INVESTIGATION AND ASSESSMENT ON POTENTIAL OF WIND ENERGY IN THE CENTRAL REGION OF THAILAND

BY

PHAM QUAN

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN
ENGINEERING AND TECHNOLOGY
SIRINDHORN INTERNATIONAL INSTITUTE OF TECHNOLOGY
THAMMASAT UNIVERSITY
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A Thesis Presented

By

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Submitted to
Sirindhorn International Institute of Technology
Thammasat University
In partial fulfillment of the requirements for the degree of
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Abstract

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by

Pham Quan

B.Eng, Mechanical Engineering, Sirindhorn International Institute of Technology, 2012

In this paper, both wind energy resource and financial feasibility are mainly investigated to assess potential on electrical energy production of wind turbines in the central region of Thailand. Wind maps and field surveys are employed as technical tools to decide on suitable locations of wind masts. Accordingly, one-year wind data is collected from three ultimately selected sites of wind masts at Ratchaburi (S1), Pathum Thani (S2), and Saraburi (S3), which are all the provinces in the central region of Thailand. For each site, wind speed and direction are measured at three levels: 65 m, 90 m, and 120 m from ground level with a sampling rate of one minute. The data set is applied to the WAsP™ program for wind data analysis. It is found that annual mean wind speed is more and less between 3 and 5 m/s at each site. Also, the Weibull distributions of wind data are reported. Annual energy productions, which are generated by Bonus™ 1 MW wind turbines at heights of 65 m, 90 m, and 120 m, are determined to be (255;338;465) MWh, (329;426;574) MWh, and (493;633;829) MWh for the sites S1, S2, and S3, respectively. In another matter, Carbon credit sale and effect of reduced import crude oil are considered in economic analysis. In feasibility analysis, none of potential sites for generating wind energy with large wind turbine seems to be attractive. As a result of that, factors such as design, capacity, rotor diameter and technology of wind turbines for different brands are analyzed with satisfactory financial indicators under rational scenarios in this study. In final, Vestas^{TM} V60 850 kW wind turbine is considered as the most suitable one among available turbines for the concerned region. Lastly, good agreements between financial and economic analysis are presented to insist great feasibilities on electrical energy production from wind energy in the central region of Thailand.

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Chapter 1

Introduction

1.1 Introduction

Nowadays, electricity is mainly produced by fossil fuels. As known, fossil fuels are limited resources due to the long time creation. Therefore, renewable sources have been the main concerns of most scientists and engineers recently. Wind power which is considered as a likely alternative source is free and available most of time. However, the difficulty we have to face is that the wind is not stable. When the wind is strong, it may break the mechanism inside the turbine. When the wind is too weak, it cannot push the blade of the turbine to rotate. As a result of that, predicting the performance of a certain wind farm or wind turbine will be hard. Therefore, it will be impossible to propose and invest in any wind project because of the lack of scientific prediction. Furthermore, the height, location and position of a certain turbine that can produce the highest efficiency should be determined. To be able to deal with those problems, it is applied to simulation program "WAsP" to predict the power, speed and even the most suitable location for a certain wind farm or wind turbine. "WAsP is developed and distributed by the Wind Energy Division at Risø DTU, Denmark." In technical terms, "WAsP is a PC program for predicting wind climates, wind resources and power productions from wind turbines and wind farms". The program includes a complex terrain flow model, a roughness change model and a model for sheltering obstacles. WAsP is able to provide us a "complex terrain flow model", "a roughness change model" and "a model for sheltering obstacles". Therefore, the program can generate a detailed result of the wind potential power that we can have. The accuracy and reliability are high due to the concern of many problems of wind energy in the program itself such as wake effect, "the pitfalls in orography", "spot elevations", etc. Moreover, in the world there are "161 certified WAsP users in 27 different countries". As a result of that, it is confident to use WAsP as a tool to analyze my case study. It is believed that results are reliable and applicable for the real project or serve as a reference for a further study.

A further study which is a case study to analyze the finance and economics of the real project is conducted in the report. Many factors such as net present value (NPV), internal rate of return (IRR), benefits of investments (B/C), cost per unit of energy (COE) which have to be satisfied as shown in Table 1.1 and the sensitivity of the project are calculated to investigate the real project.

Table 1.1 Financial indices for feasible projects.

Index	Value
NPV	> 0
IRR	> MLR
BCR	>1
PBP	< 7-10 years*

Remark * values may vary upon various purposes of projects

Moreover, many suggested situations and scenarios have been considered with calculated factors that give a further look at the project. The investor can have many choices or ways to invest to the project in order to get the highest benefits. In addition, the economic analysis mentions about the sale of carbon credit which is the concern of scientists and engineers nowadays for the non-carbon project. Wind turbine project can generate "greener and cleaner" electricity for the world by reducing the sulfur oxides (SO_x), nitrogen oxides (NO_X), carbon dioxide (CO_2), and dust particles from producing electricity. The project has a very important meaning which will motivate the investor for producing electricity from the renewable resources.

It is known that renewable resources are hot issues nowadays among engineers and scientists. Getting knowledge about how to exploit benefits of wind energy which is one of the main renewable resources is very important. Generally, as a mechanical engineer, it is not enough to focus on only the mechanism parts. How to manage and how to produce energy from those mechanisms efficiently are also very significant. Therefore, it is very useful and important for a mechanical engineer to know about a renewable resource – wind energy and how to manage, produce, predict and simulate it effectively.

Nowadays, generally, it is a very common task of an engineer that he/she has to predict results or simulate the situation, then analyze it carefully before starting a real project. Wind energy which is a compressible fluid seems to be difficult to control its behavior. Properties of wind profile will change significantly after passing any kind of obstacles. Furthermore, wind is unstable during a day. Hence, there are many difficulties when dealing with power calculation for a certain wind turbine and especially for a wind farm. As a reason of that, DTU did create a useful simulation program WAsP to solve those problems. As investigated for many situations with many theories related to wind profile, WAsP is even able to connect to Google Earth to calculate results based on the real geography. Moreover, WAsP contains information of many kinds of turbine around the world. As a result of that, it is very convenient to know what kind of turbine is suitable for a certain project. Because of those advances of WAsP, it is widely used to analyze wind resources in the world nowadays.

After being able to predict the Annual Energy Production (AEP) of a certain wind turbine, the information will be applied to a real project or investment with the financial and economic analyses. Financial analysis is to determine the financial situation which may occur during the project. Financial analysis will tell us the information that can be used for investors to consider about the feasibility of the project. Furthermore, it is also used to show the bank when making a loan from the bank. The bank will look for the information in Financial analysis to determine whether the project can be successful and be able to return the money or not? In another hand, Economic analysis is the real thing that we can get from the project. The reason is that because the project is about non-carbon energy. Therefore, the energy produced from the turbines will be able to earn some money from selling carbon credits. Moreover, by producing non-carbon energy, the project also saves a lot of money for importing barrels of oil to the country. That money is considered in the Economic analysis and that is what really earned from the Wind turbine project.

1.2 Statement of problem

In this study, the potential of wind energy and financial feasibility in the central region of Thailand are investigated by using one-year measured data of wind at three levels: 65 m, 90 m, and 120 m. The recorded data of the on-site wind is treated as statistical characteristics of wind. Additionally, topographical data such as height variation, roughness and sheltering obstacles are used in develop wind resource map at potential areas. Mapping potential energy helps to find surrounding area, at which wind turbines can generate maximum electricity output. Studies determine wind powers by using WAsP™ software , which is well-known commercially available PC program for estimating mesoscale wind climate, wind resource, and wind power production. There are wind turbines are applied in this study such as Bonus™ 1 MW wind turbine, and smaller capacities of wind turbines. The potential of wind power generation is assessed through each scenario of some financial conditions. The feasibility analysis in finance is able to determine whether the project should be invested or not. However, the most important concern is whether the project can create a great profit and what the sizes of wind turbines should be installed . As a need of that, the study is going to find out the answer for all raised regards.

1.3 Objectives

The main objectives of this study are as followed:

1) To assess the wind potential energy in the central region of Thailand.
2) To study about the feasibility analysis of a wind project.
3) To study about a case study which are based on a practical situation.

1.4 Scope of study

In this work, a wind map of Thailand is initially investigated for finding accessible areas with high potential of wind energy. Field surveys to those areas are done with observing wind speed at ground level and personally questioning local people about wind potential during a whole year. There are many feasible locations, which are intended to install wind masts of 120 m height as illustrated in **Fig. 1.2-3** . They are selected by maximizing indices of wind speed, security, and easy accessibility to existing power lines. In addition, all locations are in the high demanding areas. Moreover, **Fig. 1.1** provides general information about wind speed in Thailand at 90m/s with the central region bounded in the back line. As a result of that, most three suitable sites are chosen to cover the central region of Thailand; those are Ratchaburi (S1), Pathum Thani (S2), and Saraburi (S3) as shown in **Fig. 1.1**. The detailed locations of wind masts for wind measurement are listed in **Table 1.2**. Measurement devices are mounted on wind masts for detecting wind speeds and wind directions at heights of 65 m, 90 m, and 120 m. A three-cup anemometer of NRG#40C and a wind vane of NRG#200P are used to measure a wind speed and a wind direction, respectively. The wind speed and the wind direction are recorded by the Nomad 2^{TM} wind data loggers during the whole year 2012 at a sampling rate of 1 minute with averaging values in every ten minutes.

Table 1.2 Details of 120-m wind masts.

Site	Location: (latitude,longitude)	Height (asl,m)	Place
S1	(N13.35°,E99.30°)	99.9	King Mongkut's University of Technology Thonburi, Ratchaburi
S2	(N14.07°,E100.60°)	3.9	Thammasat University, Pathum Thani
S3	(N14.53°,E100.90°)	16.1	Royal Thai Army Cavalry Center, Adisorn military camp, Saraburi

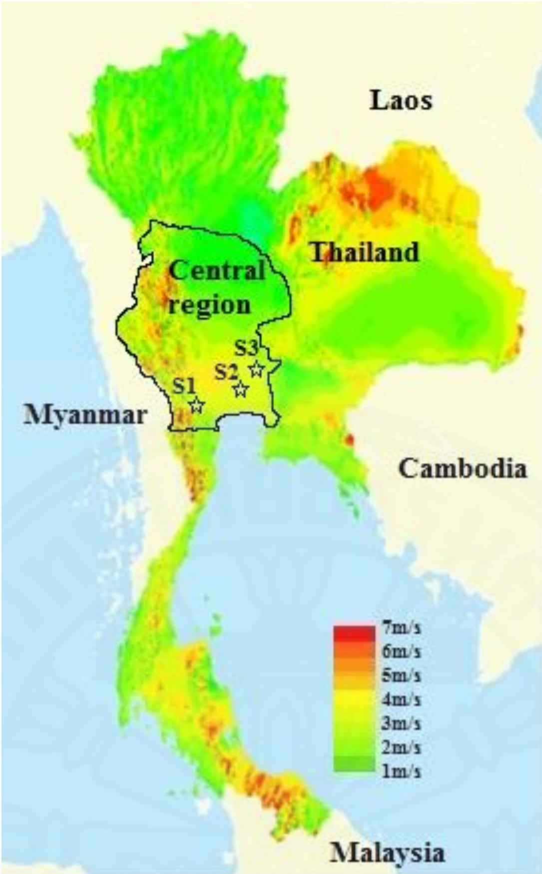


Fig. 1.1. Locations of masts in the central region of Thailand.

Fig. 1.2. Installation of wind masts and measurement devices.

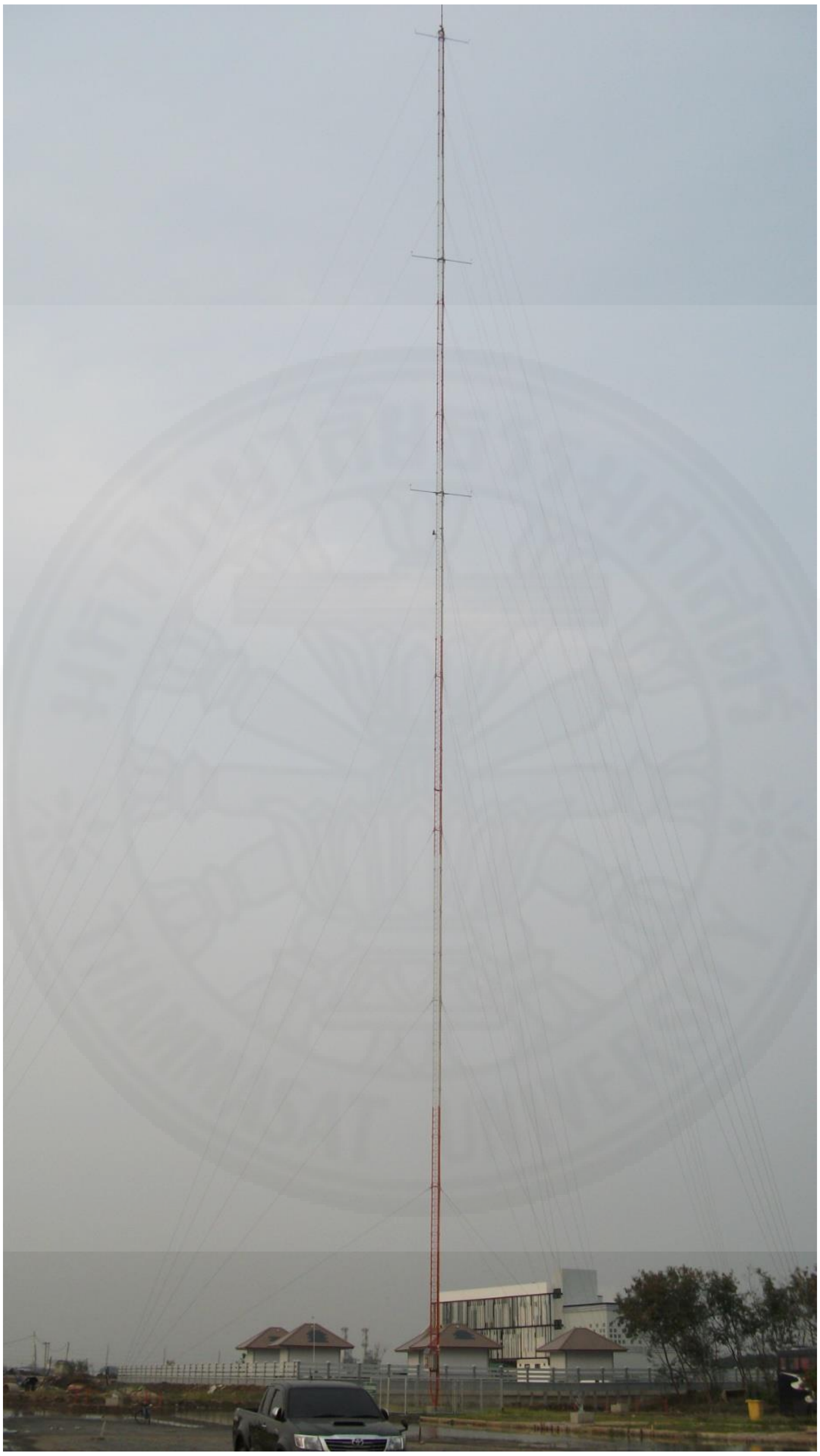


Fig. 1.3. Wind mast inside Thammasat University, Pathum Thani

Chapter 2

Literature Review

Currently, wind energy is one of the most promising alternative renewable energy in Thailand. Wind-energy technology with low-operating and non-fuel costs has grown considerably in recent decades to efficiently capturing kinetic energy of wind. Especially, commercial-scale wind turbines (> 500 kW) are usually installed to feed wind energy converted into grid of electricity distribution. Both improvement of efficiency and reduction of unit cost in wind turbines make wind power generation competitive to other conventional energy resources. Wind resource assessment is technically required as an imperative step in estimating annual electrical energy production from wind energy at potential locations. Recently, investigation and assessment for wind resource have done at many countries worldwide. However, it is a difficult task to choose a specific site where windmill or wind farm may be installed because many factors have to be taken into account. One of the most concerned factors is feasibility study in terms of both wind analysis and financial analysis at those prospective locations. In fact, the central region of Thailand is a vast plain area, which is a location of national capital, Bangkok and it is surrounded by high mountains along borders of northern, eastern and western regions as shown in **Fig. 1.1**. Its area is about a quarter of Thailand's area and its climate is mostly a tropical monsoon, which consists of northeast monsoon taking place from November to March and southwest monsoon taking place from May to October, and trade wind with short period between those. Recently, potentials of wind energy in the central region of Thailand have been on researchers' working issues due to extensive accessible areas. The stability of electricity in the region will be improved if potentials of wind energy can be exploited. According to the latest wind map of Thailand as illustrated in **Fig. 1.1**, the average annual wind speeds at 90 m from ground level is from moderate wind speed (3-4 m/s) at mid of the central region to high wind speed (6-7 m/s) at edge of the central region of Thailand. The explanation of these facts is due to wind-impacting levitated mounts surrounding the central region of Thailand.

Nowadays, electricity is mainly produced by fossil fuels. As we know, fossil fuels are limited resources due to the long time creation. Therefore, the renewable sources have been the main concerns of all the scientists recently. Wind energy is one of the main renewable resources that have been concerned recently. As a result of that, many studies about the behavior of wind as well as the difficult when dealing with the wind has been conducted. Wind power which is considered as a likely alternative source is free and available all the time. However, the difficulty we have to face is that the wind is not stable. When the wind is strong, it may break the mechanism inside the turbine. When the wind is too weak, it cannot push the blade of the turbine to rotate. As a result of that, it is impossible to predict the performance of a certain wind farm or wind turbine. Therefore, there is no proposal and investment in any wind project because of the lack of scientific prediction. Furthermore, it is important to know the height, location and position of a certain turbine that can produce the highest efficiency.

Because of the significance of wind energy, wind energy resource assessment is done for many places in the world. Naif M. Al-Abbadi did assess five locations in Saudi Arabia for wind resources. Lin Lu, Hongxing Yang, John Burnett had investigated on wind power potential on Hong Kong islands with an analysis of wind power and wind turbine characteristics. The West Central Part of Karnataka is also done a statistical analysis of wind speed data which is based on Weibull distribution function. Mohamed Abbes and Jamel Belhadj did a similar work as in Tunisia but concentrate more in wind shear, turbulence intensity, short-term wind speed and long-term wind speed characteristics. Many researchs provide many formulas which can calculate the power density and annual energy production based on Weibull distribution. In another place Turkey, E. Kavak Akpinar and S. Akpinar had collected wind speed data and used two different probability density functions for their statistical analysis. Bonfils Safari also modeled wind speed and wind power distributions in Rwanda. He tried to model with many distribution functions and analyzed the results. Both of them draw a conclusion that Weibull function is quite suitable for most of areas compared to other functions. That confirms that WAsP is able to provide accurate simulations because WAsP is build based on Weibull distribution.

In details, the research tried to give out results which are come from two different samplings; 10 minutes and 30 minutes data. Naif collected data in the same way for five different areas which are Dhulum, Arar, Yanbu, Gassim and Dhahran. Additionally, at every single site, three levels which are 20, 30 and 40 m in height are installed with speed sensors. Wind direction sensors are only installed at two heights, 30 and 40 m. According to the reported results, data of five locations are shown for wind speed and power density in every month and at 40 m height. Wind speed is given in maximum and mean speed of every month. After that, the diurnal variations of wind speed are plotted for five places at 40 m above the ground. The distribution of wind speed frequency and wind rose which are main parts for any wind power analysis are then discussed. Finally, wind energy calculations are done by using $1/7^{th}$ power law for a Nordex N43/600 wind machine. As a result of the analysis, Dhulum has the highest wind energy potential with annual wind speed average of 5.7 m/s and with wind speed higher than 5.0 m/s for about 60% of the time compared to other sites. With annual average wind speed of 5.4 m/s and with wind speed higher than 5.0 m/s for about 47% of the time, Arar gets the second position in wind evergy potential. Yanbu and Dhahran which are at the costal sites have wind speed reach up to 8 and 7 m/s during afternoon hours respectively. The lowest annual wind speed which has higher than 3 m/s for 71% of the time is at Gassim.

Another wind power potential analysis is done for local weather data with typical wind turbine characteristics on Hong Kong islands by Lin, Hongxing and John. They proposed an optimum wind speed for different weather conditions. By using different hub heights of the wind turbine, they simulate the annual power generated. Firstly, background for probability density function, wind speed variation with height, the average power in the wind, the optimum wind speed and power output characteristics of wind turbines are provided. Calculations are done by following Weibull distribution. Main factors which are shape parameter and scale parameter are shown for different hub heights. Consequently, power generated for every month in one year is plotted in a bar graph. The proposed simulation model is concluded to be applicable for assessing the potential of wind power generation at a location. The hub height of a wind turbine is found to be an important parameter in power generation. It is used the same concepts for three sites to calculate scale parameter, shape parameter and power density. In another study, researchers put more efforts on analyzing the wind shear and turbulence intensity characteristics. That is also shows the results when comparing the parameters calculated from short-term and long-term wind speed.

As discussed above, the research uses Weibull distribution for their analysis. It is tried to figure out the better probability density function by comparing Weibull and Rayleigh distributions. Wind speed data are collected for a five year period from 1998 to 2002 hourly in the east region of Turkey. By following the same way for wind potential analysis, theoretical background is provided. Frequency distribution for Weibull and Rayleigh distribution as well as wind speed variation with height and statistical analysis of distributions are shown in main formula. Results for collected wind speed data are shown monthly and hourly of a day. Then, data are fitted in Weibull and Rayleigh distributions for calculating wind power density. As a consequence of that, the Weibull distribution is concluded to be better in fitting the measured monthly probability density distributions than the Rayleigh distribution for the whole year. In addition, in all 12 months the Weibull distribution provided better power density estimations than the Rayleigh distribution. In another research, six distribution functions which are Weibull LSq, Weibull Lh, Rayleigh, Normal, Lognormal and Gamma are analyzed and compared the results for four regions in Rwanda. The final conclusion was drawn that Weibull distribution is more suitable and fitted well in most of areas.

After reviewing all publications about wind power investigation, it is noticed that wind power in Thailand especially in the central has never been done before. As a result of that, it is a good chance to study about the wind resource in the central of Thailand. Three locations which are Ratchaburi, Saraburi and Pathum Thani are able to be representatives for the central of Thailand; results from three locations can be represented the general properties of the wind power in the central region. Furthermore, the feasibility of the practical analysis can describe a general picture of the exploitation of wind energy in Thailand.

In another aspect, the feasibility analysis should be concerned carefully due to the differences in politics of the country. In generally, net present value (NPV), internal rate of return (IRR), benefit cost ratio (B/C) and payback period (PBP) are common indices which determine the possibility of the project.

NPV is defined to be the difference between the present value of cash inflows and the present value of cash outflow. It is used to analyze the profitability of an investment or a project. All the costs such as initial costs and O&M cost is considered to negative. The benefits yielded from the project are positive. The project is said to be successful or worthy to be invested when NPV is positive. The project is definitely rejected if NPV is calculated to be negative because the cash flow to the project will be negative. In short terms, NPV is the sum of net benefits which reflect the value of time.

Internal rate of return is defined to be the discount rate often used in capital budgeting that makes the net present value of all cash flows from a particular project equal to zero. IRR is not related to or dependant on the interest rate.

Benefit-Cost ratio is a ratio attempting to identify the relationship between the cost and benefits of a proposed project. B/C is also a criterion for investment decisions at a minimum acceptable rate. In general, the project is expected to get the value of benefits to be more than the cost.

Especially, there is one factor that is concerned the most is adder. Sopitsuda T. and Chris G. have updated the information about the feed-in program. It is concluded that Thailand has the foundations for a good feed-in tariff program but changes enacted after June 2010 have slowed down market expansion. In another aspect, recently Khalid M.N., Mohamed S. and Hasimah A.R. have assessed the feasibility of wind energy resources in Malaysia based on NWP models.

Background about wind analysis

Actually, wind analysis includes identification of crucial parameters of distribution functions of wind data. With those results, determination of average power density is carried out for competence of energy resource at determined sites. In assessing potential on electrical energy production from wind energy, all of performance factors are analytically investigated from measured data of wind around the areas, which are feasible to install wind turbines at desired heights. Physically, a wind speed is a height-dependent variable to be determined for how strong the wind drives blades of a wind turbine. To predict a wind speed at a given height, an equation of the power law is widely applied as the profile of change in the wind speed against height. The application of this empirical model in **Eq. (1)** is to determine the wind speed at hub center of wind turbine when the wind speed near ground level is known.

$$\tilde{v} = v_o \left(\frac{z}{z_o} \right)^{\alpha} . \tag{1}$$

The $\tilde{v}$ is the estimated wind speed, which is be determined at a desired height z and v_o is the measured wind speed at the accessible height z_o while the ground friction coefficient α is dependent upon geographical and atmospheric factors. Typically, the one-seventh-power law may be considered acceptable approximation of wind-profile prediction. It can be interpreted that more electrical energy production can be obtained by installing a larger-capacity wind turbine at higher elevation if financial analysis is feasible to satisfactory investment.

The power of the wind that flows at a wind speed v through a blade sweeping area is the cubic function of the wind speed. In other words, the power density of the wind flowing through a wind turbine is determined as:

$$P(v) = \frac{1}{2} \rho v^3 . \tag{2}$$

The annually measured data of wind speed at a given wind mast can be characterized by the Weibull probability distribution:

$$f(v) = \left(\frac{k}{c} \right) \left(\frac{v}{c} \right)^{k-1} e^{-\left(\frac{v}{c} \right)^k} . \tag{3}$$

The distribution of wind speed is very important for the design of wind farm and power generator. The scale parameter and the shape parameter of the Weibull distribution can be determined by a best fitting implementation to such nonlinear function of the observed wind speed.

Besides characteristics of wind, the wind power density is one of the most important indicators of potential in electrical energy production from wind energy at the investigating area. From **Eq. (4)**, the power density is dependent upon variation of wind speed. The average power density of wind can be expressed as:

$$P_{av} = \int_{0}^{\infty} P(v) f(v) dv \quad . \tag{4}$$

As the shape parameter and scale parameter are known, the average power density can be determined as:

$$P_{av} = \frac{\rho v_{av}^{3} \Gamma(1 + 3/k)}{2(\Gamma(1 + 1/3))^{3}}, \tag{5}$$

with the average wind speed:

$$v_{av} = \frac{\sum_{i=1}^{m} v_i}{m} . \tag{6}$$

For the annual energy production, the wind turbine is properly selected by a crucial performance characteristic, i.e. a capacity factor. The capacity factor is defined by a ratio of the actual power generated by wind turbine to the rated power output over a period of year.

$$c_f = \frac{P_t}{P_r \times 365 \times 24} \tag{7}$$

The capacity factor varies depending on both wind resource and wind-turbine technology. Typically, the capacity factors of wind power are 20-40%. A higher capacity factor is more economical to judge whether a wind power generation is feasible.

Chapter 3

Methodology

3.1 Wind resource assessment

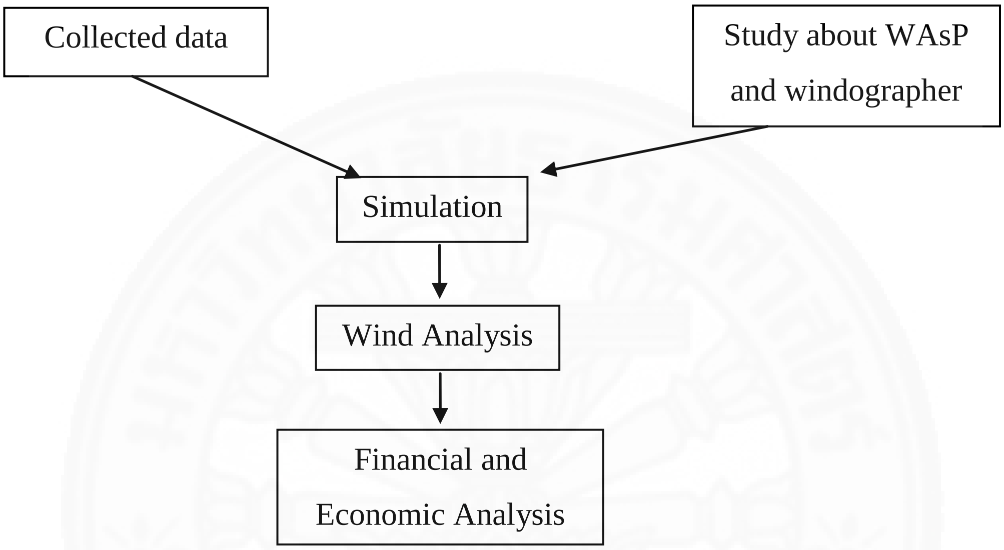


Fig. 3.1. General process of methodology

Generally, methodology consists of some main parts as shown in **Fig. 3.1** above. Firstly, every mast sends data of every day set to the e-mail. Collected data are given the date due to the perspective day. One-year data is collected for doing research. Studying about WAsP and Windographer program is a preparing step to deal with the data and simulation. By applying Windographer and WAsP to the collected data, simulation can be progressed. First result from simulation is wind analysis. Then, all parameters attained from wind analysis are used to analyze financial and economic analysis.

3.1.1 Wind data analysis

The main steps of how to attain the observed wind climate are shown in **Fig. 3.2** below. As mention above, all masts have a task to send collected daily data to the e-mail. However, the data is saved in a data-base type which cannot be used directly. Because of that, all raw data is input into Windographer program to convert into a usable and readable file. After that, all usable data for one year is input into WAsP Climate Analyst program to produce the observed wind climate. Instructions of how to work with the program are shown in details in later parts.

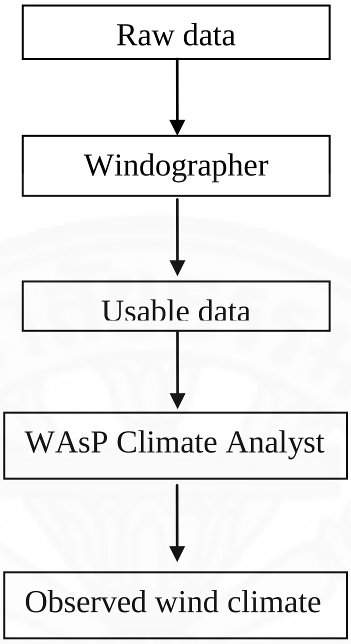


Fig. 3.2. Process to attain the observed wind climate

"Wind Measurement International offer a range of instruments to measure wind speed, turbulence, wind shear, wind direction, pressure, temperature and humidity" .The WAsP application needs the wind speed and wind direction for the wind power potential prediction. In the real project, the data are recommended to be measured by the cup anemometry as shown in **Fig. 3.3**.

Fig. 3.3. The cup anemometry

The wind data have to be collected for at least 1 year to be able to input to the WAsP Climate Analyst. The more years collected, the better the prediction we can get. When inputting the collected data to the WAsP Climate Analyst, the parameters concerned the most are the data discretisation (resolution) and the calm thresholds, for example the direction cannot be greater than 360°. The calm thresholds will help to eliminate the error that may occur due to the device. The way to specify the main parameters is shown in **Fig. 3.4** below for the wind speed and wind direction.

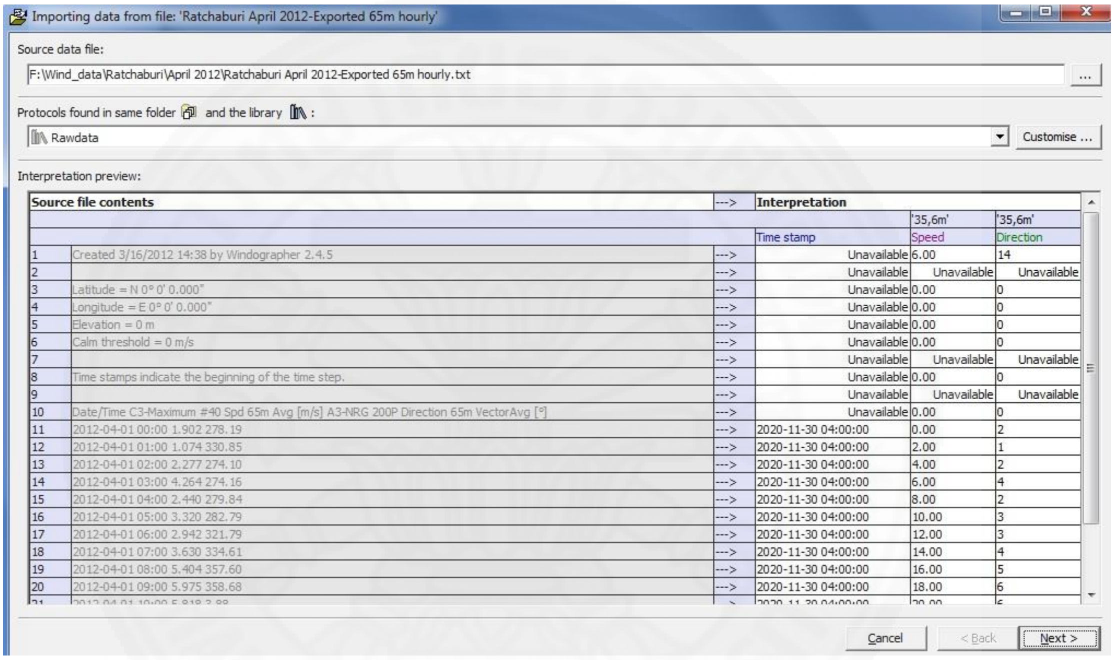
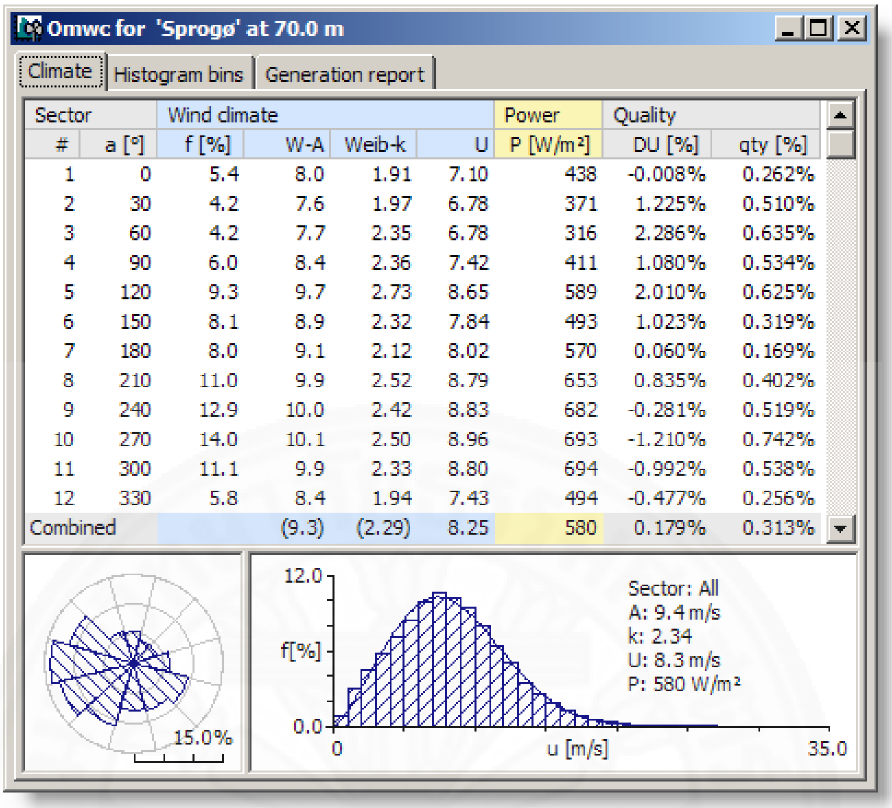


Fig. 3.4. The data specification

There are many factors that mainly affect the quality of the wind data. The accuracy of the wind data depends on the design and specification of the device. Furthermore, the calibration of sensors and the way a sensor is set up also affects the quality of the data. It is also important that the data statistics have to be collected continuously for full years. Last but not least, the verification of sensor outputs should be concerned to have a suitable adjustment with the data.

After the wind data is input into the WAsP Climate Analyst, it can create an observed wind climate file that will be used in the main WAsP application later on. An example of the observed wind climate is shown in **Fig. 3.5** below.



Sector		Wind climate				Power	Quality	
#	a [°]	f [%]	W-A	Weib-k	U	P [W/m²]	DU [%]	qty [%]
1	0	5.4	8.0	1.91	7.10	438	-0.008%	0.262%
2	30	4.2	7.6	1.97	6.78	371	1.225%	0.510%
3	60	4.2	7.7	2.35	6.78	316	2.286%	0.635%
4	90	6.0	8.4	2.36	7.42	411	1.080%	0.534%
5	120	9.3	9.7	2.73	8.65	589	2.010%	0.625%
6	150	8.1	8.9	2.32	7.84	493	1.023%	0.319%
7	180	8.0	9.1	2.12	8.02	570	0.060%	0.169%
8	210	11.0	9.9	2.52	8.79	653	0.835%	0.402%
9	240	12.9	10.0	2.42	8.83	682	-0.281%	0.519%
10	270	14.0	10.1	2.50	8.96	693	-1.210%	0.742%
11	300	11.1	9.9	2.33	8.80	694	-0.992%	0.538%
12	330	5.8	8.4	1.94	7.43	494	-0.477%	0.256%
Combined			(9.3)	(2.29)	8.25	580	0.179%	0.313%

Fig. 3.5. The wind distribution

3.1.2 Wind resource prediction

Next, it is integrated all the things above to the main WAsP application. By using the application, it is also able to estimate or evaluate the wake effect in the wind farm. Wake effect occurs in the wind farm when the wind blows through a row of the wind turbines. The wind turbines extract the energy from the wind and the downstream wind will have a lower speed. As the result of that, the wind production is reduced due to the reduction in the wind speed. The wake effect is illustrated in **Fig. 3.6**.

Fig. 3.6. The wake effect

In WAsP application, it is needed indicate the reference site, the turbine site, the wind farm and the resource grid as shown in **Fig. 3.7**. The reference site is a single site that the wind climate results are input. The turbine site is a single site that indicates the position that we collect data to get the wind and power results. The wind farm is a collection of turbine sites to evaluate the wake effect which is mentioned above. Finally, the resource grid is used to show the prediction in the wind power, the wind speed, annual energy production (AEP), etc. in colored pictures.

Fig. 3.7. Wind resource objects

Firstly, it is able to edit the grid by setting up the resolution and the concerned area. The "fine" prediction depends on the resolution chosen. Then setting up the way of demanded masking for example masking by polygons, by elevation or by node properties. **Fig. 3.8** shows the node property which is power for a whole selected area. **Fig. 3.9** shows the prediction within the boundary line. Finally **Fig. 3.10** shows the wind potential power by the elevation.

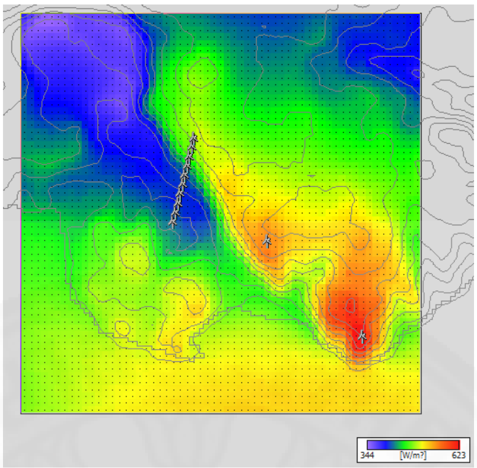


Fig. 3.8. The wind power prediction of the chosen area

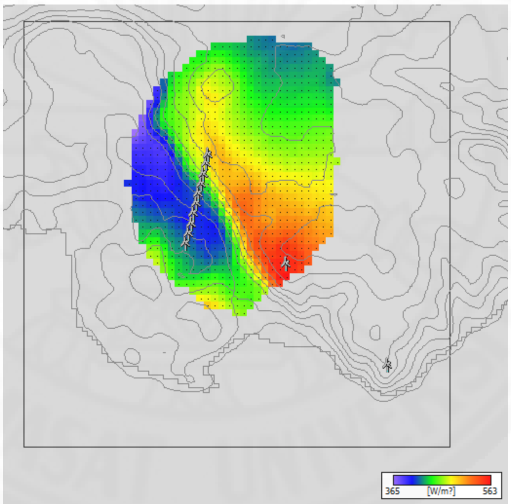


Fig. 3.9. The wind power prediction within the polygon

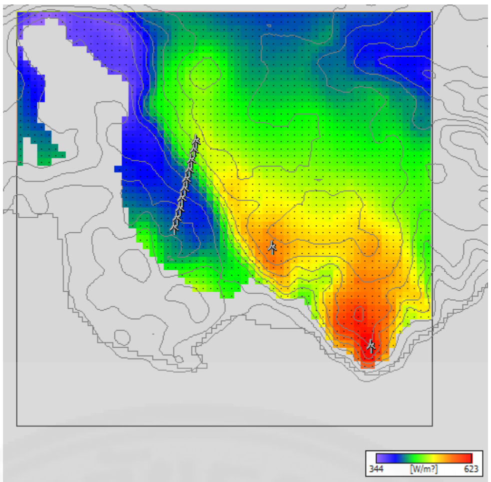


Fig. 3.10. The wind power potential by the elevation

3.1.3 WAsP instruction

3.1.3.1 How to create the observed wind climate from collected data

In this section, WasP Climate Analyst is applied first. Firstly, adjust the height of the reference site that collected data. To import data from file, right-click “Observed data” and then choose import data set as shown in **Fig. 3.11**.

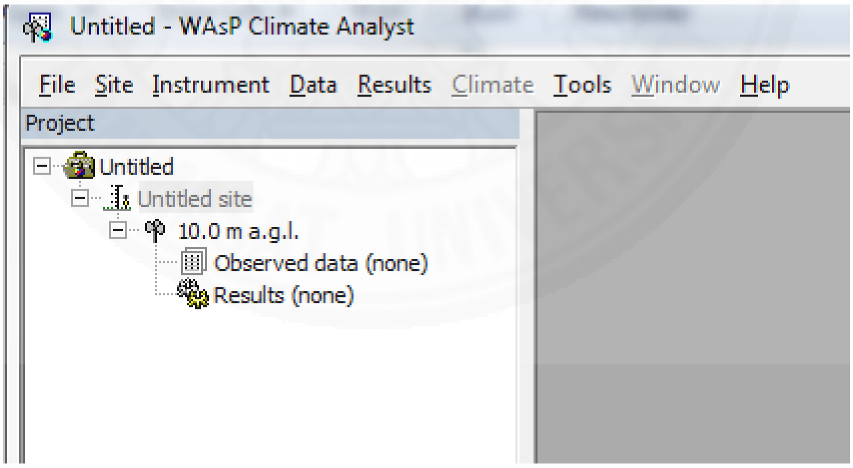


Fig. 3.11. Main window of WAsP Climate Analys

Now the window to import data from file appears as shown in **Fig. 3.12**. In the next step, have to create a protocol for that data set.

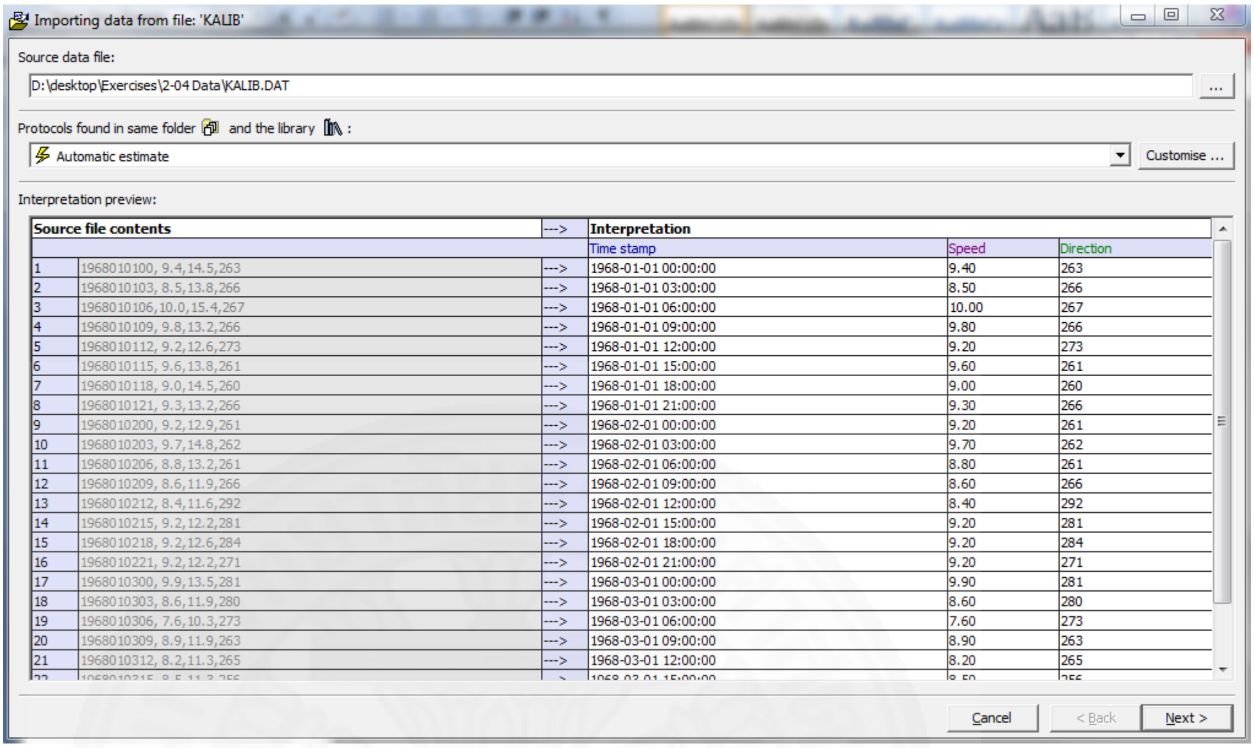


Fig 3.12. Import data from file

Left-click "Customise" and then the window as shown in **Fig. 3.13a** will appear.

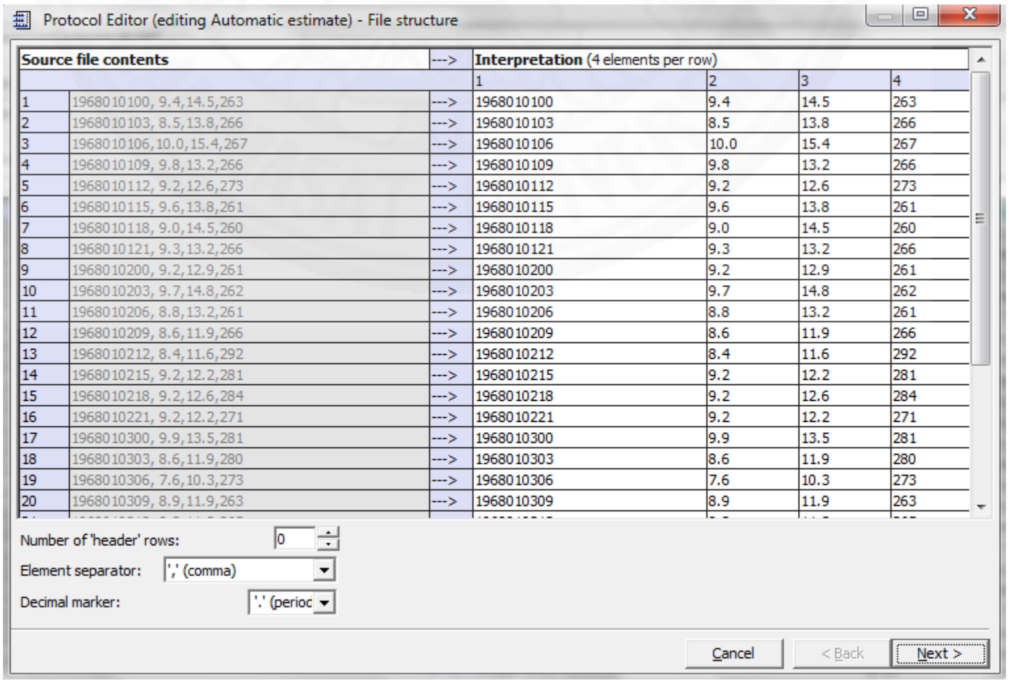


Fig. 3.13a. Edit a protocol

In this step, just need to left-click "Next" and the window as shown in **Fig. 3.13b** will appear.

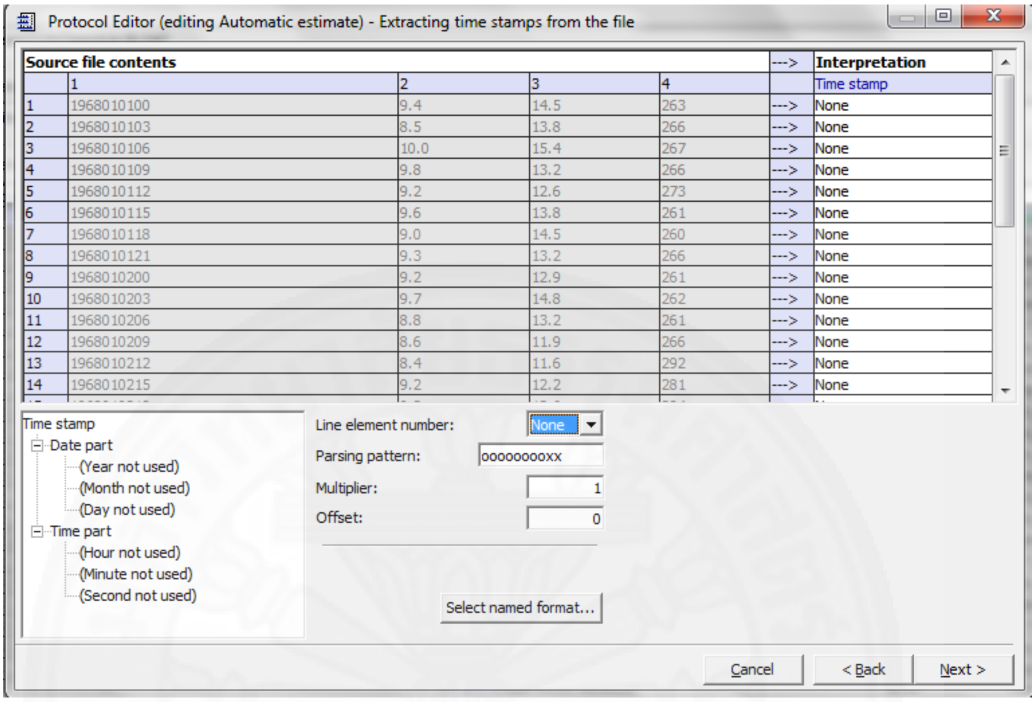


Fig. 3.13b. Edit a protocol

In this step, there is no exact information about the date and time, change all "Year, Month, Day, Hour, Minute and Second" to "None" as shown in **Fig. 3.13b**. After that, left-click "Next" and the window to set the recording interval will appear as shown in **Fig. 3.13c**.

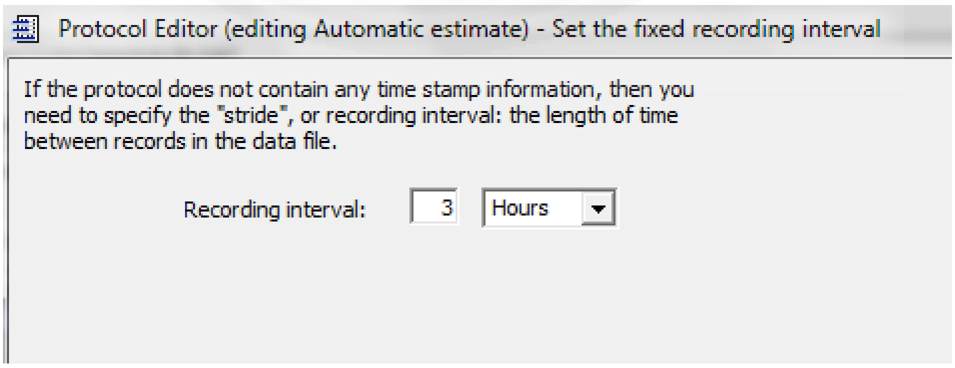


Fig. 3.13c. Edit a protocol

The program automatically realizes the interval of time as shown in **Fig. 3.13c**. In fact, the year, day and time are shown in the data set. Then, left-click “Next” and the window to extract data values will appear as shown in **Fig. 3.13d-e**.

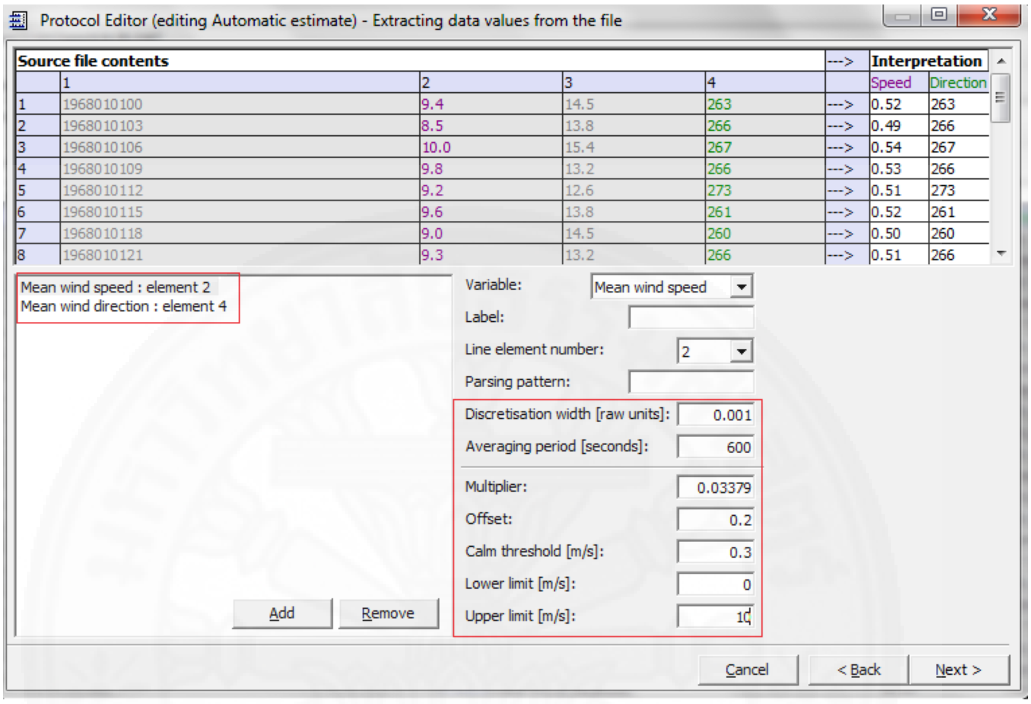


Fig. 3.13d. Edit a protocol

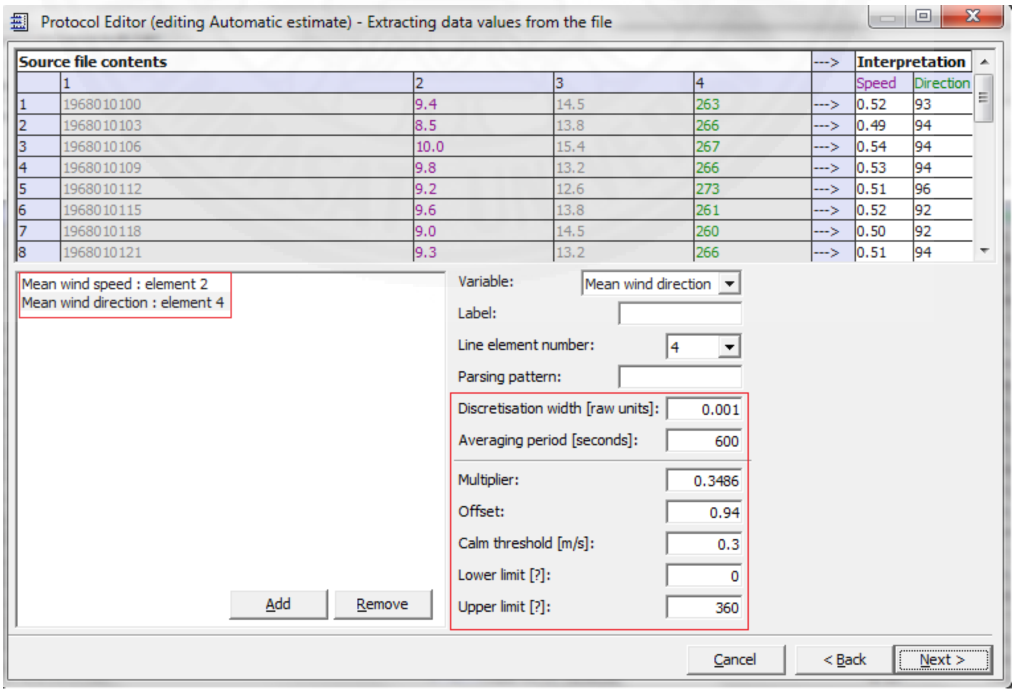


Fig. 3.13e. Edit a protocol

In this step, have to input the multiplier and offset; also set up the lower and upper limits for both speed and direction. After that, left-click “Next” and the window of the final stage for creating protocol will appear as shown in **Fig. 3.13f** below.

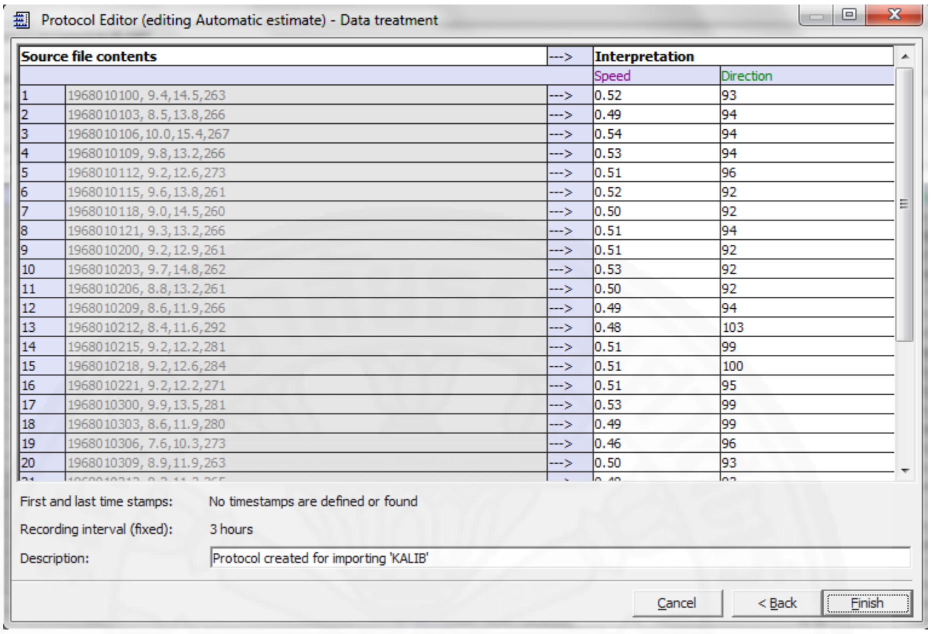


Fig. 3.13f. Edit a protocol

Then left-click “Finish” to finish creating a new protocol. Next, save the protocol to a file. After doing that, the previous window will come up again with the created protocol as shown in **Fig. 3.14a**.

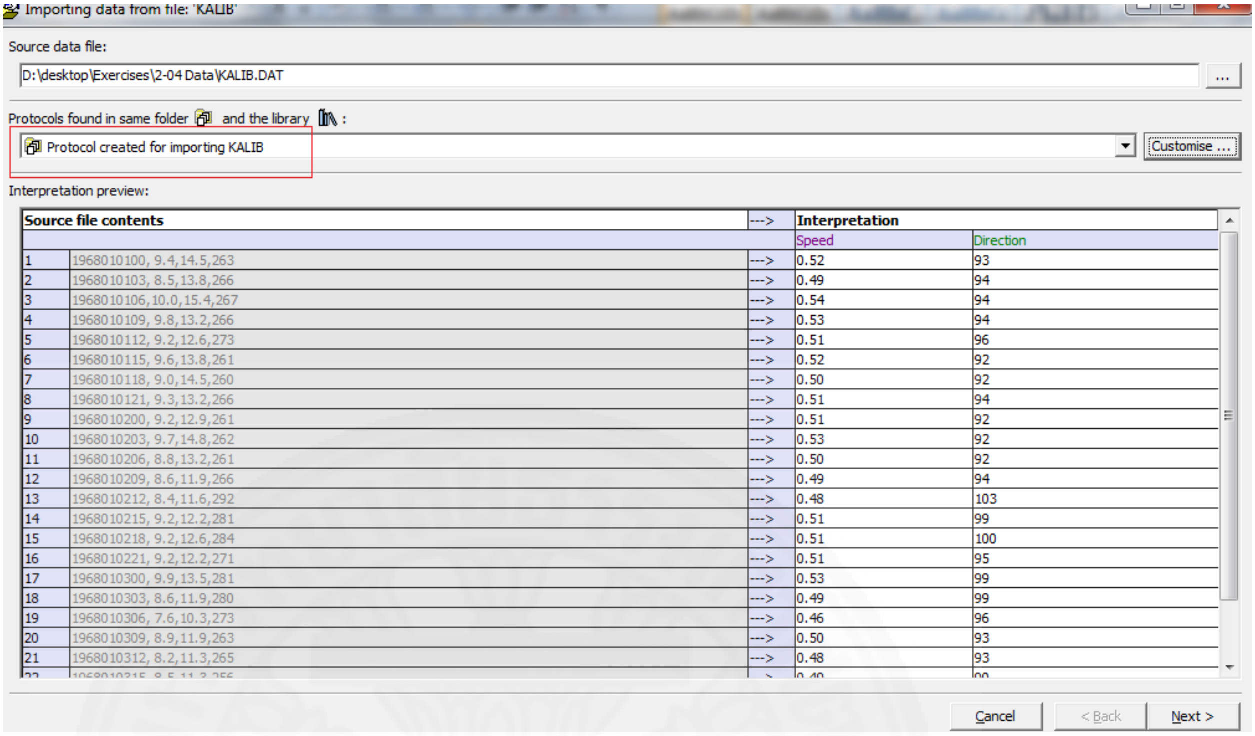


Fig. 3.14a. Import data from file with protocol

Now left-click "Next" and the window to specify the time of recording will appear as shown in **Fig. 3.14b**.

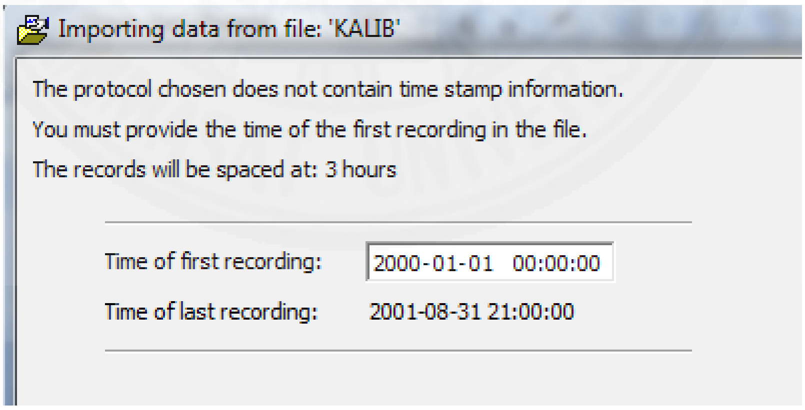


Fig. 3.14b. Import data from file with protocol

After entering the time of recording, left-click "Next". There will be a short report of data as shown in **Fig. 3.14c**. From that report, it will be able to know how many "bad" or unwanted values of the data set.

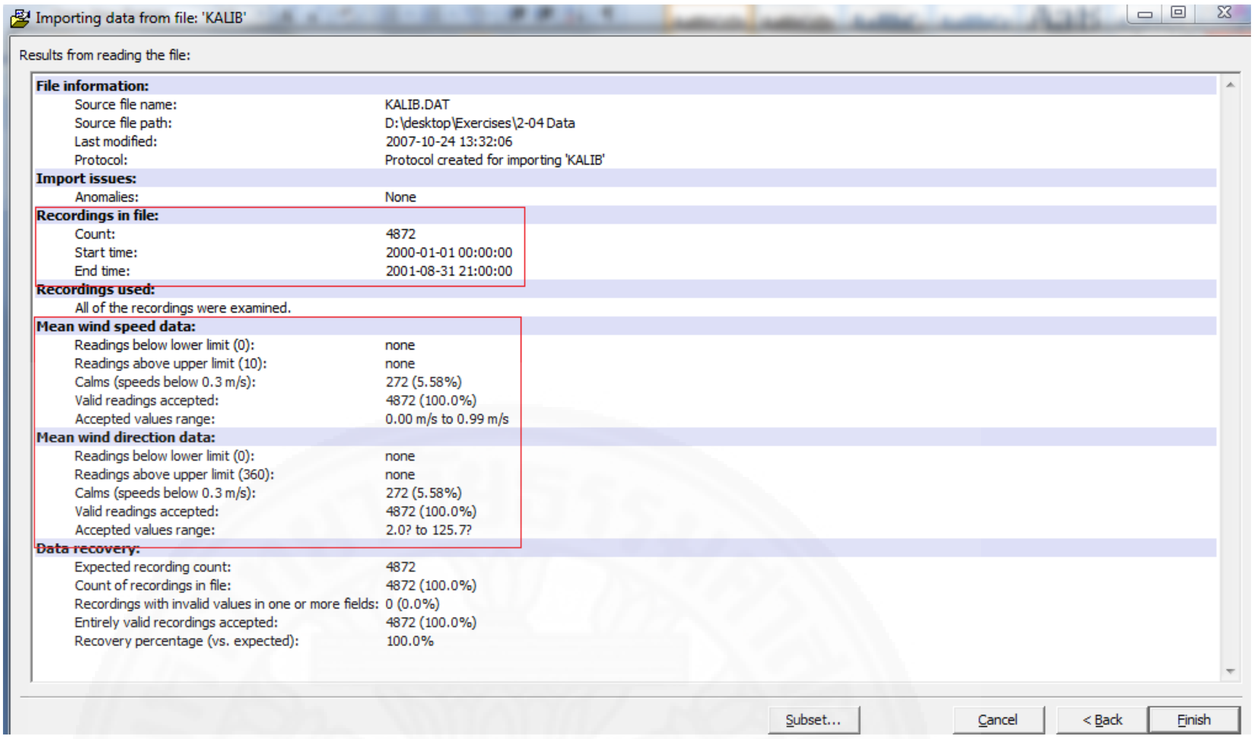


Fig. 3.14c. Import data from file with protocol

Finally, left-click "Finish" to completely importing the data set. In the main window, right-click "Results" and then choose "Create an Omwc" to get the wind climate file.

3.1.3.2 How to generate the resource grid and determine the AEP (annual energy production)

Now open the main program WasP. Then, create a new project and name it. In the next step, input the wind atlas, vector map from file. Next, create a resource grid, set up a wind farm and indentify all positions of turbines. In addition, have to set up the wind turbine generator which is specified at that project as shown in **Fig. 3.15** below.

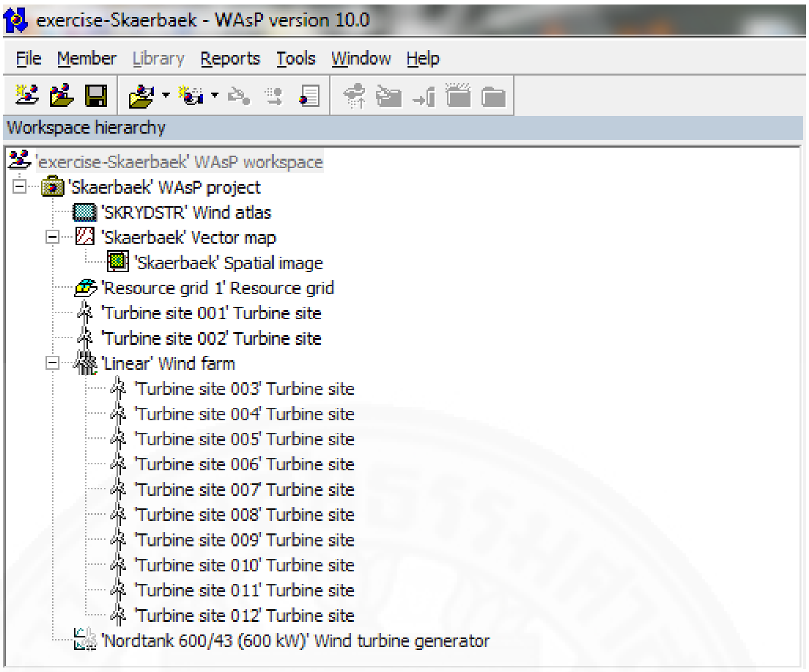


Fig. 3.15. Feature of a complete project

At this time, open "Resource grid" as shown in **Fig. 3.16a** to edit it.

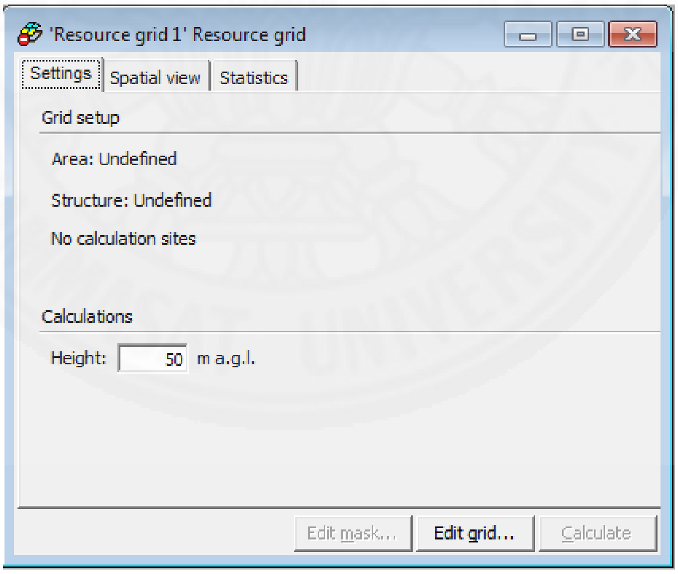


Fig. 3.16a. Edit the resource grid

After left-clicking "Edit grid", a new window will appear as shown in **Fig. 3.16b** below. Now, have to define the boundary of concerned region. Then, choose the resolution that want to get. Especially, have to keep in mind that the smaller resolution, the more beautiful grid and the more time consuming.

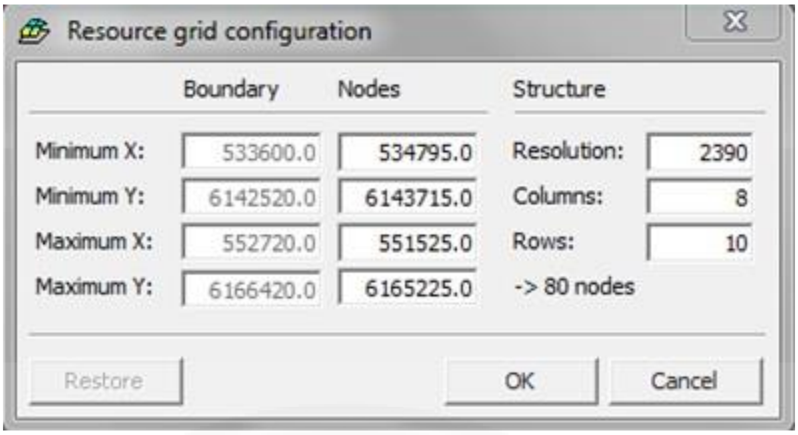


Fig. 3.16b. Edit the resource grid

After that, left-click "OK" and then "Calculate". have to wait until the program finish calculating everything. After the calculation, left-click "Edit mask" to choose how the map look like.

The result for masking by node properties is similar to masking by elevation. Next, have to define the properties of concerned nodes such as nodes that have mean speeds from 3 to 4 m/s. Finally, open the wind farm to see AEP and the other factors such as mean speed, power, wake effect loss, etc as shown in **Fig. 3.17** below.

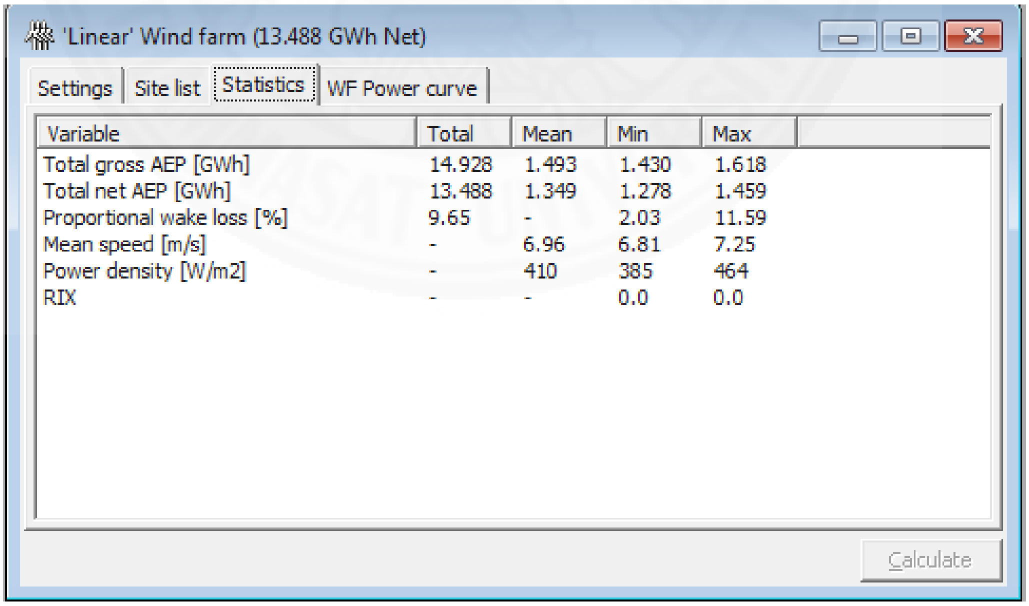


Fig. 3.17. Wind farm statistics

3.2 Financial analysis To be able to access the financial return, we firstly have to analyze the cost of the project for the installation of wind turbines to produce electricity. Moreover, benefits arisen from the project also have to be analyzed. Benefits include profits from the sale of produced electricity and adders from the power purchase because of renewable energy. According to Dr. Pallapa Ruangrong, Energy Regulatory Commission of Thailand, the rate of adder for wind energy in Thailand on 26 November 2007 is approved to be 3.5 baht/kWh and is extend from first 7 to 10 years of the project's life by NEPC.

3.2.1 Cost of the project

The total project cost to install wind turbines to produce electricity consists of the turbine cost, the construction cost and the management cost. In addition, every year the project costs for the value of operation and maintenance. It is noticed that the cost for the land is already provided for the installation of the turbines.

Recently, it is reported that the cost of a turbine has reduced and been low compared to the period of time that the price reached the peak in 2008. According to many reports, the cost of a turbine is varied from 1.2 to 2.6 million USD. The size of the turbine should be selected to be suitable to the condition as well as the position of the area.

The construction cost or installation cost is one of the big issues that have a great effect on the project because it is high cost and dependant on many factors. Main factors can be listed such as making roads for easy transportation of raw materials, the auxiliary systems such as transformers, the connection to the power of the system of Provincial Electricity Authority… In Thailand, the installation after considering all the factors varies from 40-60% of the turbine cost.

The last cost of the initial investment that we have to consider is about the management of the construction. Generally, it will cost about 10% of the construction cost. Last but not least, the amount of money that we have to pay to operate and maintain the condition of the turbine is very important. As applied in many projects, the operation and maintenance cost is about 2% of the price of the wind turbine.

3.2.2 Benefit of the project

To calculate the benefits arisen from the project, we have to know how much electricity a wind turbine or a wind farm can produce for each year. It is known as Annual Energy Production (AEP) which is the result we can get from WAsP program or any similar applications. In this project, we will assume that the turbine can produce the same amount of electricity every year. However, because of the reduction in electricity every year, we will take AEP is lower a bit than the one calculated or predicted. Another factor that has a main effect on the benefit is the electricity rate that we can sell. As recorded on 10 April, 2009 the base tariff is 2.84 baht/kWh and the average wholesale electricity rate known as F_t average wholesale is 0.9101 baht/kWh. There is one essential factor that encourages people to invest to the wind project is the adder from the government. In Thailand, the government puts many efforts to reduce the use of oil and natural gas for power generation. It is encouraged to use the indigenous renewable energy resources to produce the electricity. The target is to reduce environmental impact as well as global warming which is the main issue nowadays. As a result of that, every kWh produced by using renewable energy resources such as wind energy, solar energy… will be added an amount of money to the electricity rate. According to the policy, the adder will be added to the first 7 to 10 years during the project life. Therefore, the power purchase rate will increase 3.5 baht/kWh.

3.2.3 Net present value (NPV)

NPV is defined to be "the difference between the present value of cash inflows and the present value of cash outflows". It is "used to analyze the profitability of an investment or a project". All the costs such as initial costs and O&M cost is considered to negative. The benefits yielded from the project are positive. The project is said to be successful or worthy to be invested when NPV is positive. The project is definitely rejected if NPV is calculated to be negative because the cash flow to the project will be negative. In short terms, NPV is the sum of net benefits which reflect the value of time. NPV is calculated from the equation (8) below

$$NPV = X_n/(1+m)^n \quad (8)$$

Where NPV is net present value (baht)

X_n is the net cash flow of the year (baht)

n is the year of the project

m is the discount rate (%)

It is noticed that the value of benefits received and costs incurred throughout the project life is not stable due to the effects of inflation (inflation rate, f). As a result of that, the price of the product will be increased year by year. For example, the value in year 1 is c, the value in next year will be c*(1+f) and in year n is $c*(1+f)^{(n-1)}$.

In summary, the positive NPV indicates that the project results in a greater return on the costs incurred in the project. NPV is just one of main indicators in deciding whether the project is acceptable and the benefits worth the investment or not. NPV is the cumulative total net present value over the whole life of the project. The feature of NPV is not related to other decision indicators. During the calculation of NPV, the most important point is the assumption about the rate of return which will affect all the stream of cash flow throughout project life. In addition, the discount rate assumed in the project should be lower than the minimum rate of return which will be discussed later.

3.2.4 Internal rate of return (IRR)

Internal rate of return is defined to be "the discount rate often used in capital budgeting that makes the net present value of all cash flows from a particular project equal to zero". IRR is not related to or dependant on the interest rate. There are two kinds of IRR which are FIRR and EIRR. FIRR is not related to the sale of Carbon credit or the reduced of imported crude oil which will be discussed later but EIRR.

The main reason for the project to analyze IRR is not this indicator can be used without having to know the discount rate. IRR is also one of the essential criteria to decide whether to accept the investment. The range of possible discount rate should be lower than the calculated IRR. IRR is higher than the interest rate means that the project is well worth the investment. In addition, the higher IRR indicates "the more desirable it is to undertake the project". The method to find IRR is trial and error of the rate of return to make NPV be equal to zero.

3.2.5 Benefit-Cost ratio (B/C)

Benefit-Cost ratio is "a ratio attempting to identify the relationship between the cost and benefits of a proposed project". B/C is also a criterion for investment decisions at a minimum acceptable rate. In general, the project is expected to get the value of benefits to be more than the cost.

If B/C > 1 the project is accepted

B/C < 1 the project is rejected

B/C = 1 there is no effect. The decision may depend on other indicators

It is noted that B/C needs to be used carefully and should be used along with other criteria in making selection of the project. That is due to many reasons. First reason is that costs and benefits of the project may be increased or decreased without any reason throughout the project life. It is depended on how the analysis of the transaction is. Another reason may be related to the public policy. Public policy should not be restricted without a reason. It can be changed the way that we achieve benefits or cost with only one small change in policy. Therefore, there is risky to make a decision which is based on only Benefit-Cost ratio.

*Cost per unit of energy (COE)**

A measure of cost per unit of energy is also one of significant criteria to check whether the project is worthy to invest or not. It is also considered the impact of inflation and discount rate. The cost per unit of energy will be able to tell how much the minimum price that we should sell is. Furthermore, it is also used as a basis for determining the suitability of the selected area to install wind turbines. Assessing COE has gained popularity in the evaluation of a certain project. The reason is that it considers the total cost of the project which consists of the initial cost and the value of operation and maintenance throughout the project life. After that, it is divided by the amount of electricity that wind turbines can be produced throughout the project. Finally, the COE will consider only the evaluation of the cost of the project. It does not have financial and economic returns as assessed by other indicators before.

3.3 Economic Analysis

Economic Analysis also includes three main factors which are NPV, IRR and COE with the sensitivity analysis. However, economic analysis considers two issues which are the advantages of the renewable energy project. There are the dropped value of crude oil import and the selling carbon credits due to the amount of air pollution reduced.

3.3.1 The value of crude oil imports dropped

Electricity generated from wind turbines is a way of producing electricity from renewable energy. Therefore, that clean energy will reduce the cost of fuel for power generation. Generally, it is related to crude oil imports dropped. To evaluation that amount of money, it is necessary to know the relationship between crude oil and the electricity produced. The electrical energy is related to the supply of crude oil with the ratio 0.0000000852 kilotons of oil equivalent (kTOE) per one kilowatt-hour. However, for the trading, the unit of barrel is used to calculate amount of money. We have the relation that one barrel is equivalent to 0.000137 kTOE. As recorded in January 2012, the cost for one barrel of crude oil is about 106.89 USD. As we can see that, the crude oil price is quite high for one barrel. It is also noticed that the price of crude oil still keeps increasing which means we can save or earn money more from the project. In addition, the benefits have been due to reduced imports of crude oil which means the amount of electricity generated in the area. As a result of that, the energy value of crude oil import reductions will be used to evaluate the economic benefits of the project.

3.3.2 Selling carbon credits

Production of electricity using wind turbines can get benefits in another way which is to reduce air pollution emissions from power plants. Air pollution occurs due to sulfur oxides (SO_X), nitrogen oxides (NO_X), carbon dioxide (CO_2) and dust particles. So far, air pollution is always a big concern of scientists and engineers because of the effect to human health, damages to agricultural production and even the destruction of houses. According to reports of contaminants in air from the smokestacks of power plants of the Electricity Generating Authority of Thailand (EGAT), an average of contaminants released to the air of all types of power plants respected to 1 MWh of electricity is

- 0.41 kg of sulfur dioxide
- 1.41 kg of nitrogen oxides
- 520 kg of carbon dioxide
- 0.04 kg of dust particles

These pollutant emissions can be calculated as the rewards in economic analysis. As we can observe that there is still no obvious effect caused by those pollutants in Thailand. However, the carbon dioxide has been widely quoted today due to the global warming issue. "Carbon credits" which is quite common nowadays for trading is under the supervision of Thailand Greenhouse Gas Management Organization (TGO) in Thailand. The sale price of carbon credits is based on BlueNext Spot reference price, which refers to the Spot trading of EUA (European Union Allowance). As recorded on March 7th, the price to sell carbon credits is 8.34 euro/ton carbon dioxide. We will use this rate to calculate throughout the whole life of the project.

3.4 Assumption and example for feasibility analysis

❖ The life of the project is 20 years.

❖ The cost of a wind turbine is about 1.1 million USD per 1 MW. In this project, we will use 1 MW wind turbine. The selection of turbine is based on the situation in central region of Thailand which has low or medium wind speed.

❖ No cost for the supplied area.

❖ The operation and maintenance charge is 2% of the value of the wind turbine.

❖ The construction cost is 40% of the value of the wind turbine.

- Foreign exchange rates are 31.65 THB/USD and 42.27 THB/Euro. (updated on September, 2013)
- The base tariff is 2.84 baht/kilowatt-hour. The average wholesale electricity rate or Ft average wholesale is 0.9101 baht/kilowatt-hour. (As of April 10, 2009).
- Power purchase rate of increase or Adder is 3.5 baht/kilowatt-hour within first 10 years of the project life.
- Inflation rate of 0% (no inflation) and 3% in accordance with core inflation updated in February 2012.
- The discount rate is 7% which is used as the base case in the project. (as updated 31 December 2010)
- 0.0000000852 kilotons of oil equivalent (kTOE) per one kilowatt-hour.
- One barrel is equivalent to 0.000137 kTOE.
- One barrel of crude oil is about 106.89 USD.
- The price to sell carbon credits is 8.34 euro/ton carbon dioxide.
- The analysis of sensitivity of the project is composed of three factors which are foreign exchange rates, the cost of construction and the value of operation and maintenance.
- Three factors what are net present value (NPV), internal rate of return (IRR) and benefits of investments (B/C) are evaluated for both financial and economic analysis.

Table 3.1 Numerical values of financial parameters.

Factor	Value
Cost of turbine	1,000,000 EUR/1MW
USD exchange rate	31.65 THB/US$
Euro exchange rate	42.27THB/EUR
kTOE* per kWh	0.0000000852 kTOE/kWh
kTOE* per barrel	0.000137 kTOE/barrel
Crude oil cost	110.3 US$/barrel
Sale rate of carbon credit	8.34 EUR/ton
Sale rate of electricity	3.75 THB/kWh
Adder within first 10 years	0.117 US$/kWh
Minimum loan rate (MLR)	7%
Inflation rate	3%

*TOE: Ton of Oil Equivalent

Example for feasibility analysis

First of all, the initial important values have to be calculated. Then, the exchange rates are input to the excel file because many calculation will be related or based on those exchange rates. There is the table as shown in the **Fig. 3.18** below

baht per USD	30.76	baht/USD
baht per Euro	40.44	baht/Euro

Fig. 3.18. Exchange rate

As known above that, the wind turbine is 1 MW turbine which costs 1.9 million dollars. The exchange rate is 30.76 baht/USD. Therefore, the cost of the turbine is

1.9 million USD * 30.76 baht/USD = 58,444,000 baht

Then calculate the operation and maintenance cost which is equal to 2% of the value of the wind turbine.

O&M = 58,444,000 * 0.02 = 1,168,880 baht

The next step, calculate the construction cost (installation cost) which is assumed to be 40% of the turbine cost.

Construction cost = 58,444,000 * 0.4 = 23,377,600 baht

The management cost can be calculated by knowing to be about 10% of the construction cost

Management cost = 23,377,600 * 0.1 = 2,337,760 baht

Finally, the initial cost is found by summing the turbine cost, the construction cost and the management cost.

Initial cost = 58,444,000 + 23,377,600 + 2,337,760 = 84,159,360 baht

*Note that: excel application is used for the project. In excel file, formula which is the relationship between each item is set up. Then, just input the value of the wind turbine, there is the table as **Fig. 3.19** below

price of turbine	1,900,000.00	USD
	58,444,000.00	baht
O&M	1,168,880.00	baht
contruction cost	23,377,600.00	baht
management cost	2,337,760.00	baht
initial cost	84,159,360.00	baht

Fig. 3.19. Cost of the project

In the next step, input the sale of electricity to the excel file. According to the assumptions, the base tariff is 2.84 baht/kWh, Ft average wholesale is 0.91 baht/kWh and adder is 3.5 baht/kWh. The sale of electricity is the sum of tariff and Ft. The total sale is the sum of sale of electricity and adder. There will be a table as shown in **Fig. 3.20** below

tariff	2.84	baht/kWh
wholesale electricity	0.9101	baht/kWh
sale of electricity	3.7501	baht/kWh
adder	3.50	baht/kWh
total sale (with adder)	7.2501	baht/kWh

Fig. 3.20. Sale of electricity

Next, input the power of electricity produced or AEP which is taken from the predicted result. After inputing the value, there will be the table as shown in **Fig. 3.21** below

electricity produced	1,402,000.00	kWh/year

Fig. 3.21. Produced electricity for one year

By following that, now calculate the amount of money that earned from selling the electrical power. Without adder, the sale of electricity is

1,402,000 * 3.7501 = 5,257,640.20 baht

The net income without adder is

5,257,640.20 – 1,168,880 = 4,088,760.20 baht

With adder, the sale of electricity is

1,402,000 * 7.2501 = 10,164,640.20 baht

The net income with adder is

10,164,640.20 – 1,168,880 = 8,995,760.20 baht

By assigning the formula as above steps, there is the table as **Fig. 3.22** below

sales of Electricity (baht/year)		no adder	5,257,640.20
		adder	10,164,640.20
Net income with O&M		no adder	4,088,760.20
		adder	8,995,760.20

Fig. 3.22. The net income per year in financial return

There are two informations which are very important for calculating all the criteria. They are discount rate and inflation rate. The base for discount rate is chosen to be 7% and the inflation rate is 3%. After inputing all the information to excel file we can get the table as shown in **Fig. 3.23** below

discount rate (base)	0.07
inflation rate	0.030

Fig. 3.23. Discount rate and inflation rate

- Net present value (NPV) calculation

Now, we will create the cash flow of the project throughout 20 years with 0% inflation rate. For year 0, the initial cost will be input which is 84,159,360 baht. It is noticed to be negative because it is the cost of the project. Without adder, we will earn the same amount of money for 20 years which is 4,088,760.20 baht. However, with adder added as calculated above we get 8,995,760.20 baht for the first 10 years. After first 10 years, the income will be back to normal which is equal to amount of respective year without adder. After inputing everything, we can get the table as shown in **Fig. 3.24**.

To be able to calculate NPV, we use the function npv(rate, value1, [value2],…). It is noted that value 1 is the amount of year 1 and so on. Finally, we will get NPV after summing up the amount for year 0. Then NPV will be calculated as follow

NPV = npv(rate, value1, [value2],…) + value of year 0

year	no adder, financial return	adder, financial return
0	- 84,159,360.00	- 84,159,360.00
1	4,088,760.20	8,995,760.20
2	4,088,760.20	8,995,760.20
3	4,088,760.20	8,995,760.20
4	4,088,760.20	8,995,760.20
5	4,088,760.20	8,995,760.20
6	4,088,760.20	8,995,760.20
7	4,088,760.20	8,995,760.20
8	4,088,760.20	8,995,760.20
9	4,088,760.20	8,995,760.20
10	4,088,760.20	8,995,760.20
11	4,088,760.20	4,088,760.20
12	4,088,760.20	4,088,760.20
13	4,088,760.20	4,088,760.20
14	4,088,760.20	4,088,760.20
15	4,088,760.20	4,088,760.20
16	4,088,760.20	4,088,760.20
17	4,088,760.20	4,088,760.20
18	4,088,760.20	4,088,760.20
19	4,088,760.20	4,088,760.20
20	4,088,760.20	4,088,760.20

Fig. 3.24. Cash flow with 0% inflation rate in financial analysis

Now, we will consider about the situation that inflation occurs with 3%. The inflation rate will affect the operation and maintenance cost and the F_t average wholesale. In details, the amount of money in year 1, year 2 and year n will be calculated as following formula.

$$\text{Year } n = (\text{electricity produced})*(\text{tariff}) + \{(\text{electricity produced})*(F_t)-(O\&M)\}*\{(1+f)^\wedge(n-1)\}$$

Where n is the year

F_t is the average wholesale

f is the inflation rate

For example:

Year 1 = 1,402,000*2.84+ (1,402,000 *0.9101–1,168,880)*{(1+0.03)^(1-1)}=4,088,760.20 baht

Year 2 = 1,402,000*2.84+ (1,402,000 *0.9101–1,168,880)*{(1+0.03)^(2-1)}=4,091,972.61 baht

……

For the case of considering adder, we just need to add the amount of adder to every year. For example

Year 1 = 4,088,760.20 + 1,402,000 * 3.5 = 8,995,760.20 baht

Year 2 = 4,091,972.61 + 1,402,000 * 3.5 = 8,998,972.61 baht

…….

After that we will get the table as shown in **Fig. 3.25** below

year	no adder, financial return	adder, financial return
0	- 84,159,360.00	- 84,159,360.00
1	4,088,760.20	8,995,760.20
2	4,091,972.61	8,998,972.61
3	4,095,281.38	9,002,281.38
4	4,098,689.43	9,005,689.43
5	4,102,199.71	9,009,199.71
6	4,105,815.30	9,012,815.30
7	4,109,539.36	9,016,539.36
8	4,113,375.14	9,020,375.14
9	4,117,325.99	9,024,325.99
10	4,121,395.37	9,028,395.37
11	4,125,586.83	4,125,586.83
12	4,129,904.04	4,129,904.04
13	4,134,350.76	4,134,350.76
14	4,138,930.88	4,138,930.88
15	4,143,648.41	4,143,648.41
16	4,148,507.46	4,148,507.46
17	4,153,512.29	4,153,512.29
18	4,158,667.26	4,158,667.26
19	4,163,976.87	4,163,976.87
20	4,169,445.78	4,169,445.78

Fig. 3.25. Cash flow with 3% inflation rate in financial analysis

- Internal rate of return (IRR) calculation

We are using the same tables attained in NPV calculation to calculate for all situations which are no inflation and inflation with and without adder. We will use a function in excel which is

IRR = irr(values, [guess])

Where values are values since year 0 and guess is any random number.

- Benefits of investments (B/C) calculation

We calculate benefits and costs separately. As mentioned earlier, costs include initial cost for year 0 and the operation and maintenance cost during 20 years. On the other hand, benefits are the money from sale of electricity and the power purchase (Adder).

For benefit calculation, we just input the money we can get from sale of electricity and with or without the power purchase for 20 years. In the case of inflation, the sale of electricity is increase by formula

Sale of electricity of year n = (sale of year 1)*((1+f)^(n-1))

After inputing, we have the table for benefits as **Fig. 3.24** below

year	no adder, financial return	adder, financial return
0	0	0
1	5,257,640.20	10,164,640.20
2	5,257,640.20	10,164,640.20
3	5,257,640.20	10,164,640.20
4	5,257,640.20	10,164,640.20
5	5,257,640.20	10,164,640.20
6	5,257,640.20	10,164,640.20
7	5,257,640.20	10,164,640.20
8	5,257,640.20	10,164,640.20
9	5,257,640.20	10,164,640.20
10	5,257,640.20	10,164,640.20
11	5,257,640.20	5,257,640.20
12	5,257,640.20	5,257,640.20
13	5,257,640.20	5,257,640.20
14	5,257,640.20	5,257,640.20
15	5,257,640.20	5,257,640.20
16	5,257,640.20	5,257,640.20
17	5,257,640.20	5,257,640.20
18	5,257,640.20	5,257,640.20
19	5,257,640.20	5,257,640.20
20	5,257,640.20	5,257,640.20

Fig. 3.26a. Benefits without inflation

year	no adder, financial return	adder, financial return
0	-	-
1	5,257,640.20	10,164,640.20
2	5,295,919.01	10,202,919.01
3	5,335,346.18	10,242,346.18
4	5,375,956.16	10,282,956.16
5	5,417,784.45	10,324,784.45
6	5,460,867.58	10,367,867.58
7	5,505,243.21	10,412,243.21
8	5,550,950.10	10,457,950.10
9	5,598,028.21	10,505,028.21
10	5,646,518.65	10,553,518.65
11	5,696,463.81	5,696,463.81
12	5,747,907.33	5,747,907.33
13	5,800,894.15	5,800,894.15
14	5,855,470.57	5,855,470.57
15	5,911,684.29	5,911,684.29
16	5,969,584.42	5,969,584.42
17	6,029,221.55	6,029,221.55
18	6,090,647.80	6,090,647.80
19	6,153,916.83	6,153,916.83
20	6,219,083.93	6,219,083.93

Fig. 3.26b. Benefits with inflation

For cost calculation, the year 0 is the initial cost that we have to invest at the beginning. The next 20 years are filled up by the operation and maintenance cost. With inflation, the operation and maintenance cost is calculated by the formula

O&M of year n = (O&M of year 1)*((1+f)^(n-1))

After inputing, we will have tables as **Fig. 3.27** below

Cost	Cost
84,159,360.00	84,159,360.00
1,168,880.00	1,168,880.00
1,168,880.00	1,203,946.40
1,168,880.00	1,240,064.79
1,168,880.00	1,277,266.74
1,168,880.00	1,315,584.74
1,168,880.00	1,355,052.28
1,168,880.00	1,395,703.85
1,168,880.00	1,437,574.96
1,168,880.00	1,480,702.21
1,168,880.00	1,525,123.28
1,168,880.00	1,570,876.98
1,168,880.00	1,618,003.29
1,168,880.00	1,666,543.39
1,168,880.00	1,716,539.69
1,168,880.00	1,768,035.88
1,168,880.00	1,821,076.95
1,168,880.00	1,875,709.26
1,168,880.00	1,931,980.54
1,168,880.00	1,989,939.96
1,168,880.00	2,049,638.16

Fig. 3.27. Cost of the project without and with inflation

Then, we calculation the net present value of each cost and benefit by the same way that we calculate NPV above. After that, we divide benefits by costs respectively.

- Sensitivity of the project.

As mentioned before, many factors which are rate of exchange,the cost of wind turbine, the construction cost and the value of operation and maintenance will be varied to analyze the sensitivity of the project. NPV, IRR and COE are analyzed by the change of each factor. In this analysis, we just have to change the input for the factor and see the change in each item. Then, we draw a graph to show the change.

*** Cost of energy (COE)

As discussed above, COE is not belong to financial or economic analysis. It is just a measure of cost per unit of energy. It can tell you the minimum price that should be the selling price of electricity. The COE is also influenced by the inflation and discount rate. In order to calculate COE, we just need to calculate the present value of cost for first 10 years by the same method to calculate the cost of the project.We consider only first 10 years because of the adder or the power purchase involved. After that, we divide that cost by the total energy produced during first 10 years.

In economic analysis, everything is done by the same way as financial analysis. There is only thing we have to change is to add the reduced cost from crude oil and the carbon credit sale to the benefit and the money earned every year. By doing like that we will have new tables as **Fig. 3.28** below

Economic return(baht/year)	no adder	8,370,277.38
	adder	13,277,277.38
Net income with O&M	no adder	7,201,397.38
	adder	12,108,397.38

Fig. 3.28a. The net income per year in economic analysis

year	no adder, economic return	adder, economic return
0	- 84,159,360.00	- 84,159,360.00
1	7,201,397.38	12,108,397.38
2	7,201,397.38	12,108,397.38
3	7,201,397.38	12,108,397.38
4	7,201,397.38	12,108,397.38
5	7,201,397.38	12,108,397.38
6	7,201,397.38	12,108,397.38
7	7,201,397.38	12,108,397.38
8	7,201,397.38	12,108,397.38
9	7,201,397.38	12,108,397.38
10	7,201,397.38	12,108,397.38
11	7,201,397.38	7,201,397.38
12	7,201,397.38	7,201,397.38
13	7,201,397.38	7,201,397.38
14	7,201,397.38	7,201,397.38
15	7,201,397.38	7,201,397.38
16	7,201,397.38	7,201,397.38
17	7,201,397.38	7,201,397.38
18	7,201,397.38	7,201,397.38
19	7,201,397.38	7,201,397.38
20	7,201,397.38	7,201,397.38

Fig. 3.28b. Cash flow without inflation

year	no adder, economic return	adder, economic return
0	- 84,159,360.00	- 84,159,360.00
1	7,201,397.38	12,108,397.38
2	7,297,988.90	12,204,988.90
3	7,397,478.16	12,304,478.16
4	7,499,952.11	12,406,952.11
5	7,605,500.27	12,512,500.27
6	7,714,214.88	12,621,214.88
7	7,826,190.93	12,733,190.93
8	7,941,526.26	12,848,526.26
9	8,060,321.64	12,967,321.64
10	8,182,680.89	13,089,680.89
11	8,308,710.92	8,308,710.92
12	8,438,521.85	8,438,521.85
13	8,572,227.10	8,572,227.10
14	8,709,943.51	8,709,943.51
15	8,851,791.42	8,851,791.42
16	8,997,894.76	8,997,894.76
17	9,148,381.21	9,148,381.21
18	9,303,382.24	9,303,382.24
19	9,463,033.31	9,463,033.31
20	9,627,473.91	9,627,473.91

Fig. 3.28c. Cash flow with inflation

year	no adder, economic return	adder, economic return	Cost
0	0	0	84,159,360.00
1	8,370,277.38	13,277,277.38	1,168,880.00
2	8,370,277.38	13,277,277.38	1,168,880.00
3	8,370,277.38	13,277,277.38	1,168,880.00
4	8,370,277.38	13,277,277.38	1,168,880.00
5	8,370,277.38	13,277,277.38	1,168,880.00
6	8,370,277.38	13,277,277.38	1,168,880.00
7	8,370,277.38	13,277,277.38	1,168,880.00
8	8,370,277.38	13,277,277.38	1,168,880.00
9	8,370,277.38	13,277,277.38	1,168,880.00
10	8,370,277.38	13,277,277.38	1,168,880.00
11	8,370,277.38	8,370,277.38	1,168,880.00
12	8,370,277.38	8,370,277.38	1,168,880.00
13	8,370,277.38	8,370,277.38	1,168,880.00
14	8,370,277.38	8,370,277.38	1,168,880.00
15	8,370,277.38	8,370,277.38	1,168,880.00
16	8,370,277.38	8,370,277.38	1,168,880.00
17	8,370,277.38	8,370,277.38	1,168,880.00
18	8,370,277.38	8,370,277.38	1,168,880.00
19	8,370,277.38	8,370,277.38	1,168,880.00
20	8,370,277.38	8,370,277.38	1,168,880.00

Fig. 3.28d. Benefits and Costs without inflation

year	no adder, economic return	adder, economic return	Cost
0	-	-	84,159,360.00
1	8,370,277.38	13,277,277.38	1,168,880.00
2	8,501,935.30	13,408,935.30	1,203,946.40
3	8,637,542.96	13,544,542.96	1,240,064.79
4	8,777,218.85	13,684,218.85	1,277,266.74
5	8,921,085.01	13,828,085.01	1,315,584.74
6	9,069,267.16	13,976,267.16	1,355,052.28
7	9,221,894.78	14,128,894.78	1,395,703.85
8	9,379,101.22	14,286,101.22	1,437,574.96
9	9,541,023.86	14,448,023.86	1,480,702.21
10	9,707,804.17	14,614,804.17	1,525,123.28
11	9,879,587.90	9,879,587.90	1,570,876.98
12	10,056,525.13	10,056,525.13	1,618,003.29
13	10,238,770.49	10,238,770.49	1,666,543.39
14	10,426,483.20	10,426,483.20	1,716,539.69
15	10,619,827.30	10,619,827.30	1,768,035.88
16	10,818,971.72	10,818,971.72	1,821,076.95
17	11,024,090.47	11,024,090.47	1,875,709.26
18	11,235,362.78	11,235,362.78	1,931,980.54
19	11,452,973.27	11,452,973.27	1,989,939.96
20	11,677,112.06	11,677,112.06	2,049,638.16

Fig. 3.28e. Benefits and costs with inflation

The method and procedure to calculate is the same as financial analysis. There is noticed that the cost of the project is the same with financial analysis, only benefits are changed.

Chapter 4

Result and Discussion

4.1 Wind resource assessment

4.1.1 Monthly variation of mean wind speed

Fig. 4.1 shows monthly mean wind speed at Ratchaburi, Saraburi and Thammasat Rangsit. As observed, the peak period of time is varied from June to August of all regions. In each graph, 3 levels at 65m, 90m and 120m are shown respectively. Ratchaburi and Thammasat show that the mean wind speed is varied uniformly at 3 different levels of height. In another region, Saraburi pictures an unexpectedly varied mean wind speed at 65m height. The reason behind may mainly come from the malfunction of measurement devices. Both upper levels are changed correspondingly to each other. Additionally, those unexpected records may come from many aspects. Firstly, a great effect from surroundings may play an influent role. The place where mast is located is quite near to the residence area. Therefore, effects from obstacles such as high buildings, trees… are highly effective. Another reason, however, may originate from raw data itself. During the period of recording, there are some problems occurred to devices many times. Hence, collected data may get low quality for some certain intervals.

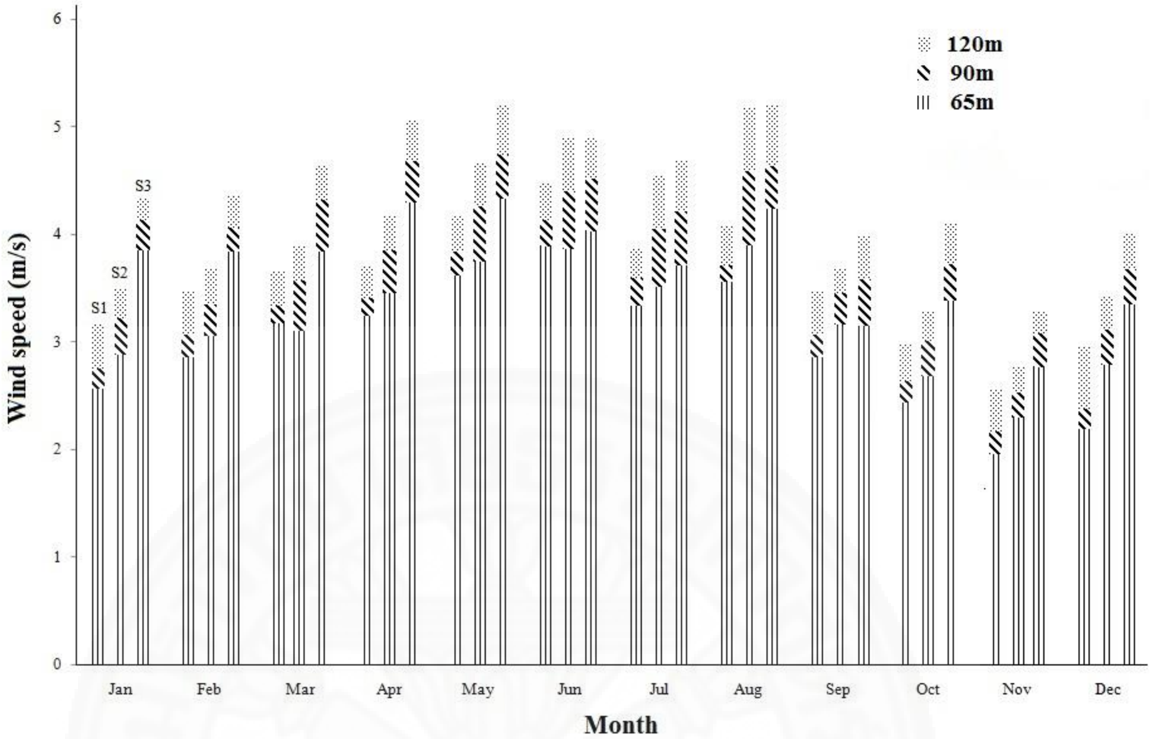


Fig. 4.1. Monthly mean wind speeds for three sites.

4.1.2 Yearly mean wind speed and wind power density

Table 4.1 shows the corresponding hourly mean wind speed at three levels at each location. Accordingly, Saraburi has the highest mean wind speed (4.15, 4.21, 4.57 m/2). Following that, the ground friction coefficient is also calculated at each station based on the power law . According to the calculated result, the ground friction coefficient is highest at Saraburi. Moreover, it is observed that the higher level the stronger wind there is. In addition, mean wind speeds at 3 levels do not differ critically (about 7~8% difference). In addition, the wind power density at Saraburi yields the highest value as well (99 W/m2 at 120m). That can be easily understood due to the strongest and most stable wind speed at the station.

Table 4.1 Parameters of wind data at three sites.

Site	Height (m)	Ground surface friction coefficient (α)	Shape parameter (k)	Scale parameter c (m/s)	Mean wind speed (m/s)	Power density (W/m^2)
S1	65 90 120	0.17	1.42 1.48 1.80	3.25 3.49 3.97	3.02 3.25 3.65	35 41 58
S2	65 90 120	0.17	2.09 2.09 2.10	3.60 4.08 4.50	3.49 3.92 4.01	42 59 70
S3	65 90 120	0.30	1.44 2.11 2.08	3.43 4.53 4.93	4.15 4.21 4.57	63 69 99

4.1.3 Diurnal variation of wind speed

Mean diurnal profile at Ratchaburi, Saraburi and Thammasat are shown respectedly in **Fig. 4.2-4**. According to graphs, each region shows its own characteristic of wind profile. At Ratchaburi, it is observed that during a day time the wind speed keeps changing. In details, there is a big different between the wind speed before and after noon. Ratchaburi shows a faster speed of wind after 12PM. The biggest variation during a day is up to 2.3m/s. Absolutely opposite to Ratchaburi, Saraburi pictures a stable profile of mean diurnal wind. Especially, the mean diurnal profile at Saraburi is considered as an ideal type of wind to apply for a wind turbine. Blades of wind turbine can be imagined to be rotating for whole day at a constant speed. The largest variation during a day is not up to 0.5m/s. Nevertheless, Thammasat seems to reflect a mixed characteristic of Ratchaburi and Saraburi. The shape of obtained graph is quite similar to Ratchaburi. Variation in wind speed at Thammasat is only up to 1.3m/s. It is noted that Thammasat is geographically located between Ratchaburi and Saraburi.

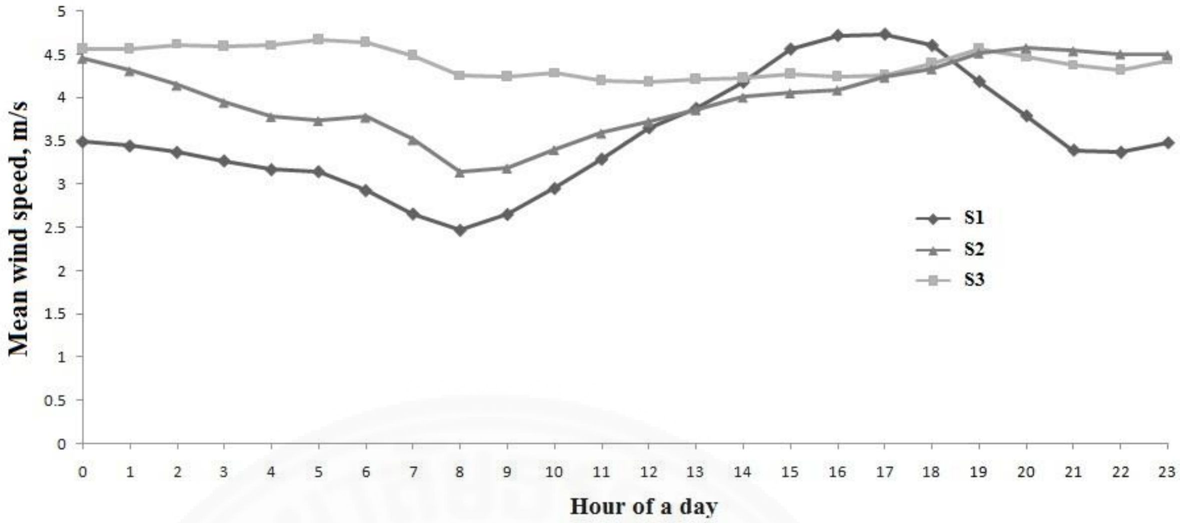


Fig. 4.2. Hourly mean wind speeds for three sites at height of 120 m.

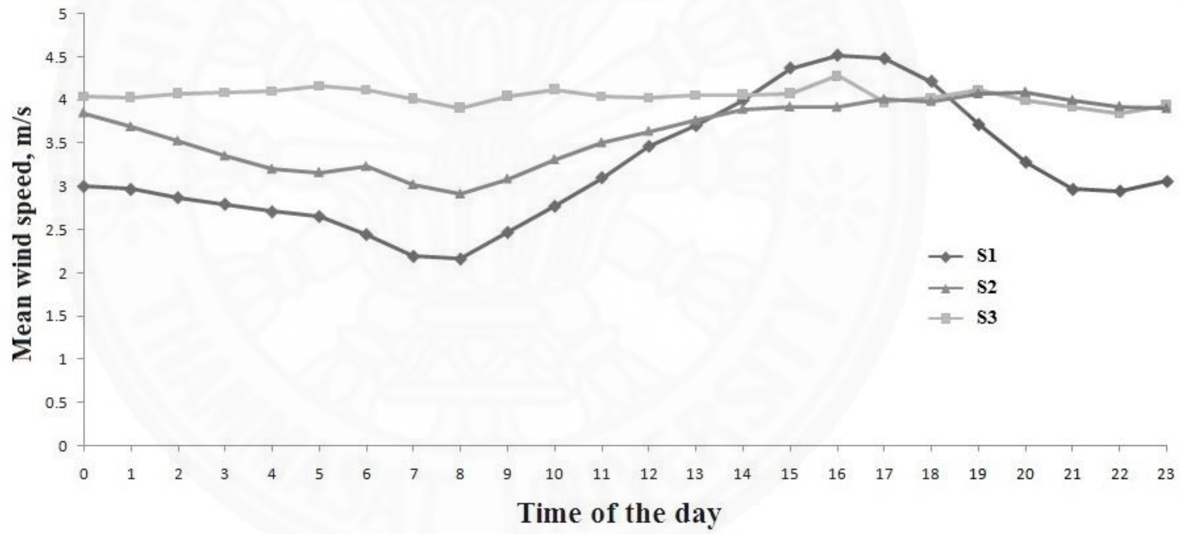


Fig. 4.3. Hourly mean wind speeds for three sites at height of 90 m.

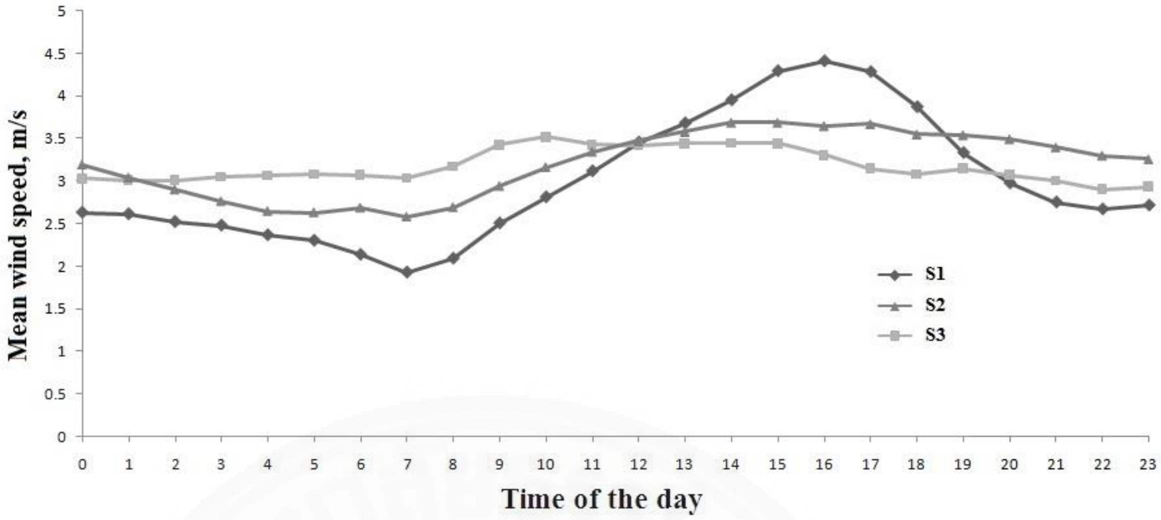


Fig. 4.4. Hourly mean wind speeds for three sites at height of 65 m.

4.1.4 Yearly probability density function and wind rose

Yearly probability density function and wind rose can provide more information about the characteristic of wind at a certain location. All recorded data including wind speed and direction, therefore, are used to construct **Fig. 4.5-6** at 3 stations correspondingly. Probability density function at all locations seems to have a quite similar trend. The details about wind parameters which are also shown in Table 3 contains the scale parameter c and the shape parameter k. In another aspect, wind rose shows the most frequent direction that the wind blows. **Fig. 4.6** shows obviously totally different characteristics of wind profile at 3 regions. At Ratchaburi, it is recorded that wind blows mainly at Southwest direction for all levels. In another place, Saraburi shows a North direction of wind. At last, Thammasat has wind behavior to be distributing around but significantly at Southwest direction. That information about wind characteristics is very useful to set up a high efficient wind farm.

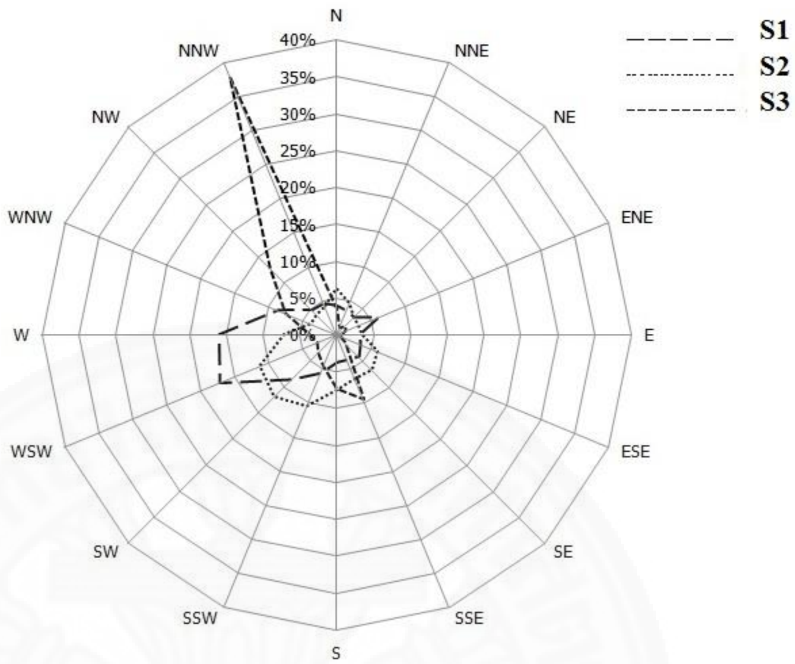


Fig. 4.5. Wind rose diagrams for three sites at height of 120 m.

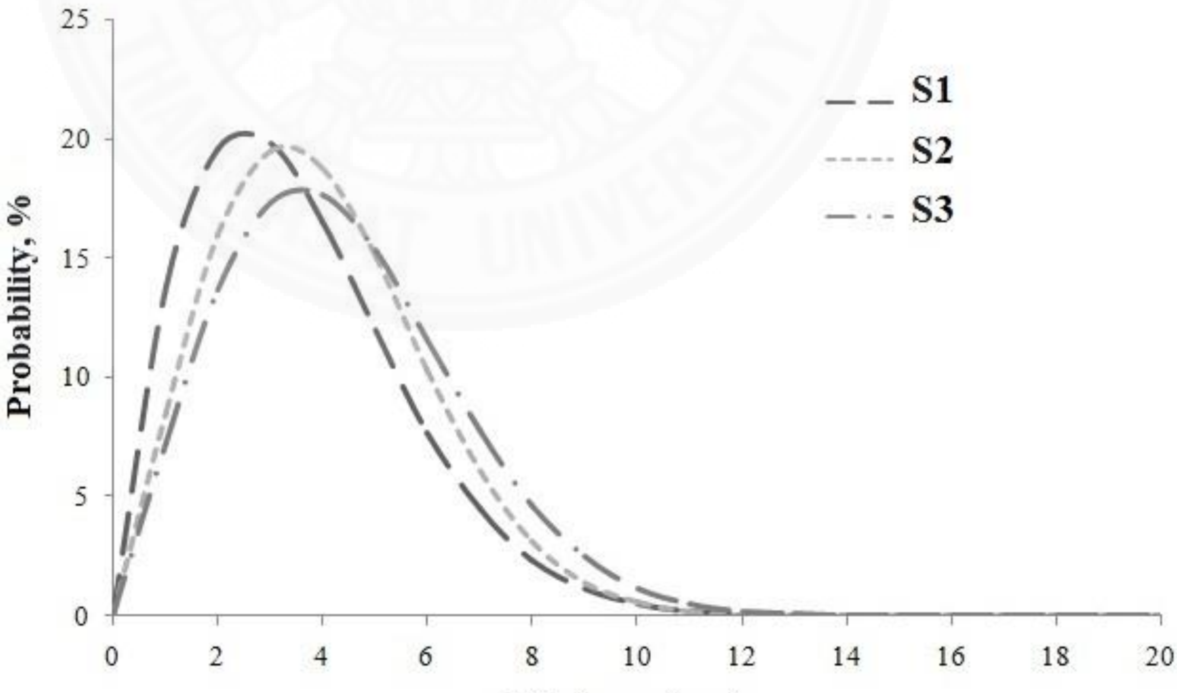


Fig. 4.6. Weibull distributions of wind data for three sites at height of 120 m.

4.1.5 Ground surface friction coefficient

The ground surface friction coefficient of all regions are plotted as shown in **Fig. 4.7-9** below from the equation (1)

$$\tilde{v} = v_o \left(\frac{z}{z_o} \right)^{\alpha}$$

Then, taking logarithm both sides yields

$\ln(v/v_o) = \alpha \ln(z/z_o)$

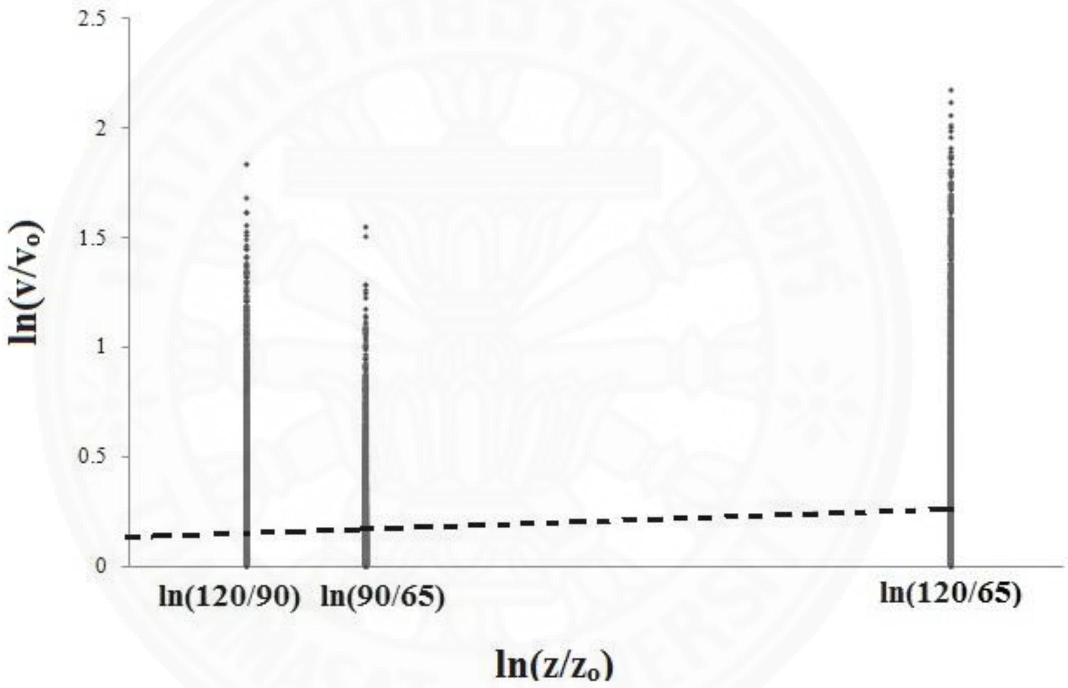


Fig. 4.7. Ground surface friction coefficient at Ratchaburi

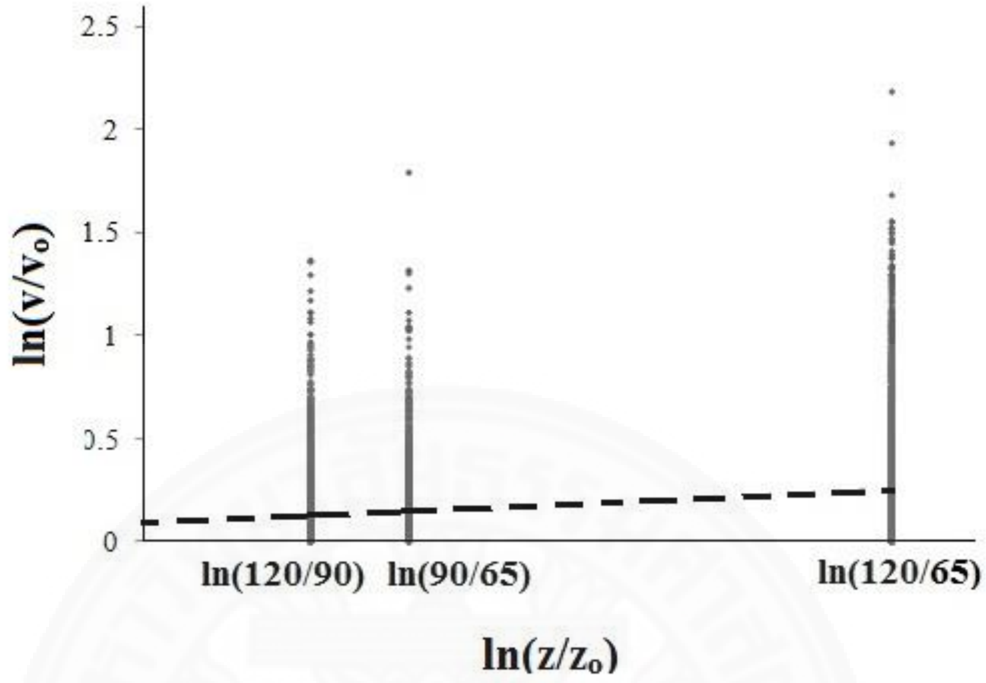


Fig. 4.8. Ground surface friction coefficient at Pathum Thani

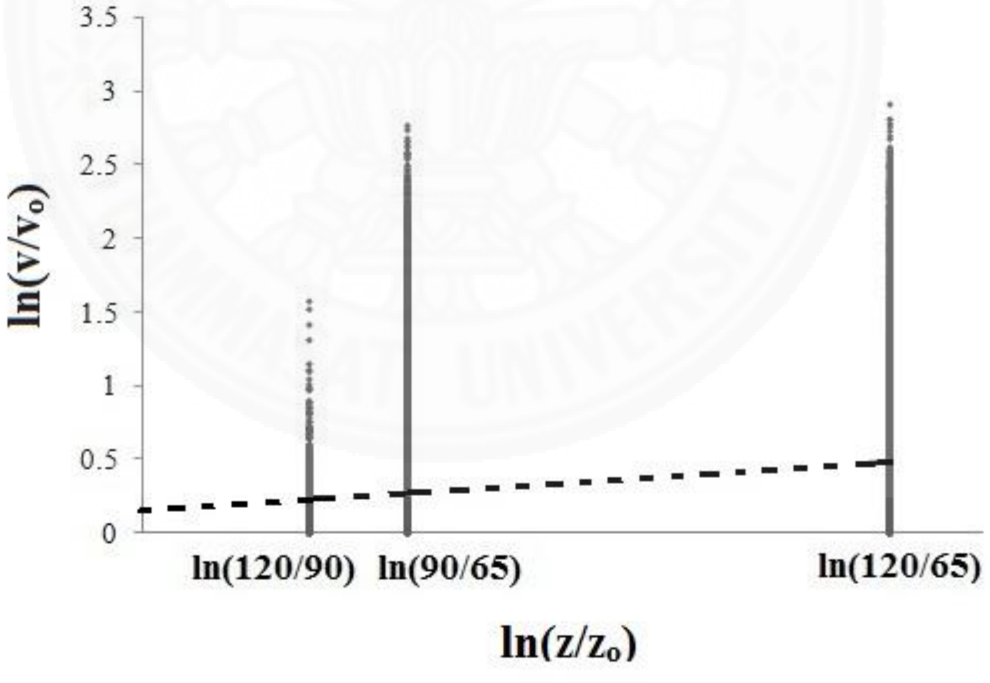


Fig. 4.9. Ground surface friction coefficient at Saraburi

4.1.6 Predicted annual energy produced and wind map

According to wind analysis, annual energy produced by 1MW Wind Turbines at heights of 65 m, 90 m, and 120 m are predicted to be (255,338,465)MWh, (493,633,829)MWh, and (329,426,574) MWh for the sites S1, S2, and S3, respectively. It is shown that Saraburi has the highest value of annual energy produced. Therefore, in the case study below, all calculated values are come from applying Saraburi's data. Wind maps around Ratchaburi and Saraburi are shown in **Fig. 4.10-11** below.

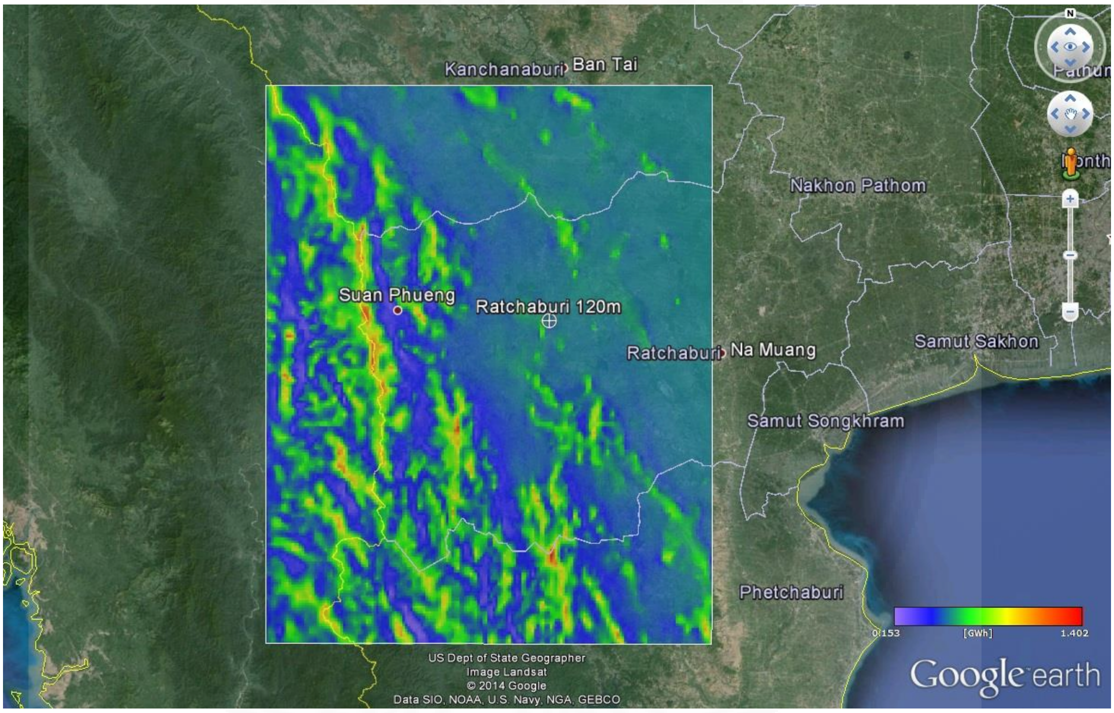


Fig. 4.10. Wind map around Ratchaburi

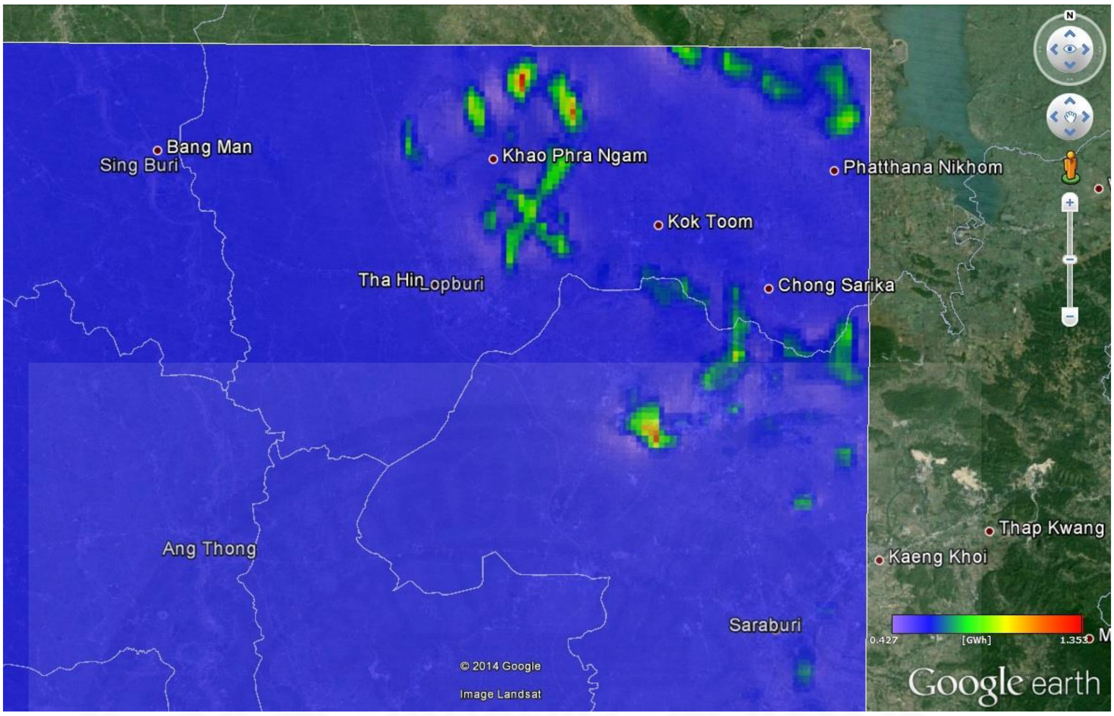


Fig. 4.11. Wind map around Saraburi and Pathumthani

4.2 Feasibility Analysis

In this section, a financial analysis is applied to determine whether the investment project is feasible to install wind turbines in the central region of Thailand. As illustrated in **Fig. 4.12**, the costs of the project mainly consists of four components that are turbine cost, construction cost, operation and maintenance cost $O\&M$, and management cost.

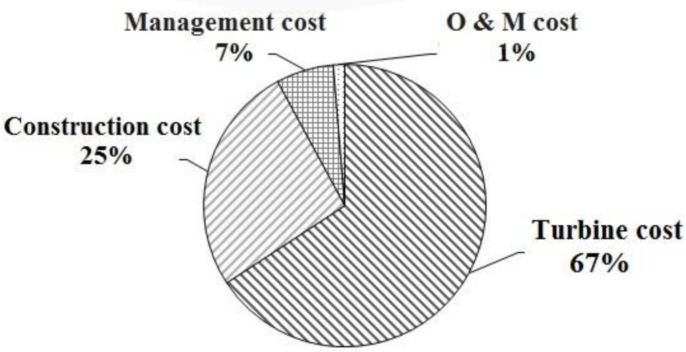


Fig. 4.12. Proportions of the investment costs.

The turbine cost, which is the largest proportion (67%) of the investment cost, is estimated about 1,000,000 EUR per 1MW. Other numerical values of financial parameters, used in this study, are listed in **Table 3.1**. The wind turbine of Bonus™ 1 MW is initially used to assess financial fesibility for investment at all sites at height of 120 m. **Table 4.2** shows the values of AEP, capacity factor c_f, generation cost GC and four financial indices with/without the adder.

Table 4.2 Electricity production and financial indices at Site S1, S2 and S3 .

Site	AEP (MWh)	Capacity factor c_f (%)	GC (US$/kWh)	Condition	NPV (US$)	IRR (%)	BCR	PBP (years)
S1	465	5.31	0.33	No adder	-1,197,865	-2.72	0.47	>20
				Adder	-815,748	0.15	0.63	20
S2	574	6.55	0.27	No adder	-944,371	-0.1	0.59	>20
				Adder	-472,682	3.29	0.78	14
S3	829	9.46	0.19	No adder	-351,335	4.66	0.85	14
				Adder	329,903	9.34	1.13	9

As expected, the site S3 yields the best evaluation of the highest AEP of 829 MWh, c_f of 9.46 % and the lowest GC of 0.19 US$/kWh. According to indices in **Table 4.2**, the 1 MW wind turbine is feasible to be installed only at the site S3 if the adder is given. The corresponding values NPV, IRR, BCR, PBP are 329,903 US$, 9.34 %, 1.13 and 9 years, respectively. It should be noted why the adder has an important role to make investment projects feasible in Thailand. **Table 4.3** presents amounts of imported crude oil and carbondioxide, which are reduced from electrical power production of the wind turbine in a year at the three sites.

Table 4.3 Reduction of amounts of imported crude oil and carbondioxide.

Subject	S1	S2	S3
Amount of imported crude oil (kTOE/year)	0.039	0.049	0.071
Amount of imported crude oil (barrels)	289	357	516
Cost of imported crude oil (US$/year)	31,897	39,374	56,866
Amount of CO_2 (ton/year)	0.19	0.24	0.34
Cost of CO_2 (US$/year)	2,693	3,325	4,802
Total cost (US$/year)	34,590	42,699	61,668

However, the sites S1 and S2 cannot gain any financial benefits. **Fig. 4.13** illustrates the simulated results of AEP, c_f, NPV, IRR, BCR and PBP with different sizes of wind turbine listed in **Table 4.4** at the site S3.

Table 4.4 Wind turbines available in WAsP^{TM}.

No.	Wind turbines	No.	Wind turbines
T1	Vestas V27 225 kW	T9	Vestas V44 600 kW
T2	Vestas V29 225 kW	T10	Vestas V47 660 kW
T3	Bonus 300 kW MKIII	T11	NEG-Micon NM 750-44
T4	Bonus 450 kW MKIII	T12	NEG-Micon NM 750-48
T5	Vestas V39 500 kW	T13	Nordex N50 800 kW
T6	Bonus 600 kW MkIIIC	T14	Vestas V52 850 kW
T7	Vestas V39 600 kW	T15	Vestas V60 850 kW
T8	Vestas V42 600 kW	T16	Bonus 1 MW

In **Fig. 4.13(a)**, it is obviously realized that the values AEP increase as the turbine sizes increase while **Fig. 4.13(b)** illustrates the plots of the capacity factor c_f. The maximum value of c_f is found to be 13.83% from the wind turbine T15. Correspondingly, **Figs. 4.13(c-f)** illustrates outstanding NPV of 1,304,423 US$, the highest IRR of 16.96%, BCR of 1.65 and the lowest PBP of 6 years for the wind turbine T15. The wind turbine of Vestas^{TM} V60 850 kW can be recommended at the site S3. However, the wind turbine T3 of Bonus 300 kW MKIII can alternatively chosen for a small wind turbine if the installation area is not limited.

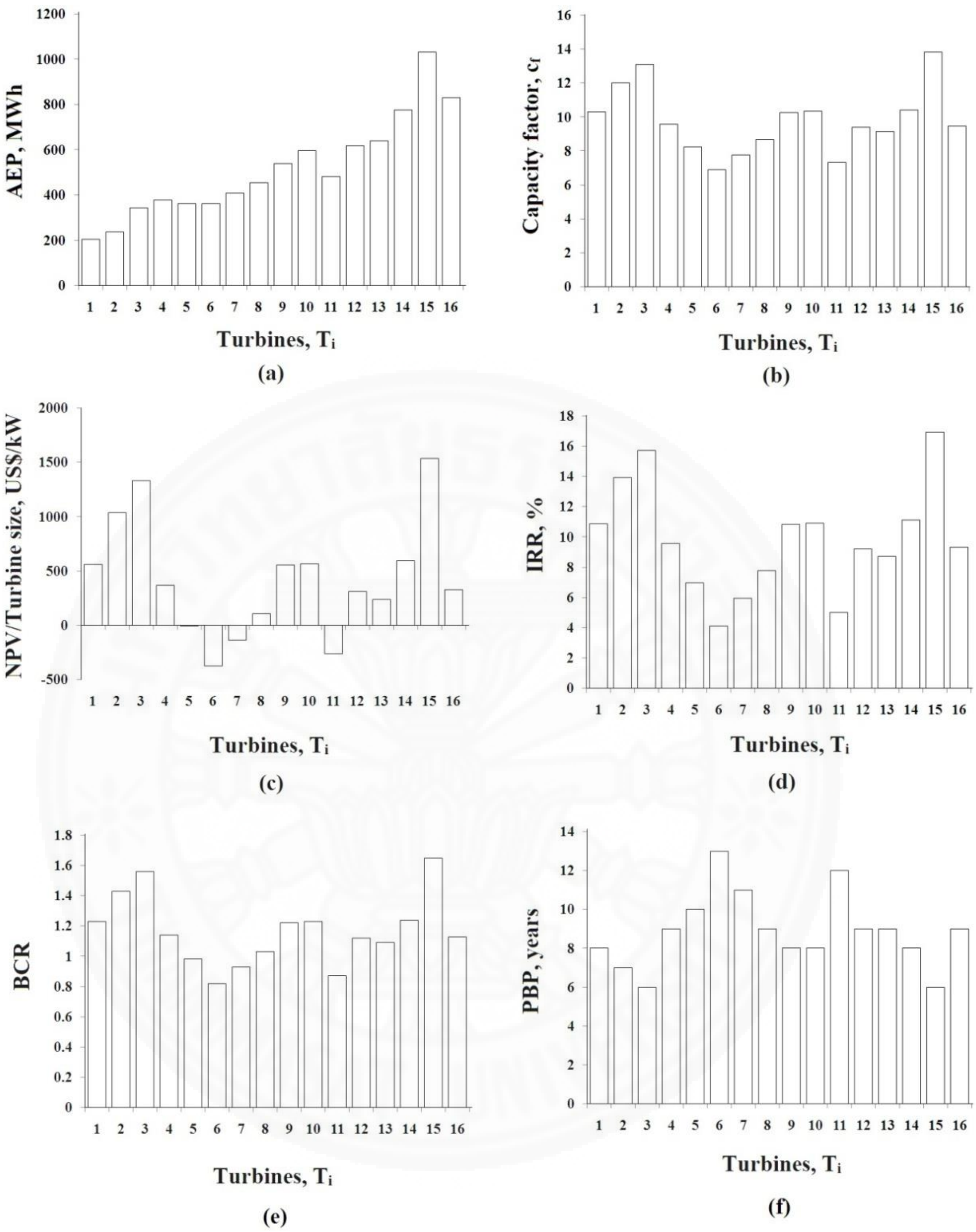


Fig. 4.13. Plots of: (a) AEP, (b) c_f, (c) NPV, (d) IRR, (e) BCR and (f) PBP against turbine sizes.

The reason to explain the outstanding effects of the turbine is to consider the power curve of turbines. As shown in **Fig. 4.14-15**, Bonus™ 1MW and Vestas™ V60 850 kW have different cut-in and cut-off wind speed. Vestas™ V60 850 kW can capture the wind speed at 3m/s which is lower than the cut-in wind speed Bonus™ 1MW (4m/s). Lower cut-in speed will generate electricity with higher efficiency.

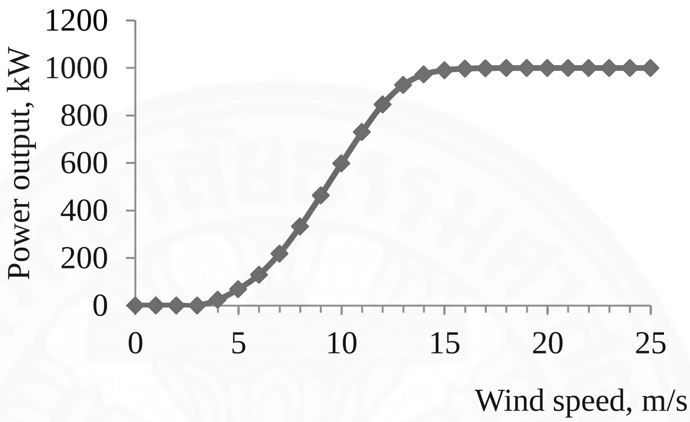


Fig. 4.14. Power curve of Bonus™ 1MW.

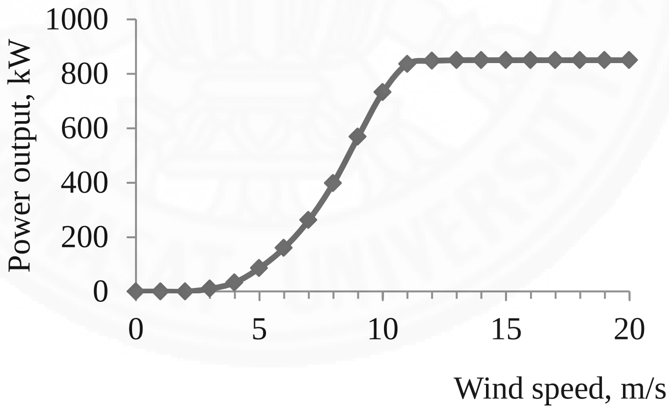


Fig. 4.15. Power curve of Vestas™ V60 850 kW.

It should be noted that the wind turbine of Vestas™ V60 850 kW is selected among wind turbines available in the WAsP™ software. Also, the financial parameters are to be up to date before considering installing a wind farm.

Chapter 5

Conclusion

In this work, the central region of Thailand is investigated as a potential area for electrical energy production from wind energy. Three sites of wind masts, which are located at Ratchaburi (S1), Pathum Thani (S2) and Saraburi (S3), are chosen to measure wind speed and wind direction at heights of 65 m, 90 m and 120 m for one year. The wind data are then applied for studying the wind resource assessment and statistical distribution models of wind in the central region of Thailand. The yearly mean wind speed is about 3 m/s - 5 m/s and the wind frequently blows in the southwest direction according to the influences on southwest-northeast monsoon. The data of wind measurement is analyzed by the WAsP™ software to determine the annual electricity productions of (255;338;465) MWh, (329;426;574) MWh, and (493;633;829) MWh (at heights of 65 m, 90 m and 120 m) for the sites S1, S2, and S3, respectively, when the wind turbine Bonus™ 1MW is simulated for electrical power generation. The site S3 has the highest potential compared with the sites S1 and S2. In case studies, feasible projects of various wind turbine installations at the site S3 are further studies for maximum financial interests. From features available in the WAsP software, Vestas™ V66 850 kW wind turbine is one of the most suitable wind turbines to make the project feasible with great benefits according to the financial indices. Some parts of the central region of Thailand can be stated to be feasible to invest wind farm. However, wind energy combined with other renewable energy such as solar energy should be considered to maximize benefits from local performaces in real situations.

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