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Wind Data Management

and the Impact on Wind Power Farm Investments

Jonas Corné
Andreas Lindström
Department of Electric Power Engineering
Division of Energy and Environment
CHALMERS UNIVERSITY OF TECHNOLOGY
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Abstract

To generate and sell electric power from wind power turbines is an emerging industry in Sweden. The many new projects require financing. In order to assess such a project and acquire capital, the production potential needs to be proven. This implies that the wind speed conditions over the project lifetime need to be predicted and incorporated into the project's Net Present Value. However, recent studies show that overestimations are common, which is likely to have a devastating impact on a project's Net Present Value.

In order to decrease uncertainty, a more efficient way of managing wind data is required. Through interviews in Sweden and literature study it becomes clear that all actors; developers, consultants and financial institutions are in favor of more extensive on site measurements.

The report goes on to investigate how wind data is currently managed, i.e. from measurement and collection to final bankable report, and attempts to identify areas of improvement are finally made. Two areas of improvement that are clear are:

1. More extensive measurements are needed
2. Increased accountability and/or less dependency on consultants are needed

The wind power industry is still young in Sweden and developments are made rapidly. Industry structure, company responsibilities and companies' level of vertical integration are in an evolving state.

Sammandrag

Produktion av elektricitet från vindkraftverk är en industri som är på frammarsch i Sverige. Vindkraftprojekt är kapitalintensiva och kräver finansiering. För att få tillgång till det kapital som krävs måste projektets produktionspotentialbevisas innan projektet realiseras. Det innebär att bland annat att vindstyrka under projektets livstid måste uppskattas och inkluderas i projektkalkylen. Studier visar dock att uppskattningar av vindstyrka och således även produktion ofta är överdrivet optimistiska. Sådana optimistiska uppskattningar kan ha en förödande inverkan på finansiärers lönsamhet i vindkraftprojekt.

För att minska osäkerhet tidigt i projekt måste därför vinddata hanteras på effektivt sätt. Genom intervjuer i Sverige och en litteraturstudie kommer rapporten fram till att de olika aktörerna; vindkraftsprojektörer, konsulter och finansiella institutioner, är i behov av bättre on-site vindmätningar.

Rapporten undersöker även hur vinddata hanteras idag, från att den mäts och samlas in till färdig projektrapport, och försöker identifiera olika områden med förbättringspotential. Två huvudområden som rapporten identifierar är:

1. Bättre vindmätningar behövs
2. Större ansvarstagande av och/eller lägre beroende av externa konsulter

Vindkraftsindustrin är fortfarande förhållandevis ung i Sverige och utvecklas kontinuerligt. Industristruktur, ansvarsområden och grad av vertikal integration är i utvecklingsstadiet.

Acknowledgements

During the process of writing this master thesis we have received valuable help and support from academia, industry and very reasonable and loving girl friends.

Foremost we would like to thank our supervisor at the Swedish Wind Power Technology Center, Chalmers University of Technology Professor Ola Carlson for help, inspiration and understanding. We are very grateful towards all interviewees from industry who have made the Master Thesis possible. Thank you Professor Chokani from Eidgenössische Technische Hochschule, Zürich, for insights highlighting the relevance of this report.

During the process of writing this Master Thesis we have found that the industry is very open for discussion and humble to the technical complexities and organizational challenges it is faced with.

We hope you enjoy reading this Master Thesis as much as we have enjoyed writing it and that you find the synthesis of our findings useful.

Table of Content

1. Introduction

This section aims to give a short background to the Swedish industry for generation of electric power from wind energy and the industry of financing such projects. The background information is followed by a problem analysis and purpose of the report is stated. Finally, limitations and structure of the report are explained.

1.1. Background

The increased focus on global warming and energy independency the past years has led to a wide range of new goals set by governments regarding the transition to renewable energy resources. Sweden is, and intends to continue being, a forerunner in this transition. The country currently produces 40% of its electric energy need from renewable resources. This is primarily from hydro and bio power. The current target is to provide 49% of the country's electric energy need from renewable resources by 2020 (Regeringskansliet 2010).

A large part of these renewable resources will produce energy in the form of electricity. Wind power is predicted to be a major contributor in reaching the 2020 target. The Swedish government has set a goal of 30 TWh yearly wind power production in 2020. 20 TWh is planned to be delivered from land based wind power and 10 TWh from offshore wind power. Wind power is a relatively proven technology which today has the lowest cost per produced energy unit among newly produced forms of capacity. (Energimyndigheten 2007)

Modern wind turbines of 2 MW rated output produce approximately 0.006 TWh/year which is equivalent of operating at rated output 3000 hours/year. Hence the goal of reaching 30 TWh of yearly energy production from wind power means constructing approximately 5,000 wind power turbines in the coming years. (Energimyndigheten 2007). Figure 1 illustrates the massive growth rate of electricity generation from wind power during the past 25 years.

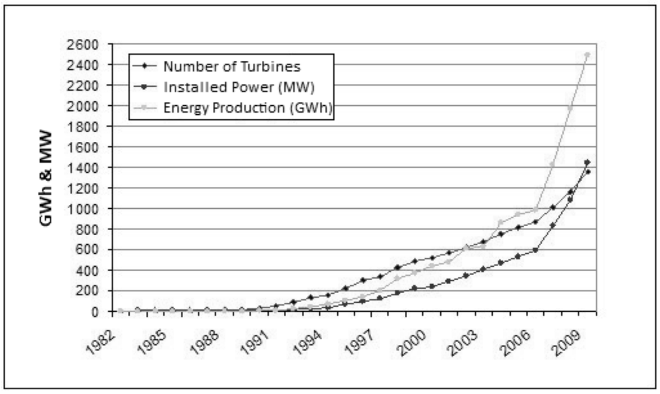

Figure1. The development of the wind power electricity generation industry in Sweden the past 18 years. **(Energimyndigheten 2010)**

As a result of increased focus on wind power, there has been a great increase in wind power projects and hence also in investments within this field. In the first quarter of 2010, approximately $ 14.1 billion were invested in new wind power capacity worldwide (The Economist 2010). Before financing for such a wind power farm can be attained, the business case has to be sufficiently proven. In this process robust production estimates based on local wind speed measurements are gaining greater importance. This is largely because the industry is moving towards larger projects which involve larger amounts of capital and hence also greater risk. The predicted wind conditions have great importance on the predicted revenues and are crucial for the investment decision. The importance of robust wind data translated into electric power production estimates and more sophisticated tools and methods to estimate long term electric power production are further enhanced by the increased installation of large scale wind power farms in complex terrain (Palma et al. 2008).

1.2. Problem Analysis and Purpose

Given the great importance of long term wind conditions in the capital acquisition phase, an understanding on its impact as well as accurate and efficient ways of working with data is of great interest. In this report the aggregated wind measurements are referred to as wind data which contains factors such as speed, direction and density. The industry of generating electricity from large scale wind power farms is in an early phase and there seem to be no real standards or practices established for the management of wind data. Currently the costs of managing wind data are large, which excludes many smaller actors from the competition of capital. In addition to this, there are often problems in the communication between the different actors handling the wind data and discrepancies between electric power production estimates performed by different actors based on the same data are common.

This together indicates that the industry could benefit from a better understanding of this process and that there exist areas of improvement. There are many actors which could benefit from a better knowledge about this and hence also from a more efficient management of wind data. Examples of such actors are companies generating and selling electricity from wind power, banks and investors, and producers of wind production equipment such as the wind power turbines.

Based on this, the purpose of this report is to:

"Investigate the impact and management of wind data in wind power electricity production investments, and indentify areas of improvement."

In order to fulfill this purpose, it can be further broken down into four research questions which this report aims to answer:

- What impact does wind data have on profitability of wind power farm projects?
- How is wind data managed from the time of measurement to a final production assessment – the wind data management chain?

- Who are the main actors along the wind data management chain and how are they linked together?
- Are there any perceived problems and hence areas of improvements along this wind data management chain?

By answering these questions, this report aims to contribute to a better and more efficient way of assessing electricity generation from wind power farms and hence decrease risks. Given the pragmatic approach and focus on actual industry conditions, people with different backgrounds within wind power industry will benefit from reading this report.

1.3. Limitations

This report focuses solely on the pre-construction usage of wind data and therefore excludes other potential areas of usage. The scope of the report is limited to investment in large scale projects and focus is on the Swedish industry.

Furthermore, it is important to note the boundaries between wind data, electric power production and generation of revenues. Wind data is only one part of the electric power production estimate and one of several elements in the cash flow analysis and hence the investment decision. This report focuses solely on wind data and its role in the investment. Therefore, other factors that are important in the investment decision are just briefly discussed in order to give the reader a general understanding and to highlight the role of wind data in the larger picture. Hence, factors not directly connected to wind data are not discussed or only briefly discussed.

Details of how wind data is obtained and other technical aspects are neglected or only briefly discussed.

1.4. Structure of the Report

This report adopts a top down approach in order to give the reader an overview and understanding of the importance and usage of wind data.

The report starts by introducing the reader to wind power and further breaks this down into investments in electric power generation from wind power. Investments in electric power generation from wind power are further broken down into different parts where electric power production is highlighted. The objective with these sections is to explain the context in which wind data is used.

After this, production is broken down into wind data. Focus is on the importance and management of wind data, which is the central part in this report. Based on the findings in this section a discussion is made and conclusions are finally presented. The structure of the report is graphically illustrated in figure 2.

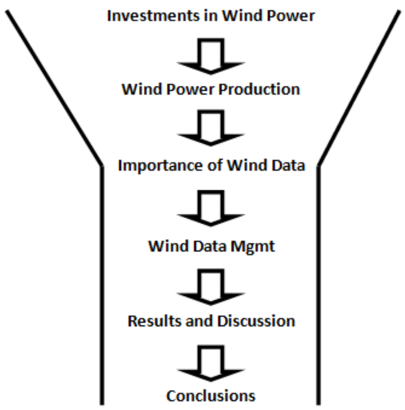

Figure 2. The structure of this report follows a top-down approach.

2. Method

This chapter explains the methodology of the report and highlights potential weaknesses which the reader should be aware of.

2.1. General approach

The area investigated in this report is fairly unexplored and an open-minded approach is therefore preferable. Given this, an inductive approach has been used which implies that generalizations are made based on specific observations. This report is based on observations from interviews and a theory is derived from these observations.

Furthermore, the report has mainly followed a qualitative approach rather than a quantitative approach. In this case, this implies that rather than using data and statistics derived from structured research, a broader perspective is applied in order to generate a general understanding. Interviews are used to create an understanding of the processes as well as mapping the specific answers to pre-defined qualitative questions.

2.2. Design

A study can be conducted in an explorative way, in a descriptive way or in a mix of these two. An explorative approach is mainly used in a new field where little or no theoretical knowledge exists, while a descriptive approach is used when an area is well defined and understood by at least some other people (Björklund & Paulsson 2003).Due to the nature of this report, where very up to date information is needed, and the fairly small amount of up to date literature about how the industry work today, an explorative approach has been used. However, in order to understand this field and give the reader a wider picture, other areas connected to wind data management have been investigated and explained, using a more descriptive approach.

2.3. Procedure

The content and findings are mainly based on information extracted from interviews, which have been done in two rounds. The first round took place early in the process and had the purpose to give the authors a general understanding of the business and the different perspectives of wind data and investments in wind power electricity production. The main focus was on vertically integrated companies which prospect, develop and own wind power farms. These companies are present along the entire wind data chain. These types of companies are defined as the developer, owner and producer of electric power. Information from these interviews was then summarized and, when possible, complemented with information from literature and other publicly available information from databases and companies. The second round of interviews aimed to fill in empty gaps and answer new questions that emerged during the process of writing the report.

Parallel to the interviews, the more theoretical parts of the report have been constructed and results have continuously been summarized. The final step included a discussion part as well as performing conclusions and suggestions for further research.

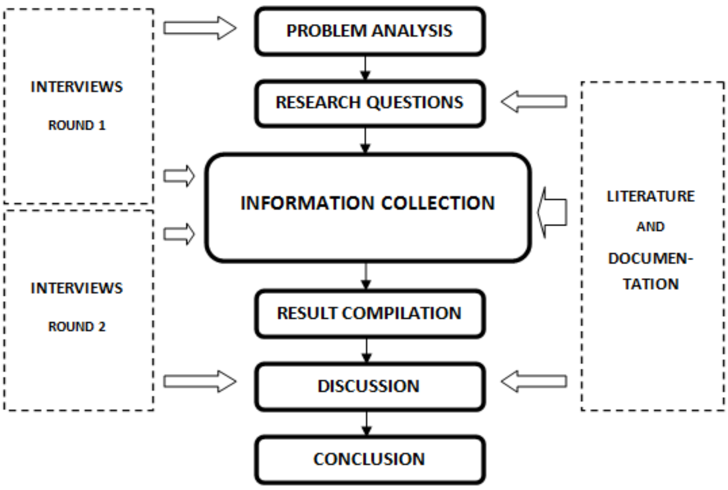

Figure3. Schematic illustration of the process.

This illustration in figure 3 shows a schematic overview over which procedure was used in each of the different phases in the process.

2.3.1. Literature

There is a limited amount of up to date academic literature concerning how the industry manages wind data. Some up to date information has been found in trade magazines and internal proprietary reports. Other literature used are scientific articles and books, which have provided more general information about investments in electric power generation from wind power turbines, rather than detailed knowledge concerning wind data management. However, most information needed regarding wind data management have been extracted from interviews.

2.3.2. Interviews

Interviews have been a crucial source of knowledge and a total of 16 interviews have been conducted. The purpose of the interviews has been twofold. Firstly, they have given the authors basic information and provided a general understanding of the field of wind power investments. Secondly, the results have, after being aggregated, provided a picture of how wind data is managed as well as highlighted problems in this process.

There are a limited number of companies and people working in this field, why the main goal and challenge has been to find and interview all the different types of actors active. There were three different main actors identified and at least three representatives per actor have been interviewed. As a result of this, several different questionnaires have been used, which is in line with the qualitative approach of this report. Furthermore, a semi-structured approach has been used in most interviews inferring that there has been a structured questionnaire with the possibility for the interviewee to extend and diverge when necessary.

Most of the interviewees requested to be anonymous, why each one of them has been assigned a specific code. A summary of all interviews made and which type of actor they represent is shown in the tables in figure 4 and 5:

Round 1		
Code	**Type of Actor**	**Characteristics**
EPP1	Electric Power Producers from Wind Power	Large producer of electricity
EPP2	Electric Power Producers from Wind Power	Large producer of electricity
EPP3	Electric Power Producers from Wind Power	Medium sized producer of electricity
EPP4	Electric Power Producers from Wind Power	Medium sized producer of electricity
INV1	Investor	Large investment fund
BAN1	Bank	Large Scandinavian bank
CON1	Consultant	Large actor in the market

Figure4. List of interviewees from Round 1.

Round 2		
Code	**Type of Actor**	**Characteristics**
CON2	Consultant	Large actor in the Swedish market
CON3	Consultant	Regional actor in the Swedish market
INS1	Insurance Company	International actor
BAN2	Bank	Large Scandinavian bank
BAN3	Bank	Large Scandinavian bank
EPP5	Electric Power Producers from Wind Power	Medium sized producer of electricity
EPP6	Electric Power Producers from Wind Power	Medium sized producer of electricity
EPP7	Electric Power Producers from Wind Power	Medium sized producer of electricity
EPP8	Electric Power Producers from Wind Power	Medium sized producer of electricity

Figure5. List of interviewees from Round 2.

As can be inferred from the table above interviews were conducted in two phases. Round one was performed in order to gain an understanding of the industry so that more in depth questions could be asked in round two.

Some of the interviews were conducted face to face and some over telephone. A questionnaire was sent to the interviewee prior to the interview and each interview lasted between 50 and 90 minutes.

2.4. Validity andReliability

Validity basically measures how well the results reflect the truth (Björklund & Paulsson 2003). Given the qualitative approach and the subjectivity of the interviews, the validity in this report is hard to evaluate why different measures to decrease the risk of low validity have been performed. In order to avoid bias and too much subjectivity, representatives of the three different actors within the field of wind data management have been interviewed. Secondly, the summarized results and analysis have been shown to at least one representative for each actor in order to ensure that the answers have been interpreted in a correct way and that the overall results are reasonable.

The reliability is a measure of the consistency of the report and hence a question of trust. Given that this is a new field and that many of the questions asked have never been asked before, the reliability of this report is hard to guarantee. Furthermore, the rapidly changing environment within this business makes it possible that many results found today are misleading in a near future. Given this, the reader needs to bear in mind that the report gives an understanding of today's situation and be cautious when applying the findings in the future.

2.5. Problems and Risks

Many of the problems and possible shortcomings of the report have been discussed earlier in this chapter. It is important to consider these when reading and interpreting the results of this report.

The large focus and dependency on interviews has lead to a risk of losing objectivity as well as for biased results. In order to decrease these risks, the authors have actively worked to avoid leading questions during interviews, as well as tried to highlight as many different perspectives as possible. Nevertheless, a larger amount of interviews would have decreased these risks and hence increased the quality of the results. However, because the market is small the set of actors that have been interviewed do in fact represent a substantial part of the market.

3. Wind Power Investments

This section gives an overview of how investments in wind power farms are managed and which factors that are of importance. A framework is used to visualize this and highlight the role of wind data. Furthermore, academic references and interview findings are used intermittently.

Investments in electric power generation from wind power projects are highly capital intensive and very complex in nature. This causes banks to be cautious before lending money to companies and other actors that aim to build wind power farms. Given this, there are many questions to answer and risks that need to be mitigated. It is also important to mention that it in general takes many years from the initial idea until the wind power farm can be built. This is mainly because of a long and complicated permit process with many stakeholders involved. (CON1)

3.1. Actors in the Market

There are a large amount of companies working with electric power generation from wind power in different capacities in Sweden (Företagsdatabasen 2010). However, there are only a few companies with the necessary organization and resources to develop large scale wind power farms (CON1).Figure 6 and 7 show up to date information of the Swedish industry.

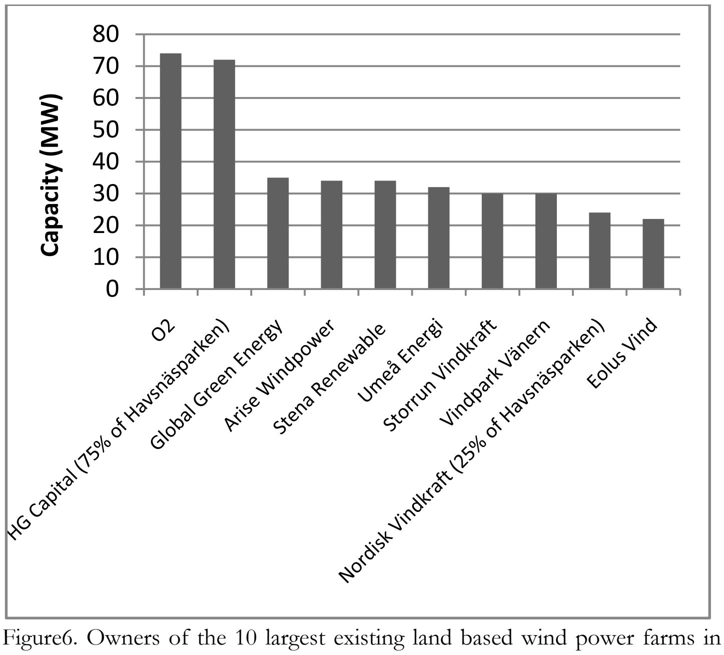

Figure6. Owners of the 10 largest existing land based wind power farms in Sweden, > 10 MW (January 2010). **(Svensk Energi 2010)**

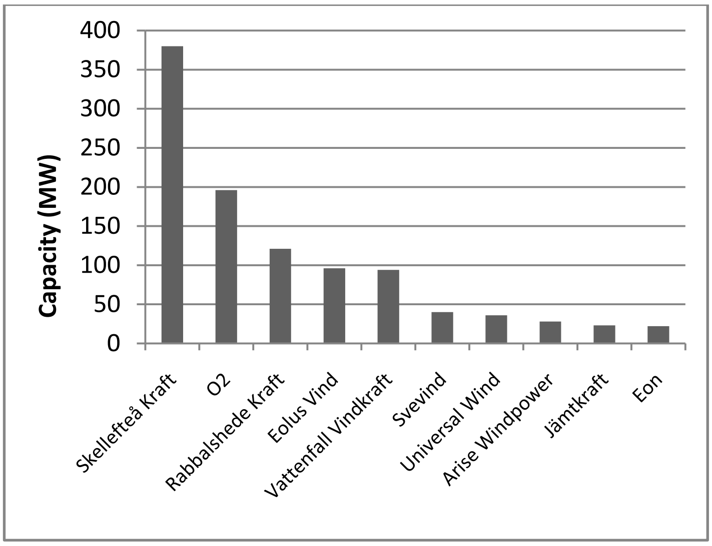

Figure7. Owners of the 10 largest land based wind power farms in Sweden under construction, > 10 MW (January 2010). **(Svensk Energi 2010)**

Around these companies other actors are providing services and materials. From the perspective of this report the most interesting other actors are the companies providing financial services in the form of capital and wind data analysis services. Companies providing capital range from banks to private equity investors. The companies which provide wind data analysis services are engineering consultancy firms, often with extensive technical experience from other businesses (BAN1). Together companies generating electric power from wind power turbines, financial services companies and consultancy firms produce and exchange the necessary data and information to determine if a wind power farm is to be produced (BAN1). This report will analyze the interactions and specifically the exchange of wind data between these three actors. A more in depth description of these different actors can be found in the Chapter 6.

3.2. Return on Investment

There are large risks involved in investments in wind power farms. Given a portfolio of sites with proven production potential and a successful capital acquisition phase, there are good chances to make large profits from wind power electricity production. (EPP3)

When financing a wind power farm, it is in general good to attain a high leverage level. Leverage is achieved by using debt in order to increase return on equity (CON1). Banks are however not prepared to provide unlimited amounts of debt since the operation is involved with risk. In order to mitigate risk extensive technical due diligence and a significant portion of equity is required. Leverage ratios of 70-80% are typically achieved in these kinds of investments (BAN1).

3.3. Capital Acquisition

There are two different types of methods often used to finance heavily capital intensive industry like wind power electricity production: project and corporate financing. Project financing implies that the investment is focused on the specific project's financial potential and the net present value of this. Corporate financing focuses on the financial aspects of the whole parent company. Hence capital is lent to a parent company which can allocate capital to several projects.(Kistler et al. 1997)

To use corporate financing in wind power farm investments, a large company with a strong balance sheet is required. Therefore, project financing is currently the most common form of financing since many of the companies working with these kind of investments are fairly young and do not have balance sheets that are strong enough to bear high debt to equity required by corporate financing. (CON1)

It is important to note that there are also several kinds of debt available and combinations are often used in order to decrease fluctuations due to external changes in interest and exchange rates. There are many banks that have specialized departments working with green-tech companies or even specialized on wind power production. (BAN1)

In addition to borrow capital for investments and hence use debt, owners must also provide or acquire additional capital in the form of equity. To do this, a normal procedure is to let personal investors or different kinds of funds, often with focus on green-tech, invest in exchange for shares. It is also possible to have private investors and in later stages for larger companies, to become publically traded on the stock exchange. (CON1)

3.4. Investment Framework

Many factors affect the possible returns on wind power investments. The framework in figure 8 is developed as a structured method to analyze the different factors. (CON1)

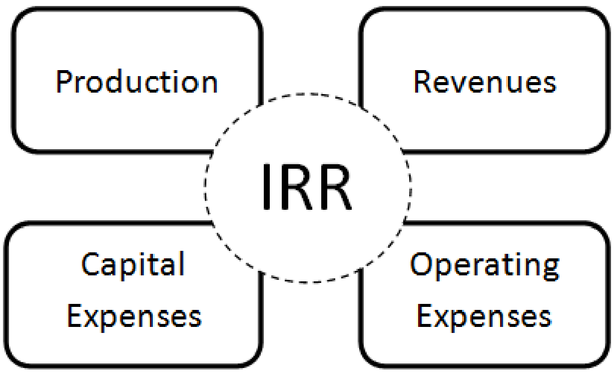

Figure8. The investment Framework

These four factors are all very important and are influencing the investment decision in different ways. In this report, focus is on wind data, which is used to forecast the economic lifecycle electricity production before investment decisions are made. The production part of the framework will therefore be most thoroughly investigated and most of our research and analysis handle this part. However, in order to fully understand the importance of wind data, an overview of other factors affecting an investment decision is needed. Therefore, the other factors are also discussed on a more general level.

3.4.1. Revenues

Revenues from wind power in Sweden are generated in two ways: electricity sold on the market and through renewable energy certificates, RECs (Arise Windpower 2010). Both of which are markets prone to large price fluctuations.

3.4.1.1. Renewable Energy Certificates

The system of using RECs has been in place since 2003 in Sweden and is valid until 2030 (Svensk Energi 2010)(Svensk Energi 2010). RECs work as incentives for renewable energy production and will help Sweden to reach the set targets. RECs can only be granted for 15 years in Sweden.(Lucia & Schwartz 2002)

Each renewable energy producer is granted a certain number of RECs based on how much renewable energy that it has produced, which then can be sold on the market. The demand is created by forcing energy suppliers to buy RECs and the costs are in the end paid by the consumers via the electricity price. The price of RECs is based on supply and demand and negotiated between buyers and sellers for each transaction.(Lucia & Schwartz 2002)

In addition to this, another environmental support has historically been granted to wind power producers. This bonus has been gradually diminished but was in 2008 13 öre per kWh for offshore production and 2 öre for production onshore. In 2009, the bonus was completely abated for on shore wind power and a bonus of 12 öre per kWh was granted to offshore electricity production.(Svensk Energi 2010)

Governmental support in the shape of RECs correspond to a substantial part of the revenues and are today crucial for keeping wind power production profitable for companies. A rough estimate is that RECs amount to approximately 40 % of the revenues. (Svensk Energi 2010)

3.4.1.2. Electricity Price

In Scandinavia, electricity is traded on NordPool, which is a marketplace for trading of electrical power, emission allowances and emission credits. On NordPool, spot and forward prices on electricity are dealt with, which allows for power producers to secure prices up to five years into the future. This is very important since the electricity price normally fluctuates significantly, as the graph in figure 9 clearly demonstrates.

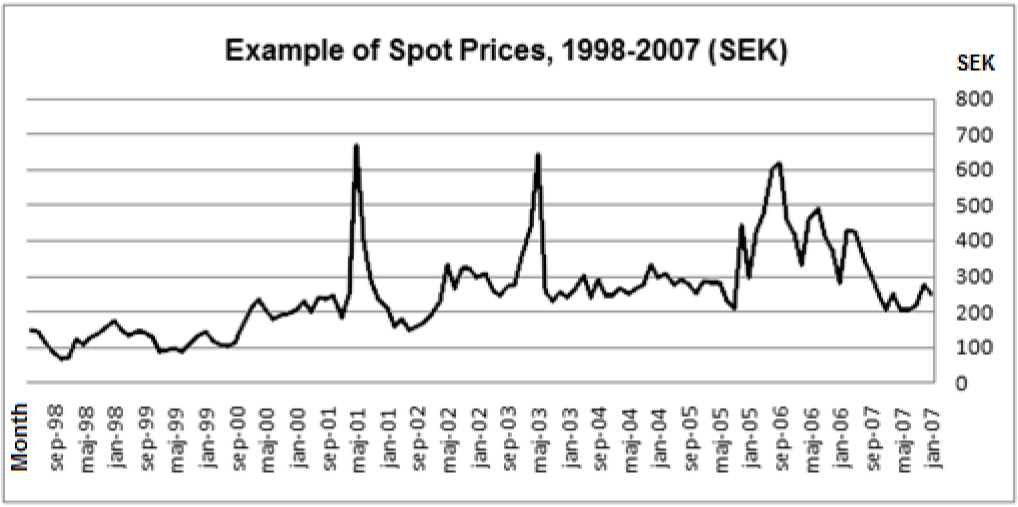

Figure9. Example of fluctuations in electricity spot prices. **(NordPool 2010)**

Given the fluctuations, it is difficult to predict electricity price and hence revenues for up to 20 years into the future. Therefore, the usage of futures and other tools to decrease the fluctuations are of great importance in order to attract capital. (Holt 2005)

3.4.2. Capital Expenditures(CAPEX)

Capital Expenditures are outlays for large investments in fixed assets or costs to upgrade these in order to create future benefits (Berk 2007). When building wind power farms, examples of capital expenditures are investments in wind power turbines and infrastructure.

3.4.3. Operating Expenses (OPEX)

The operating expenses are expenses derived from all activities required to produce electricity. Examples are costs for maintenance of wind power turbines, cost of land, insurances and administration costs. (EPP1)

Normally companies want to be able to predict the future expenses. Fluctuations are therefore eliminated by using different kinds of contracts as delivery contracts and service contracts(Oxelheim 2005).There are however a limited amount of suppliers and in order to raise large amounts of capital for large wind power farms, just a few large suppliers of wind power turbines with the most proven technologies are accepted by the banks (CON1). This makes this market a sellers' market with captive buyers (Bensaoa 1999).

3.4.4. Production

There is great need for predicting future electric power production before building a wind power farm. Banks and investors require production estimates and predicted revenue streams for the economic life cycle of the wind power farm (EPP4). This makes this part of the framework extremely important. It is easier for a wind power electricity producing company to raise capital and increase its debt level if it can present well performed and accurate production predictions. Therefore, this part of the framework is the focus of this report and the next chapter continues with explaining how estimates for the wind production are conducted.

3.4.5. Other Risks

As mentioned earlier, handling risks is crucial in such large investments as wind power farms. Assessing all risk and creating a complete risk landscape for wind power investments is however a highly complicated task which requires great resources (INS1). This is therefore excluded in this report and just the most obvious risks connected to the investment framework are mentioned.

The four categories in the framework above all have different risks connected to them, which need to be managed in different ways. In addition to these risks, there are other risks that also need to be taken into consideration. One example is the currency risk. Most of the trading when planning and setting up wind power farms in Sweden is done in Euros, which obviously expose the company to currency fluctuations. One way to handle this risk is to hedge the investment using forwards or options (Berk 2007).

Another important risk is the political risks. Wind power production is still very dependent on RECs and other subsidies, which in the end is controlled by politicians (Wood 2007). In addition to this, there is also a long term risk of substitutes that could make wind power production an inefficient and unprofitable technique to produce energy. Banks and investors are however well aware of this and take this into account before lending out money or investing in a wind power farm (BAN1).

4. Production and Wind

This section continues the top down approach and starts by introducing the different variables taken into account in a production measurement. Because wind speed is one of the main determining factors (CON2), the section explains the fundamentals of wind and how production estimates are derived from wind data.

4.1. Production Estimates

When estimating production in large scale wind power farms, there are many factors that need to be take into calculation. The list below outlines some of the most important factors (Klug & Strack 2001):

- Wind speed measurements
- Quality of the long term assessment
- Flow model for the micro-siting
- Farm efficiency model (shading of the turbines)
- Power performance of turbines and related warranties

Production estimates are in general based on an economic life of twenty years for the wind power farm (CON3). As wind measurements are generally performed for one year and winds can be highly volatile from year to year the data needs to be adjusted to provide for an average annual energy prediction which can then be extrapolated over the whole life cycle. The average annual energy prediction is established by using normalized wind data and wind power turbine power curves from different manufacturers. These curves vary depending on what kind of wind power turbine that is being used. This is because different kinds of turbines can be optimized for different wind conditions. (EPP4)

An example of wind characteristics at a location, a corresponding power curve and estimated production at different wind speeds is presented in figure 10. Figure 10 shows the most common wind speed at this location to be 6 m/s (16 % of the time). Further, it is also evident that wind speeds above 15 m/s are rare.

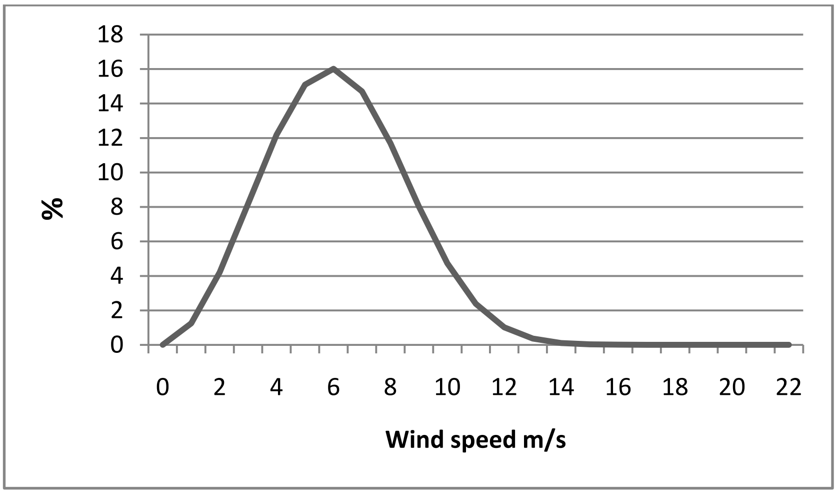

Figure10. Distribution of wind speed during one year at a specific location.

In figure 11, the darker line tells us that this specific turbine reaches its rated (maximum output) power output at a wind speed of around 12 m/s and that stronger winds do not add any extra power output. Further, the brighter graph in figure 11 shows that most energy over the period is produced at a wind speed of around 8 m/s. At wind speeds below 4 m/s and above 16 m/s, the turbine does not produce electricity at all. In this case the lack of production below 4 m/s is because these winds are too weak to power the turbine.

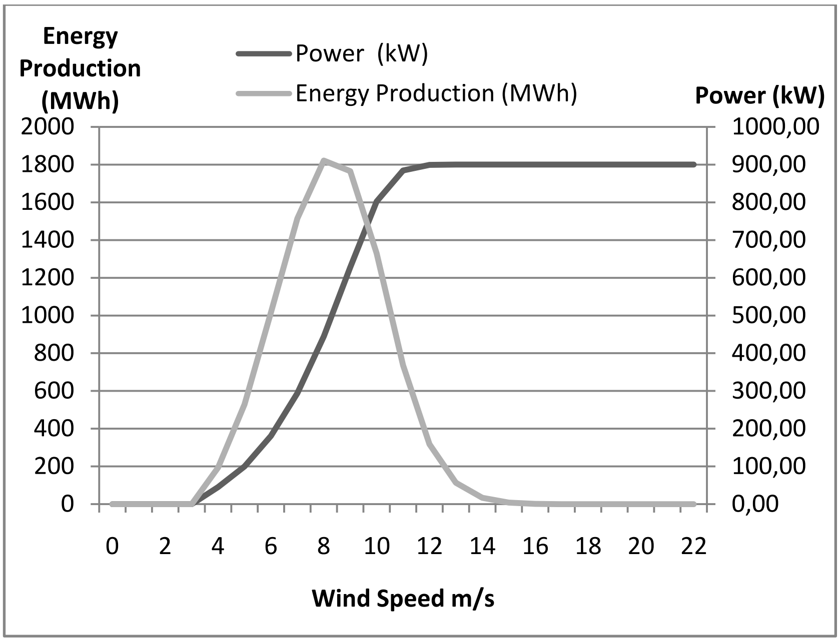

Figure11. This Figure shows the power output at different wind speeds and, combined with the wind speed allocation in Figure10, the total energy production for the different wind speeds.

The lack of production at wind speeds exceeding 16 m/s is merely because these winds have not occurred sufficiently often in the data sample to appear in the graph.

Average Wind Speed	6,16
Total Energy Production (MWh)	4480.54
Capacity Factor	28%

Table1. Data from example above.

The average annual energy production prediction shown in table 1 is based on closely analyzing the project's wind conditions at the sites where turbines are to be erected and long term wind data from a nearby site. In order to produce a complete business case, external factors such as energy price, exchange rates, construction costs, capital costs are added to the complete profitability calculation.

4.1.1. Capacity Factor

All wind power turbines have a maximum power output. The maximum power output is closely related to wind conditions. A wind power plant reaches its' rated power (maximum output), p_n, at the rated wind speed v_n. For modern wind turbines with three blades, v_n is commonly 12-15 m/s(Wizelius 2007). At v_n, a

1MW wind power plant produces 1 MWh of electricity per hour. In Figure11, the turbine reaches its rated power at 12 m/s.

Manufacturers of wind turbines make choices in the design of turbines in order to reach rated output at different wind speeds. This can be done by studying how efficient the turbines are in converting kinetic energy in the wind to mechanical energy in the blades. A common measure to optimize turbine efficiency is to study the effects of production at different tip speed ratios, the ratio between tip speed and wind speed.

Intuitively, a high tip speed ratio means that the rapidly rotating rotor with blades will appear as a wall to the wind, while the wind will pass by a slow rotating rotor unaffected.

Figure 12 illustrates how the power coefficient varies at different tip speed ratios λ and pitch angles Θ. Pitch angle is the angle between the plane of rotation and the blade profile's chord. The chord is an imaginary line drawn from the front edge to the back edge of the blade. The pitch angle is also known as the "setting angle".

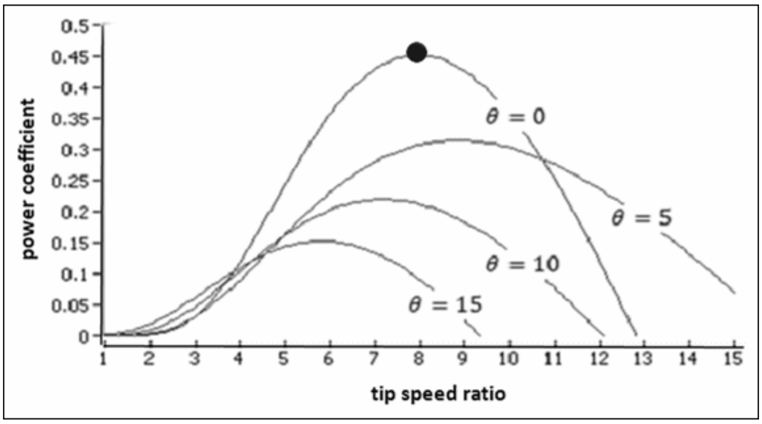

Figure12. Power coefficient at varying tip speed ratios and pitch angles.

Figure 12 indicates that the turbine reaches its maximum efficiency at a tip speed ratio of 8 and a pitch angle of 0. Hence, a turbine manufacturer has some influence on how efficient a wind turbine is. Modern wind power turbines have variable rotor speed so that a high power coefficient can be maintained at a larger interval of wind speeds (Wizelius 2007).

When assessing a wind power turbine or site's performance, the capacity factor is of great interest. The formula for calculating the capacity factor is:

$$Capacity\ Factor = \frac{Actual\ produced\ wind\ power}{Produced\ power\ if\ turbine\ operated\ at\ max\ output\ 100\%\ of\ the\ time} \quad (1)$$

A normal capacity factor for a wind power plant is between 20 and 40 %(University of Massachusetts 2008). This can be compared with 30-60 % for hydro power and 60 to 75 % for nuclear power (Svensk Energi 2010). However, the marginal cost of producing a new unit of electricity is very low for wind power as the fuel, wind itself, is free of charge. Hence, an increase in capacity factor has a large effect on profit. (University of Massachusetts 2008)

In addition to this approach, studies of wind power capacity factors can also be made on a national or regional level. In order to calculate a regions or countries average capacity factor the following formula is used (Hofstad 2009):

$$Capacity\ Factor = \frac{E}{((PT - Pi)*8760 + Pi*4380)} \quad (2)$$

Where:
E = energy produced
PT = total installed capacity
Pi = capacity installed during the past year

The formula assumes that newly installed capacity during the year is used for half that year. The figure below shows the average capacity factor from a number of countries and as can be seen, Sweden has an average capacity factor below the international average. (Hofstad 2009). Figure 13 also illustrates the high degree of variability among different geographical areas.

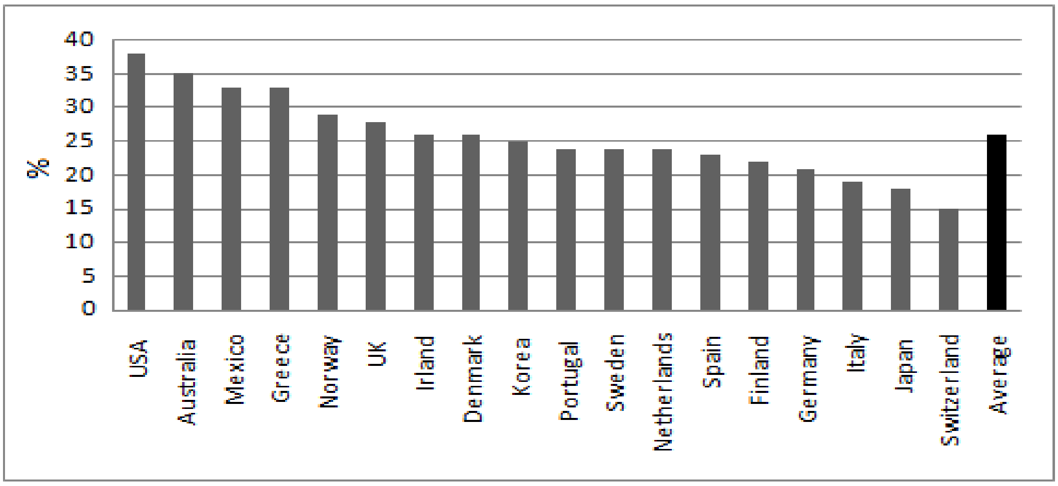

Figure13. Different countries' average capacity factors. **(Hofstad 2009)**

4.2. Effect of Wind Speed

Wind is one of the main factors affecting production output (CON3). Wind speed and electric power production are related according to the following formula:

$$KE = \frac{mv^2}{2}$$ *Formula for Kinetic Energy* (3)

$$P = \frac{\dot{m}v^2}{2}$$ *Differentiation of mass as a function of time to determine mass of air passing wind turbine* (4)

$$P = \frac{\rho A v v^2}{2}$$ *Mass of air passing turbine is determined by air density(ρ), swept area (A) and wind speed (v)* (5)

$$P = \frac{\rho \pi r^2 v v^2}{2}$$ *Area converted to contain blade length (r)* (6)

$$P = \frac{\rho \pi r^2 v^3}{2}$$ *Power available to be extracted in wind increases cubically with wind speed* (7)

This implies that as wind speed increases the kinetic energy contained in the wind is increased cubically. Hence a slight increase in wind speed has very large effects on the amount of electric power that a wind power turbine can produce. Implications for the preconstruction phase is that finding and proving the production potential of wind power sites with high quality winds is very important in order to prove a good business case that can be used to raise capital.

However, it must be noted that the derivation above is a theoretical maximum which can never be achieved. Intuitively 100 % conversion efficiency from kinetic energy to electricity would mean that movement of air would stop behind the wind turbine. Betz's law states that no wind turbine can convert more than 59.3% of the kinetic energy contained in wind to electric energy. (Wizelius 2007)

4.3. Wind Complexity

Given the great importance of wind in production estimates, the complexity of wind and hence the difficulties in prediction are now discussed.

Wind is a natural phenomenon which, on a macro level, is explained by different pressure zones at different places. Nature seeks to balance pressure and hence air is transferred from high pressure zones to low pressure zones. Wind is the transportation of excess air form a high pressure zone to a low pressure zone. Winds contain massive amounts of kinetic energy which can be converted to other forms of energy. Wind power turbines transform kinetic energy contained in the moving air to mechanical energy and then to electric energy.

On a macro level winds can be predicted using meteorology. On a micro level, winds are extremely complex as they are very dependent on local conditions that cannot be generalized. Hence, the successful prediction of production requires a local presence and long term measurements. Modern scientific results show that this is true for both onshore and offshore wind power projects. Observations in the Baltic Sea have shown that off shore winds show an even larger degree of complexity and inhomogeneity than has previously been expected (H. Bergström 2006).

Factors such as topography, landscape roughness and vegetation all affect wind quality (CON2). Ideally wind speeds should be stable and above 10 m/s (Vestas nd) to maximize production output from wind turbines. Varying topography and landscape roughness affect wind quality negatively as wind shear and wind turbulence are increased creating instability in wind conditions which affects immediate production negatively and increases wear on the turbines raising direct service costs and indirect service costs due to lost production. In general, the following factors are important to take into consideration when evaluating a potential location:

- Turbulence
- Wind Shear
- Stable Wind Direction
- Average Wind Speed
- Air density

All of the above are obtained from measurement data and standard calculations. In this report they are all encompassed by the term *wind data*.

5. Wind Predictions and Wind Data

The previous sections have shown that wind has a great impact on electric power production levels and a general sense of the complexity in measuring wind and performing long term estimates. This section aims to show the many uncertainties in wind measurements and long term predictions and how often results are inaccurate. Finally, the section outlines the importance of accurate wind assessments through a sensitivity analysis demonstrating the effect various wind conditions have on electric power production and hence on a project's profitability.

5.1. Exceedance Probabilities

Because there is uncertainty in average energy production (AEP), the level of uncertainty needs to be quantified in order for the AEP to be valuable. This is most commonly done using exceedance probabilities of the order P50, P75 and P90. P50 is the AEP that is reached with 50% certainty (Klug 2006). AEP levels with increasing exceedance probabilities decrease as it is more difficult to be certain of a higher electric power production levels.

AEP with pertaining exceedance probabilities are the values that banks are most interested in.AEP figures are presented in Table 2.

Exceedance Probability (1-year)	Forecasted MWh	Explanation
P50	100	50% chance that the project will produce at least 100 MWh in any given year
P75	92	75% chance that the project will produce at least 92 MWh in any given year
P90	85	90% chance that the project will produce at least 85 MWh in any given year
P95	80	95% chance that the project will produce at least 80 MWh in any given year

Table2. Explanation of Exceedance Probabilities.

The credit research institute Moody's recently performed a retrospective analysis on US based wind power farms to compare their performance to the AEP that was estimated before construction of the wind power farm. On average the 34 onshore wind power farms that were included in the analysis had been in operation 6 years. It becomes very clear that forecasts for these projects have been overly optimistic. (Moody's 2010a)

Figure 14 illustrates how overly optimistic forecasts were on average. The dark grey bars show the actual occurrence of the exceedance probabilities shown in the light grey bars.

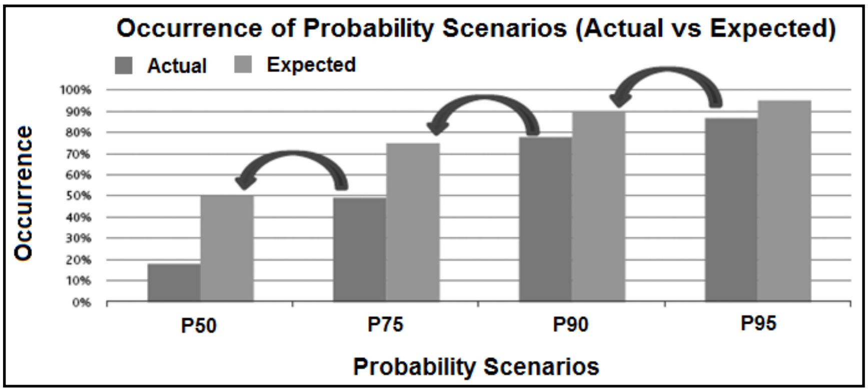

Figure14. Actual occurrence of the exceedance probabilities. **(Moody's 2010a)**

Hence, all four exceedance probabilities occur less than expected. Based on the dataset used by Moody's it seems that the forecasted P95 value is equivalent to the expected P90 value and so on as indicated in the graph.

5.2. The inaccurate wind predictions

When comparing electric power production levels from larger datasets of for example five year average production levels, these tend to show closer to 5% volatility (CON1). This means that it is very difficult to estimate production before a site has been constructed and been producing for many years. As will be presented in a sensitivity analysis below, differences in wind speed have great impact on the final investment decision. Therefore, measures are taken to estimate production in order to mitigate risks and to obtain accurate predictions.

A large survey made by the Norwegian authorities showed that the actual wind power production in 2008, homogenized and adjusted for the wind conditions that year, was 25 % lower than the predicted production. This is a very significant difference, especially since the wind conditions that year was "normal" and the production should have been 99 % of normal annual production. Furthermore, the report states that the same pattern of overestimations can be seen in previous years too and conclude that it is obvious that better production predictions are needed. (Hofstad 2009)

In the Moody's article referred to earlier, similar findings are made. In their sample of 34 onshore wind power projects and in total 141 wind years, the median actual energy production was 9 % below the estimated case (Moody's 2010b). The report further states that wind speed forecasting shortfalls are the likely main contributors to these optimistic electric power production predictions.

As mentioned above, it is important to note that there are several other factors than wind affecting the production. One such factor is that the availability is lower than expected (Hofstad 2009). This was found to be a contributing factor in the Norwegian survey. However, Prof. Chokani at Eidgenössische Technische Hochschule (ETH), Zürich, means that availability is only an issue during the initial two to three years of operation and that inaccurate wind predictions and unexpected wind turbine response are the main reasons for the difference in actual and predicted production.

5.3. The impact of inaccurate wind predictions

In order to highlight the great importance of accurate wind predictions, an analysis is done on the impact of wind speed on net present value (NPV) and internal rate of return (IRR) of a wind power project. The NPV is defined as the present value of a project's future cash flows. By forecasting future earnings and costs, and discounting them with a discount rate, the NPV is obtained. The formula is (Berk 2007):

$$NPV = -I + \sum_{t=0}^{r} \frac{CF_t}{(1+r)^t} \tag{8}$$

Where:
I = Initial Investment
CF = Cash Flow
r = discount rate
t = time of the cash flow

The discount rate is the cost of capital, which often is calculated using the weighted average cost of capital (WACC) approach, where cost of equity, cost of debt and the tax rate are taken into account. The WACC formula is:

$$WACC = y * \frac{E}{(D+E)} + d * (1-T) * \frac{D}{(D+E)} \tag{9}$$

Where:
E = Equity
D = Debt
y = Cost of equity
d = Cost of debt
T = Tax ratio

The IRR is closely related to the NPV. Instead of finding the present value of the cash flows, the IRR is the discount rate resulting in a present value of zero of the future cash flows and initial investments. Both methods are commonly used, but the NPV method is in general accepted as the superior one. (Berk 2007)

To visualize the ceteris paribus impact of wind speed, five scenarios are used with a difference in average wind speed of 0.5 m/s. This magnitude of difference in predicted wind speed is realistic since two reports performed on the same project by two different actors can differ with to between 0.5 and 1 m/s (CON1).

It is important to notice that the main purpose of this scenario analysis is to investigate the impact of wind and the calculations should hence not be seen as an example of an entire investment assessment. As mentioned earlier, wind data includes several factors like wind speed, wind shear and turbulence which all affect the wind turbine and profitability. However, in this scenario analysis, only average wind speed is taken into consideration. Furthermore, several rough assumptions are made in the NPV calculation. However, the main data is from a real wind power project and even if tax and interest are neglected in this example, the simulated cash flows are close to the real case cash flows and the analysis can therefore be assumed to give fairly accurate results. The calculations and cash flow analysis are presented in Appendix II.

In this case, a project with the aim to build eight Vestas V 90 1.8 MW wind power turbines is evaluated. The initial investment for the farm is calculated to be 198 MSEK and the project life time is 20 years. The cash flows are calculated using income for produced electricity and for certificates. The costs include all costs derived from the project and are assumed to increase with an annual rate of 2 % throughout the entire project. Furthermore, the electricity price and price for certificates are assumed to be constant. NPV is calculated using a discount factor of 8 %.

The following results are obtained for the five different scenarios:

	NPV (MSEK)	IRR
Case 1 (5 m/s)	-120.1	-4%
Case 2 (5.5 m/s)	-75.1	2%
Base Case (6m/s)	-25.6	6%
Case 3 (6.5 m/s)	26.3	10%
Case 4 (7 m/s)	78.4	14%

Table3. Summary of results from scenario analysis.

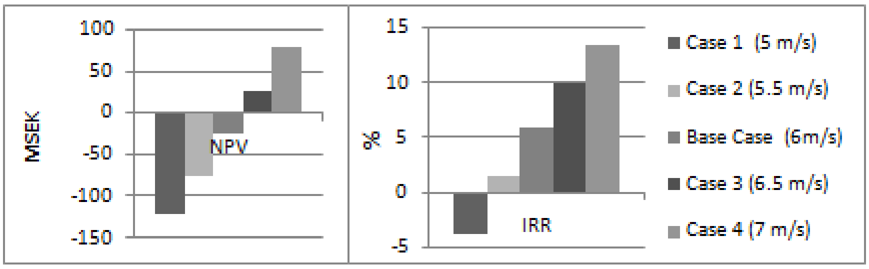

Figure15. Visualization of results from scenario analysis, NPV and IRR.

The results show that the different scenarios have very different results and hence that the wind speed has a great impact on NPV and IRR of a project. An increase in average wind speed from 6 m/s to 6.5 m/s does for example increase the IRR from 6 % to 10 %. This is a very significant difference and could be the difference between a profitable and unprofitable project. The impact on return on equity (ROE) is even greater due to the high leverage ratios (CON1).

In addition to this, more accurate wind predictions can be assumed to lead to less uncertainty and risks, which also can help to further increase the leverage ratio. A reduction of the error margin to 7-10 % (compared to 12-15 % for P90), can reduce a project's cost of funds by 0.5-0.75 %(The Economist 2010). This reduction in cost of funds would lead to an even higher impact on ROE.

To summarize, this example shows that the predicted wind speed has a great impact on future cash flows and hence NPV and IRR. Furthermore, since it has been shown that wind predictions often are inaccurate, the great importance of accurate wind predictions and hence correct and efficient wind data management is obvious.

6. The Management of Wind Data

Because wind data is an important parameter in the valuation of wind power projects it is pertinent to closely scrutinize how wind data is managed. This section aims to describe the process of acquiring wind data and how it is managed through the collection and analysis phases to finally be used, among other parameters, as a basis for investments decisions.

Findings in this section are based on empirical studies and literature from journals, IEC standards and articles.

The section presents a loosely shaped pragmatic industry approach for the development of electric power production estimates during wind power farms entire economic life cycle based on yearly series of wind data. It is clear that all phases contain arbitrary assumptions leading to uncertainty in the investment decision.

6.1. Overview

In this report, management of wind data is segmented into five phases:

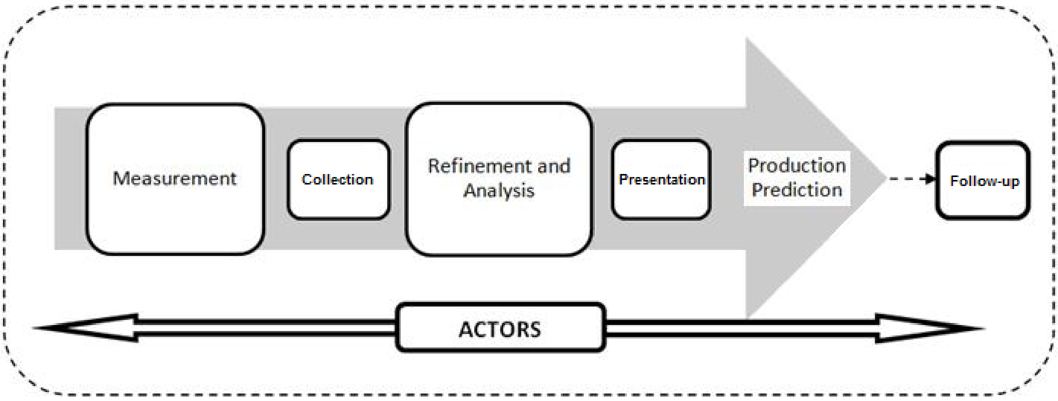

Figure16. The five phases of wind data management.

In the sections below actors involved and their activities in the different phases is presented.

6.2. Actors

The main actors concerned with wind data are presented in table 4:

Actor	Interest in wind data
Electric Power Producers from Wind Power (EPP)	Prove business case in order to acquire capital and realize projects
Investors and banks (IaB)	Seek investments which offer the desired risk-return profile or lending out money to EPP
External Consultants (CON)	Analyze wind data to convert data into production estimates used to by EPP to acquire capital

Table4. The 3 different actors concerned with wind data management.

Findings below due in some cases represent generalizations as there are varying degrees of consistency in empirical results.

6.2.1. Electric Power Producers from Wind Power

The electric power producers from wind power are initiators and owners of whole projects. Companies vary in size, from small entrepreneurial organizations to a few large actors, some of which are listed companies. Within the different size segments actors also differ in their level of vertical industry integration. This ranges from companies being pure providers of interesting projects but lacking the capital intensity to realize large scale projects themselves to companies purchasing projects and being fully integrated into the electric power market. Large and vertically integrated companies are learning more and more about the factors affecting cash flows from wind power production and are pursuing portfolio strategies to limit volatility (EPP5).

In terms of wind data, electric power producers from wind power are the owners of wind data and are involved to varying degrees in all phases (EPP). Some electric power producers from wind power have internal capabilities for collection and analysis of wind data, while some outsource all this activity (BAN1). Despite internal capabilities banks always require second opinion from independent consultants on all calculations in order to limit subjectivity (BAN1). Further, electric power producers from wind power are most often the owners of assets used to measure and collect wind data (CON1).

6.2.2. Banks and Investors

Banks and investors are the receivers of the results derived from wind data. Although not explicitly concerned with the details of wind data measurement techniques they are the ones setting requirements on the accuracy of production estimates. Banks and investors are most often involved in the final phase.

Banks and investors also differ in size and competency resulting in varying interest for different target projects. Some of the large banks in Scandinavia have dedicated departments working with the special requirements set by large scale renewable projects. These banks generally prefer to work with large and capital intensive projects. Market consensus seems to be that all wind power projects should be financed with at least 30% equity (BAN2).

Investors range from private angel investors to institutional funds. However, it is clear that the large Swedish pension funds have very little exposure to the market for electric power production from wind power.

6.2.3. External Consultant

External consultants are the companies analyzing data and providing banks and investors with a quality assurance by adding their brand name to the report incorporated in the investment decision.

Consultant companies can have two different roles in the management of wind data and it is important two differ between these.

Advisor

Offer advisory services on how to structure internal processes in the measurement and analysis phases. Advisory services also include measurement device siting plans, analysis, data collection monitoring etc. (CON3)

Independent Evaluator

Banks do in general require at least two independent reports containing production estimates based on the same data. These reports are often done by one of the large and established actors on the market. Results in the report vary depending on which models and assumptions are used. (CON1)

6.3. Step 1 - Measurement

Before the measurement phase is initiated an area has usually been deemed interesting based on a meso scale atmospheric model indicating wind conditions. In Sweden the MIUU model from Uppsala University is commonly used (CON1). The MIUU model has lately received criticism for being much too granular and imprecise especially in environments with high topographical complexity (EPP6), but is still being used.

In the measurement phase wind measurement devices are placed on sites that are deemed to have the most representative wind conditions for each of the sites upon which wind power turbines are planned to be erected. Measurement devices are not placed on each site. Wind power consultant companies often offer electric power producers advisory services in the siting of wind measurement devices (CON2).

The devices most often used are met masts and Sound Detection and Ranging devices (SODARs) (EPP2). Met masts are tall masts containing measurement devices such as anemometers, anemographs, barometers and thermometers. Met masts are often up to 100 meters tall and equipped with multiple sets of devices placed at arbitrary heights on the mast. In recent projects met masts of 120 m height have been constructed to reach hub height of modern wind power turbines. SODARs measure wind speed and direction by means of sound based radar technology. SODARs enable measurements to be performed at intervals of five meters from 0 to 200 meters above ground. SODARs are as of yet not approved by financial institutions (BAN4). In areas of large topographical complexity SODARs are used in order to more thoroughly understand an areas wind conditions (CON2). Using SODARs also works as a mean to check the quality of the data models which are used in the analysis phase to extrapolate wind conditions from a met mast to another mast using GIS and CFD simulation (CON2). Because of SODARs' intensity in wind measurements at various heights they are especially efficient in providing understanding in an areas wind profile (CON1).

Met masts are normally treated as fixed devices while SODARs are highly mobile. SODAR technology is an early stage technology and is not yet a proven and accepted technology upon which to base investment decisions (EPP6). However, due to lower investment cost and mobility they are heavily used for internal analysis of potential sites (EPP6).

Through an increased use of SODARs in forested areas in Sweden it has become clear that the leading model used for calculation of wind farm production, WAsP, fails to accurately predict winds in forested areas. The wind flow estimated by

EXAMPLE: FURUBY

In Furuby a project containing 11 wind power turbines is planned to be established. Wind data is collected using one met mast placed on a site which is deemed to be representative for the whole farm. The met mast will remain in place for at least 12 months. When the measurement phase is complete the data will be normalized to represent an average annual wind speed during the economic life cycle of the wind power farm. Software will be used to extrapolate data to all of the planned eleven turbine sites. Software takes topography and other external factors into account when producing a production estimate.

WAsP based on wind data from a mast at a nearby site can often vary with up to 10% compared to results obtained from a SODAR that has been placed at the same site in order to compare model calculations to real data. (CON2)

Banks most often require all data used to develop production estimates to be based on data from met masts (BAN1). This is largely because the warranties provided by manufacturers of turbines related to the turbines power curve are based on production estimates that have been developed using anemometers certified according to IEC 61400-12-1 ((Klug & Strack 2001).

As the industry is becoming more mature, standards on measurement devices and procedures are emerging. One such standard is the IEC 61400-12 Wind Turbine Standard which establishes:

- Measurement equipment and its calibration
- Measurement procedure
- Management of the derived results (IEC 2005)

The standard is used by wind turbine manufacturers as a means for performance testing. In order to compare results from wind power projects the same measuring procedure is used in all wind power projects. This is a requirement from banks and investors. The standard was developed in 2005 and is still the guiding standard for all measurements. (EPP7)

Despite the fact that a nearly universally adopted standard exists the complexity of the problem makes comparability between sites very difficult due to the large uncertainties. (EPP2)

Even calibrated anemometers show significant deviations in wind speed variations in the order of 2-3 % (Klug & Strack 2001). Because small deviations have a very large effect on the profitability of projects the international Measuring Network of Wind Energy Institutes (MEASNET) has been established to homogenize wind measurements by seeking to ensure that anemometers are calibrated on a yearly basis by qualified personnel (Measnet 2009).

In order to account for seasonal wind condition variations met masts remain in the same position for at least one year (EPP8). This is an industry standard and requirement from investors and banks (CON3). The most ambitious electric power producers let the met masts remain at the same site in order to be able to compare the production predictions to the real production when the wind power farm has been constructed.

SODARs are managed very differently by the industry´s different actors. Some actors use SODARs in order to evaluate wind potential before a met mast is constructed. Other actors use SODARs to evaluate sites within a project and compare the different sites´ wind conditions relative to data obtained from the met mast. (CON1)

The amount of devices used in the measurement period is based on the size and topographic complexity of the wind power farm (EPP3). Measurements are most commonly done by the electric power producer. These companies own their own measurement equipment such as mast and SODARs. Within the companies there are often personnel dedicated to performing measurements (EPP3). Companies that do not have measuring capabilities purchase the service from consultant companies (CON3).

The annual costs for collection of wind data are divided among the costs shown in table 5:

Activity	Approximated Cost	Comment
Purchase met mast	200,000 SEK	1 MSEK investment but are often considered having a depreciation rate of 20% per year.
Construction, transport	200,000 SEK	This cost only appears the first year.
Monitoring of data, bi-monthly report	25,000-30,000 SEK	
Siting, reparation, land lease	50,000-100,000 SEK	
Data analysis and production estimate	50,000-100,000 SEK	Depends on size and complexity of project.

Table5. Costs in the measurement phase. (EPP8)

Estimated total cost for obtaining one year of wind data from a met mast is 500,000 – 550,000 SEK in the first year of the met mast (EPP8). If the met mast remains in the same position, the annual cost of wind data acquisition is lower because the cost for construction etc. has already been taken in the first year (EPP6). In cases when wind data is exchanged between actors the monetary value is often determined by the cost of acquisition (EPP8).

Modern owners of large wind power farms let a met mast remain on site in order to track production and how it corresponds to predictions. Met masts are also expected to play a large role for future optimizations of production and forecasting (EEP7).

Data that is acquired by the measurement devices is collected by servers which monitor the incoming wind data. This is done in the collection phase.

6.4. Step 2 - Collection

During the measurement period wind data is sent from measurement devices to a central storage device, a server, on a daily basis (EPP2). This is most commonly done by having modems request data from the devices in 24 hour intervals. The data is then transmitted from the measurement device to the server over a GSM network. As measurement devices are often placed in remote areas with weak GSM coverage, transmission is in some cases a problematic issue. When data is received by the server it is stored in files. The format in which the wind data is stored depends on the measurement equipment being used. In order to compare data from different sites with different measurement devices data needs to be converted to a universal format. There is currently no standard format being used. Instead, software packages convert data to their proprietary data format (EPP5).

Transmission of data is more and more going towards GPRS with faster updating times and lower latency which means that data can be collected in close to real time with higher reliability than with GSM (EPP2).

During the collection phase incoming wind data is monitored in order to check for inconsistencies in the data. Inconsistencies could be due to rapidly changing wind conditions (EPP8). However they can also be caused by external factors such as data transmission problems, icy conditions, high humidity, sabotage, low voltage, equipment failure etc. All inconsistencies not affected by wind should be avoided in order to provide a complete data set for analysis. In cases when inconsistencies are discovered wind power companies strive to manage the problem swiftly.

Many electric power producers manage monitoring themselves and others buy the service from wind power consultants. When monitoring services are provided by an external consultant these cost approximately 25,000-30,000 SEK/year. Monitoring often includes a bi-monthly status report (EPP8).

When a yearly data set has been collected electric power producers often create production estimates based on this data in order to be able to calculate on the project’s profitability over time (EPP3).

6.5. Step 3 - Refinement and Analysis

Refinement and analysis usually start when one year of wind data has been accumulated (EPP6). Before any production estimates can be made the wind data series needs to be complete. In cases when large anomalies have occurred or data is missing, data is often replaced by data from a location nearby with a decent correlation during the periods when both series contain data. Data can also be replaced by other time periods from the same data set. Refinement of data is to a large extent a manual task. The software packages most often used to refine data are Microsoft Excel, Windographer, WindSim and WindPro (CON1).

In many cases a wind power farm is planned to contain multiple turbines but the measurements have only been collected from one met mast. In these cases mathematical models and software are used to extrapolate the findings from the met mast to the planned sites of the turbines. In forested environments the mathematical models provide weak approximations compared to real wind data. This is because of the complex terrain and roughness of the vegetation. In many cases vegetation may also change during a wind power farm’s life cycle. This is especially true in areas where forest may be cut down during the wind power farm’s lifetime. (CON1)

Input data needs to be normalized to represent an annual average over the economic life cycle, as wind conditions show large variations from year to year.

Normalization is preferably done by comparing wind data from the met mast to long term measurements from a nearby long term measurement station. Data from the mast is compared in order to determine how representative data from the measurement period is for a longer period. Data can then be adjusted to represent average annual wind conditions (CON3).

In cases when there are no long term reference data available the NCEP/NCAR dataset is used (Nilsson & H Bergström 2009). This system contains global mesoscale data from 1946 (Kalnay et al. 1996).

The most reliable means to estimate long term production is to use production and wind data from nearby wind power turbines, if these are available.

When data has been normalized, software is used to determine wind conditions on sites where turbines are planned to be constructed. The data is once again manipulated in order to eliminate all influences of the surrounding topography. The software converts data to represent wind conditions which would have been observed at 10 meters above ground in each wind sector if the surroundings had been completely flat with roughness factor 0. The roughness factor is a measure of the surrounding areas surface and is in the range of 0-5 (Wizelius 2007). Hence the dataset now contains a wind frequency distribution in 12 sectors at 10 meters above ground. Data is then converted to multiple heights at the different sites. Using topographical maps and different roughness factors in different areas wind conditions are then computed for the different sites. The dataset can be used to produce wind condition estimates for turbines sites within a 20 km radius (Wizelius 2007).

When the wind conditions have been estimated for each site, software can be used to model the production from different types of turbines in order to find the optimal turbine. This is because some wind turbines perform better than other depending on the wind conditions (CON1).

During the analysis phase a number of assumptions are made which all affect the uncertainty of the production estimates (CON3). These assumptions along with results are accounted for in a report which is presented to potential investors along with a similar independent report produced from another wind power consultant based on the same dataset(The Economist 2010).

During the past three years there has been a homogenization on how wind data is analyzed. There are still a few different methods and software being used. In Sweden it is industry practice to use WindPro for analysis (CON3). However, software with more complicated algorithms based on Computational Fluid Dynamics such as WindSim is gaining greater popularity in areas of topographical complexity (CON3). Requirements on the homogenization of wind data analysis and refinement of methods is led by banks and investors who are constantly demanding electric power producers to provide data with less uncertainty as the projects keep on growing in terms of capital intensity and effective output (CON2).

In line with the homogenization of process for creating production estimates, cost differences between different consultant companies are also beginning to conform (EPP8).

An analysis takes approximately one month to be performed from that the electric power producer provides all data until a report is delivered (EPP8).When the analysis is complete the actor performing the analysis creates a report which, along with another independent report, forms the foundation upon which the investment decision is based. Other factors such as currency risk, energy prices etc are also taken into account but are usually not project specific and hence not in the scope of this thesis.

6.6. Step 4- Presentation

In the capital acquisition process wind data is used to prove a project's viability for investors and lenders. Results of the wind data analysis are provided in a report which presents the most important results and the assumptions made to arrive at these results (CON1).

The first pages of the report generally contain a summary with the most important results such as (BAN1):

- Mean wind at different heights and the data availability of raw data
- Mean wind at different heights and the data availability of quality assured data
- Mean wind at different heights and the data availability after modeling
- Mean wind at hub height after long term correctness with P50, P75, P84 and P90 values
- Occurrence of extreme winds
- Turbulence
- Gross production
- Yearly net production with P50, P75, P84 and P90 values

Following the summary is a report outlining the techniques, methods and assumptions used to arrive from the raw data to the results (EPP7).Investors and banks most often focus on the summary data as the remaining parts of the report tend to be highly technical. It is the brand name of the consultant company and the first page which matter to investors and banks (BAN1). A well known brand indicates that the proper methodology has been used.

The most important values are the exceedance probabilities (EPP7). These probabilities indicate the uncertainty provided with the Annual Energy Production (AEP) prediction (Klug 2006). A P75 value is the annual energy production which is reached with a probability of 75%.

Because of the assumptions that need to be made in creating the Annual Energy Production for the entire wind power farm often based on only one year of data from one site, investors and banks often require that two analysis of the same dataset be made (BAN1). These different production estimates of the same project can vary significantly in annual average wind speed and production estimates. In these cases the decision to invest is made arbitrarily (EPP7).

6.7. Follow up

The objectives with the follow up phase are to (EPP5):

- Learn and analyze how the accurate production estimates in order to become better at siting wind turbines.
- Predict short term production
- Follow up turbine manufacturer’s guarantee commitments
- Optimize production

When a wind power farm has been constructed it starts producing electric power. It often takes some time to have all turbines fully operational. By paying careful attention to the individual wind power turbine’s configuration at different wind conditions the farm’s production as a whole can be optimized (EPP8). This sometimes means configuring one turbine to produce less in order for the turbines affected by its wake to produce more. Hence, optimizing one wind turbine to produce to its full potential may in fact be a sub optimization of the farm as a whole (CON1).

The companies with most experience tend to keep the measuring device that was used in the measurement phase on the same site (CON2). This is done for the following reasons

- To make sure estimates were correct. This has substantial learning effects.
- Warranties provided by the supplier of the turbines are based on the wind data gathered in the measurement phase.
- Wind turbines have anemometers on the nacelle. These anemometers are affected by the turbine’s wake effects. By comparing data generated from these anemometers compared to the met mast disruptions/noise from the turbine can be filtered out.
- Farm optimization. By analyzing how the wind power farm is performing at varying wind conditions the wind power farm can be configured for optimal production.
- Historical wind data can, with the proper statistical techniques, be used to forecast production.

In cases when production is lower than expected it is important to distinguish between if the wind farm is under performing or if the wind potential was overestimated.

7. Main Areas of Improvement

This section summarizes and compiles the main areas of improvements derived from the results in the previous sections.

To start with, one main key finding is that wind speed has a great impact on the overall profitability of a wind power farm. This implies that accurate wind predictions are of great importance and findings show that such predictions often are misleading. Another overall finding is that there are few standards and it is unclear or undefined who should create such standards and new ways of working.

The following list states the main areas of improvements found for each of the five phases:

Measurement

- To short and little measurement - Longer measurements with higher quality at more sites within a project is needed
- Unclear directives and standards regarding the usage of SODAR and met masts

Collection

- Insufficient data quality assurance
- Lack of standardization of data formats and data transmission

Analysis

- Price level of consultancy services is very high
- Arbitrariness in assumptions upon which production estimates are based
- Lack of transparency and openness in terms of documentation from software and model providers

Presentation

- Alignment of consultants, banks and energy producers incentives
- Lack of knowledge and understanding within banks
- Bank have a too high dependency on external consultants

Follow up

- Insufficient follow up of production and wind conditions post construction are done

In the discussion below we discuss around some of the most interesting methods for improvement.

8. Discussion

This section seeks to use the results and main areas of improvement from previous sections to provide additional insights for the importance of wind predictions and how wind data is managed.

The presented investment framework, scenario analysis and results from interviews indicate that production and hence wind speed has a crucial role in the profitability of wind power projects. This is because installed capacity does not equal electricity. The sites in which wind power turbines are constructed must have wind potential and this wind potential must be proven to investors in order to realize projects (The Economist 2010). Exactly which factor in the process of creating production predictions that is subject to most uncertainty varies based on interviewee and cannot be established. The results from different interviews differ and the great complexity of measuring wind and creating predictions make the answers quite subjective.

To further complicate the matter of realizing profitable wind power projects are organizational and financing aspects such as operational efficiency, CAPEX, OPEX and Revenues. All these company specific aspects play important roles and their respective internal hierarchy in terms of affecting a project's profitability varies depending on situation.

Given the great impact of wind data management on the projects' predicted NPV, we believe that investors and wind power companies should be more cautious and restrictive when using wind data in production predictions. This is further strengthened in a survey made by the wind energy group led by Prof. Chokani in the Laboratory for Energy Conversion at ETH, Zürich. The Laboratory for Energy Conversion's survey of 153 wind power projects in the EU, US and China shows that there is a "significant difference between predicted and actual production".

There seem to be few people who have a complete overview of the market, especially within banks and other investors, and these results in a great trust in external consultants. This is also likely to have an impact on how responsibility is divided among actors and today no actor is taking full responsibility for the accuracy of the wind predictions. Banks do in many cases lack to expertise and do not trust the wind power companies, which are their customers and hence could be biased. Therefore, external consultants usually have the final word, even though they do not take responsibility for the results. It is also important to note that the level of knowledge varies between the actors and one should be cautious when generalizing.

The wind power industry is very young in Sweden and this is most likely an explanation for the fairly low level of knowledge and understanding of the importance of wind data within some organizations. There are at the moment many new wind power projects under construction and our findings indicate that the demand for accurate wind predictions is increasing. Besides the previously shown impact on NPV, another factor making this discussion pertinent is that the market is facing a consolidation where assets need to be valued. Wind data is one of the key parameters in these project valuations. Further, it has become clear that projects, in which wind turbine positions are flexible as opposed to fixed, tend to be valued more as the positioning of wind turbines is of great importance. The management of wind data is expected to also become more important in the production phase as a larger part of the energy system in the future will be based on production factors with large intermittency such as solar power, tidal power, wave power etc. These types of energy production depend on external factors which require forecasting techniques of especially local weather conditions to become even more sophisticated in order to maintain a stable provision of electricity.

Along with banks and other investors, insurance companies start to enter the market. These companies offer insurances for production losses and are an emerging stakeholder for accurate wind predictions. This is likely to put more pressure on the wind power companies to have more thoroughly performed wind predictions and possibly also on investors to be more restrictive before lending or investing money. Together, these factors are likely to make wind power a more mature industry which will have higher requirements on accurate wind data than previously.

An interesting development on the Swedish wind power market is the change in vertical integration largely due to the required capital intensity to realize projects. Actors which previously intended to build, own and sell electricity from wind turbines have in many cases been forced to alter their business models to sell complete projects to better capitalized actors in order to generate instant cash flow. In these cases it is the complete permits to build in areas with confirmed wind potential which is the fundamental value parameter.

The influence this has had on the management of wind data is that more actors need to be able to trust the reliability of wind data.

8.1. Measurement

Wind measurements form the basis for yield predictions and profitability evaluation. The importance of well performed wind measurements are gaining in relevance for all market actors. This is because they all seek to minimize risk using real data.

The IEC-61400-12-1 forms a stable foundation upon which to base the measurement procedure. Our belief is that this standard will remain the main guideline for coming years. A problem with standardizing the measurement phase is the complexity of the problem. All sites are different in terms of topography, seasonal wind variations etc. Hence, the standard needs to be flexible to local variations. In terms of standardization it is paradoxical to flexible. The standard's objective is to provide comparability between projects and their measurement data. Keeping this in mind experts can analyze projects by carefully studying the project specific assumptions that are indicated in consultancy reports.

A feasible and pragmatic approach to increase certainty in the investment decision is to have longer measurement periods and/or use more measurement devices in the measurement phase in order to rely less on model based estimates and more on actual data. Moody’s states that wind data could be improved and that longer measurement periods would be useful for more accurate predictions (Moody's 2010a). The planning and preparations time is however already fairly long and increasing the measuring time is likely to be very expensive. However, as projects gain in capital intensity it will make more sense to increase spending in this phase and prolonged measuring phases could be feasible. The alternative to use measurement devices based on improved state-of-the-art might be more doable and according to Prof. Chokani, “the accuracy of wind predictions could be significantly improved by using state-of-the-art technology measurement devices”. He further states that this is a relatively small increase in cost and that there are “no legitimate excuses for not using state-of-the-art measuring devices”.

Another way to increase measurement quality and intensity is to use more flexible measurement devices such as those based on SODAR and LIDAR technology. These types of devices are both cheaper and more flexible in terms of deployment and portability. However, the devices are currently not certified by banks. This means that data which they generate cannot be used for production estimates. Instead they are used to quickly get a general overview of a site’s wind potential. If the result is positive, a met mast will be erected. All actors are positive to using SODARs as complementary devices to met masts. However, the market is polarized in their view of if SODAR and LIDAR technology will ever be trusted as reliable enough to base investment decisions upon data generated by these devices. It is the banks which need to give consent in this matter, and banks will not give consent unless consultants, the experts, clearly state that SODARs are reliable. A cynic would say that consultants are inclined to support the view which is best for their business.

The advocates of SODARs claim they are much better than estimates given by models and that SODARs in some cases also provide more accurate data than met masts. It is true that data generated from SODARs has a better resolution as a data point is given every 5 meters to 200 meters above ground. In comparison a met mast may be equipped with measurement devices at three different heights with data being extrapolated between these to obtain a height curve. Antagonists claim that providers of SODAR technology are too secretive in their methods of calculation which causes their methods to never be critically evaluated and hence will not be certified.

Despite the many uncertainties, we deem it highly likely that SODAR technology will soon be accepted by banks. The reason for this is that we believe the increasing quality, price advantages and potential for more actual data will soon overcome the many technological doubts.

To summarize, well performed measurements is fundamental in the wind data management process and affect a projects valuation in the short term as other actors are inclined to purchase projects with high certainty in production estimates. There are still many uncertainties and measurements are in many cases poorly performed. The industry is however likely to adapt in the near future and it is very likely that the increasing demand for better measurement will improve measurement procedures. Further, the many uncertainties regarding standards in this phase is also likely to disappear as new standards are emerging.

8.2. Collection

The collection phase is important in terms of raising data quality in the incoming data that measurement devices generate during the measurement periods. Quality is raised by carefully studying data looking form anomalies pointing to one of the many factors mentioned in the Result Section. Many of these factors can be managed if data is regularly checked and the resources to physically take action on site when data indicates a malfunction due to external factors are provided. This requires a network of personnel either closely tied to the company, but most often tied to the company through connections with the land owners.

In many cases the slow decay in data quality are not noticed by the monitoring software or personnel. In cases when changes in data quality are noticed the communication from monitoring personnel to the person responsible for on-site reparations is lacking. This leads to slow repairs which can affect the measurement devices functionality for longer periods of times, sometimes weeks. Because a 100% complete data set is in itself a small sample for the 20 year production prediction a 10% data loss is very severe. Data losses are managed in the analysis phase through correlation with other data sets which in itself is a process prone to increase uncertainty in the data.

In some cases data quality can be affected by poor GSM network. Modern measurement technology is being equipped with GPRS technology in which data can be “pushed” from the source device to the server. This is not possible in the TCP/IP protocol on the GSM network as all data must be requested, an inherent property in the TCP/IP protocol. GPRS technology will most likely be a large step for data transfer reliability.

Many of the consultant companies are entering the market of measurement device surveillance in order to ensure that the data quality is high before they perform micro-siting and long term production estimates. That consultants are entering this area is a sign that the market is maturing as wind power companies are to a greater extent becoming more focused on managing projects than providing the in house wind data expertise.

8.3. Analysis

Analysis is based on performing a series of calculations on the collected measurement data. The objective with the calculations is to predict the project's production potential during the project's complete lifetime. This is a matter subject to large uncertainty and a process in which many assumptions need to be made. To mitigate the influence of these assumptions calculations on the same data are often performed by at least two independent consultancy firms. A second opinion improves the credibility of results. However, the fact that results often vary despite the fact that calculations are based on the same data really shows how arbitrary energy predictions can be.

In the process an extensive use of the software WindPro is a frequent method pursued. Despite the same data and same software the resulting values such as average wind speed and yearly net production values often vary significantly. This is due to the varying assumptions performed by consultants. Because banks sometimes do not have the skill set to analyze assumptions which are made they need to trust the consultants and make a decision based on the data at hand. It is very rare for banks to communicate directly with the consultant companies delivering the reports as it is the wind power company's responsibility to manage the consultant companies. A possible area of improvement is to initiate a dialog among the consultancy companies when both of their respective analysis has been completed. However, as they are competitors this might not be received well. It is also very likely that the banks would benefit from having more expertise within the organization and hence decrease the dependency of external opinions. The trend seems to be pointing in this direction and the banks that have been working with wind power for a while seem to have realized this weakness. The different players do however still find themselves in different maturity stages and it will take some time before they all have reached an equal and satisfactory level of knowledge and experience.

In Sweden many large projects are being planned to be constructed in forest environments. To create production estimates in this type of environment is especially difficult as the roughness is often very unpredictable and changing due to seasonal variations. The roughness is also affected by changes in vegetation over the projects lifetime. In some interviews it becomes obvious that a few international firms are completely unaware of local characteristics of the Swedish forest environment. Given this, and the general over reliance on models, results presented by foreign firms could be less accurate at the time being. To learn about local phenomenon such as production forests is clearly a minor problem that foreign companies could easily learn. Still it has been a problem until very recently why it is reasonable to believe that there is improvement potential in this field.

Although it is in many cases very practical with standards in order to produce a high level of comparability, some standards are not for the best. WindPro has a clear market leadership in terms of being the software used for producing production estimates. However, frustration has been noted among technical staff wishing to closer evaluate the inner workings of WindPro. Because WindPro is market leader they are not inclined to share. This causes many of the calculation assumptions within WindPro to be a held in secrecy. In complex terrain WindPro is experiencing competition from the Norwegian based WindSim which in contrast to WindPro's linear model uses Computational Fluid Dynamics for calculation. This approach has been proven more accurate in areas of large topographical complexity. This competition could imply changes for the industry and hopefully also provide better analyses for Swedish conditions in the future. The emergence of new technologies and hence maybe new standards could also create opportunities for new actors. This is however very hard to predict and it will probably take several years before competitive technologies are strong enough to be potential standards. It is also worth noting that consultants and their reports are becoming less expensive due to an increase in competition, which can result in new ways of working in this phase.

To summarize, this step is still time consuming and requires plenty of resources. The results differ and the accuracy is often questioned by both banks and wind power companies. Even though changes are taking place, there is much room for improvements. The general level of knowledge for specific geographical regions needs to increase in order to lower the over reliance in data models. This can only be done through experience and local expertise, why a more decentralized approach could be beneficial. It is also likely that new standards need to be developed and the system of often using two independent consultants needs to be evaluated. There are probably many potential measures to improve this step. However, it needs a very thorough investigation and this is excluded in this report.

8.4. Presentation

The presentation phase is closely related to the analysis phase. The fact that several reports are presented with different results often creates confusion and uncertainty. As the analyses are getting cheaper to buy, a potential trend could be to buy even more independent reports in order to decrease the risk. However, the rationale behind this could be questioned and it is possible that focus instead should be on improving the quality of the data and analysis rather than the quantity.

The presentations provided often lack strong opinions due to the lack of responsibility from the external consultants. If the bank has a good understanding of wind data analysis, this is not a problem since they can backtrack all findings and create their own opinions based on the data. However, in cases where banks lack competence, more subjective opinions expressed by consultants would probably ease the overall understanding for the report. Since banks are increasing their level of knowledge within this area, this problem might be solved in the future but is currently a real problem. Further, the increase in knowledge among banks is likely to solve the problem of too high level of complexity in the reports and hence decrease the dependency of consultants.

The overestimation in average wind power expressed by Moody's and Hofstad (2009) can to a certain extent probably be expressed by the formats of the reports. In cases with a high overestimation, P50 values have been in focus rather than P75. This implies a more aggressive approach with lower risk margins. A potential way of improving reports and hence lower the risks for overestimations would hence be to focus more on P75 values and maybe even P90 values which are inherently lower.

8.5. Follow-up

The follow up phase occurs post construction. As there have not been many large scale wind power project's realized in Sweden, the management of the follow up phase is not clear. However, given the evidence for overestimation as well as an increasing demand for short term prediction, it is likely with an increased focus on this phase in the future.

9. Conclusion and Further Research

This report isolates production from other factors affecting the profitability of a wind power farm project. Production can be broken down into several factors, where wind conditions are of great importance. A main finding is that wind has a great impact on the overall profitability of such a project. Recent research shows that overestimation of production in the preconstruction phase is common. This research also draws the conclusion that overly optimistic wind predictions based on wind data are a main contributor to this. The reasons for these inaccurate wind predictions are most likely a combination of several factors, as for example lack of knowledge.

Several actors along the wind data management chain are identified and there seems to be an unclear interrelation of responsibilities among these actors. Due to lack of expertise and potential biasness of electrical power producers, banks and other investors rely heavily on independent consultants when forecasting production. However, these consultants do not take any responsibility for the accuracy of assessments. Findings indicate that these consultants sometimes lack the proper knowledge for forecasting a wind farm's production, especially in areas of large topographical complexities and changing roughness factors such as forested areas in Sweden. These indications are further strengthened by Prof. Chokani at ETH, who states that "the track record of consultants shows that we can do very much better with new and different approaches".

The management of wind data is found to follow several phases where measurement and analysis are the two most important ones. There are many uncertainties in this process and still new formal standards, such as those developed by the IEC, and informal methods of working are emerging. SODARs are likely to become generally accepted by banks in the future, since they improve their accuracy and make it possible to measure more. In the analysis phase, there are several problems due to lack of knowledge by some actors and overconfidence in data models. It is however evident that the different actors are improving their level of knowledge and today's dependency of external experts when analyzing wind data could be decreased as a result of this.

To summarize, wind data is shown be tremendously important in the realization of wind power farm projects and there is still plenty of room for improvements. However, the industry is adapting and learning rapidly why it is reasonable to believe that both the demand for and quality of wind data will increase in the future.

9.1. Further Research

As shown in the report, there are many areas in this emerging industry that can be improved in order to decrease uncertainty and improve project profitability. To succeed with this, further research is needed along the entire chain of wind data management. It would also be of great interest to extend the research and investigate how wind data is managed and used in other countries than Sweden. By doing this, both weaknesses and best practices could be found.

There are other usage areas for wind data which are just partly discussed or totally neglected in this report. One example is the increasing importance of short term wind forecasts needed when selling electricity to NordPool as well as to continuously optimizing electric power production from the wind power farm. It would be of interest to analyze how wind data should be managed in the best way to meet this short term demand.

Further, with larger turbines and more capital intensive projects the effect of efficient micro-siting becomes larger. This has traditionally been done with a mix of wind data, data extrapolation and models. More research is needed to find out how an increased amount of wind speed data affects certainty in long term prediction and if it is economically reasonable to increase the amount of wind speed data and to what extent this should be done in the future.

Finally, it would be of great interest to investigate how a potential improvement of wind speed predictions would affect the industry. Which actors would gain from such a development and are there are actors that actually would lose? Answering these questions could give a hint of who the driver of this development should be.

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Appendix I - Interviews

The interviews have been conducted in two rounds. Most interviewees have required to be anonymous, why no company or personal names are shown in this report.

List of Interviews:

Round 1 (2010-06-25 to 2010-07-18)		
Code	**Type of Actor**	**Characteristics**
EPP1	Wind Power Company	Large wind power company
EPP2	Wind Power Company	Large wind power company
EPP3	Wind Power Company	Medium sized wind power company
EPP4	Wind Power Company	Medium sized wind power company
INV1	Investor	Large investment fund
BAN1	Bank	Large scandinavian bank
CON1	Consultant	Large actor in the market

Round 2 (2010-08-10 to 2010-09-30)		
Code	**Type of Actor**	**Characteristics**
CON2	Consultant	Large actor in the swedish market
CON3	Consultant	Regional actor in the swedish market
INS1	Insurance Company	International actor
BAN3	Bank	Large scandinavian bank
BAN4	Bank	Large scandinavian bank
EPP5	Wind Power Company	Medium sized wind power company
EPP6	Wind Power Company	Medium sized wind power company
EPP8	Wind Power Company	Medium sized wind power company
EPP7	Wind Power Company	Medium sized wind power company

The questionares have differed for the two interview rounds. They have to a certain extent also been adjustad for each interviewee. Two typical examples of questionaries are shown below:

Frågeformulär vindkraftbolag

Om Examensarbetet:
Examensarbetet syftar till att undersöka hur det praktiska arbetet med genomförande, analys och uppföljning av vindmätningar kan underlätta kapitalanskaffning inför anläggning av vindkraftparker.

Allmänt

- Hur många verk har ni i drift idag (antal och effekt)?
- Hur många verk/MW ämnar ni driftsätta kommade året/fem åren?
- Hur många personer arbetar hos Er (anställda och engagerade konsulter)?

Organisation

- Utförs vindmätningar internt?
- Hur många personer arbetar dagligen med vindmätningar?
- Vad har dessa personer för bakgrund?
- Hur många mätenheter använder bolaget?
- Ämnar bolaget utöka antalet mätenheter?
- Hur ser processen ut från att beslut om mätning tas till beslut om investering genomförs?
- Hur och av vem utförs analyser av vinddata?
- Vem fattar beslut om att utföra investering?
- Hur många projekt i mätfas klarar organisationen av att utföra parallellt?
- Är markägare intresserade av att ta del av mätdata?
- Har bolaget köpt mätdata?

Metod

- Vilka verktyg använder bolaget för att analysera vind?
- Hur lång är en vindmätning?
- När är vindmätning av ett område komplett för analys?
- Hur avgör bolaget var mätenheter ska placeras?
- Hur överförs vinddata från mätenhet till företaget?
- Hur lagras vinddata?
- Gör bolaget en uppdelning mellan tillförlitlig och ej tillförlitlig data?
- Hur hanterar bolaget ”glapp” i vinddata (p.g.a. isning, luftfuktighet osv)?
- Hur hanterar bolaget långa tidsserier uppdelade i flera datafiler?
- Hur hanterar bolaget normalårsjustering av vinddata?
- Hur utför bolaget produktionsberäkningar?
- Hur utför bolaget jämförelse mellan potentiella platser för anläggning?
- Anpassar bolaget turbintyp baserat på vindförhållanden?
- Genomför bolaget aktiv uppföljning av vindmätningar?
- Vilka grafer är mest intressanta för bolaget i utvärdering av vinddata?

Kapitalanskaffning

- Hur viktigt är tillförlitliga vindmätningar i kapitalanskaffningsprocessen?
- Vilka krav har investerare på underlag från vindmätningar? (Vad ska finnas med i prospektet?)
- Vilken expertis upplever bolaget att investerare har?
- Följer investerare upp produktionen kopplat till vindmätning under projekteringsfas?

Omvärld

- Vet bolaget hur andra aktörer arbetar med vindmätning?
- Upplever bolaget att det finns en etablerad metodik bland marknadens aktörer för hur vindmätning ska utföras?

Problem

- Upplever bolaget problem med nuvarande process av att utföra vindmätningar och genomföra analys?
- Upplever bolaget tekniska begränsningar i den nuvarande processen?
- Upplever bolaget problem med skillda format av mätdata?
- Upplever bolaget att mätdatans tillgänglighet är ett problem?
- Har bolaget förslag på hur processen kan underlättas?

Intervjuunderlag

Om Examensarbetet:
Examensarbetet syftar till att undersöka hur det praktiska arbetet med genomförande, analys och uppföljning av vindmätningar kan underlätta kapitalanskaffning inför anläggning av vindkraftparker.

Allmänt om företaget

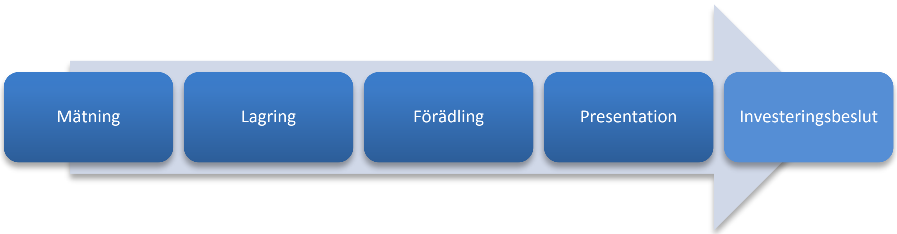
- Hur många verk har ni i drift idag (antal och effekt)?
- Hur många verk/MW ämnar ni driftsätta kommade året/fem åren?
- Hur många personer arbetar hos Er (anställda och engagerade konsulter)?

Omgivning

- Hur viktigt är tillförlitliga vindmätningar i kapitalanskaffningsprocessen?
- Vilka krav har investerare/banker på underlag från vindmätningar? (Vad ska finnas med i prospektet?)
- Vilken expertis upplever bolaget att investerare/banker har?
- Följer investerare/banker upp produktionen kopplat till vindmätning under projekteringsfas?
- Vet bolaget hur andra aktörer arbetar hanterar vinddata?

Hantering av Vinddata

Frågorna nedan är indelade i följande fem områden.



Mätning

- Utförs vindmätningar internt?
- Hur många mätenheter använder bolaget?
- Hur många projekt i mätfas klarar organisationen av att utföra parallellt?
- Köper bolaget in mätdata externt?
- Hur lång är en vindmätning?
- Vad beräknar ni att Er mätutrustning kostar per månad?
- Hur många timmar arbetar ni aktivt med mätningar?
- Görs en kostandskalkyl för projektet i projekteringsfasen och hur ser denna ut?
- Hur mycket kostar mätning under ett projekt (hårdvara, mantimmar, konsulttjänster osv)?

Lagring

- Finns det några sätt som detta steg kan förbättras? Effektivare, billigare etc. ?
- Hur fungerar överlämning till nästa steg (var utförlig)?

Förädling

- Hur och av vem utförs analyser av vinddata?
- Hur mycket data brukar saknas eller vara oanvändbar på årsbasis?
- Vilka är de vanligastse orsakerna till att datakvalitet är låg?
- Vad uppskattar ni kostnaderna till för detta steg?
- Vad kostar det att utföra en oberoende analys på vinddata för ett projekt?
- Hur lång är leveranstiden från rådata till komplett rapport från oberoende konsulter?
- Vilka är de stora svårigheterna och utmaningarna med detta steg?
- Finns det några sätt som detta steg kan förbättras? Effektivare, billigare etc. ?

Presentation

- Hur presenteras vinddata?
- Hur levereras rapporten? (Är konsulterna närvarande och tar ansvar?)
- Levereras det en fil med rapporten?
- Vilken insyn har vindkraftföretaget i hur den oberoende konsultens rapport är genomförd och sammanställd?
- Hur får den oberoende konsulten tag på indata till rapporten?
- Vem betalar den oberoende konsulten, hur mycket och hur sker upphandlingen av konsulter?
- Finns det endast vissa konsulter som är godkända av olika banker?
- Vem måste vindkraftföretaget anpassa sig efter?
- Är det klart och tydligt vem som kommunicerar med vem?
- Kommunicerar banken någonsin direkt med konsulterna?
- Är banken kapabel att själva göra en bedömning av värdet av ett projekt?
- Finns det externa krav på hur detta steg ska utföras?
- Finns det etablerade standarder för detta steg?
- Vilka är de stora svårigheterna och utmaningarna med detta steg?
- Finns det några sätt som detta steg kan förbättras? Effektivare, billigare etc. ?
- Hur fungerar överlämning till nästa steg (var utförlig)?

Investeringsbeslut

- Hur viktigt är vinddata för att ta beslut om investering?
    - Hur tas beslut om investering när oberoende rapporter visar olika?

Appendix II – Scenario Analysis

The purpose of the scenario analysis is to investigate and visualize the impact of wind speed alone. Hence, the calculations are based on rough assumptions and should not be considered as a complete investment calculation.

Assumptions	
Initial Investment (MSEK)	198
Discount Factor	0,08
Number of Turbines	8
Electricity Price (SEK/MWh)	450
Electricity Certificate Price (SEK/MWh)	300
Total Investment (MSEK)	197
Debt Ratio	0,75
Equity Ratio	0,25

	Gross Production (MWh/y)	Deduction for Losses & Availability	Net Production (MWh/y)	NPV	IRR
Case 1 (5 m/s)	2677	10%	2409	-120,1	-4%
Case 2 (5.5 m/s)	3572	10%	3215	-75,1	2%
Base Case (6m/s)	4557	10%	4101	-25,6	6%
Case 3 (6.5 m/s)	5588	10%	5029	26,3	10%
Case 4 (7 m/s)	6624	10%	5962	78,4	14%

Formula for calculating NPV is:

$$NPV = -I + \sum_{t=0}^{r} \frac{CF_t}{(1+r)^t}$$

Where:
I = Initial Investment
CF = Cash Flow
r = discount rate

For calculating IRR, the specific Excel function is used.

The results are shown below:

Cash flow from investment and operation (MSEK) - BASE CASE

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Sold electricity		14,8	14,8	14,8	14,8	14,8	14,8	14,8	14,8	14,8	14,8	14,8	14,8	14,8	14,8	14,8	14,8	14,8	14,8	14,8	14,8
Sold certificates		9,8	9,8	9,8	9,8	9,8	9,8	9,8	9,8	9,8	9,8	9,8	9,8	9,8	9,8	9,8	0,0	0,0	0,0	0,0	0,0
Sum income		24,6	24,6	24,6	24,6	24,6	24,6	24,6	24,6	24,6	24,6	24,6	24,6	24,6	24,6	24,6	14,8	14,8	14,8	14,8	14,8
Sum expences		5,0	5,1	5,2	5,3	5,4	5,5	5,6	5,7	5,9	6,0	6,1	6,2	6,3	6,5	6,6	6,7	6,9	7,0	7,1	7,3
Cash flow (CF) from operation (excluding interest and tax)	**-198**	**19,6**	**19,5**	**19,4**	**19,3**	**19,2**	**19,1**	**19,0**	**18,9**	**18,7**	**18,6**	**18,5**	**18,4**	**18,3**	**18,1**	**18,0**	**8,0**	**7,9**	**7,8**	**7,6**	**7,5**
PV		18,2	16,7	15,4	14,2	13,1	12,0	11,1	10,2	9,4	8,6	7,9	7,3	6,7	6,2	5,7	2,3	2,1	1,9	1,8	1,6
Initial Investment	**198,0**																				
NPV	**-25,6**																				
IRR	**6%**																				

Cash flow from investment and operation (MSEK) - CASE 1

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Sold electricity		8,7	8,7	8,7	8,7	8,7	8,7	8,7	8,7	8,7	8,7	8,7	8,7	8,7	8,7	8,7	8,7	8,7	8,7	8,7	8,7
Sold certificates		5,8	5,8	5,8	5,8	5,8	5,8	5,8	5,8	5,8	5,8	5,8	5,8	5,8	5,8	5,8	0,0	0,0	0,0	0,0	0,0
Sum income		14,5	14,5	14,5	14,5	14,5	14,5	14,5	14,5	14,5	14,5	14,5	14,5	14,5	14,5	14,5	8,7	8,7	8,7	8,7	8,7
Sum expences		5,0	5,1	5,2	5,3	5,4	5,5	5,6	5,7	5,9	6,0	6,1	6,2	6,3	6,5	6,6	6,7	6,9	7,0	7,1	7,3
Cash flow (CF) from operation (excluding interest and tax)	**-198**	**9,5**	**9,4**	**9,3**	**9,1**	**9,0**	**8,9**	**8,8**	**8,7**	**8,6**	**8,5**	**8,4**	**8,2**	**8,1**	**8,0**	**7,9**	**1,9**	**1,8**	**1,7**	**1,5**	**1,4**
PV		8,8	8,0	7,3	6,7	6,2	5,6	5,1	4,7	4,3	3,9	3,6	3,3	3,0	2,7	2,5	0,6	0,5	0,4	0,4	0,3
Initial Investment	**198,0**																				
NPV	**-120,1**																				
IRR	**-4%**																				

Cash flow from investment and operation (MSEK) - CASE 2

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Sold electricity		11,6	11,6	11,6	11,6	11,6	11,6	11,6	11,6	11,6	11,6	11,6	11,6	11,6	11,6	11,6	11,6	11,6	11,6	11,6	11,6
Sold certificates		7,7	7,7	7,7	7,7	7,7	7,7	7,7	7,7	7,7	7,7	7,7	7,7	7,7	7,7	7,7	0,0	0,0	0,0	0,0	0,0
Sum income		19,3	19,3	19,3	19,3	19,3	19,3	19,3	19,3	19,3	19,3	19,3	19,3	19,3	19,3	19,3	11,6	11,6	11,6	11,6	11,6
Sum expences		5,0	5,1	5,2	5,3	5,4	5,5	5,6	5,7	5,9	6,0	6,1	6,2	6,3	6,5	6,6	6,7	6,9	7,0	7,1	7,3
Cash flow (CF) from operation (excluding interest and tax)	**-198**	**14,3**	**14,2**	**14,1**	**14,0**	**13,9**	**13,8**	**13,7**	**13,5**	**13,4**	**13,3**	**13,2**	**13,1**	**12,9**	**12,8**	**12,7**	**4,8**	**4,7**	**4,6**	**4,4**	**4,3**
PV		13,2	12,2	11,2	10,3	9,4	8,7	8,0	7,3	6,7	6,2	5,7	5,2	4,8	4,4	4,0	1,4	1,3	1,1	1,0	0,9
Initial Investment	**198,0**																				
IRR	**1,5%**																				
NPV	**-75,1**																				

Cash flow from investment and operation (MSEK) - CASE 3																					
Year	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Sold electricity		18,1	18,1	18,1	18,1	18,1	18,1	18,1	18,1	18,1	18,1	18,1	18,1	18,1	18,1	18,1	18,1	18,1	18,1	18,1	18,1
Sold certificates		12,1	12,1	12,1	12,1	12,1	12,1	12,1	12,1	12,1	12,1	12,1	12,1	12,1	12,1	12,1	0,0	0,0	0,0	0,0	0,0
Sum income		30,2	30,2	30,2	30,2	30,2	30,2	30,2	30,2	30,2	30,2	30,2	30,2	30,2	30,2	30,2	18,1	18,1	18,1	18,1	18,1
Sum expences		5,0	5,1	5,2	5,3	5,4	5,5	5,6	5,7	5,9	6,0	6,1	6,2	6,3	6,5	6,6	6,7	6,9	7,0	7,1	7,3
Cash flow (CF) from operation (excluding interest and tax)	**-198**	**25,2**	**25,1**	**25,0**	**24,9**	**24,8**	**24,7**	**24,5**	**24,4**	**24,3**	**24,2**	**24,1**	**24,0**	**23,8**	**23,7**	**23,6**	**11,4**	**11,2**	**11,1**	**11,0**	**10,8**
PV		23,3	21,5	19,8	18,3	16,9	15,5	14,3	13,2	12,2	11,2	10,3	9,5	8,8	8,1	7,4	3,3	3,0	2,8	2,5	2,3
Initial Investment	**198,0**																				
IRR	**10%**																				
NPV	**26,3**																				

Cash flow from investment and operation (MSEK) - CASE 4																					
Year	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Sold electricity		21,5	21,5	21,5	21,5	21,5	21,5	21,5	21,5	21,5	21,5	21,5	21,5	21,5	21,5	21,5	21,5	21,5	21,5	21,5	21,5
Sold certificates		14,3	14,3	14,3	14,3	14,3	14,3	14,3	14,3	14,3	14,3	14,3	14,3	14,3	14,3	14,3	0,0	0,0	0,0	0,0	0,0
Sum income		35,8	35,8	35,8	35,8	35,8	35,8	35,8	35,8	35,8	35,8	35,8	35,8	35,8	35,8	35,8	21,5	21,5	21,5	21,5	21,5
Sum expences		5,0	5,1	5,2	5,3	5,4	5,5	5,6	5,7	5,9	6,0	6,1	6,2	6,3	6,5	6,6	6,7	6,9	7,0	7,1	7,3
Cash flow (CF) from operation (excluding interest and tax)	**-198**	**30,8**	**30,7**	**30,6**	**30,5**	**30,4**	**30,2**	**30,1**	**30,0**	**29,9**	**29,8**	**29,7**	**29,6**	**29,4**	**29,3**	**29,2**	**14,7**	**14,6**	**14,5**	**14,3**	**14,2**
PV		28,5	26,3	24,3	22,4	20,7	19,1	17,6	16,2	15,0	13,8	12,7	11,7	10,8	10,0	9,2	4,3	3,9	3,6	3,3	3,0
Initial Investment	**198,0**																				
IRR	**14%**																				
NPV	**78,4**																				