wind speed values, wind speeds, wind potential and frequency distribution to determine their results. Assessment also included the technical specification of wind turbines with different capacity to produce yearly energy output and capacity factor. Data of wind were recorded at height of 10m AGL. The final assessment of the study stated that height affect the wind speed characteristic and understanding of long term pattern of wind speed gives reliability in the power prediction.

Jowder (2008) conducted a study to find the optimum location-turbine selection for maximum wind power production. Hourly wind speed data for three years were collected at the height of 10m, 30m and 60m. Similar with Mostafaeipou, wind data of 30m and 60m were extrapolated from 10m data using Power Law. From there, WPD is plotted and statistically analysed to determine potential of wind power generation. Average annual wind power density was calculated in two different ways and WPD showed more accurate prediction of average wind speed and average power density than graphical method.

Much of the studies conducted used different methods to assess and determine their findings. The results of these studies are not of great relevance. The main concentration is the parameters that were chosen to be examined in each study and the different methods executed to produce theirs results. Some of the studies have shown to overlap each other but this only proved that the parameters selected in their studies are proven to be crucial. The analysis and discussion of their results provides a better understanding of the importance of these parameters mentioned. The selection of the parameters in this study is based upon the information and knowledge gathered here.

CHAPTER 3

MULTI CRITERIA DECISION MAKING

3.1 Analytic Hierarchy Process

Analytic Hierarchy Process (AHP) is a simple approach to decision making. It allows decision making to stemmed from both rational and intuitive method to select best option from a number of alternatives evaluated with respect to several criteria. Developed by Saaty in 1980, this method is simple to use, allows the flexibility of mixing qualitative and quantitative criteria in its decision making. Previous studies have shown that AHP is selected widely for multi-criteria decision making tool.

The main reason AHP is chosen in this study is because it is powerful yet easy to understand and apply. As the name implies, the decision making is based on a hierarchical level.

According to Saaty, the simplest form used to structure a decision problem is a hierarchy of three levels; the goal of the problem at top most level, criteria at the second level and alternatives at the lowest level. This can be referred at Figure 2.1. The environment surrounding the problem should be considered to identify the issues that contribute to the solution in the construction of the hierarchy. There are two purpose of arranging the goal, criteria, issues and stakeholders in the hierarchy: it provides an overall view of the complex relationship for the situation and allows decision maker to determine whether the compared issue is of same order of magnitude.

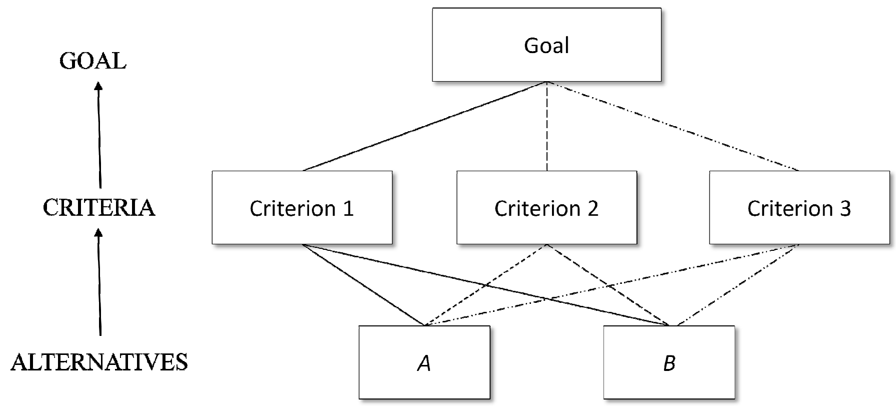

Figure 3.1 : A three level AHP

Here, the compared element should be homogeneous. It is also stated by Saaty that the hierarchy does not need to be complete where an element in an upper level does not have to functions as a criterion for all elements at lower level. Thus, the hierarchy can be divided into sub hierarchies sharing only a common topmost element. Furthermore, levels in the hierarchy can be inserted or eliminated as necessary to clarify task of setting priorities. Elements of less immediate importance can be represented in general terms at higher level and elements of critical importance to the goal can be developed in greater depth and specificity. The task of determining priorities demands that the criteria, sub-criteria and alternative be compared among themselves with respect to the next higher level.

This means that when applying AHP, the problems will be broken down into multi-level of categories and characteristics. This forms the structure of the hierarchy and very much suited the intentions of this project. Each level can be further divided into sub-hierarchy sharing only one common top element. It should be constructed where elements at the same level are of the same order of magnitude and can be related to element of the next level.

Once it is done, the elements are being evaluated individually by comparing them to one another. The AHP requires pair-wise comparisons to be made for each element within the criteria. The paired comparison shall be made one at a time, until all elements are compared. After evaluation have been made on the impacts of all the elements with respect to the goal and their priorities have been computed, possibly, less important elements can be dropped from further considerations due to their small impact on the goal.

The judgment among compared elements may be taken from actual measurements or from fundamental scale which potrays the relative strength of preference and feelings. AHP is a nonlinear framework for executing deductive and inductive thinking made possible by taking several factors into consideration simultaneously, allowing for dependence and for feedback, making numerical tradeoffs to arrive at a conclusion or decision. In AHP, rationality is used to conduct the judgment and it is defined as (Saaty & Vargas, 2001) :

- Focusing on the goal of solving problem
- Knowing enough about a problem to develop a thorough structure of relations and influences
- Having enough knowledge and experience and access to knowledge and experience of others to assess the priority of influence and dominance among the relations in the structure
- Allowing for differences in opinion with an ability to develop a best compromise.

Hence, the hierarchy building of AHP can be simplified into:

1. Goal on top
2. Decompose into sub-goals
3. Further decomposes if necessary
4. Indentify criteria to measure achievement of goals

3.2 Pairwise Comparison and Fundamental Scale

Paired comparisons in AHP are applied to pairs of homogeneous elements. Again, this requires the elements to be of the same level magnitude with respect to the same criteria. The pairwise comparison in AHP utilises the Saaty fundamental scale. This fundamental scale represents the intensities of judgments and is shown in Figure 3.1.

Table 3.1 : The fundamental scale (Saaty & Vargas, 2001)

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to each other
3	Moderate Importance	Experience and judgment slightly favour one over the other
5	Strong Importance	Experience and judgment strongly favour one over the other
7	Very Strong	Experience and judgment very strongly favour one over the other. Its importance is demonstrated in practice.
9	Extreme Importance	The evidence favouring one over the other is of the highest possible validity
2, 4, 6, 8	Intermediate value between two adjacent values	Compromise is needed between two judgment
Reciprocals	If activity I has one of the preceding numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i	

Comparison are not made based only upon how many times one is larger than another as there are situations where elements are equal or almost equal in measurement but also what fraction one is larger than the other. One simple example is shown in Table 3.2.

Table 3.2 : Example of AHP pair-wise comparison (Saaty & Vargas, 2001)

	Which Food has more protein?						
	A	B	C	D	E	Estimated	Actual
A : Steak	1	9	9	6	4	0.345	0.37
B : Potatoes	1/9	1	1	1/2	1/4	0.031	0.04
C : Apples	1/9	1	1	1/3	1/3	0.030	0.00
D : Soybeans	1/6	2	3	1	1/2	0.065	0.07
E : Whole Meat Bread	1/4	4	3	2	1	0.124	0.11

For the final stage, eigenvalue method is used to estimate the relative priorities of the parameter criteria. AHP is designed to include a consistency index for the entire hierarchy. An inconsistency of 10 percents or less implies that the adjustment is small. If the value is not less than 0.10, the problem has to be restudied and judgments revised. Overall, AHP can be summarized as Figure 3.2

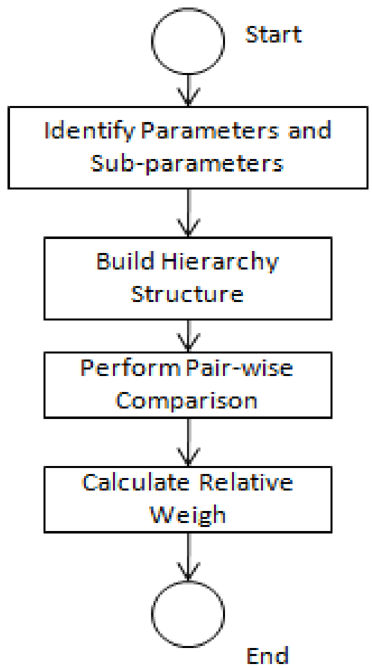

Figure 3.2 : AHP Flow Chart

3.3 AHP Applications

Due to the flexibility of AHP in providing a decision, it is vastly adapted into today's complex world of decision making. Apart from practical applications, it has been used widely in researches and studies of different fields. Similar application of AHP can easily be adapted into this study based on the available information gathered.

Frair, Matson & Matson (1998) applied AHP to design a university undergraduate Industrial Engineering (IE) curriculum which has to satisfy the university's core curriculum requirement, ABET 2000 criteria as well as providing adequate treatment for appropriate subjects of required credits. In their efforts, the goals and objectives were set. A detailed survey for the composition of IE at 29 different schools was conducted where data were tabulated and summarized. Next AHP model was build based on the decided curriculum alternatives: Level 1 represented the IE curriculum recognized as excellent by all affected parties, Level 2 listed the affected parties, Level 3 listed the curriculum components and lastly, level 4 is the curriculum alternatives listed as manufacturing, engineering management and general. Judgements were collected from the Level 2 parties and analysis performed to produced ranking of the curriculum alternatives.

Another study developed a scientific and objective maintenance schedule for power lines using AHP (Lin, Gao, Zhang, Ren & Li, 2006). Power lines maintenance plan was always drawn only by experience and trials due to the complexity of the work hence there were many disadvantages. The study comes up with solution by implementing AHP to indicate ranking of power lines in service that requires maintenance by building the model as shown in Figure 3.3. The criteria are being analysed and judged carefully to produce a priority order that served as a maintenance schedule.

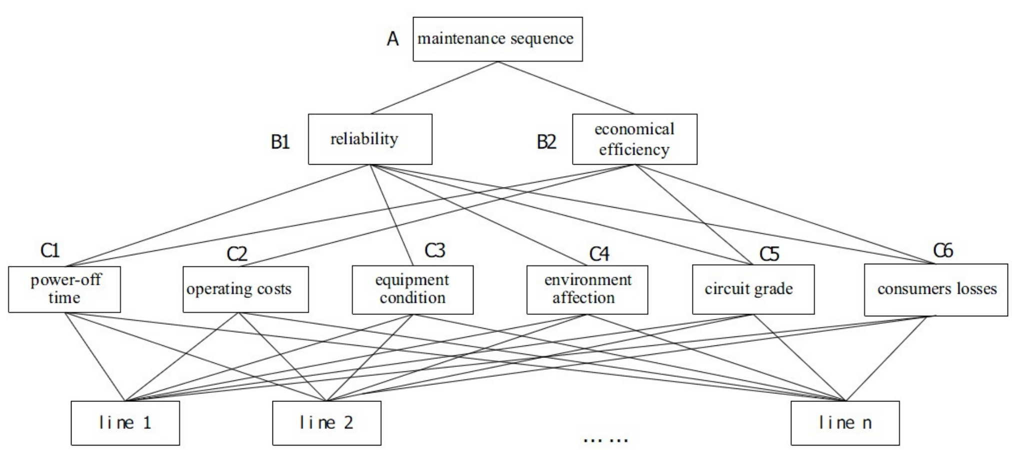

Figure 3.3 : AHP structural model of power lines maintenance.

Cimren, Budak & Catay (2004) developed a system using AHP for the design and development of a successful production environment. In this study, they proposed a user-friendly decision support system for the selection of appropriate machine tool that is critical in the production system. The AHP system guided the decision-makers to select available machines based on evaluation procedures of economical consideration using cost, reliability and precision analysis. A large database of available machines is gathered. Decision makers were asked to specify the desired machine specification and the selection criteria is based on the shortlisted machines.

Another study implemented AHP to developed a model to reduce energy usage on residential space heating (Sheth, 2008). Space heating consumes a large part of energy usage in cold climate countries, hence policies are developed to enhance energy security and numerous studies conducted to analyse different way of space heating to reduce energy demand. Here, Sheth developed a means to rank the various reduction and replacement method to be implemented in the residential area of Nova Scotia. In the study, existing energy sources, suppliers, infrastructure, demand and potential alternatives were collected for different types of energy sources. Then, reducing energy usage required identifying and ranking various conservation methods and energy efficiency measures. Lastly, the replacement requires the selection of secure, preferably domestic and renewable for a particular method. Information was gathered from decision maker and was processed using software developed in the study.

Similarly, Vijayakumar (2010) used AHP to find an alternative manufacturing process in replacing the conventional method to reduce total mass of vehicle body structure. The production processes were broken down based on the vehicle body parts and material used. Each of these sections was studied and information was gathered individually. AHP is applied to each section of the body to indicate the best solution with respect to the goal. Then, each outcome was combined to form a complete alternative production process.

Noureddine (2010) come up with a prioritisation system for school rehabilitation projects using AHP. In the time of financial difficulty, school district in California faces challenges in maintaining existing buildings. Hence, maintenance has to be prioritized based on urgency of maintenance and not subjective judgment made by decision maker. The study created a computer assisted decision support system to help allocate funds in a structured manner that assures fare distribution to appropriate projects. Questionnaires were carried out in the form of visual inspection for the buildings. Building structures were also broken down into different section according to their individual specification. Data were gathered and processed using the developed computerized system to indicate which structure requires maintenance first.

Yan (2010) studied and produce a method using AHP to measure the quality for health care systems. The study covers not only the technical elements which referred to the medical expertise and equipment but also the administrative, environmental and interpersonal quality for health-care services. Although health-care service has been constantly stressed for improvement, the key dimension in constituting health-care has not been fully understood and there were no studies carried out to measure the quality stated. Elements stated were based upon previous researches and information gathered. A pilot study consisting of simple questionnaire was carried out involving physician, student and patients to apply AHP method for deriving relative important weighs.

Briggs (2010) used AHP to develop a risk management model to assess risk for upstream oil supply chain. The study is intended to understand and underline the risk involved, the risk sources and their impacts on the industry's operation system. The AHP model build consisted of three level: overall goal of risk management, various risk factors and alternative criteria of decision maker. Risk management experts were survey and major criteria were defined. Survey carried out in the study assessed the risk criteria and determined the area of which crucial risk management is required.

The method of AHP implementation studied in this section roughly defines the methodology in the next section. It is clear that applications of AHP usually involve questionnaires and surveys from group of experts or people which is involved in the related studies. Judgments are based upon experience and in some case, personal preferences. Derivatives of relative weight are carried out in many forms, mostly with the aid of a simple program. In some cases, special programs are developed to repeatedly assess the same issue for different intended purposes.

CHAPTER 4

METHODOLOGY

In order to find a good site for wind farm, feasibility studies have to be carried out. Developers have to go step-by-step to ensure that the project is worth investing. There are many factors to be considered and at every step, different parties are involved to make the project a success.

The lack of wind power development in this region poses certain constraints as there will be no local information support for the interest of this project. Hence, study will be based upon data, reports, guidelines and case study of wind projects globally. The work involved in this project is divided into three stages.

1. To gain general knowledge in today's wind power development.
2. To select the crucial parameters involved in the initial stage of wind power planning.
3. Rank the parameters according to importance by implementing AHP.

4.1 Phase I : Information Gathering and Study

The first stage started with gaining adequate understanding in global wind energy. The feasibility studies include parameters that are related to the technical and social element. This includes the current trends in wind farm installation and generally how far the technology has evolved since it first started in the 1970s. The most important precondition for a good wind power project is that there are good wind

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