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Development of Offshore Wind Power Price Competitiveness Using a New Logistics Construct

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FOREWORD

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Pori, March 2003

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ABSTRACT

Rinta-Jouppi, Yrjö (2003). Development of offshore wind power price competitiveness using a new logistics construct. *Acta Wasaensia* No. 117, 212 p.

This thesis falls within the area of industrial management. The goal of the thesis is to find a competitive solution for offshore wind power by using a new logistics construct. In the introduction I examine the scientific possibilities of reaching the objectives of the thesis and from assistance construct finding a competitive wind power place from a measured and calculated offshore location.

How can the right strategy lead to competitive offshore wind power. In this case a bridging strategy is followed, because wind power is the sum of so many physical and economic sciences.
Constructive research methodology has been selected in this research. The method is visualised and the same is done for measuring and for the calculation flow chart.

In the theoretical framework it is stated that this research belongs to the branch of industrial management and therefore is handled from an economic and business strategic point of view.
Strategic selection has been made twice, firstly differentiation into environmentally friendly energy and then into cost leader position for building foundations for offshore wind power. In addition it is necessary to examine wind force power, the "fuel" of wind power stations.

The construct consists of a steel foundation, a new logistical model of how to build, assemble, float and repair, if necessary, the offshore wind turbine cost effectively and optimise the construction of the foundation. The assistance construct is measurement and analysis of wind conditions offshore by using a measuring mast and fixed measuring station data.

For example in the Strömmingsbåda waters 19 km out to sea at 60 m height the wind speed difference is 13.3% and energy difference 21.0% compared with onshore measurements. The foundation, logistics and erection methods are cost effective and competitive in the market. It means that there is a possibility to sell the product at a profit.

The results are then presented. There are results from wind conditions in different offshore locations and results describing the foundation measures and features. The example used minimum requirements for foundation diameter 25 m, height 4 m, 0.5 m high concrete ballast and cost € 441 333. The power plant produces wind electricity at 3.73 €c/kWh with a cost of 1.2 M€/MW with wind speed at a 60 m height of 9 m/s. Logistic solutions and erection prices are presented as well as a sensitivity analysis concerning the foundation.

The results are appraised against theory and practice. The question is whether this construct produces the cheapest wind power electricity and whether the foundation, logistics and erection system are competitive. When the answer is positive the claim is fulfilled. A typical saving in a park of 20 turbines could be 2.97 – 6.12 M€. The conclusion summarises the construct created and evaluates the applicability and contribution of the results. Finally the need for further research is outlined.

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1. INTRODUCTION

1.1 Background

One global problem is energy sufficiency. A new restriction on energy production has been imposed by carbon dioxide (CO_2) emission limitations. International agreements on CO_2 emissions are awaiting ratification. The Kyoto objectives imply an 8 % reduction of greenhouse gas emission for the EU (corresponding to about 600 million tons per year CO_2 equivalent) between 2008 and 2012. If it will be compensated by wind power, it means that there will be a need for 250.000 1 MW wind turbines per year in that period. Wind power compensates for the loss of coal power (0,8 CO_2 kg/kWh) and those turbines are located in offshore wind conditions (C_f 0,342). Nuclear power also compensates CO_2 emission. Gas power produces nearly half as much CO_2 emission as coal power (Savolainen 1999: 139). Hydro power energy building is limited. Solar power costs are still about 4 times higher than wind power (Milborrow 1997: 81). Thus the problem is that there are not many other solutions to provide energy sufficiency other than wind power. Today there seems to be no cheap energy source available at least in the near future.

The difficulty of wind power is in the energy price compared to the other power sources (Table 1). Tarjanne & Rissanen (2000) have calculated performance and cost data for separate energy production methods (Matrix p per kWh.Nuclear). The author has made with the same program a spreadsheet calculation for wind power. In Table 1 is an experimental value for separate operating hours for every production method. The interest rate is 4.5 % / annum, but the economic lifetime varies.

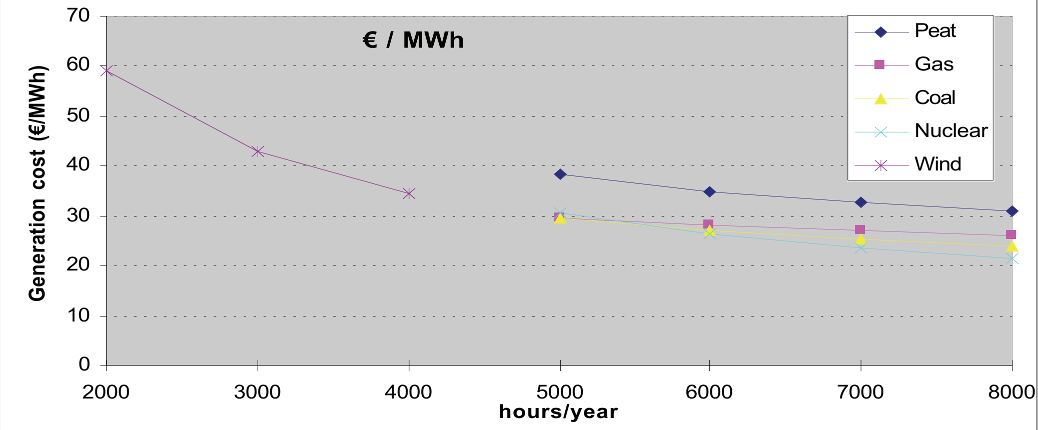
It can be seen in Figure 1 that if wind power could have more nominal power hours per year, it could be very competitive. The point is that wind power production hours with nominal power are few compared to the other production methods. The nominal power hours are mostly depending on wind mill placing on the ground.

Therefore it is most important to find places where wind power has the best production capacity. It means highest nominal power hours per year.

Table 1. Design values for different production methods and operating hours (Adopted from Tarjanne et al. 2000).

Performance and cost data for the new base - load alternatives

	Nuclear Power Plant	**Coal-fired** Condensin Power	Combined **gas turbine** Plant	**Peat-fired** Condensing power plant	**Wind** power plant	
Production	10.0	3.0	2.0	0.9	0.006	TWh / a
Electric power	1 250	500	400	150	2	MW
Net efficiency rate	34.97	40.94	54.98	38.02	-	%
Investment cost	2 186	407	229	144.7	1148	M€
Investment cost per power capacity	1 749	814	573	965	983	€/kW
Fuel prices	1.00	4.20	10.93	5.89	-	€/MWh(fuel)
Fuel costs of electricity production	2.86	10.26	19.88	15.49	-	€/MWh(electric)
Fixed operation and maintenance	1.50	2.0	1.5	2.5	0.87	%/ investment /
Variable operation and maintenance	3.41	4.92	0.31	3.1	10.00	€/ MWh (electric)
Economic lifetime	40	25	25	20	20	Years
Interest rate	4.5	4.5	4.5	4.5	4.5	% / a
Operating hours / a	8000	6000	5000	6000	3000	
Capacity Factor Cf	0.913	0.685	0.571	0.686	0.342	



Hours/a	Peat	Gas	Coal	Nuclear	Wind
2000					59,14
3000					42,76
4000					34,57
5000	38,25	29,63	29,42	(30,52)	
6000	34,97	28,06	27,04	(26,48)	
7000	32,63	26,93	25,35	(23,59)	
8000	30,87	26,09	24,08	21,43	

Figure 1. MWh prices for different production methods and nominal power hours.

On the other hand it is not possible to build such a enormous amount of wind mills on land. There is already a lack of sites in Denmark, North Germany and great problems in obtaining erection permission anywhere on land. The sea offers place and good wind conditions.

The Reasons for moving to sea locations are among other factors:

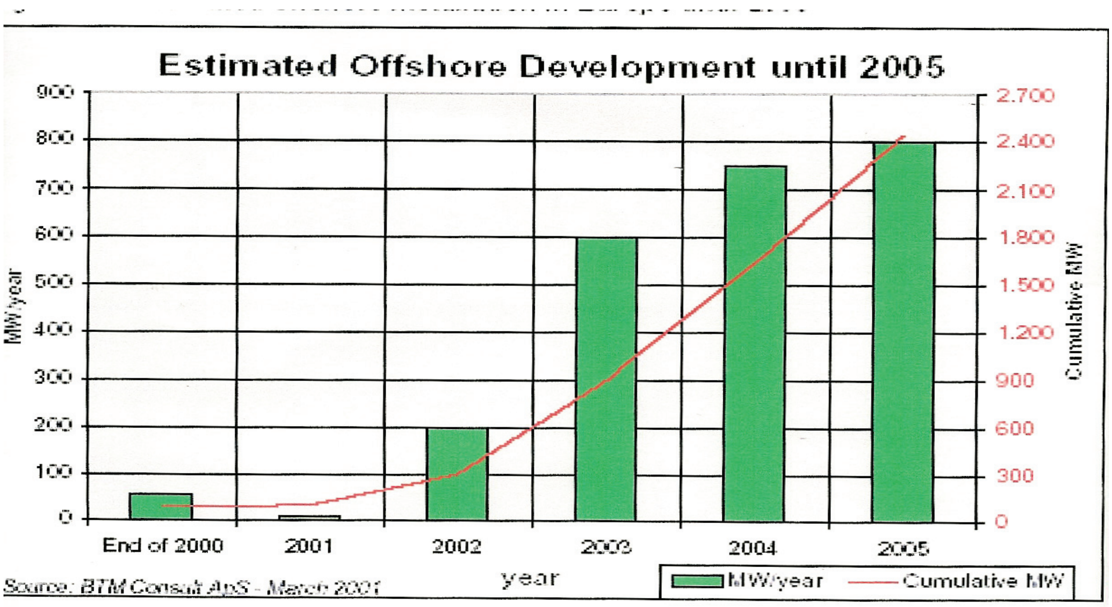
- lack of space on land
- better wind conditions at sea
  - higher wind speed
  - stability with less turbulence
- possibility to build beyond the visible horizon
- possibilities to place the turbines in optimum line
- no rent for the site
- transportation can be easier
- possibility to drive with higher tip speed, this means more noise but better efficiency

The negative point is still current the building price of offshore wind power. Offshore wind mills are nearly as expensive as to on land built power stations. The foundation and assembly costs are higher at sea. The average price could be on land 1M€ / 1 MW and at sea 1.5 M€ / 1 MW assembled and ready for production.

Table 2. Offshore wind farms (BTM Consult A/S-March 2001).

Location/Site	Number of Units	Make/Size	Total Installed MW	Year of Installation.	Country
Nogersund	1	Wind World 220 kW	0.22	1990	Sweden
Vindby	11	BONUS 450 kW	4.95	1991	Denmark
Lely (Ijsselmeer)	4	NedWind 500 kW	2	1994	Netherlands
Tunö Knob	10	VESTAS 500 kW	5	1995	Denmark
Irene Vorrink	28	NORDTANK 600 kW	16.8	1996-7	Netherlands
Bockstigen	5	Wind World 500 kW	2.5	1997	Sweden
Utgrunden	7	ENRON 1.5 MW	10.5	2000	Sweden
Middelgrunden	20	BONUS 2.0 MW	40	2000	Denmark
Blyth	2	VESTAS 2.0 MW	4	2000	UK
Yttre Stengrund	5	NEGMicon 2 MW	10	2001	Sweden
Horns Rev	80	VESTAS 2.0 MW	160	2002	Denmark
Samsö	10	BONUS 2.3 MW	23	2002	Denmark
Total by end 2002	183		279		

In Table 2 is presented the history of offshore wind power until present. Although offshore wind price is more expensive than on shore wind price the advantages are bigger and therefore the offshore wind power future could be the following:


Estimated Offshore Development until 2005

Source: BTM Consult ApS - March 2001

Figure 2. Estimated offshore development until 2005 (Offshore building is 600–800 MW/year, BTM Consult A/S-March 2001).

In Appendix 18 the graph shows the total estimated offshore building plans in separate European countries until 2010. The graph shows that the year 2006 will be the peak of current plans. It means offshore buildings of 4500 MW per year. The wind power is the most rapid growing energy source type.

1.2 Research Problems and Objectives of the Study

The sun warms the globe, but depending on the place the earth's surface warms up differently. Air which has been warmed now rises and colder air flows in and thus winds are created. At the same time the sun warms the water surface. The water evaporates and rises up as steam. In time the steam condenses into clouds and eventually rains down, collecting into seas, lakes and rivers. In other words wind and water power are affected by the sun's radiation. Water density is about 1000 kg/m^3 and standard air density is 1.225 kg/m^3. The water flow is more energy intensive and it is easier to build water power stations, but today's building materials give the possibility to build longer and higher aerodynamic wind turbine wings. That makes it possible to build bigger and bigger turbines and produce increasingly cheaper wind power. One question is: could wind and water power costs reach the same level in time? The research objective is to research what level of electricity prices wind power can obtain by using solutions of the construct.

This study attempts to clarify the costs and cost structures of wind power production, especially the costs that are caused by the logistic factors of location and erection of offshore wind power stations, and propose one possible solution.

On the other hand the end customer does not know if the quality of the offered electricity is good or not so good. However the electricity is good enough for most customers. The quality of the product does not determine the buying decision.

The other customer oriented feature could be so-called ”Green Electricity”. According to research (by Suomen Hyötytuuli Oy, the biggest wind park in Finland) in the Pori area, 500 households, or 46 % of the sample answered and 70–77% were willing to buy wind energy but not pay a higher price than ”normal” electricity. Only 40 % accepted the basis of higher prices (Satakunnan Kansa 21.7.2000, p. 6). The answers are similar in other countries. 82 % of people are interested in buying wind energy in Canada, and 59 % of people are ready to pays $ 10 more per month for wind generated energy. People, willing to support wind energy, reach a level of 86 % in the USA, in Holland 90 %, in Sweden 54 %, and in the UK 85 % (Surugiu, L et al 1999: 586).

It seems that for the customer the only reason to select the electricity supplier is the price of electricity on offer.

1.3 Research Strategy

The research strategy gives a frame and direction to the production of the knowledge. The selection of the research strategy settles the research process validity problem, in other words the acquiring and appropriate performing of the process to reach an acceptable result (Olkkonen 1994: 64).

The most important component of the wind energy price is the used wind speed (Spera 1994: 72 and Chapter 6.1). The research strategy is to measure, calculate and use outside data of the wind speed in offshore conditions. There have been very few measured data in offshore conditions on wind turbine hub height. In this research measures are taken at the coastline at separate height levels, as well as measures on an island and outside measures on an island farther away from the coast. In addition there are reliability measures to verify the used equation validity. All these measures will be compared with measures in the literature.

The second important component of the wind energy price is investment (Chapter 3.4). The strategy is to use figures from windmill producer offers, figures from completed wind power plants and to apply the new construct to offshore wind turbine foundation. A comparison with existing offshore wind power plant prices will be made.

The electricity price components interest and lifetime are in the literature established as a real interest rate of 5 % per year and a lifetime of 20 years. Both components have an effect on the electricity price (Chapter 3.4).

The operation and maintenance prices are from the literature and existing wind power plants (see Figure 34).

These components are from the electricity price in offshore wind power plants. This price gives wind power energy prices based on today’s technology and by using the construct explained later.

In this research we have to bridge separate theories from different fields. To wind speed effects we have to apply at least meteorology and flow theories. Investment, interest and lifetime are for example taken from the field of management science. Operation and maintenance could be from the field of engineering. The wind turbine itself includes in addition at least aerodynamics, engineering, electrical engineering and offshore shipbuilding and offshore technology. According to Reisman (1988) bridging strategy – bridging two or more theories from different fields and forming a new one, increases knowledge in both or all fields, in other words the resulting whole is often greater than the sum of the parts. The bridging strategy selection is particularly suitable because this research moves in the field of so many sciences.

In this research all the above research fields are a necessity. Wind power plant production and research includes many kinds of theory and practise from other fields.

1.4 Scope of the Study

The offshore wind power price demands different kinds of investigation. The research construct applies new ideas to power plant foundation. The construct needs to use wind speed measurements and reference data. These are needed to clarify the yearly wind turbine production. The investment costs and operation and maintenance costs will be calculated. The kWh price will be calculated by dividing the costs by the electricity production.

The wind conditions are researched in four separate measuring places. One of these is on an island and the others at the coast at different height levels. With the reference data the offshore wind conditions are clarified. The measuring periods are about one year excluding reference measurement. The WAsP (Wind Atlas Analysis and Application Program) computer simulation program has not been used because only the wind measurements assist the main contribution of the research.

Offer prices were asked from several windmill fabricators and BONUS, NEG Micon, NORDEX and Vestas answered, see list of statements and offers. Wind turbines are most common in the market. The foundation price is the offer price from a possible foundation fabricator (Fagerström 2000, list of statements and offers). The logistic price of getting the wind turbine to the site is offered by a company specialising in tugging and sea rescue operation (Håkans 2000, list of statements and offers). The wind turbine operation and maintenance costs are from the literature and from experience of land use over several years.

1.5 Research Approach and Methodology

Olkkonen (1994: 20, 21) states that research, if it is in character scientific and acceptable, should pay attention to the following criteria:

- Does it include a claim?
- Does it include a contribution?
- Is the method argued, acceptable and continuous?

The methods used in this research are connected to background theories, acquire and process data and above all prove and interpret the results. The methods will assure the reader that the presented results are new (contribution) and true (or useful). It means that the used research approach and method are appropriate to solve the problem (give the answer to the research question) and the observations are made and processed to achieve a way to a reliable result as well as the results being interpreted correcly.

The overall empirical research structure is as follow (Olkkonen 1994: 32):

1. Discoveries and intuition lead to understanding, which is worked into a hypothesis.
2. The research and discovery plan will verify or falsify the hypothesis.
3. The research and observations will be made.
4. The validity of the hypothesis will be appraised in the light of the results.

This study is based on empirical research. The research approach selected can be characterised as constructive. It is typical (Kasanen et al 1993: 244) of a constructive research approach in that it aims to create a new construct in order to solve a relevant and scientifically interesting problem.

Constructive research is normative in its nature. In this respect, it is close to the decision-making-methodological approach. On other hand, creativity, innovations and heuristics are close to the constructive research approach. However, testing the functionality of the construct in practice is essential (Olkkonen 1994: 76).

The main goal in the constructive approach is to build a new construct that is tied to current doctrines and theories (Mäkinen 1999: 17). This construct is a model of how to calculate electricity prices and on the other hand a new solution to make the construct more competitive. The results of the research are evaluated based on newness and applicability in the progress of scientific knowledge. Demonstration and validation of practical usability is also important in evaluation of the results.

Kasanen et al. (1991: 306) shows the constructive approach components in Figure 3. In this case the practical problem is how to get cheaper wind power. The theoretical relevance concerns many sciences. The practical relevance is in wind condition measures and in developing the needed logistics for the steel foundation. The contribution of the solution is cheaper wind electric power and the methods needed to reach it.

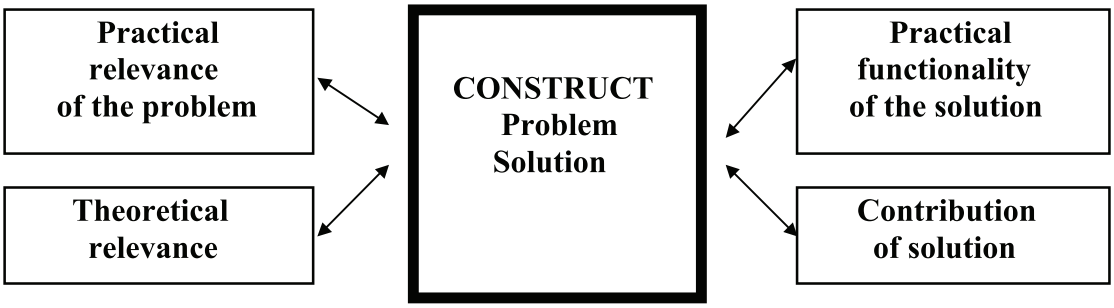


Figure 3. The components of constructive research (adapted from Kasanen et al. (1991: 306).

The research design could be summarised as illustrated in Figure 4. The figure shows what the different chapters include, what the function of the chapter is as well as how the chapters relate to each other. The figure shows the scientific question adjustment.

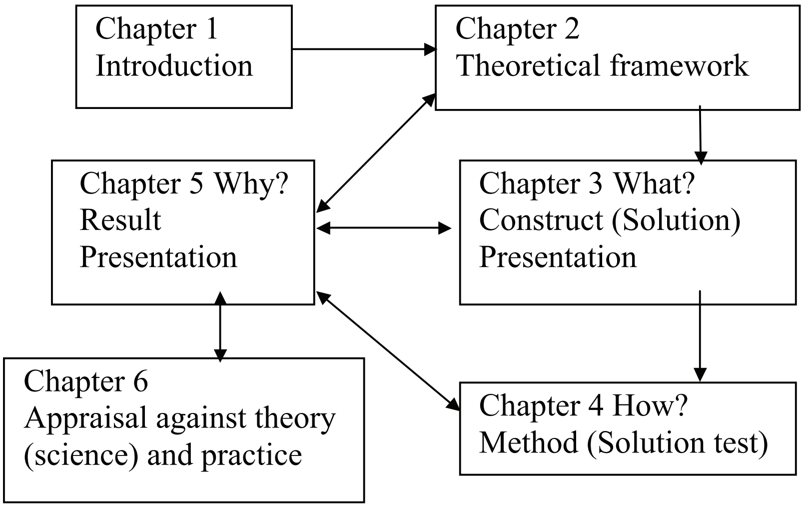


Figure 4. The structure of the research.

1.6 Research Structure

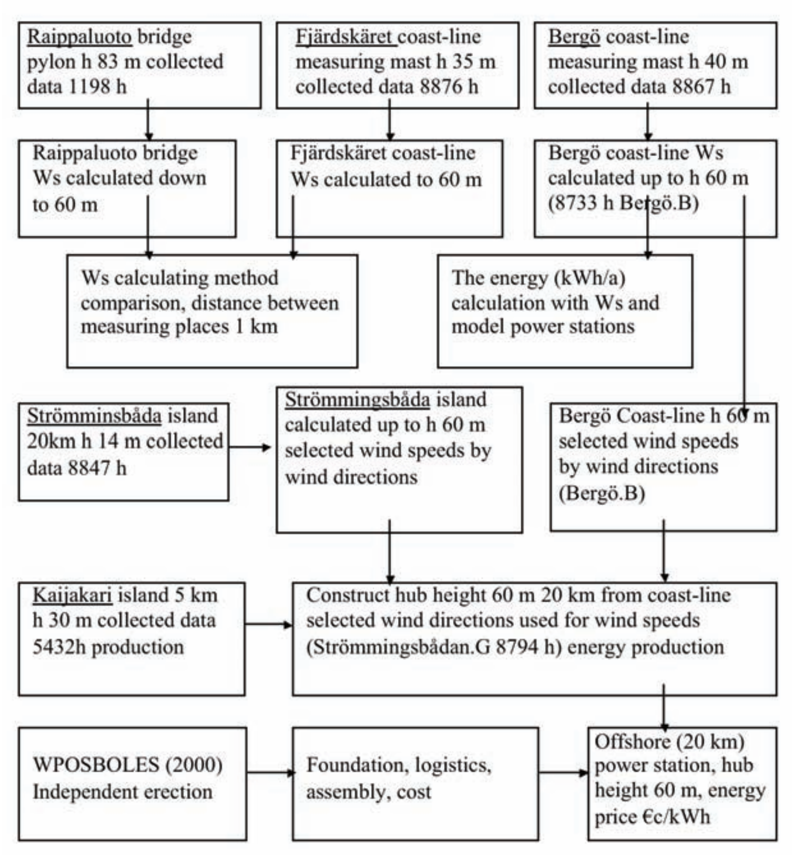


Figure 5. The measuring and calculation flow chart.

Chapter 1.3 includes the components which affect the offshore wind power price. How to measure and calculate the needed data is shown in flow chart Figure 5. First are the wind speed measures in different places and calculations to the hub height. Then come comparison measures and energy calculation with a model power station. Then wind data from the more distant island are used and converted with measures from the cost-line of energy from the model power station. Finally costs are taken from the offshore wind power plant or wind park and calculated as the offshore wind electricity price.

1.7 Summary

In Chapter one the possibilities of science to reach the objectives of the claim were examined. Chapter 1.1 verified the circumstances of where we are and what should be done to reach the Kyoto requirements. In Chapter 1.2 the research problems and objectives and also the birth of wind were examined. The question of how people accept wind power was seen to be very important. In Chapter 1.3 the research strategy was selected so as to lead to the right decision, in other words, a path could be found leading to competitive offshore wind power. In this case bridging strategy is followed, because wind power is the sum of so many physical and economic sciences. Chapter 1.4 explained the scope of the research and research sources. In Chapter 1.5 the content of the research was outlined and the most suitable research method for the case was discussed. Constructive research methodology was selected for this research. In the same chapter the components of constructive research and the structure of the research were visualised. In addition the measuring and calculation flow chart were presented.

All in all the above mentioned introduction will lead to the construction of the thesis of this research. It means the construct achieved will be proved to be a competitive offshore wind power producer.

2. THEORETICAL FRAMEWORK

There are many different branches of science which need to be applied in reaching a competitive position in selling wind power electricity. At least marketing, economies, meteorology, aerodynamics and steel construct-, electricity- and offshore technology are among those which have an effect on success. In this theoretical framework I will treat some of these sciences which lead to cost leader position.

2.1 Differentiation into Environment Friendly Energy

The product (electricity) is the same in all electricity companies, but the way how it is sold and the price at which it will be sold, vary. What strategy should be selected to be competitive in the market?

Porter (1980) says that the base for success of the company is a functioning and competitive *business strategy*, where separate business processes have connected to the real needs of customers and bring them added value continually.

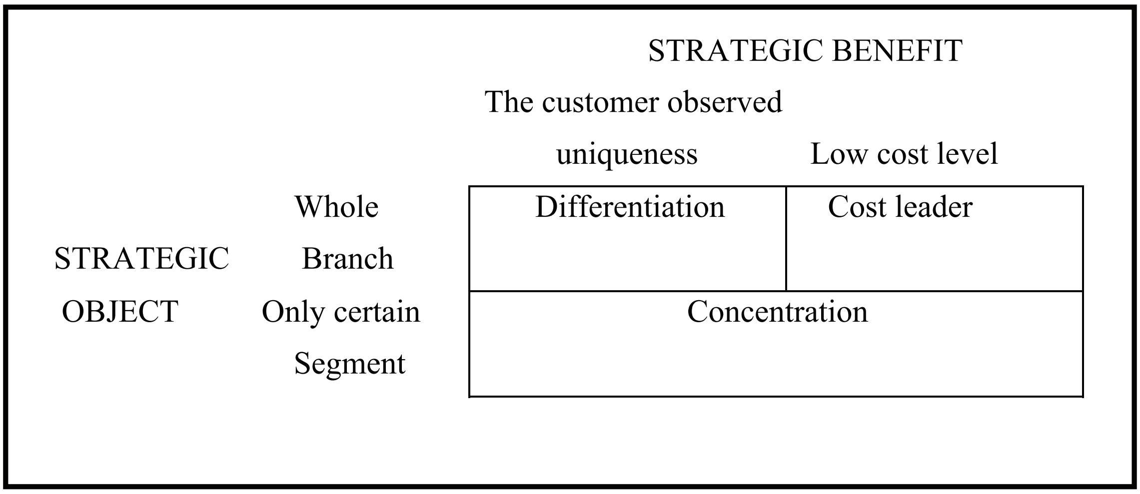


Figure 6. Three basic strategies (Porter 1980).

The *competition strategy* consists of principles which have been defined as all-inclusive analysis for every separate situation. In the Porter strategy window (figure 6, Porter 1980: 63 and modified by Porter 1985: 25) there is the possibility to reach success with the three main basic strategies.

Successful companies have been able to follow more than one basic strategy. Porter advises, however, that a normal company should select between the strategies or it will stay in - between, in other words the company will have no competitive advantage. The company serves some particular destination segment by following a *concentration strategy*. If the company has at the same time to serve many other segments, where at the same time *cost leader* or *differentiation strategy* are followed (Porter 1985: 31) then the company will have difficulties.

A company which has selected the *Cost leader strategy* tries to achieve cost leader status, in other words a low cost level with respect to competitors. The target will be reached by adapting earlier experience, following exactly the cost generation and by minimising the costs. To reach a low cost level big production volumes are needed when the market share of the company must be rather high. A low cost level demands that the production emphasises simplicity and at the same time a wide production range (Porter 1980).

How well does cost leader strategy suit this case? In chapter 1.2 in researching the use of ”green electricity” (Satakunnan Kansa 21.7.00, p. 6 and Surugiu et al. 1999: 586) the majority (60 %) of people surveyed were not willing to pay more than for ”normal” electricity. To win a majority of customers the ”green electricity” seller must be a cost leader. Cost leader position is important in this market, the only difficulty being to get into the position of being cost leader. This research handles this question.

An alternative strategy to cost leader strategy could be *differentiation strategy*. In cost leader strategy companies compete by price but in differentiation strategy they try to produce unique products. In differentiation strategy this is a will to separate from the competitors. The target is to be beyond the reach of competitors by being superior, unique; aiming at the customer. This can be achieved by product image, design of the product, technology or customer service. Often it includes originality, through which it will not reach big market shares. The companies have very limited intuition concerning the potential source of differentiation. It will not be noticed that there is potential all over in the *value chain*. All parts of the company should co-ordinate the operation, not only the marketing department, which is a base for successful differentiation strategy.

How appropriate is a differentiation position in this case? The differentiation, as mentioned earlier, can happen for example through product image. Wind power electricity has by nature an environmentally friendly energy image. This differentiation helps to win customers and gain market share. In the research of Suomen Hyötytuuli Oy (Satakunnan kansa 21.7.00, p. 6) 87 % and 97 % of the respondents of two groups recommended building more wind power stations and other highly favourable comments were received from other countries in the research of Surugiu et al. (1999: 586).

According to the research 40 % of people were willing to pay more for “green electricity” than “usual electricity”. In Finland today the difference is about 0.01 €c/kWh for customer. The problem is, however, that the electricity distribution companies buy electricity much more cheaply than wind power electricity. The buying price is less than ”usual electricity”, minus 0.01 €c/kWh. That means, in other words, that the electric company makes a loss with every wind power electricity kWh sold. The distribution companies buy a positive image but make a loss. One example of compromise is to sell, for example, 20 % ”green electricity” and 80 % ”usual electricity”. That means”green electricity” is image and”usual electricity” economy.

Porter (1985: 211) states that technical change decreases costs or promotes differentiation and that the technical leading position of the company is constant. Technical change alters the cost factors or the originality incentive to favour the direction of the company. The realisation of technical change first brings to the company the advantages of reaching benefit first and in addition the benefits of the technology. The content of this research tries to follow this strategy.

The cost leader and differentiation strategy clearly include the whole branch, but the third alternative, *concentration,* means focusing the actions on a certain segment or on a certain geographical area like differentiation (Porter 1980). The target is to serve the selected group with expertise. This strategy is based on the assumption that the company can better serve a limited strategy target more effectively by focusing the resources. By doing so concentration will be effected either through differentiation and/or low production cost bringing benefit to the selected marketing target. The condition of concentration is always barter between pricing and sales volumes. In adapting this strategy barter may be used with total cost just as in differentiation strategy.

In adapting *concentration* to this research, in selling only wind power electricity means today in Finland a very limited market. Although nearly all people in the neighbourhood of wind parks recommend building more wind power plant and parks, real wind electricity buyers are a very marginal group.

What conclusion can we make from the preceding discussion? Real competition takes place not in the end customer market but in the electricity distributor's market. The differentiation by environmentally friendly energy helps a little but the main competition is by price among the other energy producing methods. Being a cost leader or at least nearby the other competitors is achieved in this case by technology or/and by the support of the community.

2.2 Growth and Market Share Matrix

How is the ”green electricity” market placed on the growth and market share matrix? According to Porter (1980) the method is to describe the functions of a diversified company as a business activity ”portfolio”. This method comprises simple casing, with the help of this we can map or classify different business activities and place the resources defined. Adapting the portfolio method is best when the strategy is developed on the whole corporation level. The method is best in clarifying the status of a competing diversified company and planning its own strategy in these conditions. Adapting the portfolio matrix to this case helps the distribution company to clarify what status could be given to ”green electricity” markets.

The most used portfolio method is the Boston Consulting Group growth / market share matrix (Porter 1980). It is based on the use of the growth of the branch and relative market share. It represents

1. the status of the business activity unit of the company in the branch
2. the needed cash flow for a business activity

According to Porter (1980: 406) this scheme adopts the basic assumption that the experience curve is operational and that the company which has the biggest relative share will have the lowest cost.

This basis leads to the portfolio matrix which is presented in Figure 7 (Porter 1980: 406). All business activity areas can be mapped by the portfolio matrix. Although the partial field growth and relative market share are arbitrary, the growth / market share – portfolio map is divided into four fields. The main idea is that the business activity units in all four fields separate from each other in the cash flow and therefore these should be lead in a different way.

Growth (Income financing)		High	1.0	Low
	High	**Stars** (Modest + or - cash flow)		**Question mark** (Big negative cash flow)
	10 %			
	Low	**Cows** (Big positive cash flow)		**Dogs** (Modest + or - cash flow)

Relative market share
(Income financing effect)

Figure 7. Growth / market share matrix (Porter 1980: 406).

According to the logic of Porter’s (1980: 407) growth / market share portfolio the cows change to finance the other business areas of the company. In the ideal case the cows will be used to make the question marks into stars. Since this needs some capital for rapid growth and market share, so the question arises of which question marks should be grown as stars. This becomes the strategic key question.

How could Porter’s ideas be adapted to ”green electricity” selling companies? These companies produce and/or distribute electricity. The cow’s sign could be on current electricity distribution companies. These have in their business area nearly 100 % of market share, which is connected to low growth of the market. They have good income financing, which could be used to finance other, developing areas.

On the other hand the question mark could be ”green electricity”, which has a low relative share of the rapid growing market (wind power installation growth in 2000 / 1999 Germany 38 %, USA 1.2 %, Spain 61 % and Denmark 30 % , New Energy No. 1 / 2001: 44), which needs much capital for financing growth. Today the income financing is small, because the competitive position is bad, excluding the above countries. The reason is the price of wind energy. The price of wind power electricity approaches the electricity price produced by other production methods but does not yet reach it.

2.3 Natural Science

In this chapter wind, a very versatile and complex natural phenomenon, will be described from the wind power perspective.

2.3.1 What is Wind?

The sun’s radiation warms the face of the earth in different ways at different latitudes. The bilateral location between the globe and the sun means that the area round the equator receives much more solar radiation than the pole area. The earth – atmosphere – system loses energy as long wave radiation (Tammelin 1991b: 17). The sun’s energy falling on the earth produces the large-scale motion of the atmosphere, on which are superimposed local variations caused by several factors. Due to the heating of the air at the equatorial region, the air becomes lighter and starts to rise approximately to an altitude of 10 km and will spread to the North and the South. At the poles the cold air starts sinking. The rising air at the equator moves northward and southward (Figure 8, Bade & Sundermann 1996: 96). This movement at about 30° N and 30° S, causes the air to begin to sink and a return flow of colder air takes place in the lowest layer of the atmosphere (Walker & Jenkins 1997: 4, World Meteorological Organisation).

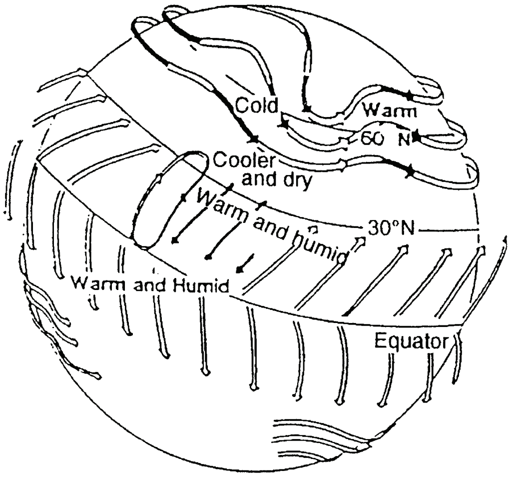


Figure 8. General circulation of winds over the surface of the earth (Bade & Sundermann 1996: 96).

Since the globe is rotating, any movement in the Northern hemisphere is diverted to the right (southern left), if we look at it from our own position on the ground. This apparent bending force is known as the *Coriolis force* (Krohn 1998, http://www.windpower.dk/tour/wres/coriolis.htm).

On average the areas between 38° latitude and the poles are losing energy. On average the areas between 38° latitude and Equator are energy winning area. In other words radiation coming to the earth is bigger than long wave radiation leaving between the latitudes. So that heat balance is preserved on the globe, the heat must be transferred from low latitudes to high latitudes. This heat pump includes the atmosphere and oceans, which transfer about 30 % of the total heat amount (Figure 9, Tammelin 1991b: 17).

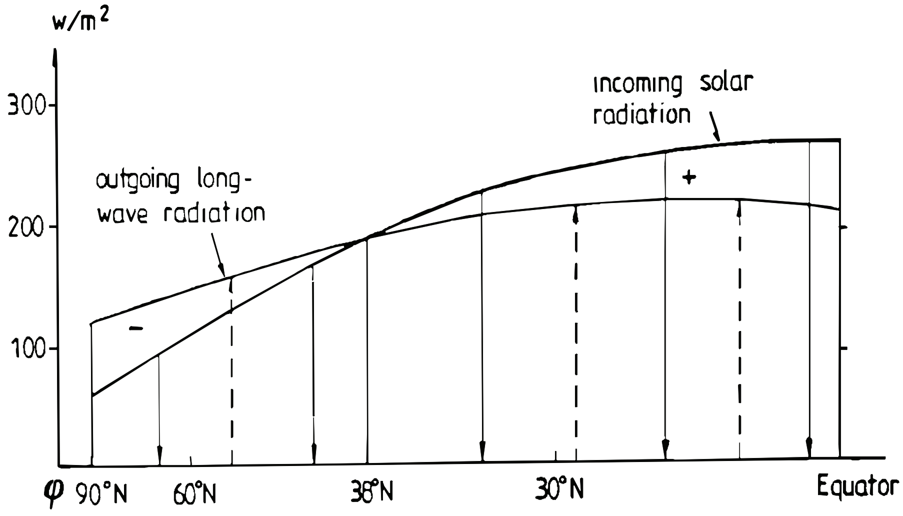


Figure 9. Medium radiation degree in the northern half of the globe (Tammelin 1991b: 17).

The flows appearing in the atmosphere can be split into many magnitude events. The most important factors in the large scale flows are

- uneven warming of the globe
- the rotation of the globe

The relative movement of air in relation to the rotary movement of globe is called wind. The following forces affect in the atmosphere:

1. Gravitation force
2. Pressure gradient force
3. Friction force
4. Centrifugal force
5. Coriolis force

2.3.2 The Height Effect

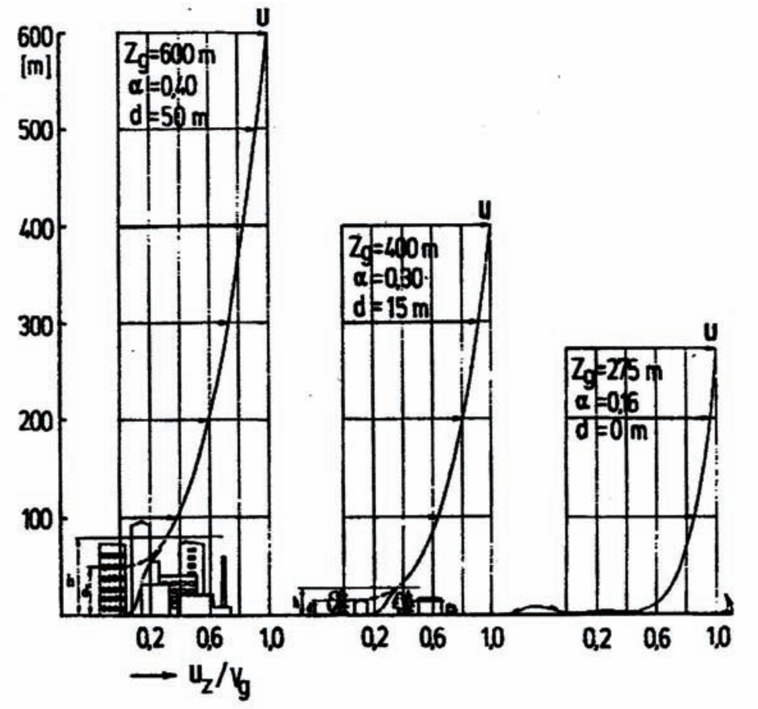


Figure 10. A principal description concerning the wind speed at different height levels (Tammelin 1991b: 20).

In the above figure the wind speed at the height u_z at different height levels and geostrophic wind speed v_g the ration of vertical change, as well as the so called gradient height above the different terrain type. h = height of obstacle, d = so called zero level transition, α = describes the exponent of vertical change of speed and Z_g = height, where the terrain no longer has an effect on wind speed

The earth surface resists the movement of air, the force depends on among other things the speed of movement and the roughness of the earth's surface (Figure 10, Tammelin 1991b: 20). The *friction force* weakens the speed of the wind and turns its direction to lower air pressure.

The changes of wind speed can be described with the *standard deviation* δ of the speed, where

(2.1) $$\delta = \sqrt{\frac{1}{T}\int_{0}^{T}(v-\bar{v})^{2}dt} = \sqrt{\frac{1}{N}\sum_{0}^{N}(n_{n}-\bar{v})^{2}}$$, where the mean wind speed is

(2.2) $$\bar{v} = \frac{1}{T}\int_{0}^{T}v(t)dt \approx \frac{1}{N+1}\sum_{0}^{N}v_{n}$$, and T the time when the observations are made

and N the number of observations (Bade & Sundermann 1996: 108). *Turbulence intensity* (TI) is defined as the ratio of the *standard deviation* of wind speeds to the mean wind speed.

(2.3) $\mathrm{TI} = \sigma / \bar{v}$ (NRG user manual 1996, p. B-20)

In wind energy research the turbulence of flow is important by estimating the energy content and the dynamic stress of the wind power station and also the uniformity of running of the wind power plant.

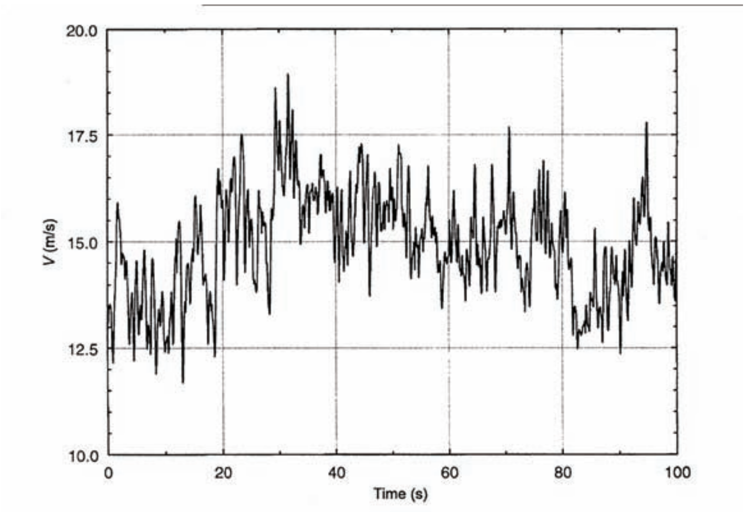


Figure 11. The conventional situation is that the wind speed changes very much (Walker & Jenkins 1997: 6).

In Figure 11 the change is during one second about 2,5 m/s. The measuring period is 100 seconds and measuring height 33 m. (Walker & Jenkins 1997: 6.)

The larger the turbulence intensity is (Tammelin 1991: 28),

- the worse the power calculated from the real speed corresponds to the real measured total power (energy) during the time period
- the larger is the real dynamic stress directed onto the construct compared to the calculated stress of the mean wind speed
- the more uneven is the momentary power distribution to the rotor area of the wind power station.
- the more unevenly the power station rotates

The turbulence is restricted in practice to the lowest layer of the atmosphere, where height varies with time, stability and weather from 0,1 to 2 km. Typical height is 300–1000 m.

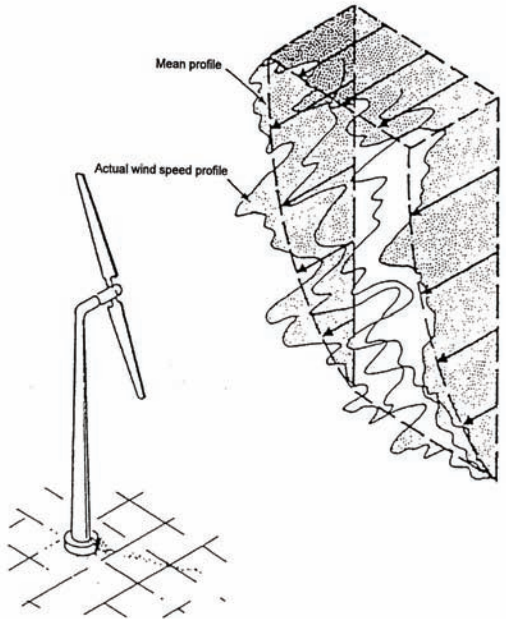


Figure 12. Representation of wind flow in the boundary layer near the ground (Walker & Jenkins 1997: 7).

The wind speed increases with height most rapidly near the ground, increasing less rapidly with greater height (Figure 12, Walker & Jenkins 1997: 7). Two of the more common functions which have been developed to describe the change in mean wind speed with height are based on experiments:

Power exponent function

$$V_{(z)} = V_r \left(\frac{z}{z_r}\right)^{\alpha} \tag{2.4}$$

where z is the height above ground level, V_r is the wind speed at the reference height z_r above ground level, $V_{(z)}$ is the speed at height z, and α is an exponent which depends on the roughness of the terrain.

Logarithmic function

$$V(z) = V(z_r)\,\frac{\ln(z/z_0)}{\ln(z_r/z_0)} \tag{2.5}$$

where $V(z_r)$ is the wind speed at height z_r above ground level and z_0 is the roughness length (height) (Walker & Jenkins 1997: 7).

The Weibull distribution has received most use in compressing wind data and in energy assessment analyses and wind load studies (Frost & Aspliden 1998: 386).

Weibull function

$$R_f = \frac{k}{A}\left(\frac{v}{A}\right)^{k-1} e^{-\left(\frac{v}{A}\right)^{k}} \tag{2.6}$$

where R_f is the relative frequency of wind speeds, A the scale factor and k shape the factor (Figure 13).

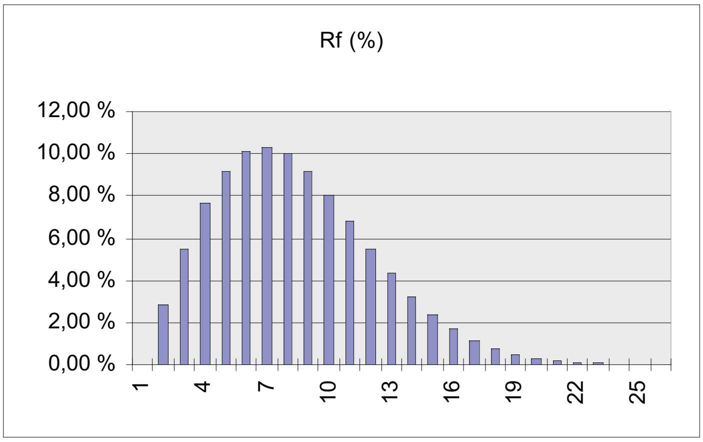


Figure 13. Relative frequency distribution special case k=2 Rayleigh distribution.

The measurement of wind speeds is usually carried out using a cup anemometer. The cup anemometer has a vertical axis and three cups which capture the wind. The number of revolutions per minute is registered electronically.

Normally, the anemometer is fitted with a wind vane to detect the wind direction. Other anemometer types include ultrasonic or laser anemometers which detect the phase shifting of sound or coherent light reflected from the air molecules. The advantage of non-mechanical anemometers may be that they are less sensitive to icing. In practice, however, cup anemometers tend to be used everywhere, and special models with electrically heated shafts and cups may be used in arctic areas.

The best way of measuring wind speeds at a prospective wind turbine site is to fit an anemometer to the top of a mast which has the same height as the expected hub height of the wind turbine to be used. This way one avoids the uncertainty involved in recalculating the wind speeds to a different height.

Guyed, thin cylindrical poles are normally preferred over lattice towers for fitting wind measurement devices in order to limit the wind shade from the tower.

The poles come as kits which are easily assembled, and you can install such a mast for wind measurements at (future) turbine hub height without a crane. Anemometer, pole and data logger will usually cost somewhere around 10,000 USD.

The data on both wind speeds and wind directions from the anemometer(s) are collected on electronic chips on a small computer, a data logger, which may be battery operated for a long period (Figure 14). Once a month or so you may need to go to the logger to collect the chips and replace them with blank chips for the next month's data.

If there is much freezing rain in the area, or frost from clouds in mountains, you may need a heated anemometer, which requires an electrical grid connection to run the heater. (Krohn 1998, http://www.windpower.dk/tour/wres/windspeed.htm).

Figure 14. NRG Symphonie logger unit.

2.3.3 Energy in the Wind

The kinetic energy in a flow of air through a unit area perpendicular to the wind direction is $E = {}^{1}/_{2}mv^{2}$. Through the unit area flowing mass flows $\dot{m} = A\rho dx/dt = A\rho v$ in other words the power is

$$P = {}^{1}/_{2}\rho A v^{3} \qquad (2.7)$$

where ρ is the air density (kg/m^3), v wind speed (m/s) and P is power (watt or joule/s).

The air density is the function of air pressure and temperature:

Density ration

(2.8) $$\rho = \rho_0 (\frac{288p}{1013T})$$

where ρ_0 is the dry air density along the International Civil Aviation Organisation (ICAO) standard temperature and pressure (1.225 kg/m^3, 15°C (288.16 K), 1013.25 mbar, Haapanen 1972: 6).

In offshore conditions air humidity can increase. An air steam statistical change is in the open air between 65 – 90 %. In the same reference in Sweden Lund, Stockholm, Haparanda and Östersund the air steam partial pressure changes from 2 to 11 mmhg. Compared to normal pressure 760 mmhg the ratio is 0.3 – 1.4 %. The effect on the density of air and to power is not notable (Strömberg 1953 p.604).

The temperature change effect is bigger. For example -30 to +30 °C or 243 and 303°K divided by 288 equals to +18.5 % and -4.9 % for density and power. The air temperature changes are taken into account in energy calculations.

The air pressure change effect is less than the temperature change. For example 980 – 1060 mbar divided by 1013 equals to –3.2 to +4.6 % for density and power. The air pressure changes are also taken into account in energy calculations.

The theoretical power $P = {}^1/_2 \rho A v^3$ is not realised in real wind power plant wings. The limiting factor is the formula known as the Betz clause (1919), which limits the power coefficient c_p to 59 % of theoretical power. In addition there are other factors, which in practise limit the power depending on wind speed after the turbine from a maximum 59 % to zero (Gasch & Maurer 1996: 122). The power coefficient c_p dependency on wind speed before v_1 and after v_3 the turbine is showed in figure 15. The maximum power coefficient $c_{p,\max}$ 0.59 will be reached with the ratio $v_3/v_1 = 1/3$.

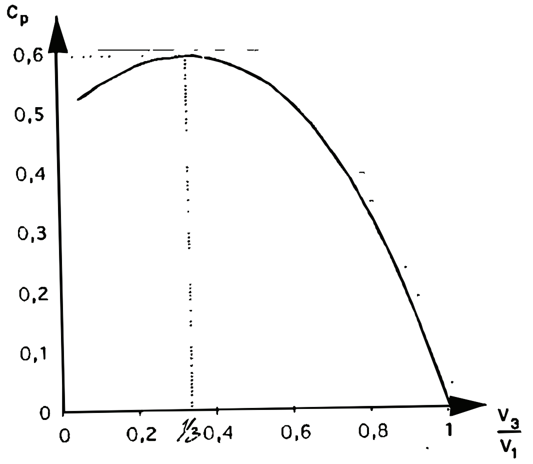


Figure 15. The power coefficient c_p dependency on wind speed before v_1 and after v_3 the turbine (Gasch & Maurer 1996: 122).

In addition there are a lot of other factors which limit the power from the wind mill manufacturer given the wind speed / power curve. For example one practice curve follows in the straight part the formula $P = {}^{1}/_{2}\rho A v^{2,2}$.

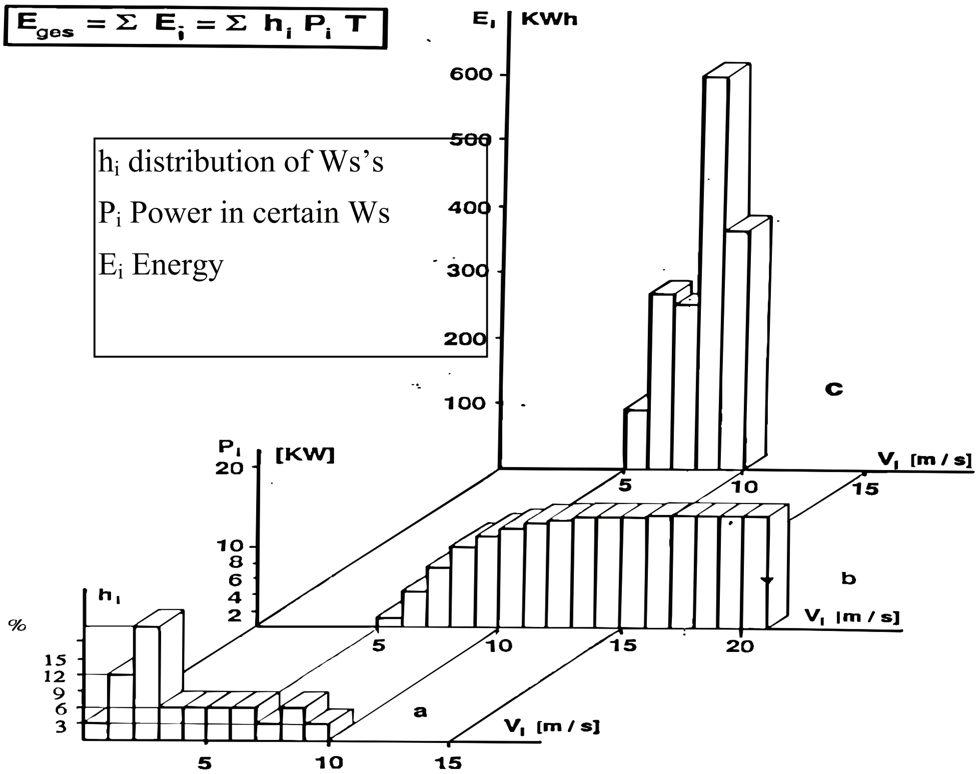


Figure 16. Three keystones connecting with wind power economy (Bade & Sundermann 1996: 111).

In Figure 16 the first distribution is the wind speed distribution in the measuring place. It describes each speed percent density. Instead of percentages the hour number of each speeds can be used. The second distribution describes the power given by the turbine on each wind speed. The last distribution tells how much wind energy is produced during the measuring period. The first and second distribution are multiplied and the result is the energy at the corresponding wind speed (Bade & Sundermann 1996: 111).

The definite energy produced by the wind turbine will be obtained by multiplying the wind speed distribution values generated from the wind speed measurement with corresponding power and adding the kilowatt hours together to the total energy. The other way is to multiply the measured wind speeds with corresponding power and add them together to the total energy during the examination period.

A rough estimation is that the offshore wind speed level is 15 % higher than onshore winds. The theoretical power formula $P = {}^1/_2\rho Av^3$ promises 50 % more energy. The reason to go offshore is the better wind speed. It is measured in two places on Kaijakari (Appendix 4 and Table 17) 1.5 km from land on an island. There the measured energy was 13.9 % better than onshore on a breakwater. The other case Strömmingsbåda is 19 km out to sea (appendix 5 and table 23). The wind speed difference at a 40 m height is 22.5 % and energy difference 43.8 %. At 60 m height the differences are for wind speed 13.3 % and energy 21.0 %. This can be due to land effect; the forest does not so much affect the wind speed at 60 m height.

2.4 Wind Energy Economics

The most important question in using wind energy is the economy of wind energy. The economy determines the success or failure of the whole wind energy area. Wind energy economy is the sum of many variables.

Today wind energy is competitive (in a narrow economic sense) at specific sites with favourable conditions, as stated in the Commission's Green Paper "For a European Union Energy Policy". If external/social costs are included, it is estimated that wind power in many countries is already competitive with fossil and nuclear power.

Several international organisations without preference for wind power estimate that wind power in a near-term time frame (2005 to 2010) will be competitive with fossil and nuclear power in a narrow economic sense, without taking into account the competitive advantage of wind power on external or social costs.

Project preparation costs depend heavily on local circumstances, such as the condition of the soil, road conditions, proximity to electrical grid sub-stations, etc. As a rule of thumb project preparation costs on flat on-shore sites can be estimated to be 33 % of ex works turbine costs. (Krohn 1998, http://www.windpower.dk /tour/econ/index.htm).

Operation and maintenance costs include service, consumables, repair, insurance, administration, lease of site, etc. The annual operation and maintenance cost is often estimated as 3 % of ex works cost of a wind turbine (or 1 c€/kWh, which is the same with 3000 operational hours and with 1 MW costs 1 M€).

Technical life time or design life time for European machines is typically 20 years. Individual components should be replaced or renewed at a shorter interval. Consumables such as oil in the gearbox, braking clutches, etc. are often replaced at intervals of 1 to 3 years. Parts of the yaw system are replaced at intervals of 5 years. Vital components exposed to fatigue loads such as main bearings, bearings in the gearbox and generator are foreseen to be replaced halfway through the total design life time.

Figure 17 shows OECD´s collected nuclear, coal and gas prices in different countries and wind power prices from the same period (Source: OECD 1993). For comparison: average new wind power in Germany 5.6 US cent/kWh, Denmark 4.1 US cent/kWh (at 1991 price level)

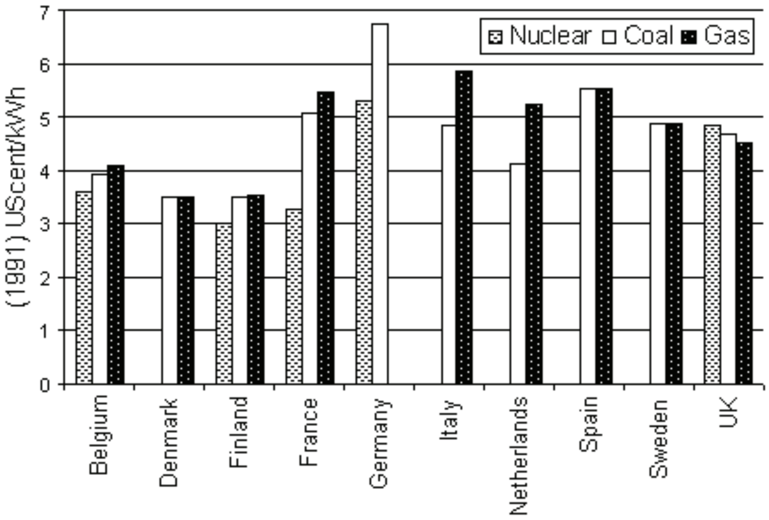


Figure 17. Cost of Electricity in (1991) US cent/kWh for selected European countries (OECD 1993).

2.4.1 What does a Wind Turbine Cost?

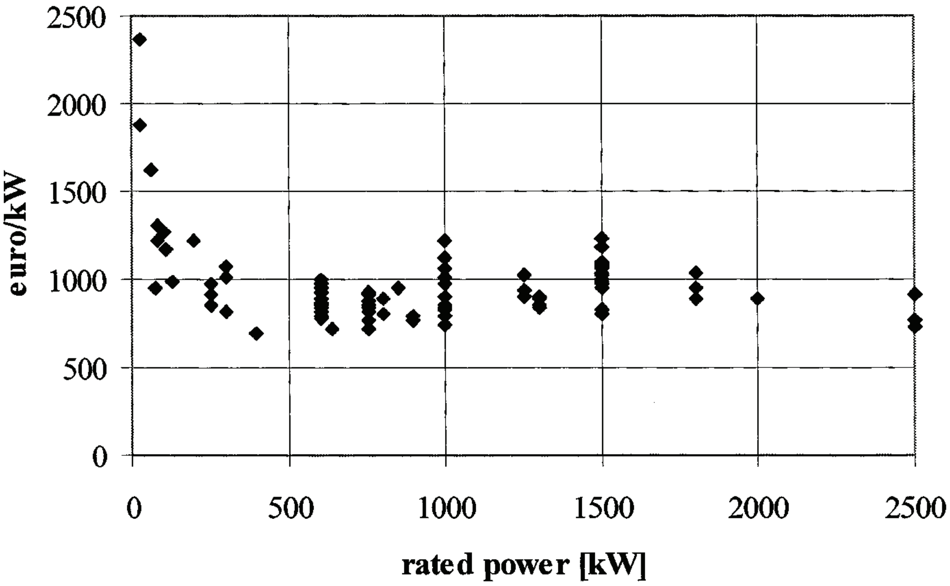


Figure 18. The cost per kW vs. rated power (Morgan 2001: 2–11).

The graph above gives an impression of the price range of modern, grid connected wind turbines (Figure 18, Morgan 2001: 2–11). The prices vary for each generator size, different tower heights and rotor diameters. One extra metre of tower will cost roughly 1 500 USD. A special low wind machine with a relatively large rotor diameter will be more expensive than a high wind machine with a small rotor diameter (Krohn 1998, http://www.windpower.dk /tour/econ/index.htm).

Commercial offshore wind turbines are made by 10 manufacturers, in rotor diameter the size range is 65 to 80 metres and rated power 1.5–2.5 MW. Hub height follows the length of rotor diameter. New offshore turbines are under design with rotor diameter of 120 m and power 5–6 MW (Morgan et al 2001: 2–6). According Barthelmie et al. (2001: 6–2 and 6–3) onshore wind investments are M€ 1 / MW and the costs for offshore wind power are M€ 1.5 / MW. Table 3 shows one cost distribution of on- and offshore cases. The distribution varies case by case.

Table 3. Investment cost by component, one example (Barthelmie et al. (2001:6–3).

	Onshore (%)	**Offshore (%)**
Foundations	**5. 5**	**16**
Turbines	**71**	**51**
Internal electrical grid	**6. 5**	**5**
Electrical system	**0**	**2**
Grid connection	**7. 5**	**18**
O&M facilities	**0**	**2**
Engineering and admin.	**2. 5**	**4**
Miscellaneous	**7**	**2**
Total	**100**	**100**

2.4.2 Installation Costs for Wind Turbines

Installation costs include 1. foundations, normally made of armed concrete, 2. road construction (necessary to move the turbine and the sections of the tower to the building site), 3. transformer (necessary to convert the low voltage (690 V) current from the turbine to 20 kV current for the local electrical grid, 4. telephone connection for remote control and surveillance of the turbine, and 5. cabling costs, i.e. the cable from the turbine to the local 20 kV power line.

The installation costs vary. The costs of roads and foundations depend on soil conditions, i.e. how cheap and easy it is to build a road capable of carrying 30 tonne trucks. Another variable factor is the distance to the nearest ordinary road, the cost of getting a mobile crane to the site, and the distance to a power line capable of handling the maximum energy output from the turbine. A telephone connection and remote control is not a necessity, but is often fairly cheap, and thus economic to include in a turbine installation. Transportation costs for the turbine may enter the calculation if the site is very remote, though usually they will not exceed 15 000 USD.

It is obviously cheaper to connect many turbines in the same location, rather than just one. On the other hand, there are limits to the amount of electrical energy the local electrical grid can handle. If the local grid is too weak to handle the output from the turbine, there may be need for grid reinforcement, i.e. extending the high voltage electrical grid. It varies from country to country who pays for grid reinforcement – the power company or the owner of the turbine (Krohn 1998, http://www.windpower.dk /tour/econ/install.htm).

2.4.3 Operation and Maintenance Costs for Wind Turbines

Modern wind turbines are designed to work for 120 000 hours of operation throughout their design lifetime of 20 years. That is far more than an automobile engine which will generally last for some 4 000 to 6 000 hours.

Experience shows that maintenance cost are generally very low while the turbines are brand new, but they increase somewhat as the turbine ages.

Most of the maintenance cost is the regular service of the turbines, but some people prefer to use a fixed amount per kWh of output in their calculations, usually around 0.01 USD. The reasoning behind this method is that wear and tear on the turbine generally increases with increasing production.

Other than the economies of scale which vary with the size of the turbine, as mentioned above, there may be economies of scale in the operation of wind parks rather than individual turbines. These economies are related to the semi-annual maintenance visits, surveillance and administration, etc.

The turbine lifetime extension means that some wind turbine components are more subject to tear and wear than others. This is particularly true for rotor blades and gearboxes. Wind turbine owners who see that their turbine is close the end of their technical design lifetime may find it advantageous to increase the lifetime of the turbine by doing a major overhaul of the turbine, e.g. by replacing the rotor blades.

The price of a new set of rotor blades, a gearbox, or a generator is usually in the order of magnitude of 15–20 per cent of the price of the turbine.

The 20 year design lifetime is a useful economic compromise which is used to guide engineers who develop components for the turbines. Their calculations have to prove that their components have a very small probability of failure before 20 years have elapsed.

The actual lifetime of a wind turbine depends both on the quality of the turbine and the local climatic conditions, e.g. the amount of turbulence at the site, as explained in the page on turbine design and fatigue loads.

Offshore turbines may e.g. last longer, due to low turbulence at sea. This may in turn lower the costs, see page 42 (Krohn 1998, http://www.windpower.dk /tour/econ/oandm. htm).

2.4.4 Income from Wind Turbines

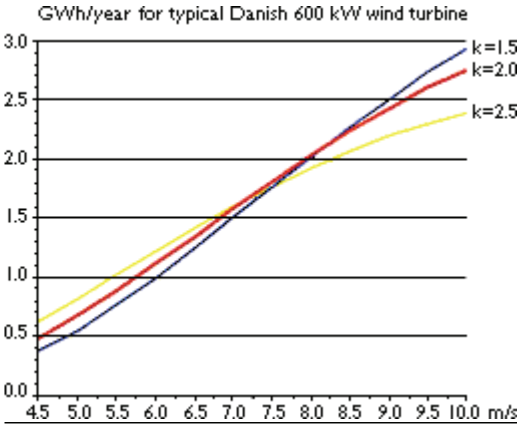


Figure 19. Energy Output from a Wind Turbine (Krohn 1998).

Figure 19. represents a typical Danish 600 kW turbine production at the separate wind speeds. The graph shows how annual energy production in gigawatt hours varies with the windiness of the site depending on the three different k-values (see shape factor, Weibull function, Chapter 5.2). With a mean wind speed of, approximately 6.75 metres per second at hub height, you get about 1.5 million kilowatt hours of energy per year.

The figures for annual energy output assume that wind turbines are operational and ready to run all the time. In practice, however, wind turbines need servicing and inspection once every six months to ensure that they remain safe. In addition, component failures and accidents (such as lightning strikes) may disable wind turbines.

Very extensive statistics show that the best turbine manufacturers consistently achieve availability factors above 98 per cent, i.e. the machines are ready to run more than 98 per cent of the time. Total energy output is generally affected less than 2 per cent, since wind turbines are never serviced during higher winds.

Such a high degree of reliability is remarkable, compared to other types of machinery, including other electricity generating technologies. The availability factor is therefore usually ignored when doing economic calculations, since other uncertainties (e.g. wind variability) are far larger.

Not all wind turbine manufacturers around the world have a good, long reliability record, however, so it is always a good idea to check the manufacturers' track record and servicing ability before you go out and buy a new wind turbine (Krohn 1998, http: //www.windpower.dk /tour/econ/income.htm).

2.4.5 Wind Energy and Electrical Tariffs

Electricity companies are generally more interested in buying electricity during the periods of peak load (maximum consumption) on the electrical grid, because this way they may save using the electricity from less efficient generating units. According to a study on the social costs and benefits of wind energy by the Danish AKF institute, wind electricity would be some 30 to 40 per cent more valuable to the grid, if it were produced completely randomly (Krohn 1998, http://www.windpower.dk /tour/ econ/tariffs.htm).

In some areas, power companies apply variable electricity tariffs depending on the time of day when they buy electrical energy from private wind turbine owners. Normally, wind turbine owners receive less than the normal consumer price of electricity, since that price usually includes payment for the power company's operation and maintenance of the electrical grid, plus its profits.

Many governments and power companies around the world wish to promote the use of renewable energy sources. Therefore they offer a certain environmental premium on wind energy, e.g. in the form of a refund of electricity taxes etc. on top of normal rates paid for electricity delivered to the grid.

Large electricity consumers are usually charged both for the amount of energy (kWh) they use, and for the maximum amount of power (kW) they draw from the grid. The reason they have to pay more is that it obliges the power company to have a higher total generating capacity (more power plant) available. Power companies have to consider adding generating capacity whenever they give new consumers access to the grid. But with a modest number of wind turbines in the grid, wind turbines are almost like "negative consumers". They postpone the need to install other new generating capacity.

Many power companies therefore pay a certain amount per year to the wind turbine owner as a capacity credit. The exact level of the capacity credit varies. In some countries it is paid on the basis of a number of measurements of power output during the year. In other areas, some other formula is used.

Most wind turbines are equipped with asynchronous generators, also called induction generators. These generators require current from the electrical grid to create a magnetic field inside the generator in order to work. As a result the alternating current in the electrical grid near the turbine will be affected (phase-shifted). This may at certain times decrease (though in some cases increase) the efficiency of electricity transmission in the nearby grid, due to reactive power consumption. In most places around the world, the power companies require that wind turbines be equipped with electric capacitors which partly compensate for this phenomenon. (For technical reasons they do not want full compensation). If the turbine does not live up to the power company specifications, the owner may have to pay extra charges. Normally, this is not a problem which concerns wind turbine owners, since experienced manufacturers routinely will deliver according to local power company specifications (Krohn 1998, http://www.windpower.dk /tour/ econ/tariffs.htm).

2.4.6 Basic Economies of Investment

What society gets in return for investment in wind energy is pollution-free electricity. The private investor in wind energy can make investments which have a high rate of return before tax and will have an even higher rate of return after taxes. The reason for this is the depreciation regulations. With rapid tax depreciation it is possible to get a higher return on an investment, because it is allowed to deduct the loss of value of your asset faster than it actually loses its value.

The difference between the value of today’s and tomorrow’s dollars is the interest rate. One dollar a year from now is worth $1 / (1+r)$ today. r is the interest rate, for example 5 per cent per year.

By taking inflation into account dollars have the same purchasing power as dollars do today. Economists call this working with real values, instead of nominal ones.

An investment in a wind turbine gives a real return, i.e. electricity, and not just a financial (cash) return. This is important, because if general inflation of prices during the next 20 years is expected, then it will also be expected that the electricity prices will follow the same trend.

Likewise, it is expected that operation and maintenance costs will follow roughly the same price trend as electricity. If all prices move in parallel (with the same growth rates) over the next 20 years, then the calculations are using real values which represent a fixed amount of purchasing power.

To calculate the real rate of return (profitability) of wind energy, the real rate of interest is usual, i.e. the interest rate minus the expected rate of inflation (1+r) / (1+i). For example, the annuity factor for an interest rate of 5 % and 20 years is 8.024 %.

Years\%	2	3	4	5	6	7	8
10	0.111	0.117	0.123	0.130	0.136	0.142	0.149
15	0.078	0.084	0.090	0.096	0.103	0.110	0.117
20	0.061	0.067	0.074	$\boxed{0.080}$	0.087	0.094	0.102
25	0.051	0.057	0.064	0.071	0.078	0.086	0.094
30	0.045	0.051	0.058	0.065	0.073	0.081	0.089

Typical real rates of interest for calculation purposes these days are in the vicinity of 5 per cent per annum or so. In countries like Western Europe they could be even down to 3 per cent. By using the bank rate of interest the nominal calculations will be made, i.e. add price changes everywhere, including the price of electricity (Krohn 1998, http://www.windpower.dk /tour/econ/basic.htm).

2.4.7 Wind Energy Economics

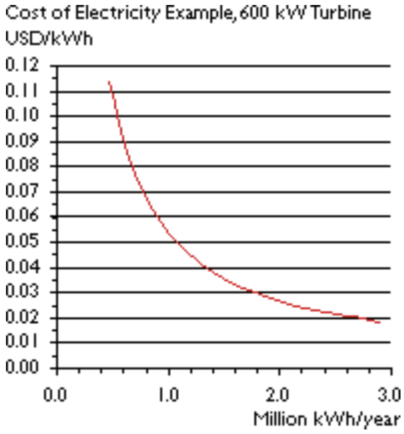


Figure 20. The cost of electricity varies with annual production (Krohn 1998).

In Figure 20 the cost of electricity produced by a typical Danish 600 kW wind turbine varies with annual production (i 5%, r 20 years and the investment 0.6875 MUSD). To produce twice as much energy per year, the price is half the cost per kilowatt hour.

There is no such thing as a single price for wind energy. Annual electricity production will vary enormously depending on the amount of wind at the turbine site. Therefore there is no single price for wind energy, but a range of prices, depending on wind speeds.

The graph below shows the relationship between wind speeds and costs per kWh. This is based on examples. The wind speeds at 50 metre hub height will be some 28 to 35 per cent higher (for roughness classes between 1 and 2) than at a height of 10 metres, which is usually used for meteorological observations.

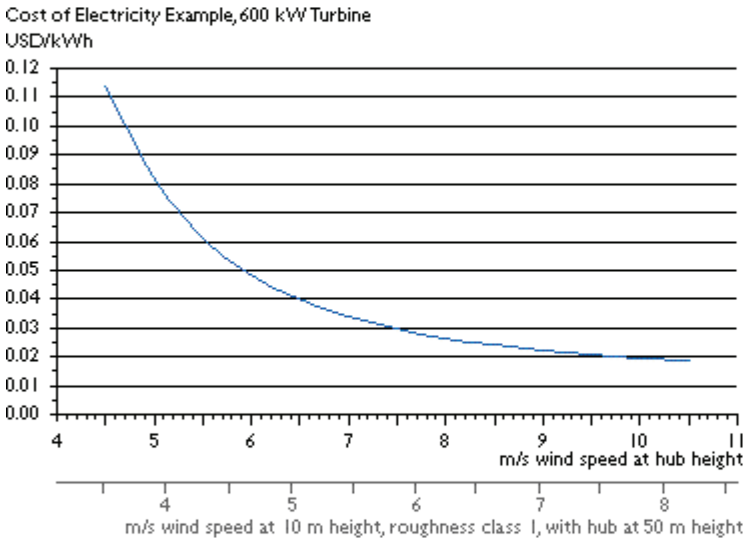


Figure 21. Cost of electricity, example 600 kW turbine (Krohn 1998).

The example in Figure 21 is for a 600 kW wind turbine with a project lifetime of 20 years; investment = 585 000 USD including installation; operation & maintenance cost = 6750 USD/year-, 5% p.a. real rate of interest-, annual turbine energy output taken from power density calculator using a Rayleigh wind distribution (shape factor = 2) (Krohn 1998, http://www.windpower.dk /tour/econ/economic.htm).

2.4.8 Economics of Offshore Wind Energy

In 1997 the Danish electrical power companies and the Danish Energy agency finalised plans for large scale investment in offshore wind energy in Danish waters.

The plans imply that some 4 400 MW of wind power are to be installed offshore before the year 2030. Wind power would by then provide some 40 to 50 per cent of Danish electricity consumption (out of a total of 35 TWh/year 1999).

The most important reason why offshore wind energy is becoming economic is that the cost of foundations has decreased dramatically. The estimated total investment required to install 1 MW of wind power offshore in Denmark is around 2 million € today. This includes grid connection, etc.

Since there is substantially more wind at sea than on land, however, we arrive at an average cost of electricity of some 0.36 DKK/kWh = 0.05 USD/kWh = 0.09 DEM/kWh. (5% real discount rate, 20 year project lifetime, 0.08 DKK/kWh = 0.01 USD/kWh = 0.02 DEM in operation and maintenance cost).

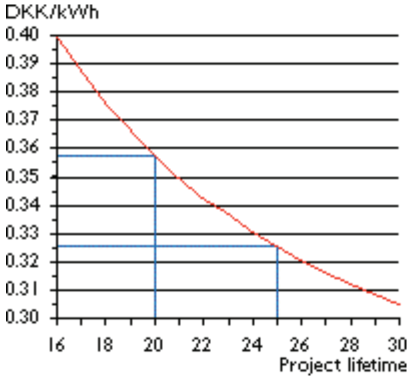


Figure 22. A project lifetime's effect on the costs (Krohn 1998).

It would appear that turbines at sea would have a longer technical lifetime, due to lower turbulence. The cost sensitivity to project lifetime is plotted in Figure 22. If a project lifetime is 25 years instead of 20, this makes costs 9 per cent lower, at some 0.325 DKK/kWh.

Danish power companies, however, seem to be optimising the projects with a view to a project lifetime of 50 years. This can be seen from the fact that they plan to require 50 year design lifetime for both foundations, towers, nacelle shells, and main shafts in the turbines. (Krohn 1998, http://www. windpower.dk /tour/econ/offshore.htm)

If assumed that the turbines have a lifetime of 50 years, and add an overhaul (refurbishment) after 25 years, costing some 25 per cent of the initial investment (this figure is purely a numerical example), we get a cost of electricity of 0.283 DKK/kWh, which is similar to average onshore locations in Denmark. (Krohn 1998, http://www. windpower.dk /tour/econ/offshore.htm)

2.4.9 Employment in the Wind Industry

The wind industry in 1995 employed some 30,000 people world wide. It includes both direct and indirect employment. By indirect employment we mean the people who are employed in manufacturing components for wind turbines, and the people who are involved in installing wind turbines world wide.

In 2000 the Danish wind industry employed 16 000 people. Wind turbine production creates about 50 per cent more jobs, since Danish manufacturers import many components, e.g. gearboxes, generators, hubs, etc. from abroad. In addition, jobs are created through the installation of wind turbines in other countries (Krohn 1998, http://www.windpower.dk /tour/econ/empl.htm).

B.Smith et al. (2001: 8–1) calculates a figure of 4.52 full time direct jobs per MW by industry sector as a result of installing some 10 000 MW of offshore wind power, see Table 4. These are direct workers. Calculating from the offshore wind power investment price of 1.5 M€ / MW and taking as the cost for one worker around 0.04 M€/year (Statistical Yearbook, 1999) the need being 4.52 workers/MW, then one worker should make one MW in 8.3 years (1.5M€/MW / 4.52FTJ/MW / 0.04M€/y = 8.3 year/FTJ). A rough calculation with the same figures, 1.5M€/MW / 0.04M€/working year makes 37.5 working years/MW or 37.5 people/MW/year but including all white, blue collar and all subcontracting people. It is assumed that nearly the whole turbine costs in the chain from first subcontractor to assembly work are working costs (author).

Table 4. Estimate of direct employment to develop offshore wind farms (B.Smith et al. (2001: 8–1).

		Full Time Jobs/MW
Project design and Development	Marine/Ground investigations	0.01
	Site development including permissions	0.1
	Design including structural, electrical And resource	0.02
	Finance	0.04
Component supply	Generator	0.15
	Gearboxes	0.9-0.4
	Rotor blades	0.5
	Brakes, hydraulics	0.04
	Electrical & control system	0.04
	Towers	0.9
Assembly	Wind turbines	1
Installation	Foundation structure	0.3
	Electrical and connecting cables	0.05
	Wind turbines	0.3
	Project management & commissioning	0.11
Operation & Maintenance	Management, routine and fault Maintenance	0.06
TOTAL		4.52

2.5 Offshore Wind Power

Wind power’s extensive potential is on the sea. Even a short movement from the coastline to the sea improves the wind conditions remarkably. In addition there is less regulation in building at sea than building on shore. The building at sea compared to on land, however, creates many additional costs. The cabling lengthens and more demanding foundations on a sea location raises foundation costs. The additional costs can be even larger in a location where waves or ice cause stress to the foundation and structure of a power station.

The size of wind power stations has grown during the last 10 years to the megawatt class. In 1997 the most common size was 600 kW, but 2.5 MW power stations have been on the market in 2000. Bigger power stations are especially tempting when building at sea, since the foundation costs do not rise compared to the reached production advantage.

2.5.1 Offshore Wind Power in Europe

In Finland in 1994 the offshore wind power building potential on small islands was researched. Then the potential on scars and islands was estimated to be 30 TWh/a, of which about 4 TWh/a could be built without strengthening the electricity net on the coast. The building on small islands reduces the foundation costs significantly compared to building on the sea bottom. However it improves substantially the production compared to building on shore. Nature reserve areas and holiday settlements severely restrict the use of small islands for wind power production (Sommardal et al 1994).

By the end of the year 2000 offshore wind power stations and parks have been built in Denmark, Holland, Sweden and the UK about 80 MW. In addition, the previous countries and Ireland, Germany, Belgium and some other counties have a target installation of 10 950 MW by 2030. In Appendix 14 are plans for 38 parks. The mapped offshore resource estimate in 14 European countries is in total 138 600 MW (Barthelmie et al. 2001: 4–2).

2.5.2 Experience from Realised Offshore Wind Power Projects

World wide nine offshore wind projects have been realised: in Denmark, in Holland, in Sweden and in UK. All projects are rather close to the coast and the water depth is in the site 3–8 m. Table 5 shows offshore projects: capacity (MW), distance from coast (km), total investment (M€) and average year’s production (Holttinen et al 1998: 15, modified by BTM Consult ApS – March 2001).

Table 5. Realised offshore wind power projects.

Country	Site	Units	Size/Producer	MW	Year	Km	Invest	Production
							M€	MWh/a
Denmark	Vindeby	11	450kW/Bonus	4.95	1991	1.5	10.4	11 700
Holland	Lely	4	500 kW/Nedwind	2.0	1994	1	4.54	4 000
Denmark	Tunö Knob	10	500 kW/Vestas	5.0	1995	6	10.4	15 000
Holland	Dronten	19	600 kW/Nordtank	11.4	1996	0.3	19.0	
Sweden	Bockstigen	5	550kW/WindWorld	2.75	1997	4	4.0	8 000
Sweden	Utgrunden	7	10.5 MW/Tacke	10.5	2000	12		38 000
Denmark	Middelgrunden	20	2 MW/Bonus	40	2000		48.8	90 000
UK	Blyth	2	2 MW/Vestas	3.8	2000	1		
Total by end 2000		78		80.4				

At sea the wind is clearly smoother than on land, since there are no obstacles. Less turbulence means that the fatigue load is smaller. It is probable that the life time for a wind power plant is longer than on land. Offshore wind power plants can be used probably for 25 years instead of 20 years. In addition, the foundations can be planned for 50 years of operating life. Then it is possible to exploit the foundations for two wind power plants.

In Denmark it has been noticed in offshore wind power plant building that if the location is further from the coast the production estimates will be exceeded by even 30 % . Earlier it was supposed that by building at sea the power plant’s distance between turbines should be increased, because the more laminar flow at sea would create more disturbances in the flow field far on rotor’s background than in onshore conditions. The experiences on the Tunö Knob offshore wind park have, however, indicated that the shadow effect between the turbines is smaller than estimated.

By placing the offshore wind power plants several kilometres from the coast it is possible to accelerate the rotor rotation speed. This increases running noise, but at the same time it increases production. In the case of Tunö Knob the rotation speed was increased from 30 to 33 revolutions per minute. On the basis of experience it is possible to increase the rotation speed still more.

Experience of offshore wind power plants shows that accessibility should still be developed further: for example it is not possible to get to the Tunö Knob power plant if the wave height is over one meter.

The offshore wind power plant costs are clearly higher than the costs of land built power plants. For example the Windeby production costs are about 8.75 €c/kWh and Tunö Knob 7.23 €c/kWh (without the demonstration phase costs 6.39 €c/kWh). In the last project in Sweden the calculated costs are nearer to 5.05 €c/kWh. The costs will in addition decrease further when the new megawatt class plants come on to the market and the foundation technology is developed (Holttinen et al. 1998: 16).

2.5.3 Building of large Wind Power Parks

100–200 MW size wind power park projects have been planned in Denmark, Germany, Sweden, Holland and Spain. Estimated production costs are 5.05–6.73 €c/kWh (In land built projects the production costs are 3.36–4.20 €c/kWh.

In Denmark a strong movement towards the building of wind power stations arises partly from the need for coal oxide reduction. In 1997 a plan was published for building 4000 MW offshore by the year 2030. The plan was published by a committee with representatives of the biggest power company (ELSAM and ELKRAFT) and a Danish cabinet member. Areas for wind power production were not allowed for other users (fishing, defence forces, nature protection areas, etc.) and they had to be 4–10 m in depth and 15–30 km from the land. About 1000 km^2 of suitable areas was found (8000 MW).

It is the intention in Denmark to build 120–150 MW parks which will be placed as far from the coast as is technically and economically reasonable, in other words about 15–30 km from land. The first stage of the plan identifies six areas on which will be built together over 700 MW of wind power during 2000–2006. The investment costs are expected to drop by about 25 % from the level of the first Danish offshore park, in other words to be 10–12 million DKK/MW. The production costs are estimated at about 4.71–5.05 €c/kWh (Holttinen et al. 1998: 18).

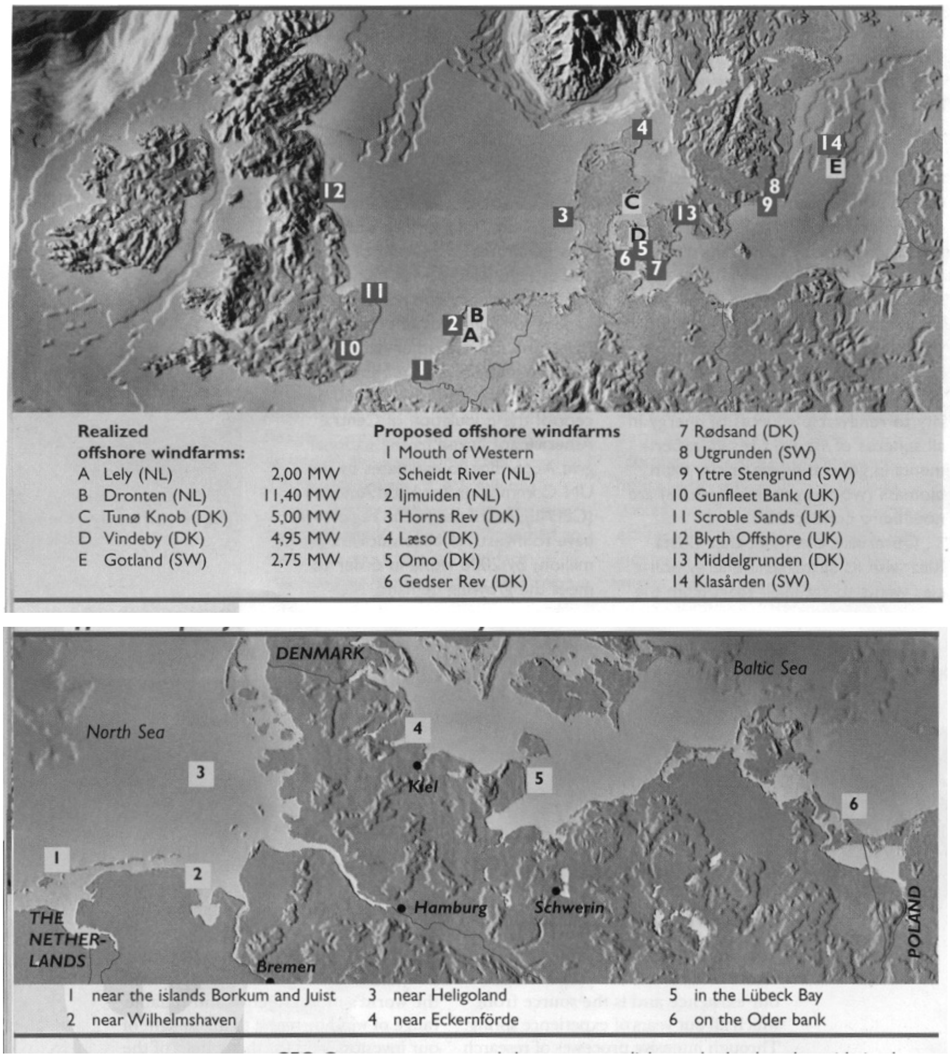


Figure 23. The existing and proposed offshore wind farms in the North Sea and Baltic Sea (New Energy 2/2000).

Figure 23 shows the existing and planned wind farms in Sweden, Denmark, Germany, Netherlands and UK (New Energy 2/2000, p. 28 and 3/2000, p. 28 more offshore plans in Appendix 14).

In Holland there is a long term plan to achieve 3000 MW wind power by the year 2020. Half of this is planned to be built at sea. In Holland a similar mapping to that made in Denmark was been carried out concerning potential offshore wind park areas near the coast. At this moment the first big offshore wind park 100 MW is being constructed about 8 km from the coast. According to the plan the building will be completed at the earliest in 2001. The production costs of the first large wind park exceed 6.73 €c/kWh. For the production costs to be appropriate for a site this far from the coast, the size of the park should be 100–200 MW. The large size of the park and the lack of experience in construction are an economic risk, so that it is appropriate to first place a smaller park nearer to the coast even if the production costs are larger (Holttinen et al 1998: 18).

2.6 Offshore Foundation Technique

In freezing sea areas the constructs are open to a harsh environment of stresses such as corrosion, erosion and ice – and wave loads. By formatting the foundations the ice load can be reduced remarkably. The design should take into consideration both local high ice pressures and cumulated total ice loads from large area, both static and dynamic loads.

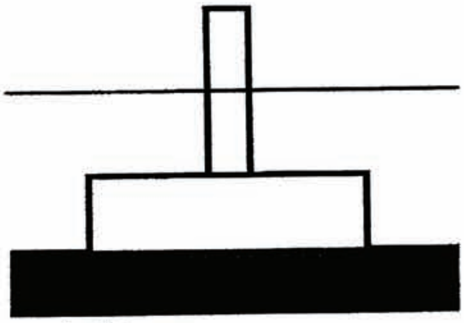
2.6.1 Offshore Constructs in Ice Conditions

A traditional water foundation construct is the caisson. Its mass holds the construct both upright and prevents the caisson gliding horizontally, Figure 24a. A continuation development is the so-called hems caisson where the hems penetrate to the bottom and increase glide resistance, Figure 24i. Another way is to ram piles through the caisson for increasing glide resistance, Figure 24j. With piles it is possible to increase at the same time the bearing capacity of the foundation against bending moment. The caisson is characteristically a massively stiff construct. Its dimensions depend on prevailing loads and on the bearing capacity of the sea bottom. The caisson foundation will be fabricated in a dry dock, floated to the site, embedded and loaded. Finally erosion protection will be carried out. The caisson foundation can be made in rather shallow water. The floating stability of the caisson also allows upper construct (wind turbine tower) assembly on the caisson in the dock.

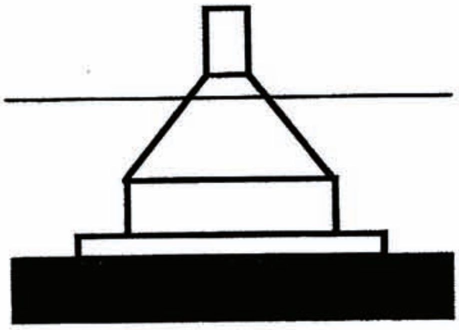
Another traditional foundation method is a pile rammed into the sea bottom, Figure 24c, or a pile anchored into a rock gully, Figure 24e. The gully is possible to compensate also with anchor bolts into the rock, Figure 24f. The dimension and foundation depth depends on the load and density of the bottom, friction and cohesion. The pile is lighter than the caisson and flexible, being sensitive to dynamic loads. The primary pile will be fabricated in the workshop. It can be floated to the site, erected and rammed into the sea bottom or tagged with concrete into rock with light crane equipment. The upper construct will be assembled after foundation. Erosion is generally not harmful to pile foundations.

Constructional effective, although more complicated to realise, are tripod – and grid foundations, Figures 24g and 24h. They can be anchored into bottom rock or through ram piles, which is common in oil drilling jacket platforms. Three feet is rather stiff therefore it also suits ice conditions. With grid – or jacket foundation there can be accumulation of ice between the feet. Dynamic loads can be harmful. Ready assembled tripod – or grid construct mounting requires heavy equipment. A jacket type construct assembly succeeds with lighter equipment. Ramming or anchoring of the pile also requires jacket piece fixing with concrete injection. The upper construct will be assembled after foundation.

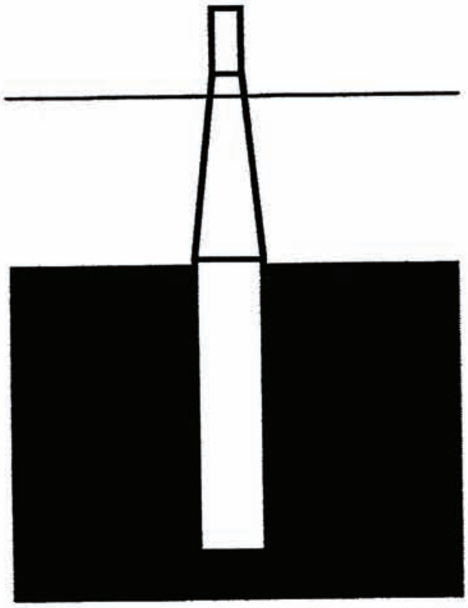
The form of foundation at the water level determines how the ice will be broken. Against a vertical structure crushing happens and against an inclined structure bending, fraction or cutting. With a narrow vertical structure the ice forces can be decreased and the ice accumulation reduced. But the increased elasticity promotes vibration caused by ice. The inclined or cone form causes breakage at significantly lower loads than with crushing against a vertical structure, despite greater breadth of the inclined structure. However the dynamic ice load effects are on an inclined structure clearly more minor compared to a vertical structure.



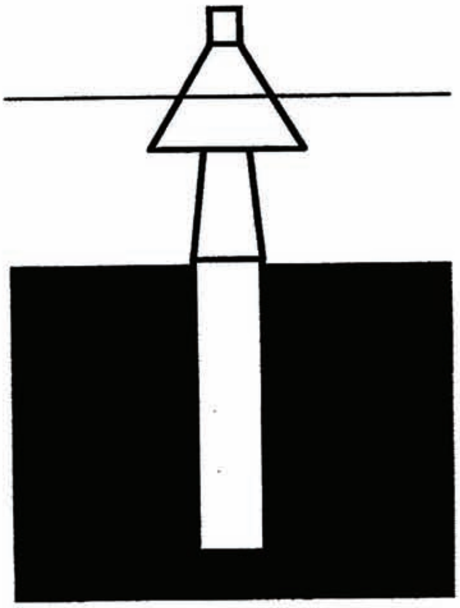
a) Caisson



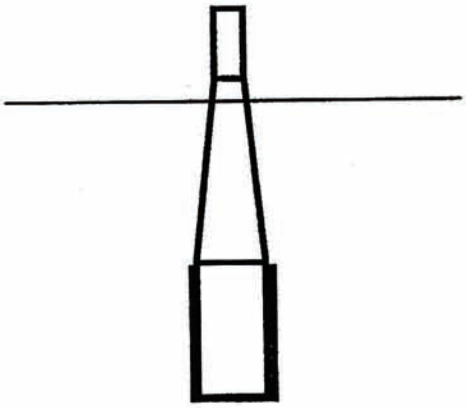
b) Cone caisson



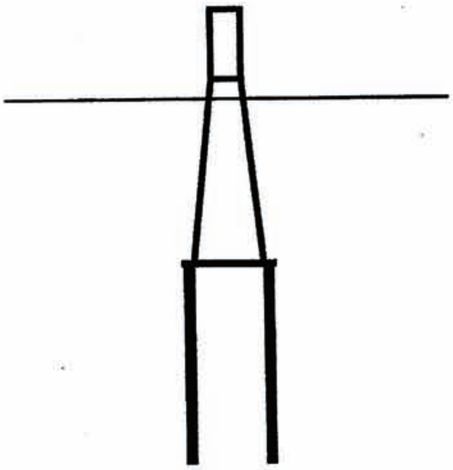
c) Mono pile



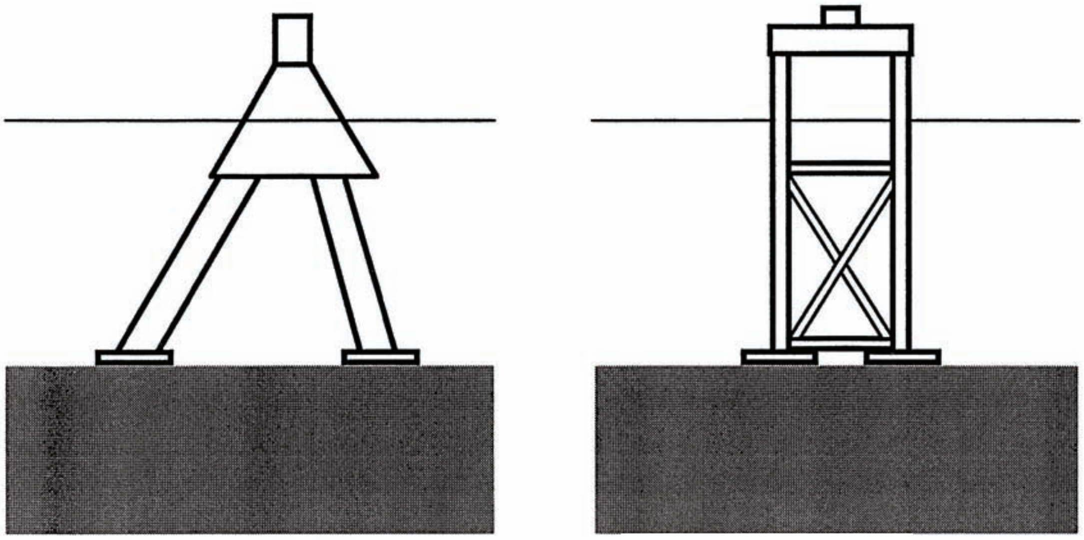
d) Mono pile + cone



e) Rock well

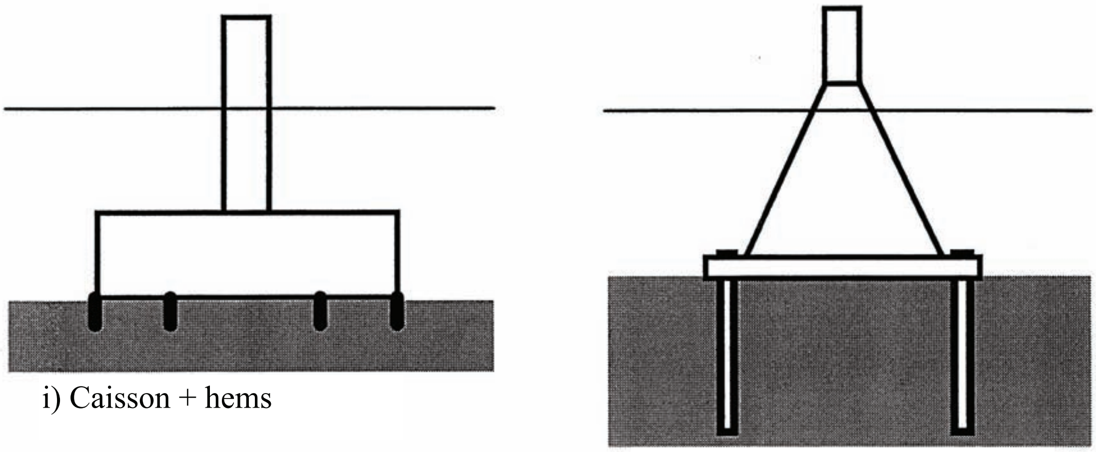


f) Rock anchoring



g) Tripod + cone

h) Grid



i) Caisson + hems

j) Cone caisson + piles

Figure 24. Different foundation alternatives (Määttänen 1998: 74–77).

The conical form can be realised by a caisson, Figure 24b, with cone collar in the pile foundation, Figure 24d, or with a cone caisson with thin additional piles, Figure 24j. The most advantageous form against both static and dynamic ice force at the water level is the cone but during assembly the stability of the cone at the floating – and sinking phase of the caisson is bad. The cone collar should be assembled separately after the basic pile or together with the upper part. By filling the cone with concrete the fastening of the basic pile and good resistance against local ice pressure will be achieved at the same time.

The construct form is easier to realise by a vertical construct form at the water level than with an inclined construct form. A vessel is considerably more difficult to fasten to an inclined structure because the waves affect the vertical movement of the vessel. During winter time ice accumulates on the front of a conical structure. This can be a problem for roads of the foundation (Määttänen 1998: 74–77).

2.6.2 Wind Power Plant Foundation on the Sea

Until now three separate types of foundations have been used on offshore wind power stations:

1) Gravity foundation which keeps upright through its own weight and with added weight mass added to the plate
2) Mono pile which is rammed deep into the bottom and stays upright due to the pressure of the sea bed
3) Tripod where the feet are mounted to the bottom and support the tower which is mounted on the topside of the feet (Määttänen 1998: 74–77).

The **caisson** suits several types of sea bottom. The caisson surface pressure is low. It needs only a smooth base. The cone caisson is suitable in shallow water against ice pressure. The **mono pile** needs the right bottom conditions: enough loose soil to allow ramming and enough stiffness to keep the mono pile upright. **Rock well** requires a rock sea bottom. Negative factors are the price and rocky sea bottom exiguity. **Tripod and grid** are suitable if it is possible to bolt them into the sea bottom. Several variations appear but those three main types of foundations (caisson based on gravity, mono pile based on digging into the sea bottom and tripod legs fastening into the sea bottom) are always the bases of several foundation variations. These types are universally suited for sea bottom building, regardless of what the construction is on top of the foundation. For example, oil rigs follow the same scheme.

The caisson and mono pile type are present in today's wind turbine offshore parks. The caisson type needs to dig depression, balance it and gravel it into a horizontal position less then half a degree from the horizontal. In the erection procedure the use of offshore cranes and assisting vessels with crews also create costs. The mono pile needs a ramming operation and the same offshore crane and assisting vessels. Both possibilities are very near each other. One example, the Middelgrunden 40 MW wind farm associated research (www.middelgrunden.dk/MG_UK/project_info/prestudy.htm) p. 9, 10/14 in Table 6 gives the following prices for the alternatives based on tenders and realised results:

Table 6. Middelgrunden foundation alternatives.

Caisson type		Mono pile
Concrete	Steel	Steel
0.315 m€	0.38 m€	0.42 m€
0.393 m€	Realised including changes	

2.6.3 Caissons in the Tunö Knob Wind Park, Denmark

Tunö Knob wind park was constructed in 1995. It includes ten 500 kW plants about 6 km from the Jutland coast and about 3 km from Tunö island. The water depth is 3.1–4.7 m.

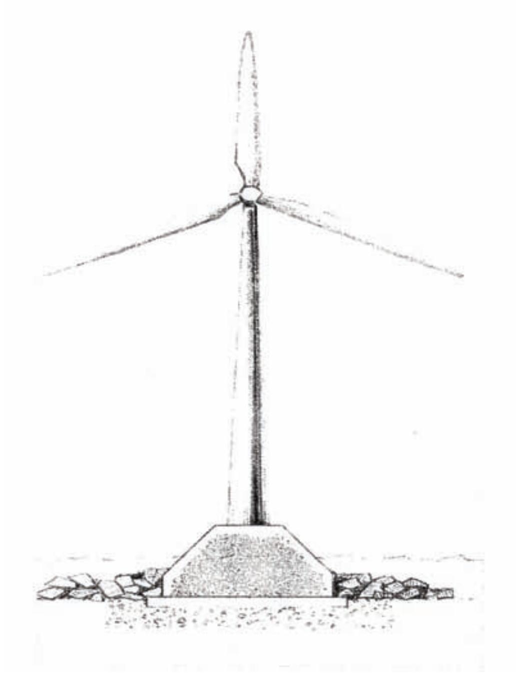


Figure 25. Tunö Knob offshore wind power plant (Holttinen et al. 1998).

Steel concrete caissons are the foundation type of these plants. They are designed to resist waves, sea flows, wind loads, ice loads and the loads effected by the wind turbine itself. The weight of one foundation is about 1000 tons including about 500 tons of filling sand. The height of the lower part of the cylindrical foundation varies with the water depth. The upper part is 2.5 m above sea level. The foundation includes the steel platform and four wooden fender piles. To reduce ice load focusing on the foundation the platforms and fender piles are designed to break at a certain ice load.

The foundations were built in Århus harbour from January to June 1995. In July these were transported to the site by a crane barge. They were assembled on the sea bottom on crushed stone and the caissons were filled with sand. Finally stone erosion protection was assembled round the foundations.

The wind power plants were erected at the beginning of August 1995 from a crane barge. The erection of ten wind power stations took only five days. The sea cable assembly and the finishing of the power stations assembly was completed in September 1995.

The erecting of big sea wind parks should be planned so that the assembly work at sea is completed in as short a time as possible. Otherwise for example a 100 MW wind power plant would not be assembled during one summer far from land. In the feasibility study the concrete caisson was thought to be too heavy. Steel caissons can be placed in several pieces into the same barge, thus saving time on the erecting work (Holttinen et al 1998: 78–79).

2.6.4 Mono Piles

A wind power plant can also be erected on a 3–4 m diameter steel pile. The pile will be rammed 15–30 m deep into the sea bottom depending on the water depth and the soil. The rammed pile is from a production – and erection technology point of view an easier solution than the caisson, since it uses direct traditional technology and is not as sensitive to wash erosion (Figure 26). Erosion protection with small stones can, however, be in place. The problem with rammed pile is the design and measuring of power station and foundation especially with dynamic vibration. Every power station would need calculations based on sea bottom ground analysis. In Holland a 100 x 1 MW sea wind park building with rammed pile foundations is being planned.

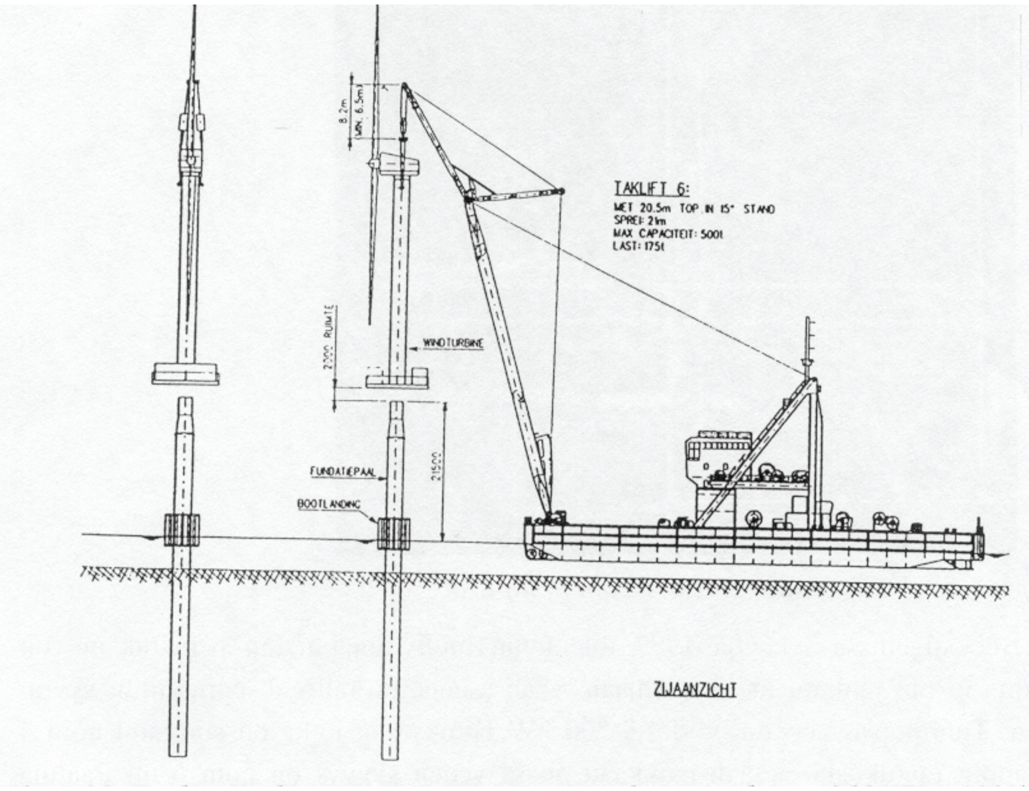


Figure 26. Wind power plant erection with rammed pile foundation (Holttinen et al. 1998).

In Bockstigen in Sweden in 1997 the sea wind park foundation was piles which were not rammed into the sea bottom but assembled into rock drilled deep holes (Figure 27). The park includes five 500 kW plants which are located about 4 km from the South Gotland coast at a location where the water depth is about 6 m. 8–10 m deep holes were drilled into the sea bottom into the hard rock for the piles. After this 2.25 m diameter piles were assembled and placed concrete into position. Since the ground on the sea bed is hard rock, it is expected that the pile side motions will be non-existent.

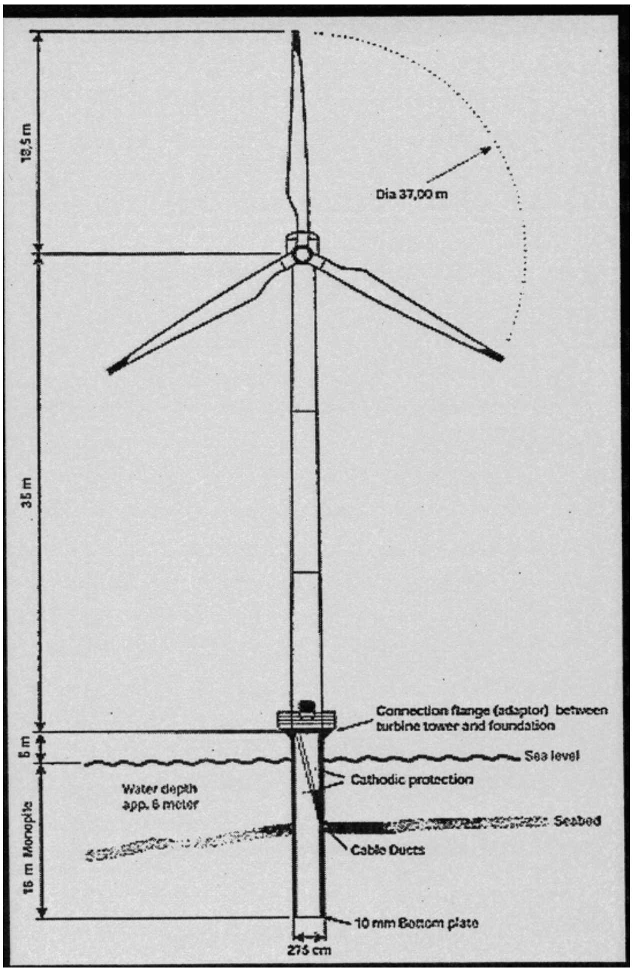


Figure 27. Offshore wind power plant on the Bockstigen wind park (Holttinen et al. 1998).

The wind power turbines were brought onto the site by barge and assembled onto the piles with the same crane vessel with which the piles were assembled. The used vessel resembles an oil drilling platform in the sense that it stays on the sea bottom high above sea level. It was noticed in the project that the used vessel limits the possible erection time when a transfer of the vessel can happen only on a totally calm sea. The transportation of wind power plant parts turns out to be more complex than was planned (Holttinen et al 1998: 80–82).

Ice cones are planned for all the basic types which come into direct with it. With the help of these cones the force of the ice decreases remarkably. The variation of sea level will be taken into consideration in the design. On the Finnish Gulf of Bothnia the upper surface of the ice cone will extend about 0.5 m above the highest sea level and the lowest surface under the lowest part of the ice.

The ice cone bends and breaks ice better when the angle between ice and cone is gently sloping. The friction between ice and the cone increases the effective cone angle, so by decreasing friction a sharper cone can be built and vice versa. The suitable cone angle for concrete is about 45–60° and for steel 55–60°. In picture 24d the cone middle diameter is at the water level. A bigger cone is needed if there is a landing plane above the cone. The minor values correspond to a tower diameter of 4 m. The friction value $\mu = 0.05$ corresponds to the painted steel surface and $\mu = 0.3$ concrete surface. In cases when the ice thickness is under 40 cm the ice loads in other cases stay under the 1 MN level.

The cone can be based on a middle cylinder of foundation and it can be made of either steel or concrete. A thin steel mantle cast full of concrete inside is a simple and advantageous solution. The steel mantle decreases friction and acts as casting mould.

When ice blows come from a direction other than the coast a one-sided cone at 180° can be sufficient and from the direction of the coast this can be in the form of a dam (Haapanen 1998: 85–86).

2.6.5 Construction Technology

The foundations and wind power station transportation to the site are problems for which it is not easy to find a cheap solution. The transportable and lifted mass are large. A foundation weighs hundreds of tons as ready-made concrete and thousands of tons filled with mass. The weight of a power station, depending on size, is 80–200 tons. The tower height is 50–80 m.

If the planned site of wind power turbine is shallow water only 1–2 m in depth, heavy lift equipment is transported to the site by barge either to dredge a channel or build a causeway for the land transport equipment. On the Finnish Gulf of Bothnia also erection on the ice can be considered. The power station can be transported over and 3 metres depth of water erected with a crane barge. Also a floated foundation can be used to which a tower, machinery and a rotor are assembled before floatation.

With the erection of a wind power turbine the effect of waves is taken into consideration as well as the assembly duration, used equipment and floating stability of the whole construct. On the basis of local wave statistics it can be estimated at what time of year assemblies are possible and how long suitable weather windows exist for assembly.

So far offshore wind power plants have been erected at sea either with offshore equipment (floating crane) or with a crane based on a barge. The erection of megawatt class plant needs about a 55 ton lifting capacity, nearly 80 m crook height and over 10 m lifting distance from the edge of foundation. There are cranes big enough in Finland which can be moved onto a barge during erection. This kind of arrangement also needs an anchoring system and is noticeably sensitive to wind and waves. It suits shallow water and a sheltered site. A ready floating crane is in this respect a more reliable solution but considerably more expensive. It is possible for a tower erected at sea to be 60 rather than 70 m in height if the cost of a crane with greater lifting height is unreasonably high.

When a large offshore wind park is to be constructed, it is attempted to erect it usually during summer time (under 150 days), so a foundation and power plant erection should not take many days.

By building 600 kW plants on shore it is possible to erect two plants in one day. A megawatt class plant construct uses ready-made foundations and in best cases takes one day. If a strong enough crane is in use, the construct could be accelerated so that the wind power plant would be lifted in long pieces (for example the tower in one piece, the machine room in one and the rotor in one piece).

The wind power plant can not be erected in strong wind: generally the wind speed should be under 8 m/s. At sea the weather conditions are especially important, the used equipment may require even lower wind speeds and wave heights. The best erection weather is naturally in summer (Haapanen 1998: 96–97).

2.6.6 Costs of Offshore Wind Power Plant

The offshore wind power costs can be divided into 4 main fields: 1) seabed conditions 2) marine environment 3) meteorological conditions and 4) turbine type. The seabed conditions describe the soil conditions at the location. The marine environment could be: water depth, tidal range, currents etc. The meteorological conditions describe in a statistical way the wind and waves. They have a strong seasonal variation and will be noticed during the installation period, turbine production time and service trips. The turbine type is the most important factor but it will be kept as a given parameter and will not be varied (Vandenbulcke 2001: 2).

At sea a wind is clearly more even than on the land and probably a wind power plant at sea will have a longer life time than on land. The life time of offshore wind power plant can be assumed to be 25 instead of 20 years. In addition the foundations can be designed for a service life of 50 years where it is possible to exploit the same foundations for two wind power plants. In this report the production costs are however calculated by using for all components a 20 year pay back time and 5 % interest.

To calculate the cost rates of 1 DKK = 0.13459 € and 1 USD = 1.13392 € are used. The costs are calculated without Value Added Tax. In Table 7 foundation costs calculated for 1.5 MW power plants are compared. These Tunö Knob and Siikajoki costs are realised costs but for a smaller plant sizes (in the table the presented cost is for a 2–3 foundation) at Rödsand and Kokkola the costs of only one foundation are estimated.

Table 7. Building and erection costs of foundations 1000 € / 1.5 MW (Holttinen et al. 1998).

Object / Place	Tunö Knob Denmark	Rödsand Denmark	Kokkola (Caisson)	Kokkola (Monopile)	Siikajoki (onshore)
Foundation	727	289	168	202	182
Erection	incl.	23	76	34	incl.
Ice cone	–	–	34	34	–
Access platform	incl.	33	34	34	–
Total	727	345	312	304	182

Tunö Knob has 10 x 500 kW plants (1995), the Rödsand estimation is 72 x 2.2 MW plants (Svenson et al. 1999: 297), Kokkola 10 x 1.5 MW plants, Siikajoki 2 x 600 kW plants (incl. road building 500 m, 1997). When building on land possible ground building works will be added to the figures. For example, road building in the Siikajoki project was over 10 % of the foundation cost in Table 7.

For the Kokkola case the calculated values are very approximate. The rammed pile diameter is 4 m and the length is 23 m. The ramming depth is 16 m into the ground. The fixing of the wind power plant to the rammed pile needs some kind of spacing piece. The cost of this piece is estimated very roughly. In the ramming work the weather conditions should be observed. In the cheapest case, without the weather causing a stoppage, the cost could be 25 000 € per plant (Holttinen et al. 1998: 106).

Using a 1.5 MW wind turbine as a reference, foundation costs are in general estimated to be only slightly higher (approx. 30 %) than expected for the 500 kW turbines at the Tunö Knob wind farm.

Although the foundation cost increases with sea depth, this increase is less than linear. Depending on the type of construction and the analysed locality, when the sea depth is increased from 5 to 11 meters the foundation cost goes up by only 12–34 %.

Monopile, Gravity and Tripod costs are remarkably close for all three types, with a maximum variation of approx. 12 % at the same location (Morthorst et al.1997: 203).

Cost information changes from reference to reference. A collected component cost list is shown in Appendix 15.

2.6.7 Cost Estimation of Wind power Project

The costs of offshore wind power plant are presented for already realised projects and for the planned projects in Denmark, Sweden, Holland and Finland in Table 8. In the Tunö Knob there are 10 x 500 kW plants (from 1995), Bockstigen 5 x 550 kW plants (from 1997), 72 x 2.2 MW plants are planned for Rödsand, and for Kokkola 10 x 1.5 MW plants are calculated. In table 4 the projected costs of land built wind power projects are also presented (Siikajoki 2 x 600 kW from 1997). As a comparison in table 8 the costs and production are presented for all projects for 1.5 MW wind turbines (Holttinen et al. 1998: 108, updated costs in Appendix 15).

The wind power plant includes transportation, erection and remote control of the plant. Net connection includes sea cables. Foundation includes design and assembly of the foundation. The Tunö Knob production costs are about 6.39 €c/kWh without demonstration costs.

Table 8. Cost comparison of Wind Power Plant (Holttinen et al. 1998).

Object / Place 1000 € /1,5 MW	Tunö Knob	Bock-stingen	Ijmuiden Holland	Rödsand Denmark	Kokkola Finland	Siikajoki (On land)
Foundation	727	706	933	321	303	182
Wind turbine	1300	1615	1253	1999	1615	1210
Net Connection	767	141	640	Incl.	185	80
Other Costs	145	sis.	34	Incl.	84	145
Total	2939	2462	2861	2321	2186	1496
Production MWh/a	4500	4800	4500	4995	4200	3375
Costs €c/kWh	7.2	5.7	7.1	5.0	5.7	4.4

A collection of cost components in offshore wind turbine exists in annex 15.

The production costs €c/kWh are calculated from the formula

$$h = \frac{Inv * (a + o)}{E} \tag{2.9}$$

where h = production cost [€/kWh]
Inv = Investment costs [1000 €]
a = annuity (= about 8 %, 20 year pay back period and 5 % interest)
o = operation and maintenance costs (3 % yearly from investment at sea and 2 % on land
E = one year's production [MWh/a]

Rödsand is a target of larger Danish offshore building. It is located on the inner archipelago where there is only some ice load. In Holland is a 100 MW offshore wind park target. The foundation costs are considerably larger than in the other projects. The reason is that there is considerably deeper water depth and the used rammed pile replaces a part of the tower of the wind turbine, in other words it reaches up to 20 m above sea level.

In this research an estimate has been made for Kokkola town in shallow water from Trullev fish harbour to the North West (Santapankki). The planned park size is considerably smaller than those in Denmark and Holland. The conditions are more demanding from the ice perspective and in terms of wave load less demanding. The water depth is 3 m (in the Danish case 5 m and Dutch case 17 m) and the distance from the coast is only 3 km (Danish 7–10 km, Dutch 8–16 km). The year's production in Kokkola is not as large as wind power parks located on far-distant sea locations. The wind conditions are medium in the area of the Finnish Gulf of Bothnia, the medium wind speed is > 7 m/s (Holttinen et al. p. 107–109).

In the Kokkola example the net joining costs for Kokkola Energy are expected to be: 110 kV / 20 kV transformer station for the wind park (cost about 1 M€), 110 kV sea cable 3 km (168 € / m) and 20 kV sea cable inside of the park so that 4–6 plants are in the same starting cable between the two plants at a 400 m distance. For accessories for the wind turbine and for strengthening of the lower part of the tower a budget of 33 638 € / plant is estimated. In the estimate are included administration costs and in addition unexpected additional costs which are about 5 % of the wind power plant price. If the project is realised additional research will be necessary for the demonstration project (for example follow-up measurement, research on environment effects). The erection - and foundation costs are based on rough estimates. The erection costs are estimated from both barge and as floated. The erection and foundation alternative production cost estimates of different power plants (1.5–1.65 MW) varied between 5.38–5.89 €c/kWh. On the basis of this first rough estimate the floating alternative was shown to be a very competitive solution in the erection of power plants.

Table 9 shows clearly that sea-built wind power production costs are greater than those of land built wind power plants. Also different project cost estimates have a great range of variations. In the Finnish Gulf of Bothnia it is possible in some locations to use an erection on the ice surface which can be expected to lower the erection costs significantly (Holttinen & Keinänen 1998: 34).

Table 9. Offshore Wind Turbine Cost by Components (note that the used sources are in the table).

Offshore Wind Turbine Investment M€:									
Conversion Coefficient	M€ 1. 5	DKK 0.13459	M€ 1/96	M€ 1/96	M€ 1/96	M€ 1.5	M€ 1.5	M€ 1.5	M€ 1
References:	Kuhn et al. 1998 [13]	Fuglsang 1998: 13	Svenson 1999: 299 Rödsand	Svenson 1999: 299 Omö	Svenson 1999: 299 Gedser	Hartnell al. 2000 [10]	DEA/CAD DET 2000 [5]	Barthelmie et al.2001: p. 6–2	www.mid-Delgrunden Dk
Turbine size	1 MW	1. 5 MW	1.5 MW	1.5 MW	1.5 MW	1 MW	1 MW	1 MW	2 MW
Turbine	0.675	1.390	1.177	1.177	1.177	0.765	0.765	0.495	1.207
Foundation	0.480	0.554	0.375	0.375	0.375	0.240	0.240	0.360	0.394
Grid connection	0.315	0.417	0.573	0.469	0.760	0.375	0.375	0.225	0.574
Management	0.030		0.083	0.083	0.083	0.060	0.060	0.030	
O&M facilities	0.000		0.031	0.031	0.031	0.030	0.030	0.345	
Miscellaneous	0.000		0.052	0.052	0.052	0.030	0.030	0.045	0.161
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Total M€/Plant	1.500	2.369	2.292	2.188	2.479	1.500	1.500	1.500	2.336
Turbine size	1 MW	1.5 MW	1.5 MW	1.5 MW	1.5 MW	1 MW	1 MW	1 MW	2 MW
Total M€/1 MW	1.500	1.579	1.528	1.458	1.653	1.500	1.500	1.500	1.168

In Table 9 are the latest costs are collected by components from 9 different sources. These figures are in different currencies, turbine sizes, sea bottom conditions, plant -, budgeted – or realised prices. I have attempted to compare that differences. It seems that in the course of time turbine prices have decreased. The research focus, foundation prices, have decreased even more, especially when calculated per 1 MW.

2.6.8 Project Size and Water Depth Effect on the Costs

By building at sea the foundation and costs of connection to the net are great. The foundation costs can be decreased by building large plants: the 1.5 MW power plant foundation is very reasonable compared to three 0.5 MW plant foundations. It is estimated that in the Tunö Knob case the 1.5 MW unit size and the newest foundation technology should decrease the costs from 6.39 €c/kWh to 4.20 €c/kWh. It is possible that wind power plant size will increase even further to several megawatts. This will in particular improve the economy of offshore parks. In this case the foundation costs in relationship to produced energy will decrease even further.

It will also be advisable to build large plants also from the point of view of ice loads. When the 600 kW size is changed up to the megawatt class the ice loads will only increase a little compared to the growth of the wind turbine. The ice loads rise in ratio to the ice faced area (in the 600 kW plant the tower base diameter is 3 - 3.5 m and in the 1.5 MW class 4 m). The wind forces are in ratio to the height and diameter of the rotor (a 600 kW plant height is 50 m and rotor diameter 40 m: a 1.5 MW plant height is 60–80 m and diameter 57–66 m). The megawatt class power plant base load is significantly bigger than that of a half megawatt power plant. The ice load effect decreases in the total load when the power station size increases.

In the case of large wind parks all fixed costs will be divided by the greater energy amount produced. Also the electricity net costs favour big project sizes. Then the sea cable costs will be divided between several units. For example in the case of the Kokkola wind park the net joining costs of 10 plants are estimated to be 185 000 € / plant, in the case of 20 plants only 100 000 € / plant and with 30 plants 75 000 € / plant.

When the distance of wind turbines is further from the coast, the costs of joining to the electricity net also grow. For example in Denmark 7.5 MW offshore park costs are calculated to be 4.37 €c/kWh when the distance is 5 km and 5.89 €c/kWh when the distance is 30 km.

When the wind park size grows the cost decreases per produced power. For example 200 MW offshore calculated costs vary from 3.70–3.89 €c/kWh when the distance to the continent is 5–30 km (Morthorst et al. 1997: 204).

Figure 28 shows how a foundation in deep water increases the costs. The water depth effects on the foundation costs are estimated to be 12–34 % when changing from a 5 m to 11 m depth (Lemming 1997: 41).

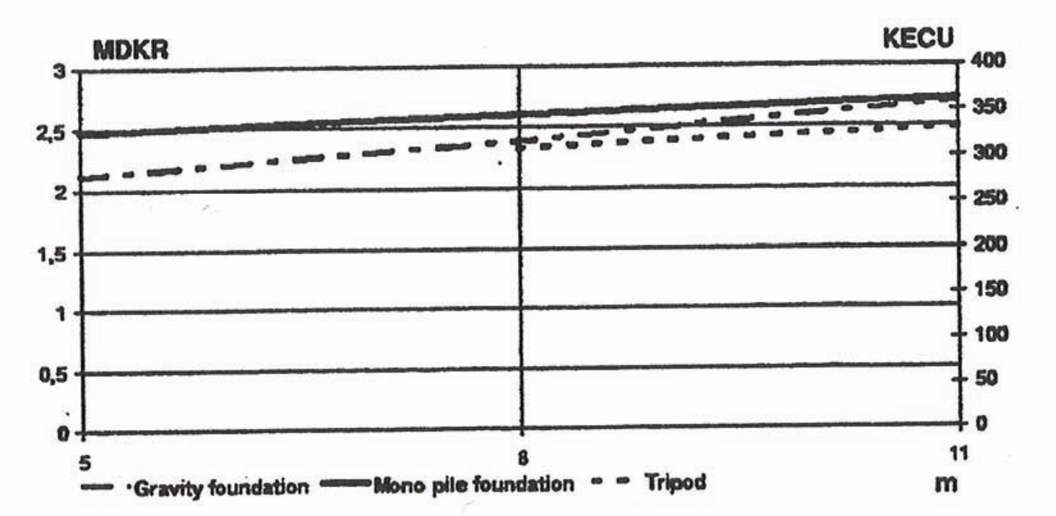


Figure 28. Three base type foundation costs at Horns Rev location (Lemming 1997: 41).

The technical potential of offshore wind power is on the Finnish Perämeri in shallow water areas. Between Vaasa and Tornio there is a potential of over 40 TWh / a. In this case a 7 m/s medium wind speed is demanded, a depth of water under 10 m and thickness of moving ice under 40 cm. The demands can be fulfilled in this area and the area could be filled with wind power plants (nearly 2000 km, over 11 000 power stations). In practice suitable areas are much more limited when we take into consideration the limitations of using the area (among others navigation, nature protection and defence forces).

The offshore foundations are remarkably more demanding than the foundations being built on land. When planning the construct we need to take into consideration all the environmental effects on the construct. In the building material and surface treatment we should pay attention to the corrosion of the steel and the effects of freezing water on a concrete interstice and to the erosion of the bottom. The roads to the wind power plant should be useable both in reasonable surf and in winter time during the period when the ice is frozen. With the design of the foundation the ice loads can be decreased significantly. The design should pay regard to both local high ice loads and from the total ice loads accumulated over a wide area, both static and dynamic. Moving ice under 40 cm thick, which will crush against the ice cone, will affect loads under 1 MN.

The transportation of the foundation and wind turbine to the site increases costs because the portable and lifted mass is big. The foundation weighs hundreds of tons as ready-made concrete and thousands of tons filled with mass. The wind turbine weight is about 200 tons. The tower height is 50–80 m.

The cost of a one megawatt class foundation is 0.25–0.42 million € including the assembly of foundation and preparation of sea bottom. For the 10 plant sea wind park preliminary cost estimates show that offshore wind power is still clearly more expensive than building wind power on land, 5.38–5.89 €c/kWh compared to 4.37 €c/kWh. By building big offshore parks the costs per produced kWh drop. For example in Denmark offshore parks will be built with over 100 turbines. The estimated production cost is about 5.05 €c/kWh (on land about 3.36 €c/kWh). At this moment 1.5 MW power plants are for sale and especially for offshore purposes 2–3 MW units are available. By development of foundation technology and by building large units at sea it is possible to reach the same production costs as wind power plants built on land especially when the best places on the coast are already built on (Holttinen et al 1998: 110–113).

2.6.9 Spreadsheet computation simulation model for steel foundation

In Figure 29 there is the basis for the simulation model. The example, the input values of the turbine are given in Figure 40 in colour. The spreadsheet computation formulae are presented in Appendix 19. The idea is to test how the turbine stays on the sea bottom with water filled tanks and floats with empty tanks, but only roughly for the construction price estimation. The given circumstances are: given moment M_y GL-II/DIBt-III (Germanischer Lloyd-TypenklasseII / Deutscher Instituts für Bautechnik (DIBt)-WindzoneIII 2001:4,6,25), hub height, turbine weight, water depth, material thickness of under water tower, foundation height, estimated required stiffeners for foundation construction, thickness of foundation steel plate, radius of under water tower, height of concrete layer and radius of foundation.

This construct gives a rough picture of how different input values affect the price. In addition those given 20 input values (Figure 40) will be calculated. Thus it can be seen at once if construction is possible in reality.

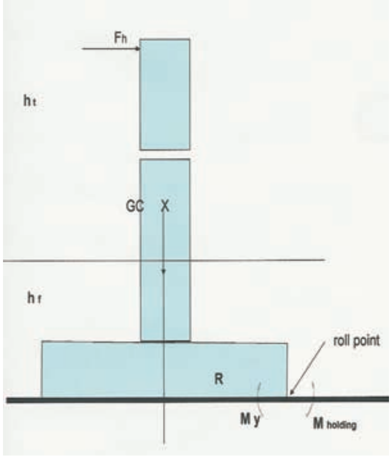


Figure 29a

Figure 29a presents the turbine standing on the sea bottom.
Fh = $^1/_2 c\rho A v^2$ is the force affecting the rotor
Bending moment $M_y = F_h$ x (hub height + foundation height)
Holding moment $M_{hold.} = G_W$ (wet mass) x R (foundation)
The stays if ratio M_y / $M_{hold.}$ is less than 1.

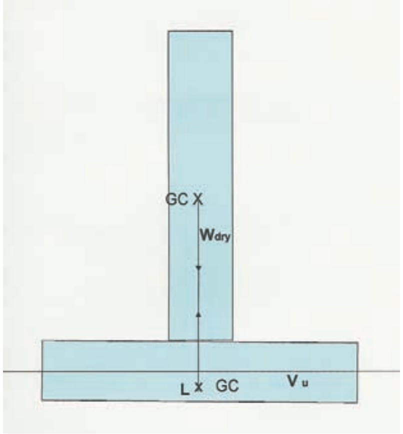


Figure 29b

Figure 29b presents the turbine floating on the sea
Dry weight W_D = turbine + foundation weight
Lift is the under water volume V_U x ρ
The power plant floats if ratio W_D / V_U x ρ is less than 1.

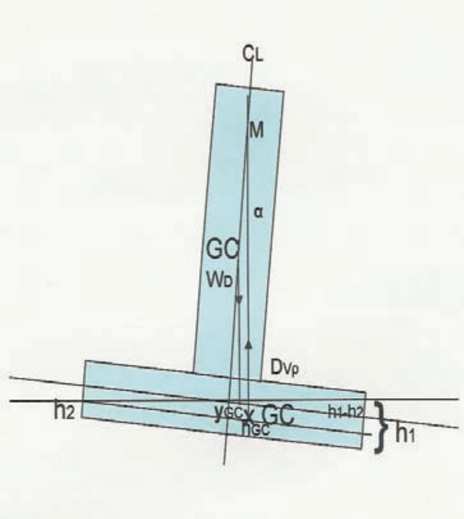


Figure 29c

Figure 29c presents the turbine floating freely
Bending moment is GC (Gravity Centre of the power plant) projection onto sea surface x W_D (dry weight) of the power plant.
GC (Gravity centre) of displacement (Valtanen 1994 p. 682): $h_{GC} = (h_1 + h_2)/4 + (h_1 - h_2)^2/16(h_1 + h_2)$ = displaced water Gravity Centre from the bottom of foundation,
$h_1 - h_2 = 2 R \tan \alpha$, Displacement height $D_h = h_2 + {}^1/_2 (h_1 - h_2) = {}^1/_2 (h_1 + h_2)$,

$h_{GC} = {}^{1}/_{2}\, D_h + (2\, R \tan \alpha)^2/32\, D_h$ (Valtanen 1994: 682)

$y_{GC} = R/4\, (h_1 - h_2)/(h_1 + h_2)$, $y = R^2 \tan \alpha /4\, D_h$

$y_{GC} = R^2 \tan \alpha /4\, D_h$=displaced water Gravity Centre from CL (Centre Line).

Only small angles are valid.
Correcting moment: Function y_{GC} projection on sea surface x D_{V_ρ} (Displacement Vu x ρ)
Bending moment: Gravity Centre projection on sea surface x dry Weight
Stability is when bending moment / correcting moment is less than 1.

The power plant is stable if the distance from M (Metacentre) to GC (Gravity Centre of power plant (M-GC) is positive. Metacentre = $h_{GC} + y_{GC} / \tan \alpha$ (Band 1970: 292).

The equations above will give the minimum requirements. For example there is no wind. For floating and assembly situation onto the sea bed the dimension of the diameter of the foundation will correspond to wind, wave, tide, sea current and bottom circumstances. The minimum requirement is a solid sea bottom. However, if the piece is floating freely (without help), the foundation surface pressure is very low. The sea bottom bears in most selected cases.

2.7 Wind Power Costs Calculation Model

2.7.1 Cost Components and Energy Production

The cost components are assumed to be the investment costs (including possible interest during construction), operation and maintenance costs, repair costs, salvage value and social costs. Apart from the social costs, only the costs which relate to the wind turbine system up to the point of interconnection with the public transmission or distribution network are considered.

In some cases it may be necessary to reinforce the public transmission or distribution system (or to include special control devices, etc.) due to the introduction of wind power. In such cases, depending on the scope of the analysis, these extra costs (or a part of them) may be included in the analysis.

The wind energy output considered could be a) the annual net energy (ANE_t) available at the wind turbine terminals, or b) the annual energy as utilised in the connected power system, i.e. the annual utilised energy (AUE_t). The relation between the annual utilised energy and annual net energy can be described by:

$$AUE_t = ANE_t \cdot K_{los,t} \cdot K_{util,t} \tag{2.10}$$

Here, $K_{los,t}$ is a factor relating to the electricity losses which occur between the wind turbine terminals and the electric grid where the energy is utilised, and $K_{util,t}$ is a factor which depends on how the transmitted wind energy is utilised in the power system, see Figure 30, example of an electrical system where the energy losses in the long medium voltage feeder are reduced due to the wind power production so that the utilised wind energy becomes higher than the transmitted net energy and $K_{util,t} > 1$.

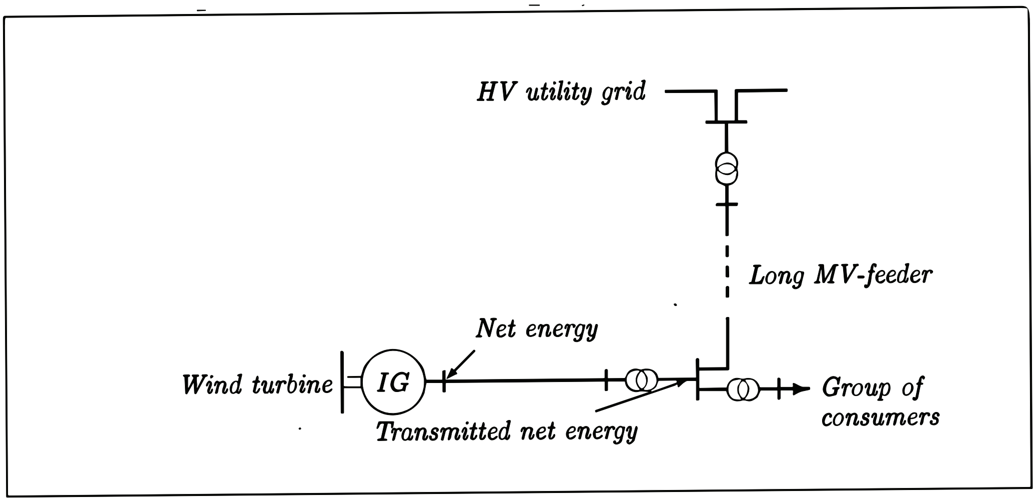


Figure 30. Example of an electrical system (Tande et al.1994: 5).

Depending on the scope and field of application, both the annual net energy output and the annual utilised energy output are recognised as adequate energy measures, and the assessor must judge which to use in each case.

2.7.2 Cost Calculation Methodology, General Approach

The measure of the estimated cost of energy adopted in this document is *the levelled production cost.* The levelled production cost *(LPC)* is the cost of one production unit (kWh) averaged over the wind power station's entire expected lifetime. The total utilised energy output and the total costs over the lifetime of the wind turbine are both discounted to the start of operation by means of the chosen discount rate, and the *LPC* is derived as the ratio of the discounted total cost and utilised energy output.

It is assumed that all costs are given in a fixed currency for a specified year. The currency and cost level year should be decided and clearly declared by the assessor when reporting the estimated cost of energy. In the calculations all costs are discounted to the present value, i.e. the first date of commercial operation of the wind turbine. The discounted present value of the total cost *(TC)* is given as:

$$TC = I + \sum_{t=1}^{n} (OM_t + SC_t + RC_t) \cdot (1+r)^{-t} - SV \cdot (1+r)^{-n} \tag{2.11}$$

The levelled production cost *(LPC)* is given as the ratio of the total discounted cost and the total discounted utilised energy, i.e.:

$$LPC = TC / \sum_{t=1}^{n} AUE_t \cdot (1+r)^{-t} \tag{2.12}$$

The annual utilised energy, AUE_t, should be specified for each year by adjusting the annual potential energy output, E_{pot}, with a number of correction factors:

(2.13) $$AUE_t = ANE_t \cdot K_{los,t} \cdot K_{util,t} = E_{pot} \cdot K_{per,t} \cdot K_{site,t} \cdot K_{ava,t} \cdot K_{los,t} \cdot K_{util,t}$$

2.7.3 Cost Calculation Methodology, Simplified Approach

In many cases it may be appropriate to assume the annual utilised energy to be constant from year to year (i.e. $AUE_t = AUE$ for t = 1 to n). In such cases, the *LPC* can be calculated as:

(2.14) $$LPC = I/(a \bullet AUE) + TOM/AUE$$

a is the annuity factor as defined in the table below. I/a is the capital to be paid annually during the assumed period in order to cover both the depreciation and the assumed interest.

TOM is the total levelled annual "downline costs", i.e. all costs other than the initial investment. TOM may for simplicity be estimated as a certain percentage of the investment. The exact definition of *TOM* is given in symbols.

2.7.4 Calculation Method

The Calculation methodology is presented in Table 10. The calculation example is taken from Table 31. The wind turbine data is from *producer D. Onshore bid prices* are from producers' offers. *Offshore calculated prices* are as mentioned in Table 10 on rows 26 to 33. *Total investment* is the sum of onshore bid price and offshore calculated price. *Operation and Maintenance* costs are presented on rows 42-46 *Levelled Utilized Energy* on row 49 is annual production multiplied with the correction factors: Performance factor $K_{per} = 1$, Site factor $K_{site} = 0.95$, Technical availability factor $K_{ava} = 0.95$, Electric transmission losses factor $K_{los} = 0.95$, Utilization factor $K_{util} = 1$. The *Production cost* including O&M costs on row 46 can be calculated with spreadsheet calculation operator on rows 54 and 60, or, for example, manually as on row 59. The factors are: real interest: row 56; refund period: row 57; total investment: row 35; annuity factor divided by levelled energy: row 49.

Table 10. Calculation Method

1	A	B	C	D	E
2	**Kilowatt Price with separate Power Plants in Euros**				
3	Measuring Periode on the Strömmingsbåda and Bergö Island on 22.11.97 - 26.11.1998,				
4	Sources and Operators				
5					
6	**Producer**		**Source**	**Turbine D**	
7	Rated Power (kW)		*Data*	**2000**	
8	Rotor D(m)		*Data*	80	
9	Hub Height h(m)		*Data*	80	
10	Weight (TON)		*Data*	268	
11					
12	**Onshore Bid Prices**		**Source and Operators**		
13	Wind Turbine ex works			1717200	=+D13/D$13
14	Transport to Dock		*Bid*	10000	=+D14/D$13
15	Transformer		*Bid*	incl.	
16	Remote Control		*Bid*	incl.	
17	Training		*Bid*	11500	
18	Accessory		*Bid*	6100	=+D18/D$13
19	Warranty Time Service		*Bid*	incl.	
20	**Total**			=SUMMA(D13:D19)	=+D20/D$13
21	Currency Factor		*Data*	1	
22	**Turbine on Dock**			**=+D20*D21**	
23	€ / kW			=+D22/D7	
24					
25	**Offshore Calculated Prices**				
26	Steel Foundation		*Figure 39*	319508	=+D26/D$13*D$21
27	Transport		*Table 25*	6487	=+D27/D$13*D$21
28	Harbour/Dock Assemblage		*Table 25*	10485	=+D28/D$13*D$21
29	Site Work		*Table 25*	16338	=+D29/D$13*D$21
30	Sea-bed Reseach (List of Statement)		*Korpinen*	20000	=+D30/D$13*D$21
31	Cabling(20+5.2km,160€/m,14 turbines)		*Chapter 5.5.4*	288000	=+D31/D$13*D$21
32	Planning		*Estimate*	10000	=+D32/D$13*D$21
33	Additional Charge		*Estimate*	10000	=+D33/D$13*D$21
34					
35	**Total Investment**			**=SUMMA(D26:D33)+D22**	=+D35/D$13*D$21
36	€/kW			=+D35/D7	
37	Investment Support	0		=+$B37*D35	
38	**Net Investment**			**=+D35-D37**	=+D38/D$13*D$21
39	€/kW			=+D38/D7	
40					
41	**Operation and Maintenance (€/year)**				
42	Operation and Maintenance (0,01€/kWh)		*Chapter 2.4.3*	=+D49*0.01	=+D42/D$13*D$21
43	Insurance		*Estimate*	15000	=+D43/D$13*D$21
44	Administration		*Estimate*	5000	=+D44/D$13*D$21
45	**Total (€/year)**			**=SUMMA(D42:D44)**	=+D45/D$13*D$21
46	O&M (€c/kWh)			=+D45/D49*100	
47					
48	Annual Production (kWh/a)		*Table 23*	9124506	
49	**Levelised Utilized Energy (0.86)**		Chapter 2.7.2	**=+D48*0.95*0.95*0.95**	
50	Annual Production/Swept Area (kWh/m^2)			=+D49/D58	
51	Nominal Power Time (h/a)			=+D49/D7	
52	Capacity Factor (Cf)			=+D49/8760/D7	
53					
54	**Production Cost (€c/kWh)**			**=-(MAKSU($B56/100;$B57;D35)/D49)*100+D46**	
55					
56	Real Interest %/Year	5	%	**Turbine D**	
57	Refund Periode Years	20	Year	**2000**	
58	Swept Area (m^2)			=+PII()*D8^2/4	
59	PC=(1+0,05)^20*0,05/((1+0,05)^20-1)				
60	PC=-MAKSU(0,05;20;1)				

2.8 Estimation and Specification of Input Parameters

In this section the input parameters are specified further and guidance is given for their estimation. In many cases one or more of the input parameters will be known explicitly, and of course, the known figures should be used whenever possible. This part considers the cost of energy from wind turbines excluding all possible taxes and subsidies.

2.8.1 Investment

The investment should include all the costs of constructing the WECS (Wind Energy Conversion System). Although only the total investment is included in the formula for calculating the levelled production cost, the analysis report should include a breakdown of the investment as indicated in Table 8.

In some cases, e.g. for very large wind farms, the construct time may be of substantial length, and the interest on the investment, during the time from when the payment is made until the start of commercial operation, should be calculated and included in the total investment:

$$I = \sum_{i=1}^{j} I_i \cdot (1 + r)^{t_i} \tag{2.15}$$

Where, j is the number of investment payments, r is the discount rate, and I_i is the investment part paid t_i years before the start of commercial operation of the wind power installation.

It is important to notice that bank interest for financing the investment is not considered, since in this document the *project* is being assessed and not how it will be financed.

Table 11. List of investment cost components for grid connected wind turbines (Tande 1994: 9).

1. Wind turbine ex factory cost.
2. Special certification or other external test procedure costs if procured.
3. Transportation costs, i.e. loading and unloading and other costs associated with transporting the wind turbine from the manufacturer to the site.
4. Site preparation costs, i.e. civil works for preparing access road(s), levelling the site, and other actions depending on the specific landscape and ground conditions.
5. Foundation costs, i.e. civil works for preparing the wind turbine foundation.
6. Erection costs, i.e. costs for erecting the wind turbine at the foundation.
7. Internal electrical connections, i.e. costs associated with the low voltage (> 1000 V) electrical works.
8. Grid connection costs, i.e. costs associated with the high voltage (> 1000 V) electrical works.
9. External monitoring and control system costs. Such external systems are typically associated with large wind farms monitored and operated from a remote utility central.
10. Consultancy services and other costs for design and supervision of the installation works.
11. General site costs, i.e. costs associated with possible temporary installations such as sanitary installations, work-shops, etc. at the site while installing the wind turbine.
12. Land costs, i.e. the cost of buying or renting land for the wind power installation. The use of land near a wind turbine may be restricted by regulations concerning safety and noise aspects as well as restrictions for avoiding construct of buildings or other obstacles which would reduce the wind turbine output. The costs should be discounted to the first date of commercial operation using the discount rate as specified in section 2.8.7. In cases where the land is also used for farming or other activities, the land investment cost should be reduced by the discounted income of these activities.

2.8.2 Operation & Maintenance

The O&M costs will depend on the number of wind turbines, the wind turbine type, the site conditions and the connected system. Accordingly, this document recommends project specific estimates of the O&M costs to be specified for each year of the scheme's lifetime. Although only the total annual O&M cost for each year is included in the formula for calculating the levelled production cost, the analysis report should include a break-down as indicated in table 8.

Table 12. List of operation and maintenance cost components for grid connected wind Turbines (Tande 1994: 10).

1. Normal liability and property insurance costs covering sudden wind turbine damage and operational losses due to such damage.
2. Special insurance for an annual energy output guarantee.
3. Service costs may include the man-power costs of the scheduled services. Service costs during the first years are sometimes included in the wind turbine price.
4. Consumable spare parts for wear and tear as well as lubrication grease and oil.
5. Repair costs, i.e. minor repairs outside the scheduled service and not covered by any insurance or guarantee surveillance.
6. Management costs, i.e. costs connected to the construct and operation management of the wind turbine(s). Management costs may be substantial for large wind farms.

2.8.3 Social Costs

The social (or external) costs of energy production are those which are caused by third parties and are not reflected in the market price of energy. Social costs may be associated with environmental damage, nuisance to people, etc.

Consensus on specific methods for estimation of social costs has yet to be established. However, it is accepted that social costs exist and that they should be included when calculating the cost of energy production. It is also widely accepted that social costs of wind energy production are small or negligible, especially when compared to those associated with energy generation from non-renewable sources.

2.8.4 Retrofit cost

The need and costs for replacements or major repairs during the adopted lifetime (see section 2.8.6) should be evaluated. These are dependent on numerous factors, and it is recommended that project specific estimates are made of the timing and cost of possible major repairs.

2.8.5 Salvage value

The salvage value is defined as the difference between the scrap value and the decommissioning cost of the entire scheme at the end of the lifetime adopted for the economic analysis.

If the adopted economic lifetime, n, is less than the assumed technical lifetime of the wind turbine, the salvage value should be a positive value reflecting the capital value of the total wind power installation after n years of operation.

Note that even if the adopted economic lifetime is set equal to the assumed technical lifetime of the wind turbine, the salvage value of the total investment may not be zero, as land, electrical cables, etc. may have a significant capital value.

2.8.6 Economic Lifetime

The actual technical lifetime of a wind power installation depends on numerous factors, and it may in fact be very difficult to predict.

Modern electricity producing wind turbines are commonly designed to have a life of 20 years, and normally a 20 year economic life can also be assumed.

The economic life should not be set to a value which exceeds the technical life of the wind turbine.

It should be noted that the economic life as described in this document is a parameter that can be set by the analyst. It should not be confused with other parameters such as the possible loan payback period.

2.8.7 Discount Rate

The discount rate, r, given in real terms may be defined as the rate at which the nominal rate, *i*, exceeds the inflation rate, *v, i.e.:*

$$1 + \mathrm{r} = \frac{1+i}{1+v} \tag{2.16}$$

The choice of the numerical value for the discount rate must be decided by the relevant country, utility, developer etc. and may reflect the cost of financing the project, the possible earned return of an alternative investment or the opportunity cost of capital, the project risks, or any policy objective or constraint.

The following points should be noted:

1. The levelled production cost of energy will be higher for a higher discount rate and lower for a lower discount rate.
2. If the energy is sold at the calculated levelled production cost, the project costs and income will balance each other and the internal rate of return will be equal to the assumed discount rate.
3. An increased discount rate will reduce the economic attractiveness of projects with high investments and low running costs compared to less capital intensive projects.

International studies of electricity generation costs often adopt 5 to 7 % as the annual discount rate in real terms, whereas private investors investigating commercial projects may adopt higher values. In general, it is recommended that an analysis is carried out to determine the cost of energy sensitivity to the discount rate.

2.8.8 Wind Energy output

Measured values give actual achieved operational statistics and production costs per kWh. Single "spot" measurements (e.g. one year of production figures) should however be used with care for calculation of the levelled production cost, as they can be significantly biased compared to the levelled lifetime figures.

The following sections consider single wind turbines only. The utilised energy output of a wind power plant consisting of more wind turbines can be estimated either by treating the plant as a single large wind turbine, or it can be found by summing the individual utilised energy output estimates of all the wind turbines in the wind power plant.

2.8.9 Potential Energy Output

The annual potential energy output, E_{pot}, of a wind turbine experiencing specific meteorological conditions is given as:

$$E_{pot} = 8766 \cdot \int_0^{\infty} p(u) \cdot f(u)du \tag{2.17}$$

Here, 8766 is the average number of hours in a year, p(u) is the power curve of the wind turbine, and f(u) is the normalised wind speed probability distribution at the hub height of the wind turbine. Often, the wind speed probability distribution is expressed by a Weibull or Rayleigh distribution.

The wind speed distribution should ideally be based on many years of on-site wind speed measurements, but in practice it will often be necessary to extrapolate long term wind data from nearby high quality measurement stations, using for instance the wind atlas method as embodied in the European Wind Atlas.

The power curve normally gives the net power output for standard air density conditions (i.e. 15°C and 1013.3 mbar) and for carefully selected weather conditions (e.g. absence of precipitation). When calculating $E_{pot,i}$, corrections must he made for actual atmospheric conditions at the specific site.

For a stall regulated wind turbine, the power curve can be approximately adapted to the actual site by applying the formula:

$$p(u) = p(u)_{std} \cdot \frac{\rho}{1.225} \tag{2.18}$$

Here $p(u)_{std}$ is the power curve for standard conditions and ρ is the actual annual average air density in kg/m^3. The standard air density is 1.225 kg/m^3.

2.8.10 Wind Turbine Performance Factor

The performance of a wind turbine may be reduced dramatically due to dirt, rain or ice on the blades. If the site conditions are likely to give such problems, then either cleaning of the blades must he included in the O&M costs or a reduction in the annual energy output relative to the potential output must he assumed. This reduction in the annual energy output, can he expressed by the performance factor, $K_{per,t}$, defined as the ratio of the reduced annual energy output and the annual potential output:

$$K_{per,t} = 1 - \frac{\Delta E_{per,t}}{E_{pot}} \tag{2.19}$$

The performance factor may change over time due to turbine wear, and changing seasonal climatic conditions.

2.8.11 Site Factor

The wind speed distribution assumed for calculating the potential energy output should be the wind speed distribution at the hub height of the wind turbine. In some cases however, the site surroundings may change with time due to the erection of new wind turbines, tree planting, construction of new houses, etc. thus influencing the wind speed distribution and energy output from the wind turbine. In such cases, it may be adequate to take the assumed annual potential energy output, E_{pot}, and then apply a site factor to take account of the reduction in annual energy output, $\Delta E_{site,t}$, due to the changed surroundings. The annual reduction may be expressed by means of the site factor, $K_{site,t}$:

$$K_{site,t} = 1 - \frac{\Delta E_{site,t}}{E_{pot} \cdot K_{per,t}} \tag{2.20}$$

2.8.12 Technical Availability Factor

The technical availability, $C_{ava,t}$, of a wind turbine is defined as the fraction of the year the wind turbine is ready for operation:

$$C_{ava,t} = \frac{8766 - T_{out,t}}{8766} \tag{2.21}$$

Here, 8766 is the number of hours in an average year, $T_{out,t}$ is the total annual scheduled and forced outage time of the wind turbine.

The resulting technical availability, $C_{ava,t}$, may in general depend both on the wind power installation and on the connected system, e.g. a grid connected wind turbine will shut down in the event of an external grid failure. In such cases, it is often adequate to specify the technical availability of the wind turbine and the connected system separately, and to estimate the resulting technical availability, $C_{ava,t}$, as the product of these two availability factors. It should be noted that for large modern power systems, the grid availability may be very close to 1, whereas for smaller rural grids, the availability will typically be lower.

The technical availability factor, $K_{ava,t}$, assumed by this document is defined by the energy loss, $\Delta E_{ava,t}$, due to the wind turbine availability:

$$K_{ava,t} = 1 - \frac{\Delta E_{ava,t}}{E_{pot} \cdot K_{per,t} \cdot K_{site,t}} \tag{2.22}$$

$K_{ava,t}$ may be different from $C_{ava,t}$, e.g. if the wind turbine servicing is scheduled during calm periods, $K_{ava,t}$ will probably be higher than $C_{ava,t}$.

2.8.13 Net Energy Output

The annual net energy output ($\mathrm{ANE_t}$) is the annual energy output at the wind turbine terminals:

$$\mathrm{ANE_t} = \mathrm{E_{pot}} \cdot \mathrm{K_{per,t}} \cdot \mathrm{K_{site,t}} \cdot \mathrm{K_{ava,t}} \tag{2.23}$$

2.8.14 Electric Transmission Losses Factor

The annual electrical transmission loss, $\Delta E_{los,t}$, is the difference between the wind turbine net energy output and the transmitted net energy fed into the point of public utilisation.

The annual electrical transmission losses may be expressed as a factor, $K_{los,t}$:

$$K_{los,t} = 1 - \frac{\Delta E_{los,t}}{ANE_t} \tag{2.24}$$

An estimate of the annual electric transmission losses may be based on the annual wind power distribution and specifications of the site transmission system. It is important to know the actual net wind power distribution as the transmission losses will be a function of the square of the net wind turbine output power. The wind energy electric transmission losses occur between the wind turbine and the grid where the wind energy is utilised.

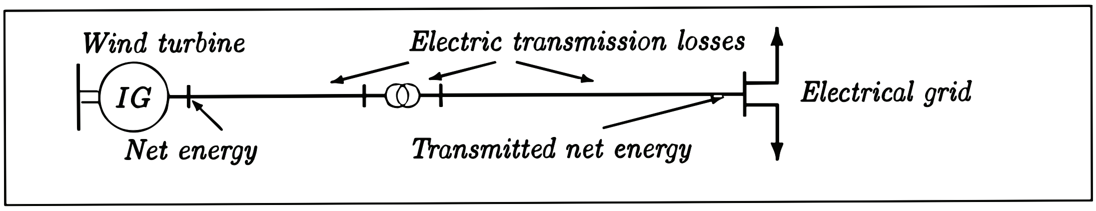


Figure 31. Example of the electrical grid connection of a wind turbine (Tande 1994: 14).

2.8.15 Utilisation Factor

In most cases, the transmitted wind energy ($ANE_t \cdot K_{los,t}$) will be very close both geographically and numerically to the wind energy utilised in the connected system (AUE_t), see also figure 31. However, in certain cases there may be a substantial difference, and the utilisation factor is defined to take account of such cases:

$$K_{util,t} = 1 - \frac{\Delta E_{util,t}}{ANE_t \cdot K_{los,t}} \qquad (2.25)$$

2.8.16 Utilised Energy

The annual utilised energy, AUE_t is the wind energy output utilised in the connected system. The AUE_t may be estimated for each year of the wind turbine's lifetime by assuming the potential output, E_{pot}, and the year specific factors $K_{per,t}$, $K_{site,t}$, $K_{ava,t}$, $K_{los,t}$ and $K_{util,t}$.

(2.26) $$AUE_t = E_{pot} \cdot K_{per,t} \cdot K_{site,t} \cdot K_{ava,t} \cdot K_{los,t} \cdot K_{util,t}$$

(Tande & Hunter 1994: 5–15)

2.9 Summary

This research belongs to the branch of Industrial Management and therefore it is handled from an economic and business strategic point of view. The theoretical framework is based on Porter’s reference: strategic benefit. As mentioned in chapter 2.1, differentiation into an environmentally friendly energy supplier is chosen and there the cost leader position will be selected.

In the grow / market share matrix ”green electricity” could be a question mark (Figure 5). Time will tell if it will move to a star. Today building wind power stations locates onto high growth in the matrix. This research is particularly concerned with building the foundations of these power stations.

Are the Porter (1980) doctrines that were developed during a period of steady growth in big companies in the USA still valid today? For the company manager, whose concern it is to earn money and not to lose it, Porter’s doctrines become less relevant immediately. Those doctrines are better suited to already existing products. For new, untried products in an unstable market, Porter’s theories have limited application.

After strategic selection come the wind and the energy from wind. The wind and wind speed are like the fuel in other power stations. The wind is free but the harnessing of the wind is not free. To harness the energy of wind needs investment of large amounts of money.

Wind power is moving offshore. The reasons are obvious: better wind conditions and places for power stations. In this research we examine how to build cheaper foundations, transportation and erection to product cheaper wind electricity.

Calculating the cost of €c / kWh or € / MWh will not be possible until the true costs of wind power plant and electricity production are known.

As mentioned at the beginning of Chapter 2 the research of wind power ”green electricity” needs the input of many different branches of science. Marketing, economics, meteorology, aerodynamics, steel construction, electricity- and offshore technology are among those which are required for success.

In Appendix 15 cost data from offshore wind power plant components are collected. In the literature there is relatively little cost information. The existing information is rather conflicting. In addition there are costs of changing currencies from country to country in different years.

3. CONSTRUCT

Between 2008 and 2012 there should be a reduction in carbon dioxide (CO_2) emission in EU countries of 600 million tons per year. To compete as an electricity producer among the others and to obtain competitive benefit the strategy that could be selected is *differentiation into an environmentally friendly energy producer* (Chapter 2.1). If the selection is made for wind power, a second strategic decision could be made to be a *cost leader* among the other competitors producing electricity without carbon dioxide emission.

This construct tries to be a solution to the problem. The problem is mentioned above, how to be the *cost leader* among other electricity production methods with no carbon dioxide emission.

The theoretical relevance to the problem is described in Chapter 2. The practical functionality of the solution is not yet verified in practice but the method WPOSFOLES (Wind Power Offshore Steel Foundation Optimisation and new Logistic- and Erection System) has obtained a Finnish patent and an international PCT application has been submitted (Appendix 1).

The theoretical contribution of the solution is the method of how to be *cost leader* among other non-emission electricity producers and how near to the price of water power the wind power price can become by using new methods.

The research approach is *constructive* because this research includes large *empirical* measurements, practical solutions to evaluate measurements of the needed values and real construct and methods to erect offshore wind power plants (Kasanen et al. 1991: 317). According to Olkkonen (1993: 44–45) this research is *normative* in trying to find results which can be used according to the aims of design science to develop new and better activities or plans. The criterion of the research methods and results is the emphasised benefit, the achieving of which has to be indicated.

3.1 Investment

The trend in wind power is to go offshore. Better wind conditions often produce in the same size of plant 50 % more energy compared to plants on land. Developed countries are short of places for wind power plants and limit the hub height and rotor tip speed to reduce noise. On land transport of the biggest power plants is limited because of wing length. Crane capacity limits tower erection and lifting the engine room (nacelle) on to the top of the tower. Therefore the trend is to go offshore.

The investment cost of a wind power plant onshore consists of the turbine itself, the building of a road, a base, a transformer, joining to a net and, in addition, in the planning of the whole project. Other costs are also calculated. Offshore constructs do not need a road to the plant but the offshore base and erection is different. The offshore turbine foundation must lie on the sea bottom and keep the tower vertical and in position against wind, sea current, fatigue load, bottom erosion, waves and possibly ice.

Subsidies are not considered in this research because subsidies are different in separate countries and are decreasing for the time being. In this research the intention is to limit the study to physical and economic phenomena. However, the wind power selling price does depend strongly on subsidies.

3.1.1 Wind Power Plant

A part of this research construct is to clarify the total price of wind power plant including foundation, erection and joining to the net near the town of Vaasa in Finland. Therefore tenders were invited for 1 MW size plant from nine wind power plant manufacturers. The tender invitation was divided into two sections

- Onshore power plants
- Offshore power plants

Four manufacturers sent a tender in time. These four represent the biggest part of the market. There were three Danish mills and one German one. All have been in production for some years. The power range is from 1–1.65 MW. The rotor diameter varies from 54 m to 66 m and the tower height from 45 m to 67 m (up to dated tenders power range is from 1.5 to 2.5 MW and rotor diameter from 65 to 80 metres). For the onshore solution there is included transportation, erection by a nearly 1000 TON capacity crane, remote control, training, additional equipment and service for a 2 year warranty period.

3.1.2 Offshore Power Plant Foundation

The reason why the whole wind power production is not yet offshore is the price of:

- The concrete caisson foundation or alternatively
  The mono pile type rammed into the seabed
- The offshore crane day rate for lifting the tower, engine room and rotor
- The long distance cabling into the seabed
- The operation and maintenance

The construct selection started from many possibilities from a quite small foundation using the weight or pressure of water. In practise the foundation will be fixed watertight to the sea bottom. This is possible on a rocky or a concrete area and smooth bottom so that the foundation can be fastened like a suction pad to a window. This was rejected because the sea bottom seldom has the required conditions and because of the need for watertight control.

A second idea was to raise the ready assembled wind power station with the help of a barge and levers as well as wires. This is complicated technically and therefore economically impossible.

A further idea was to fill the tower with water to get more load to keep the turbine vertical with a smaller and cheaper foundation. The negative point is that the centre of gravity rises and on a sandy or weak bottom there is a greater possibility that the turbine will fall down (this possibility is also in Appendix 1).

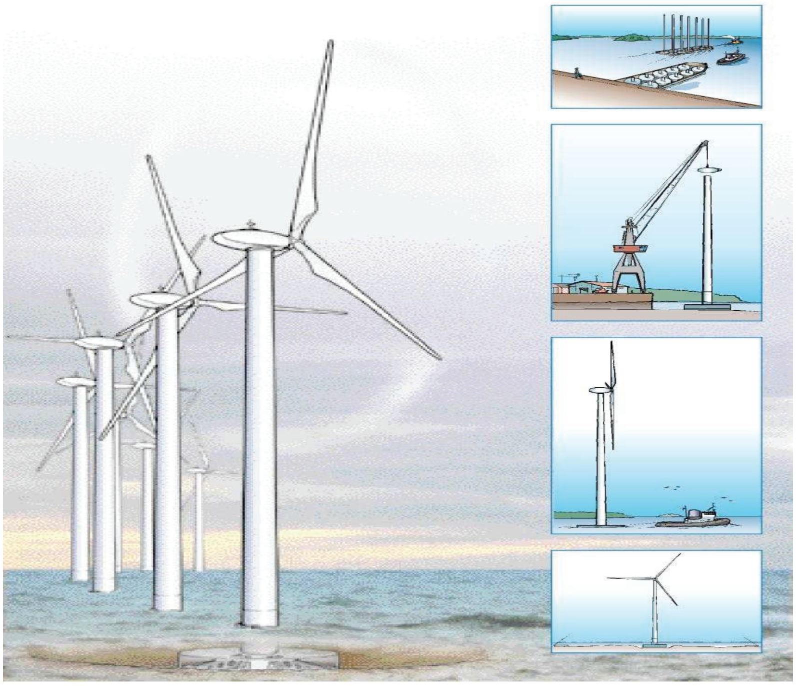


Figure 32. The selected idea for offshore wind turbine and foundation (Satagrafia 2001).

Figure 32 shows the selected offshore turbine and foundation (Figure 24a). The construct optimises the given 20 parameters preserving the features, and minimises the cost by maintaining:

- A sufficient bending / holding moment
- A sufficient floating features

In this construct the foundation material is steel. This facilitates:

- building the foundations round the world and transporting them with barges (small picture top right corner)

- floating the foundations to the assembly place, for example a yard, harbour, etc.
- lifting the tower, engine room and rotor onto the top of the tower by crane on land (next picture down)
- floating the ready-assembled wind power plant to the site (next picture down)
- sinking the foundation and anchoring the power plant to the sea bottom at the site with assistance ropes or wires at the top and bottom of the turbine keeping the turbine upright during the sinking procedure (bottom right corner)
- in the case of bigger service or repairs, the possibility of towing the power plant back to the harbour.

The selected idea must be very simple for it to be economically viable. The idea is presented in Appendix 1 and Figure 33 (patent FI 107 184). Another development is a collar to protect against possible ice. Inside the foundation bottom is ballast, e.g. concrete. To minimise the amount of steel, the ballast is used as part of the stiffening element.

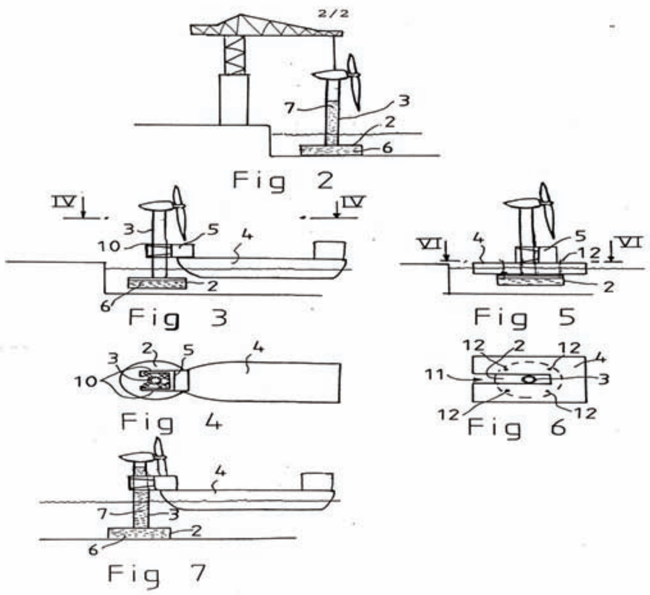


Figure 33. The selected idea for offshore wind turbine and foundation (a patent principle drawing).

In Figure 33, Fig.2 (number 2 presents foundation, 3 the tower, 6 and 7 are ballast tanks) is presented the assembly work in the harbour. It is possible that the turbine stays on the bottom of the harbour during the work (in practice a mobile crane is needed to reach about 100 m lifting height). An example of alternative technical details are also presented in Figure 40. In Fig. 3, 4 and 7 (number 4 presents transport vessel, 5 gripping device) there is a second alternative: a gripping device keeps the turbine upright during the transportation and sinking operation. The foundation keeps it floating and the gripping device allows movement up and down. In Fig. 5 and 6 (numbers 4, 11 present modified barge and 5 gripping device) there is a third alternative: a barge with a link keeps the foundation fixed to barge. In the sinking operation the steering device keeps the turbine upright.

The main benefit is to avoid using an offshore crane and assistance fleet on all three alternatives. The foundation cost is about three offshore crane days. The crane can operate only in summer time and on those days only 50 % of the time (Statement of Håkans 2002). The day rate will be charged for all days. The second benefit is that all the work will be carried out on land and not at sea. The negative point is for the first alternative the growth of the foundation diameter required to stay upright during the towing operation. In a alternatives II and III the foundation diameter is only the diameter needed to stay on the sea bottom. The negative points are the need for a special gripping device for the ship or special barge for transportation from harbour to site.

Oil rig foundation development is perhaps 20–30 years ahead of wind power plant foundations. The first oil was drilled on land, then the drilling happened in shallow water, then in deeper waters over 100 meters deep. After this come floating devices over waters of several hundred meters in depht. Today the drilling water depth is up to 2–3 kilometres. The foundations on the sea bottom are of the same 3 main principle foundations as in chapter 2.6.1. An alternative could be the “jack up” type with floating hull and jacking devices to lift the hull above the sea surface. There seems to be in the future also the possibility of floating wind mill foundations.

A mono pile alternative (Figure 24c) was rejected because the cost of foundation and assembly 0.7 M€ / 1.5 MW (Table 8 Bockstigen) and no possibility to move after installation without heavy cranes. The mono pile type only suits a certain type of sea bed.

3.1.3 Transport and Erection

Currently one of the main costs of offshore wind power is the use of offshore cranes. The caissons, tower and engine room with hub and wings are transported to the site by barge. The offshore crane lifts first the caisson or it can also be floated. When it is ready at the site on the sea bottom the tower and engine room are lifted. The offshore crane use is very costly. The anticipated downtime is 50 % during the summer months (May-August). The cost of hired equipment is in size range of 1 MDkk/24h (Morgan & Jamieson 2001: 2–32).

In this construct the wind power plant is totally ready assembled in the harbour, yard or workshop on shore. The foundation keeps the power plant floating and vertical or a modified barge or ship keeps and transports the wind power plant vertically to the site. The power plant floats with his own buoyancy. On the site the base will be filled with water and the plant sunk into shallow water (a depth of 5–15 m) to the sea bottom. One alternative possibility is a telescopic tower. Normally the tower is conical. In this solution there are for example 3 x 20 metre columns. The nacelle is in the transport mode at a height of 20 metres.

3.2 Operation and Maintenance

When the wind power park is sufficiently big it is economically possible to employ people to operate and maintain the turbines. If a turbine component is broken, normally the service people try to use the power plant’s own crane to lift the broken component out for repair or service. If this does not help they have to use an outside crane. This is costly.

This construction method allows you to take the whole power plant to the harbour routinely. Service and repair is possible at a lower cost in the harbour or yard than out at sea.

3.3 Production

An assisting construct is in the field of natural science: wind measurement and method for transferring the measured results from place to place and at different heights. The measurement takes place at a site where measurement is possible and the results are transferred higher and to the place where no measurements are possible. The wind energy price consists mainly of the investment cost, operation and maintenance costs and wind conditions. Wind conditions differ between places onshore and offshore.

3.3.1 Wind Conditions On- and Offshore

The first measurement was taken in Pori on an island 1,5 km from the nearest point of land, 1.5.1994–30.4.1995 (Rinta-Jouppi 1995). The idea was to compare the wind speeds and electricity production in two separate places. On the breakwater there is a 300 kW wind turbine with a hub height of 30 m, and about 5 km to the North West on the island of Kaijakari a measuring mast measuring wind speeds and directions at the same 30 m height level.

Between 9.1997–11.1998 the second measurement was made 15 km north of Vaasa on the island of Fjärdskäret with a 35 m mast and a third one 35 km south west of Vaasa on the island of Bergö with a 40 m mast (Rinta-Jouppi 1999).

3.3.2 Conversion from Wind to Electricity Energy

All commercial wind power plants have their own power curve measured by the authorities. It shows the produced power with different (normally 4–25 m/s) wind speeds. (Rinta-Jouppi 1999) On other hand the wind speed conditions will be measured for instance by anemometers, wind direction vanes, temperature sensors and air pressure sensors. The last two are needed to calculate power in the equation

$$P = \frac{1}{2} * C * \rho * A * v^3 \tag{3.1}$$

where P is power, C is efficiency coefficient, ρ air density, A rotor swept area and v air speed. To calculate ρ the temperature and air pressure values are needed. The 2–3 anemometers at separate heights are needed to analyse wind speed at the hub height. Wind direction vanes are needed for wind direction analysis. The 1 hour mean wind speed is calculated by adding the corresponding power ranges of the 1 hour mean wind speeds. It means adding 1 hour energies in the measured period.

3.4 Summary

The construct research approach consists in this case of the details of steel foundation, new logistic model of how to build, assemble, float and repair, if needed, the offshore wind turbine cost effective and optimisation spreadsheet program (WPOSFOLES, Wind Power Offshore Steel Foundation Optimisation and new Logistic -/ Erection System, Appendix 1 and Figure 32).

The assistance construct consists of offers of turbine prices, estimates of other needed prices, wind speed and direction measurements. To calculate the wind electricity price the main components are, according to Figure 33, investment cost, interest rate, lifetime, operation & maintenance costs and mean wind speed.

A sensitivity analysis, Appendix 2, where all wind price effecting components are multiplied from 0,4 to 1,6 shows that by far the most effecting component of the kWh price is the mean wind speed. This must always be kept in mind when the location for a wind power plant is being looked for.

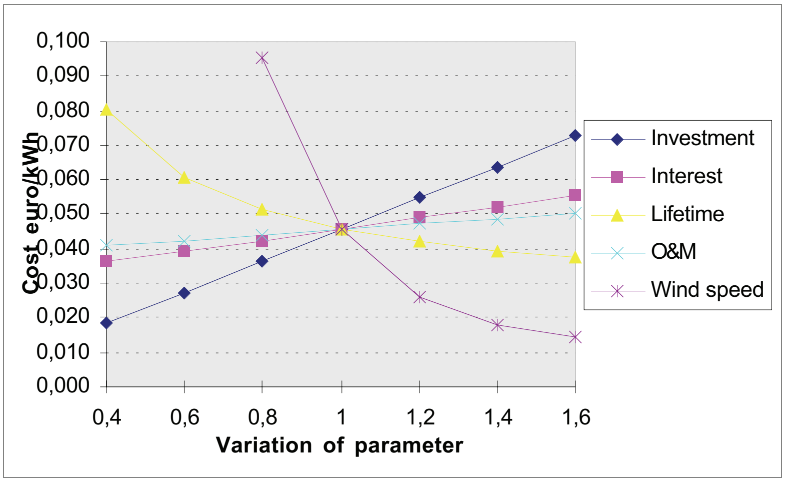


Figure 34. Energy cost as a function of selected input parameters (note that commas are used decimal points not dots).

Figure 34 shows the Vestas 1,65 MW turbine, in the measuring place of Fjärdskäret, with energy cost as a function of selected input parameters. These input parameters are Investment, Interest of Investment, Lifetime of the Investment, Operation and Maintenance Cost and mean Wind Speed (the corresponding power curve from the mean wind speed from a wind mill perspective, Appendix 2).

Among other things it can be seen that if the mean wind speed is 20 % less than estimated the effect on the energy cost is the same as if the investment cost were double. The same result is verified in the literature (Tammelin 1999b: 23).

The Construct is the solution to the problem (Figure 3). There is a wind electricity price too high to be of practical relevance to the problem.

A theoretical relevance to the solution could start from Porter's thesis and continue to the wind properties with measurements. The movement to the sea of wind power and expensive foundation costs including erection work of the whole wind power plant starts theories of cheaper solutions. If the solution is competitive, it will have a theoretical relevance, too.

The practical functionality of the solution is not yet to seen but a scale model, patent, calculations, fabrication negotiation and weak marketing test show a positive result.

The contribution of the solution is to decrease the offshore wind power price, which has great significance in the electric power market.

4. RESEARCH METHOD AND APPRAISAL CRITERIA

4.1 Wind Condition Measurement On- and Offshore

The wind measurements were made with NRG Systems Inc., a wind energy resources measuring system. The measuring was made with two masts. There is a 30 and 40 meter high steel pipe mast with fourfold gay wires. The system includes 3 (2) wind speed and 2 wind direction sensors and one temperature meter per mast at several height levels and on the logger unit. The measuring unit takes samples of wind speed, -direction and temperature. These values will be calculated to hour mean values in the logger unit. The logger unit saves the calculated hour mean values in data storage. The data storage is read about once a month and run on a pc computer. The computer has a program which converts the raw data into monthly reports and several graphics. In addition a very important feature is that it is possible to handle the data with spreadsheet computation (Appendix 3).

One calibrated wind speed sensor is on the highest level. The measurements must be kept reliable. The wind is blowing differently in different years. The uncertainty of the collected data is how windy the measured year is, compared to other years. Therefore the measuring period is to be compared to a neighbourhood measuring station over a period of 30 years average (Table 13). The other uncertainty is the anemometer value at the 30 or 40 meter level compared to conversion to the power plant hub height at about 60–80 meters.

4.1.1 Clarification of Wind Conditions in the Pori Region

The measuring arrangement consists of a 300 kW wind mill at the Reposaari breakwater near the fish harbour and a measuring mast at a 5 kilometre distance to the North West on the island of Kaijakari. The intention is to compare at the same moment the energy produced by the wind mill and the measuring mast wind speed converted to energy. The measuring height and wind mill hub height are at the same 30 meter level.

The conversion from wind speed data to corresponding wind energy data is made with the wind mill power curve values (Appendix 4).

The Danish 300 kW windmill was assembled in a closed workshop in Mäntyluoto. The windmill was erected on the breakwater. Before the measuring period the measuring mast was erected 100 meters south of the wind mill to test the anemometer sensors. The wind mill and measuring anemometers were at the same 30 meter height level (Rinta-Jouppi 1995: 17).

The island of Kaijakari is located 1.5 kilometres south of Tahkoluoto deep water harbour and about 27 kilometres north west of the centre of Pori. The mast was measured from 26.4.94 to 10.5.1995. The windmill is sheltered from north winds by a forest and Reposaari houses but at the same time the Kaijakari measuring mast is open to north winds. To the east there are wind obstacles at a 3 kilometre distant causeway and the Reposaari forest and houses shelter the measuring mast. To the south of the windmill are obstacles in the form of the Kallo pilot house and Mäntyluoto houses but south of the measuring mast is open ground. Both measuring points in a westerly direction are also open (Appendix 4).

The measuring of energy was also carried out with the so called ”Procoll” energy measuring method. It meant that the company ”Fortune Energy Oyj” read the wind mill production data through a modem. The windmill computer data and ”Procoll” measured data are compared to confirm that the windmill given data is correct. (Rinta-Jouppi 1995, in that Appendix 10.2–10.14).

4.1.2 Clarification of Wind Conditions in the Vaasa Region

A measuring mast was erected at Fjärdskäret near the Raippaluoto bridge, 15 km north west of Vaasa (Appendix 5). The mast was measured from 5.9.1997 to 31.10.1998 on the land side of the bridge. The measuring was carried out by an American NRG:n produced 30 meter measuring mast. At the top of the mast a 3 meter piece was added. The height level of the top wind speed and direction sensor was at a height of 35 m above the sea level and the other sensors at a height of 20 meters.

In addition there is a logger unit. The wind condition data are collected in the integrated circuit memory. The circuits are changed about once a month. The circuits are read through a special reader on to a personal computer. The computer processes the raw data into results and also graphics (Appendix 3).

The measuring location is about half a kilometre from the road at the northern tip of the cape. The place is open to the north, a few islands are about one kilometre away. To the east there is land at a distance of some kilometres. To the south the wind speed is limited by a forest and at half a kilometre distance by a raised road. To the south west there is the bridge with 82 meter high pylons. To the west is Raippaluoto island. Along the road there is a 20 kilovolt electric net (Rinta-Jouppi 1999a, in that Appendix 1).

The other measuring mast was erected on the island of Bergö, 30 kilometres from Vaasa to the south west. A 40 metre mast produced by a NRG was erected in the fish harbour from 21.11.1997 to 26.11.1998. The mast was equipped with wind speed and direction sensors at levels of 40, 30 and 20 meters (Appendix 5).

The location of the mast is at the end of the road in the new fish harbour. The place is open to south and west winds. To the north is a forest 300 meters away and to the east about one kilometre away. A 20 kilovolt net comes into the fish harbour. The net distance from the fish harbour to the transformer station is 32 kilometres (Rinta-Jouppi 1999a, in that Appendix 2).

4.1.3 Reference Measurements in the surrounding Area

At the same time automatic stations fixed by the Finnish Meteorological Institute were measuring. These stations are situated as follows: at Strömmingsbåda, 19 kilometres to the west, and at Bredskäret, 6 kilometres to the south east of Bergö fish harbour. The Valassaari island synoptic station measures the wind conditions every third hour. It is situated 53 kilometres to north east of Strömmingsbåda and 33 kilometres north west of Fjärdskäret (Appendix 5).

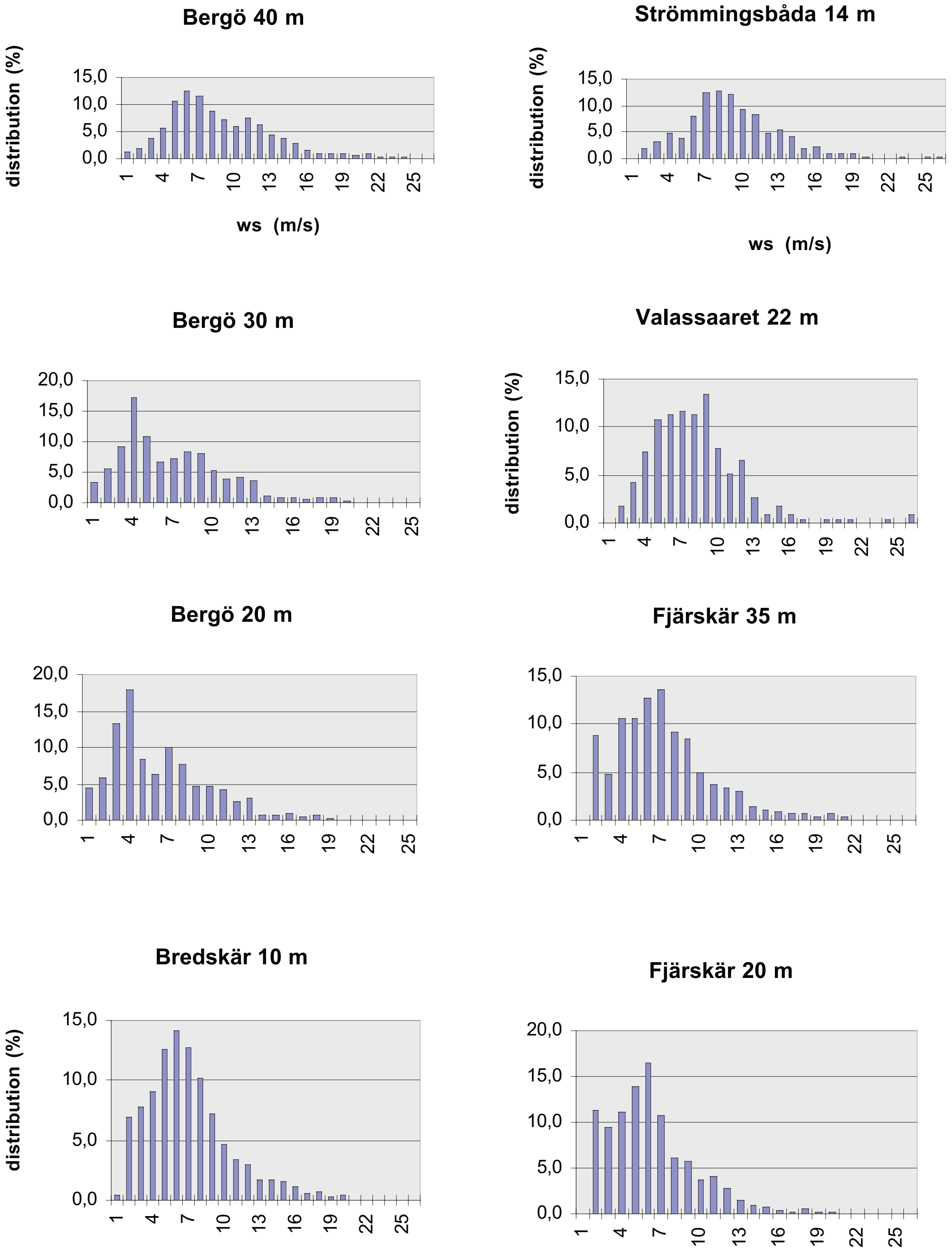
The reference measurements were made between January and July 1998. In table 14 the measurement points are in order of rising height. The measurements are not directly comparable because of the different anemometer height levels and the wind obstacles at the measuring places. But it gives in any case a general view of the winds which are prevailing in the Vaasa archipelago area.

In Table 13 and Figures 35 and 36 (wind conditions January 1998) the energy production calculation uses Vestas 1.65 MW power values (Appendix 9). The values came from a matrix (Surrounding.January98 and Surrounding.July98) of 746 rows (Bergö) date, hour, ws_{40} (wind speed on 40 m height), δ_{40} (standard deviation on 40 m height), ws_{30}, δ_{30}, ws_{20}, δ_{20}, wd_{40}, wd_{30}, T (temperature at 3 m height), E_{40} (energy at 40 m height), v_{i40} (integer for ws_{40} compatible with Appendix 9. Wind turbine characteristics: wind speed / power values), E_{30}, v_{i30}, E_{20}, v_{i20}, (Fjärdskäret) date, hour, ws_{35}, δ_{35}, ws_{20}, δ_{20}, wd_{35}, wd_{20}, T, E_{35}, v_{i35}, E_{20}, v_{i20}, (Bredskär) date, time, ws_{10}, gust, wd_{10}, E_{10}, v_{i10}, (Strömmingsbådan) date, time, ws_{14}, gust, wd_{14}, E_{14}, v_{i14}, _, (Valassaaret) place code, year, month, day, hour, wd_{22}, ws_{22}, gust, E_{22}.

Table 13. Measured wind speed values and energy production.

Observation	Month	January 98	July 98	January 98	July 98
Place	Height	v (m/s)	v (m/s)	MWh	MWh
Bredskär	10 m	5.94	5.04	228	123
Strömmings	14 m	8.22	5.58	422	179
Bergö	20 m	6.08	4.90	249	137
Fjärskäret	20 m	5.20	4.34	173	(76)*
Valassaaret	22 m	7.27	4.21	315	74
Bergö	30 m	6.76	5.25	305	157
Fjärskäret	35 m	6.16	5.23	248	(144)*
Bergö	40 m	7.68	5.66	380	190

* Measuring period 15.7–31.7.1998



Bergö 40 m

Strömmingsbåda 14 m

Bergö 30 m

Valassaaret 22 m

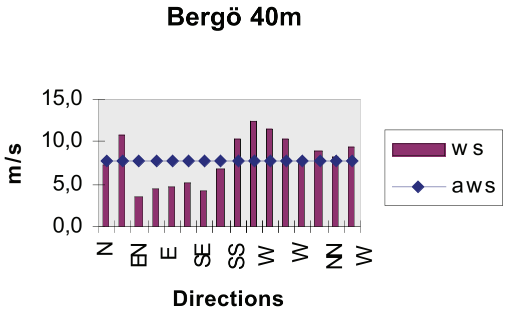
Bergö 20 m

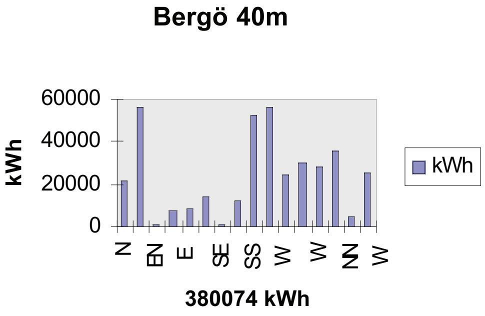
Fjärskär 35 m

Bredskär 10 m

Fjärskär 20 m

Figure 35. Wind speed distribution at several measuring points January 1998.


Bergö 40m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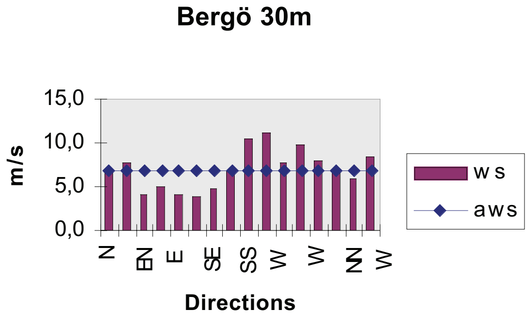
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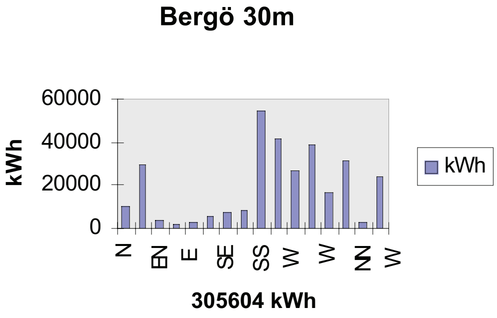
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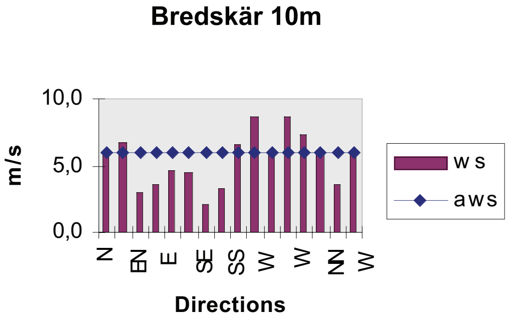
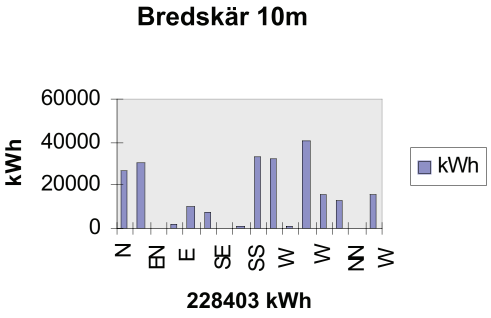
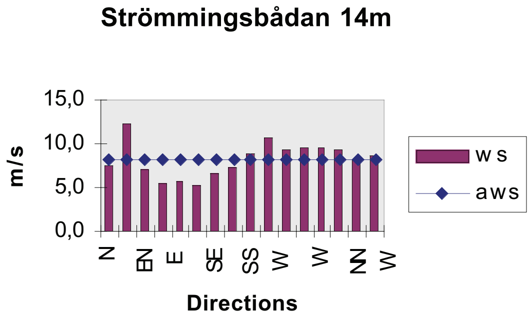
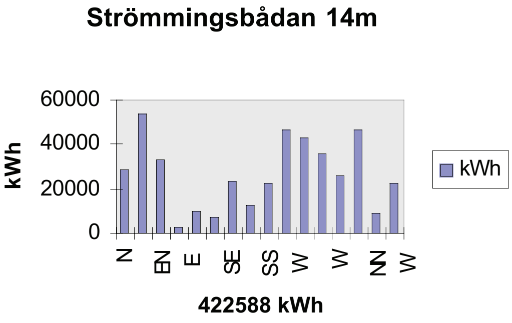

Bredskär 10m


Bredskär 10m


Strömmingsbådan 14m


Strömmingsbådan 14m

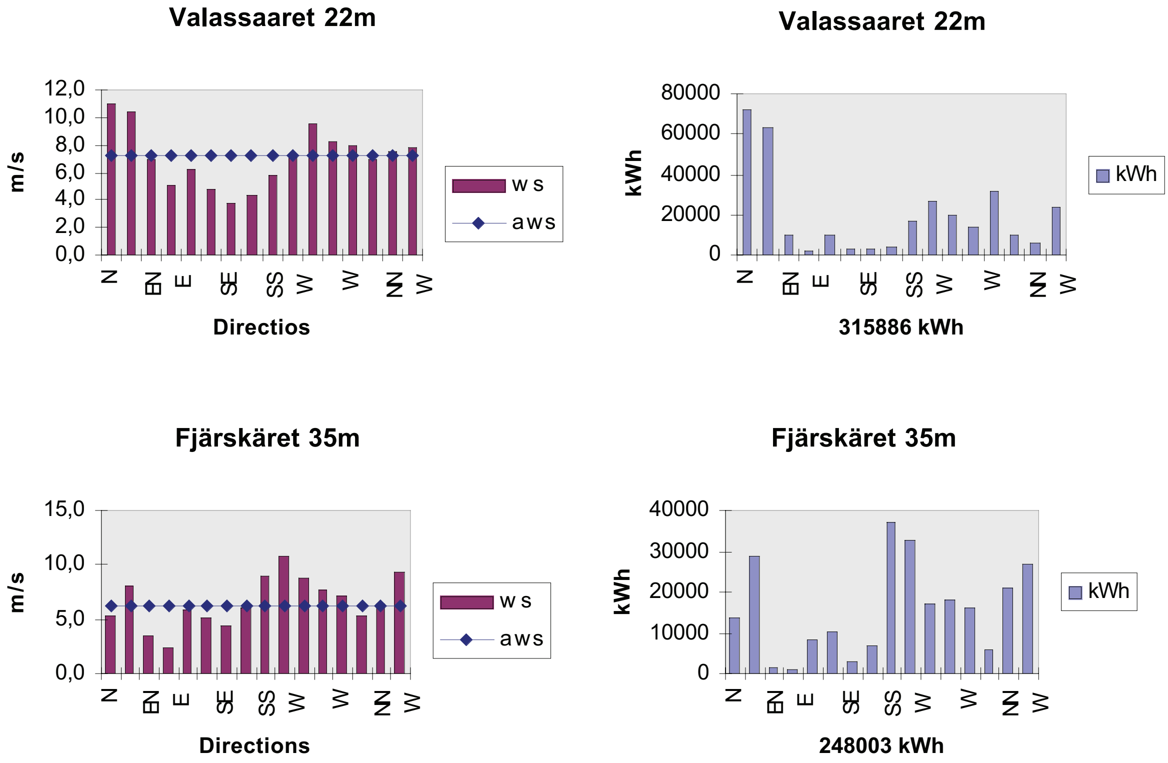


Figure 36. Wind directions / speed analysis and wind directions / energy production analysis.

Table 14. Reference values in Valassaari; wind speeds during 1961–1990.

Month	1	2	3	4	5	6	7	8	9	10	11	12	ave
1961–1990	7.1	6.8	6.3	6.0	5.8	5.6	5.3	5.8	6.7	7.5	7.9	7.8	6.6
10.97–9.98	7.3	7.0	6.2	4.7	5.2	6.4	4.2	5.4	5.8	7.0	6.4	5.6	5.9

In Table 14 on the lower row the mean wind speed values are at the same place and in the same month in the measuring year (10.97–9.98). In the measured year the wind speed was 0.7 m/s less than on a 30 year average, Appendix 5. The table shows the 30 year average wind speed for different months. The values on the lower row tell that the measuring wind year had not been as good as the average year. It means that better wind speeds and wind electrical production can be expected in the coming years at the measuring places.

4.1.4 Reference Measurements on Height Direction

The wind power plant hub height is at a higher level than the top height of the used measuring mast. Therefore formulas are used to convert the wind speed from measuring level to hub height. The formulas 4.1 and 4.2 are (Walker & Jenkins 1997) as follows:

$$v(h_2) = v(h_1) * (h_2 / h_1)^{\alpha} \tag{4.1}$$

where h_1 is reference height and $v(h_1)$ reference speed, h_2 is height, where $v(h_2)$ wants to be known and α is depending on the stability of the local climate, wind speed and roughness (Tammelin, B. 1991b: 152). The formula assumes that the wind speed increases exponentially by going upward to the higher level. The other formula is:

$$v(h_2) = v(h_1) \frac{\ln(h_2 / z_0)}{\ln(h_1 / z_0)} \tag{4.2}$$

h_1 and h_2 correspond to the preceding formula but z_0 (m) is roughness length. The term roughness length is the distance above ground level where the wind speed theoretically should be zero (Krohn 1998 http://www.windpower.dk/tour/wres/shear.htm).

The reference measurement place was one kilometre west of the Fjärdskäret measuring mast. The anemometer and wind vane were installed on top of a pylon on Raippaluoto bridge. The top is 83 meters high. The additional measurement took place during 10.5–15.7.1999 over a 1000 hour comparable measuring time. The other reason for the additional measurement is the wind obstacles to the south-west of the Fjärdskäret measuring place (Figure 35). Most energy comes from that direction (Rinta-Jouppi 1999a, in that Appendix 1).

The hub height wind speeds have been converted to power and integrated to energy during the measuring period. The same was done with the anemometer given values of Fjärdskäret at 35 meters. There were two comparable energies calculated at the wind power plant hub height and values were measured at the 35 meter height.

The wind speed is however always variable and the measuring period was only 1002 h. The ratio of the two energies was calculated. To obtain more statistically reliable results these two energy ratios were used to convert the whole measuring year (8869 h) energy (2.284.281 kWh/year) to the hub height energy of the windmill.

By using spreadsheet computation and 83 and 35 meter height wind speed data the α and z_0 (m) values were calculated. In the whole measuring period the mean wind speed at a 35 meter height was 5.6 m/s and the α and z_0 (m) values calculated the wind speed at 60 meters. The mean value between the two methods (exponent and natural logarithm) is 6.52 m/s (Rinta-Jouppi 1999b, in that Appendix 4).

The earlier corresponding calculation uses the data values of measuring mast anemometers at 35 and 20 meter heights. With the formulas 4.1 and 4.2 calculated α and z_0 values and with wind speed of 5.6 m/s at 35 meter height makes 6.52 m/s at the 60 meter height (Rinta-Jouppi 1999a, in that Appendix 18).

The difference between measurements with only the measuring mast and with the help of anemometers located on the pylon is 0.8 %.

The final appraisal regarding wind conditions is either Fjärskäret is a good or bad place for erection of a windmill? One criterion is the formed capacity factor C_f (the year's production divided by the year's hours and nominal power) compared to the other real wind power stations production, see Appendix 6.

4.2 Comparison of Windmill Power Prices

The windmill production cost according to Tande & Hunter (1994) includes the calculation method : LPC (Levelled Production Cost), where it is assumed that all costs are in a fixed currency and in the calculations all costs are discounted to the present value, i.e. the first date of commercial operation of the wind turbine. The bank interest for financing the investment is not considered, since in this concept the project is being assessed, not how it will be financed.

According to Grusell (1995: 52) there are two calculation methods. The first one is *the real calculation method*. This calculation excludes two important factors – inflation and the real increase in the price of electric energy. The second method is the *nominal calculation* method which illustrates the cash-flow during the economic life in a running value of money. In this method, consideration is taken of the nominal interest, which consists of inflation plus real interest. Consideration is also taken of an assumed real increase in the electricity price.

Walker & Jenkins (1997: 63–74) present the above methods and a comparison with other power plant costs. In this research all cost components of wind power production are considered. The calculation method is simplified by using real interest. That makes the calculation easier and in these economically turbulent times the bank interest and inflation are not predictable but the bank interest and inflation often follow each other (Statistical yearbook 1999: 250 and 387). The difference is a good estimation value. In this research the figure of 5 % real interest / year is used. The other simplification is to put the salvage value at zero. Technical development is so rapid that wind power plants from 1980 have nearly no value. Ten years old wind turbine costs round Dkk 100 000,- (list of statements and offer: Dansk Vindmölleformidling). The yearly income of wind power plant is not considered because the common electricity prices in the so-called ”NordPool” countries are not easy to forecast, on other words to state the right electricity price in the year 2020. Today the ”NordPool” electricity price follows the yearly rainwater amount in Norway and Sweden. The decision to invest in wind power will be made, however, by using the present electricity price and the wind power production cost.

In Appendix 7 the kWh prices are calculated. It is based on spreadsheet computation. Therefore it is easy to calculate with different initial values. The first prices come from offers and from up to dated version given by wind mill fabricators including prices for:

- Wind turbine ex works
- Transport to the site
- Erection cost

- Remote control equipment
- Training in operation and maintenance
- Accessories for the turbine
- Service for a 2 year guarantee

Additional costs come from the site work in the onshore case as follows:

- Site preparation work
- Wind turbine foundation
- Transformer to middle voltage
- Grid connection work
- Consultation services
- Land cost for wind power plant
- Roads to the site
- Other costs

Additional costs come from on the site work in the offshore case as follows:

- Foundation cost
- Transport
- Dock assembly
- Sea-bed research and preparation
- Site erection works
- Cabling
- Planning

4.3 New Foundation Construct, Logistics and Erection Development

4.3.1 Background

The three main objectives of new foundation construct development are: 1) to gain the offshore wind power market by technology development, 2) to reduce the installation costs of wind parks and 3) to make offshore wind power parks economically possible.

The above ideas make possible the construct presented in Chapter 3 and summary in Chapter 3.4. In this chapter the testing method will be presented and the result in Chapter 5.

The construct *technical testing* will be done with the Figure 29 and 40 spreadsheet calculation model, testing

- The sufficient bending / holding moment
- The sufficient floating features
- The centre of gravity
- The centre of buoyancy

and possibly

- The floating stability without external assistance (ship or barge) on the telescope mode

The construct *economical testing* will be done with the same Figure 40. The model calculates the price for every change of foundation construct. The logistic costs are tested through offers from companies which can carry out the logistic plan.

The construct *technology leader test* will be carried out by tenders from producers in the case. If the producer estimates that this construct is the technology leader in the growing market, it means the cheapest price and reliability of the whole construct. In other words the wind power producer or mill manufacturers will buy the foundation and logistics (List of statements and offers: Fagerström 2000).

The Reason for Offshore Development

Lack of suitable space on land, the difficulty of transporting even bigger and longer windmill parts by road and the price of the energy generated are among the bottlenecks which hinder the full exploitation of wind power. The solution for the space problem is to locate the turbine offshore. The solution for lowering the wind power price consists of three parts: 1. high local wind speed, 2. low price for the whole park investment, 3. low operation- and maintenance cost of the wind park. Offshore there is a 10–20 % higher wind speed, which produces as much as 50 % more energy. An innovative steel foundation for a wind power station, together with a logistic model including, erection and service of the plant will reduce the cost of construction to a new even lower level.

4.3.2 Scientific/Technological Objectives, Appraisal and Contents

The research objective is to develop and reduce the component, transportation and erection cost of offshore wind parks. The industrial problem to overcome is developing wind power offshore foundations, and the transportation, erection and service of wind power plants**.** The economic problem is to reduce the wind energy component cost compared to present day solutions.

A patent application WPOSFOLES (Wind Power Offshore Steel Foundation Optimisation and new Logistic- / Erection System, Patent FI 107184) is for the development a new steel foundation for power plants and new methods to transport, erect and service the new power plants.

How to estimate the offshore foundation, transport and erection market today? If half new wind power was built offshore, about 2000 MW world wide (2001) production multiplied by an installation price of about 1.5 million € / MW, of which the foundation, transport, erection and cabling is 40 % of the total investment, would result in the value of the market being 1200 million € / year (Bartelsheim & Frandsen 2001: 6–2). The wind power market grew 20–30 % / year during the nineties and it seems that wind power production will move offshore in the near future, see offshore planes 2001in Appendix 14.

The wind energy optimisation target levels in the EU are for installation costs 700 €/kW and for production cost less than 0,035 € / kWh. The cost target in this research on offshore conditions for total park investment is at the level 1000 €/kW and the production cost is less than 0,035 € / kWh (calculated with 5% / year, over a 20 year period, with operation and maintenance cost of 2 % of the total investment and a capacity factor C_f 0,342, this produces a figure of 1 million € x 10 % / 3000 MWh = 0,033 € / kWh). This production cost is the most crucial of the targets for energy prices. The installation costs, if meaning the total park investment, are typically higher than the EU targets. For example in Denmark, according to the Energy 21 plan the total investment for the parks is $ 7 billion for 4000 MW offshore power. The investment price thus comes to about 1750 € / kW (when 1 $ = 1 €). Horns Rev calculated investment 1990 €/kW (Krohn 1998 www.windpower.dk/tour/rd/offintro.htm).

The present wind power offshore parks use concrete caisson bases and mono piles installed on the sea bottom. Today's technical solution is to make the turbine ready in the factory, transport it to the coast and ship it to the site. The concrete caissons are cast in a ship yard. These are then lifted with big offshore cranes to the site on the sea bottom and filled with heavy mineral. With big (and very expensive) offshore cranes the turbines are lifted onto the caissons. In the mono pile case the piles are rammed into the sea bottom. The turbines are then lifted with offshore cranes or a jack up.

The limitations for today's solutions are the need to use expensive offshore cranes and to cast heavy and expensive concrete caissons. It is not practical to take the wind turbine back to the factory, for example, for repair work. In the mono pile case, additional lifting equipment is needed, too.

4.3.3 Value Added

The Kyoto objectives imply an 8 % reduction of greenhouse gas emission for the EU (corresponding to about 600 million tons per year CO_2 equivalent) between 2008 and 2012 (Savolainen & Vuori 1999). This means 250.000 1 MW wind turbines, if they compensate for the loss of coal power (0,8 CO_2 kg/kWh) and if these turbines are located in offshore wind conditions (C_f 0,342). The number of bases and turbines required is so huge that the production of wind mills is needed in several European countries. It means work for thousands of people. If the investment price for 1 MW is 1 million € and the average worker's annual salary with social costs or costs for the employer is 40 000 € / year, it means 6 250 000 working years for four years totally on the whole wind power industry, including subcontractor chains.

4.3.4 Economic Impact and Exploitation Potential

The measurable economic and industrial benefits are steel construction and development work opportunities for other organisations such as land transportation, offshore tasks and electric companies' work connecting the windmills to the state net, etc.

The strategic selections for business include three steps, according to Chapter 2, figure 4; to diversify to be a *green electricity* producer and from there to be a *cost leader* and further diversify to *foundation production*. The wind power world markets are in a phase of rapid development in appendix 14 and the volume of markets are one of the fastest growing ones. The contribution to this research could be the solution to produce cheaper wind power electricity.

The commercial strategy could be e. g. to find steel construction builders who have enough marketing experience and financing resources to put themselves into the offshore market. The business development could progress in a parallel way at the same time:

– product development (e. g. static -, dynamic – and fatigue load analysis)
  > all functions would be fulfilled as in Figure 32 for at least 20 years

- certification (DNV, Lloyds) > the insurance company is willing to insure
- production development (e. g. fabrication methods, corrosion protection, subcontractors, assembly and transportation) > the price of the product
- marketing development (e. g. mapping of market volume, price level, competitors) > the position of product in the offshore market
- marketing (e.g. fairs, exhibitions, seminars and above all to customer contacts)
- selling (there are only few customers therefore everyone could be contacted)

4.4 Operation and Maintenance

The operation and maintenance (O&M) costs are according to Krohn (1998 http://www.windpower.dk/tour/econ/oandm.htm) 3 per cent of the original turbine investment for older Danish wind turbines (25–150 kW) and for newer machines the estimates are around 1.5 to 2 per cent per year of the original turbine investment.

Most maintenance costs are a fixed amount per year for regular service of the turbine. Some people prefer a fixed amount per kWh which is today around 0.01 € / kWh. It means with a 1 million € per MW turbine investment, capacity factor (C_F 0.285) and money costs (5%/a, 20 years) 2.5 per cent per year of turbine investment.

O&M costs mainly related to the wind turbine can account up to 30 % and more of the energy costs. Leading wind turbine manufacturers have indicated that O&M costs, given 95 % availability warranties is about £ 30 000 per turbine per annum (Morgan & Jamieson 2001: 2–37).

In offshore conditions a boat or corresponding vessel must be used for service trips. Landing at the wind turbine site depends on the weather conditions. In any case if the service trips are twice a year, O&M costs can be calculated at the same level as onshore. But if it is a question of some repair and if an external crane is needed then the price is totally at another level.

The logistic system (WPOSFOLES, Patent FI 107184) in this construct allows us to take the whole wind turbine and the foundation to the yard or harbour. The repair and service work will be made at the onshore cost level.

Some wind turbine components are more subject to tear and wear than others. This is particularly true for rotor blades and gearboxes. At the end of technical life time it may be advantageous to replace the rotor blades and gearbox. In major cases this is possible with the help of the wind turbine's own crane.

4.5 Appraisal Criteria

According to Olkkonen (1994: 20) the general criteria of scientific and acceptable research are:

- Does it include a claim
- Does it include a contribution
- Is the method justified, acceptable and without gaps

4.5.1 Validity

Validity refers to the ability of a measure to measure what it is intended to measure (Olkkonen 1994: 39). In the literature, there is no straightforward test for validity available. Laitinen (1992: 163) has stated that if a measure can be connected to a certain property of a measurement object both empirically and theoretically, the validity of the measure is sufficiently shown.

To measure validity is this research could be weak marketing test. Is the selected strategy right, will it lead to competitive business. Implementation is not so far yet but weak marketing test gives very positive answer (List of statements and offers: Hollming Oy, Vestas A/S, NORDEX A/S and ENERGI E2 A/S, 2001).

4.5.2 Reliability

Reliability is a concept which refers expressly to statistical research methods. The method tells the degree of probability of the result holding true (Olkkonen 1994: 38). Reliability refers to the consistency of measurement results, including such characteristics as accuracy and precision. It is concerned with the estimates of the degree to which a measure is free of random or unstable error (Hannula 1999: 149). Reliability is also linked to validity; if the reliability of measurement is poor, the validity is also poor. However, good reliability does not guarantee good validity, and conversely; good validity does not guarantee good reliability.

For example the wind measurement results are statistical. The input parameters have uncertainties (Tande 1994: 16). Any input parameter may have two types of attached uncertainty:

- Category A: uncertainty which is estimated on the basis of measurements; it is typically due to random error in observation of the parameter considered,
- Category B: uncertainty estimated on basis of knowledge other than from measurements.

4.5.3 Other Criteria

Kasanen et al. 1991 p. 316 state concerning the constructive research method:
- it produces innovative and theoretically justified solutions to the relevant problem
- the results are verified to working in practice
- the results can be generalized

Table 15. Criteria according to Kasanen et al 1991.

Generalisation	X	Act on practice	X
Verified functionality	X	Theoretical novelty	X
Practical usefulness	X	Possibility to check used steps	
Relevance	X	Objectivity	
Simple	X	Autonomy	
Effortless	X	Advanced	X
Easy-to-use	X	Criticality	

Note that the receipt patent Number 10184 for the construct verifies most of the criteria (marked with X).

The patent criteria according to the law for inventions are:
- industrial usefulness
- being new
- essential difference to what is previously known

In Chapter 6, on the evaluation of the results and research methods, there are some more criteria evaluated.

4.6 Summary

The main construct was presented in Chapter 3. The assisting construct was tested in Chapter 4. The test clarifies if the main and assisting construct will deliver a competitive wind energy price, for example in the Strömmingsbåda waters. First of all wind conditions were measured in the Pori and Vaasa regions. The data were converted to the hub height and location of an expected wind turbine plant. The conversion was ensured with reference measures. The results enabled the expected energy production to be calculated.

The testing method for windmill prices was presented in Chapter 4.2 including all calculation components which affect on the price.

Competitive investments in the wind energy price were tested in Chapter 4.3 with a new foundation construct, logistic and erection method. The test method included technical testing and economic testing with spreadsheet calculation. The logistic and erection competitive costs were tested by statements and tenders from appropriate sub-contractors. The operation and maintenance costs are from the literature (Chapter 4.4).

Computer modelling of wind is complex and needs resources. The results are not always reliable. This work uses only measures of wind speeds and directions. Erecting the measuring mast and collecting data from the logger unit is difficult, as the mast is usually far away in an outlying place.

The measuring data can be kept reliable. The top anemometer is calibrated before and after the measuring period. The uncertainty starts in converting wind speeds to separate heights and continues when changing wind speeds from place to place. Ice on the anemometer also makes for some uncertainty.

5. CONSTRUCT EMPIRICAL MEASUREMENT AND CALCULATIONS

5.1 General Approach

The scientific approach, in this case construct is a model of a wind turbine park located some ten kilometres offshore. The main construct consists of wind park turbine foundations and a logistic part; transport of foundations, joining the tower and nacelle onto the foundation totally ready in a harbour or yard and transport to the site with the erection of the whole power plant.

The assistance construct consists of: 1) local wind speed measurements and calculation at the turbine hub height level, 2) the investment price of wind turbine with cabling 3) in addition the investment pay back costs and 4) the operation and maintenance cost.

By joining the main and assistance construct information the wind power kWh price can be calculated.

The most important factor in the price (Chapter 3, Figure 34) is wind speed. The three empirical wind speed measurements are made with so called twin measurements. Here the measuring is carried out at the same time moment in two different places. The same wind is to be seen in two different places. The method gives more reliable information and clarifies the wind speed and energy production differences in different places and at different heights.

5.2 Empirical Wind Speed Measurement on an Island and Comparison with Real Wind Turbine Energy Onshore

The measurements were completed in the area of Pori. The wind turbine is located on the Reposaari breakwater. The turbine is NTK 300 kW with hub a height of 30 m and a rotor diameter of 31 m. The island of Kaijakari is located 5 km north-west of the wind turbine and 1.5 km from the mainland (Appendix 4). There was a 30 m height NRG weather measuring mast. Both measurements on the turbine and the mast were made at the same time. This made it possible to compare one hour medium wind energy on the island and the energy produced by turbine onshore (Rinta-Jouppi 1995). The NRG measuring mast logger unit calculates one hour mean wind speed and saves the data. About once a month the ROM memory is changed. The ROM memory data is saved on computer and the wind speed corresponding to NTG 300kW power is calculated. In Table 16 the wind speed conditions on Kaijakari island are shown. The energy calculation will be made on the base of wind speed measures. Every measuring period 8806 hours mean wind speeds will be multiplied with corresponding power value of the NTK 300 kW wind turbine and added up for the whole measuring period energy.

Table 16. The wind speed conditions at the time of measuring 26.4.94 to 10.5.1995.

Kaijakari 30 m		
Weibull A	8.5	m/s
Weibull k	2.0	–
Mean wind speed	7.45	m/s
Mean turbulence TI	0.10	%
Measurement height	30	m
Mean air density	–	kg/m3

In Table 16 is a Weibull scale parameter and k is a shape parameter (when k = 2 the distribution is called Rayleigh distribution). TI (mean Turbulence Intensity) is defined as a ratio of the STD / δ (STandard Deviation) of the wind speed to the mean wind speed. Standard deviation is calculated as a square root of the variance, where variance is the average of the squared deviation about the mean (NRG MicroSite p. B-6). The values came from a matrix (Kaijakari.Weibull) of 7348 rows, 9 columns an 66 000 elements such as date, hour, ws_{30}, δ_{30}, _,_, wd_{30} (wind direction), ws_i (integer ws_{30} compatible with wind speed and power values in appendix 9), E_{30} (Energy with NTK 300 kW wind turbine).

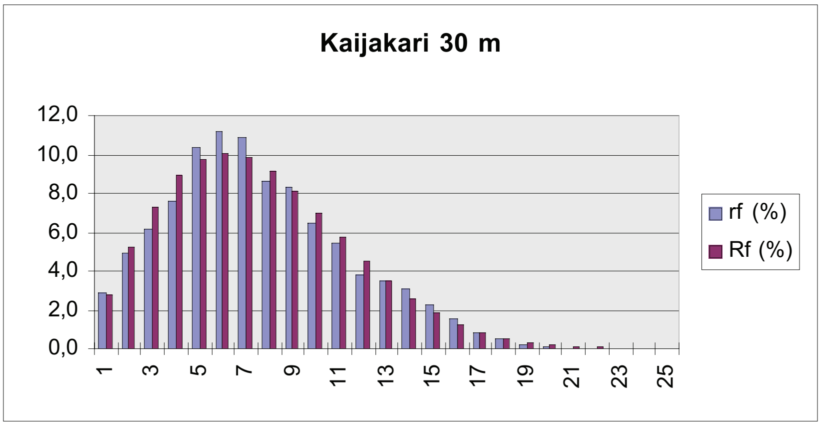


Figure 37. Wind speed distributions on Kaijakari island.

In Figure 37 wind speed distribution is showed with relative frequency rf (%) and with Weibull distribution Rf (%)

(5.1) $$R_f(\%) = \tfrac{k}{A}\left(\tfrac{v}{A}\right)^{k-1} e^{-\left(\frac{v}{A}\right)^k}$$

with the above empirical parameters at different wind speeds (Frost & Aspliden 1998: 386).

The energy produced by the power plant was measured by a remote controlled energy meter, a ”Procoll”. The measured wind speed on Kaijakari multiplied by corresponding values of the wind turbine NTK 300 kW wind speed/power curve given energy is comparable with the produced energy values at the same time on the wind turbine on the breakwater. The island measuring mast is subject to offshore conditions and the onshore wind turbine affects the difference of the energy values. In addition to wind speed measures and energy calculations two wind direction analyses were made to clarify wind obstacles both on the island Kaijakari and on the breakwater.

Table 17. The wind speed measurements and corresponding energy calculations.

	Month	June	July	Aug	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	**Tot.**
Measured hours		720	334	685	301	720	744	744	672	744	718	226	6608
Place		**Wind Speed**											
Kaijakari	m/s	6.30	5.45	5.12	7.45	7.81	8.69	9.33	8.74	7.97	7.09	5.22	7,45
		Produced Energy											
Kaijakari	MWh	49.0	17.4	30.1	32.0	81.4	102.6	115.9	93.0	88.0	65.5	10.3	684.5
Reposaari	MWh	41.4	12.9	21.5	30.2	68.0	90.4	106.4	87.0	76.2	60.3	6.8	600.9
		Energy Difference											
Difference	MWh	7.6	4.5	8.6	1.8	13.4	12.2	9.5	5.9	11.3	5.2	3.5	83.5
Difference / Reposaari %		18.4	35.0	40.2	6.0	19.7	13.5	8.9	6.8	14.8	8.6	52.0	**13.9**

At the same time wind turbine production was measured at the Reposaari breakwater. Both were measured at a height of 30 meters during 1.6.94–15.5.1995, in total 6608 comparable hours (no freezing or other disturbances). The difference is calculated as below (Matrix Kaijakari.Energy) Table 17. The measured mean wind speed during the measuring period on the island at a height of 30 meters is 7.45 m/s. The difference in energies is + 13.9 % between the measuring mast and NTK 300 kW power stations.

5.3 Measurement in Different Places and Comparison with different Heights

5.3.1 Fjärdskäret

Measurements were made 15 km north-west of Vaasa town (Table 18, Appendix 5) on the island of Fjärdskäret, which is open to north winds and closed to south winds.

Table 18. The wind speed condition on Fjärdskäret during 5.9.97–31.10.1998.

Fjärdskäret 35 m		
Weibull A	6.0	m/s
Weibull k	2.0	-
WS mean	5.60	m/s
TI mean	0.15	%
Measurement height	35	M

Standard deviation is calculated

(5.2) $$\delta = \sqrt{\frac{1}{N}\sum_{0}^{N}(v_n - \bar{v})^2}$$

and mean Turbulence Intensity

(5.3) $$(\mathrm{TI} = \delta / \bar{v}).$$

In Figure 38 wind speed distribution is showed with relative frequency rf (%) and with Weibull distribution Rf (%) with the above empirical parameters at different wind speeds (m/s).

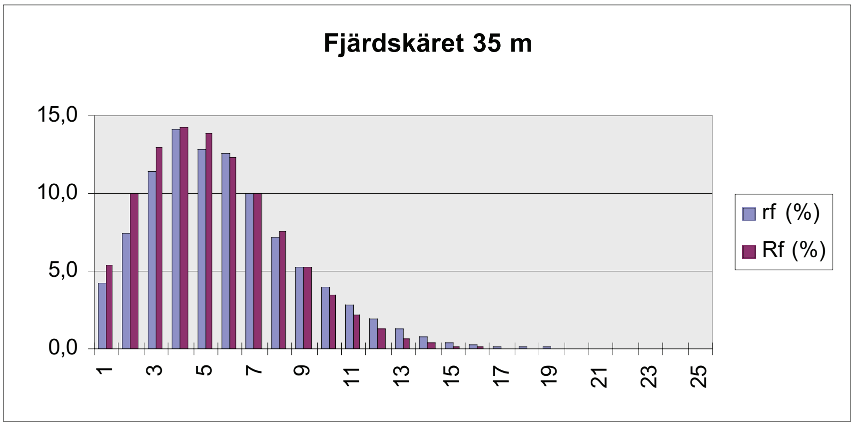


Figure 38. Wind speed distribution rf (%) on Fjärdskäret peninsula.

The terrain has an effect on the wind conditions. Generally the best directions for winds are South and South West. Unfortunately to the South and South West direction there is rising ground with forest and a high bridge (Appendix 8). An NRG wind energy measuring anemometer and wind vane were used at the height of 35 m and at 20 m. The German mast comparison states that it is not possible to obtain economical measuring equipment for the wind turbine hub height. To be sure of the wind speeds, since measuring masts reach up to 40 (50) meters in height, additional measurements were carried out.

Table 19. The mean wind speeds at the Fjärdskäret measuring place.

Place, measuring moment and comparable hours	Mean wind speeds	
Fjärdskäret North bank 5.9.97–31.10.1998 (8860 h)	4.74 m/s	5.60 m/s
Measuring height	20 m	35 m

Table 19 values came from a matrix of (Fjärdskäret.Weibull) 8876 rows, 9 columns and 80 000 elements such as date, hour, ws_{35}, δ_{35}, ws_{20}, δ_{20}, wd_{35}, wd_{20}, T (temperature) (Rinta-Jouppi 1999a: 13).

5.3.2 Raippaluoto

Wind speed measurements on Raippaluoto bridge were carried out on a pylon at a height of 83 m. An anemometer and wind direction vane were installed. The place is about one kilometre west of the Fjärdskäret measuring mast. The measuring time was during 10.5.– 15.7.1999 and comprised 1197 comparable hours of which 1002 hours represented wind speed over 4 m/s.

Table 20. Measurement at the Fjärdskäret Mast and Raippaluoto Bridge Pylon.

Place 10.5–15.7.1999	Mean wind speed (m / s)		
Fjärdskäret North bank	4.5	5.5	–
Raippaluoto bridge pylon	–	–	7.1
Measuring height (m)	20	35	83

Table 20 values came from a matrix (Fjä Rai Both) of 1201 rows, 19 columns such as date, hour, ws_{83}, δ_{83}, _, _, _, _, wd_{83}, _, date, hour, ws_{35}, δ_{35}, ws_{20}, δ_{20}, wd_{35}, $wd_{20,}$ T (Rinta-Jouppi 1999b: 1).

5.3.3 Comparison to the Height

The wind speeds at the wind turbine hub height are calculated e.g. according to Walker & Jenkins (1997: 7) with the exponent function:

$$v(h_2) = v(h_1) *(h_2 / h_1)^{\alpha} \tag{5.4}$$

where h_1 is reference height and $v(h_1)$ reference speed, h_2 is height, where $v(h_2)$ is known and exponent α describes the roughness of the surface. Another function in the literature is a logarithmic function:

$$v(h_2) = v(h_1) \frac{\ln(h_2/z_0)}{\ln(h_1/z_0)} \tag{5.5}$$

where heights h_1 and h_2 are the same but z_0 is the roughness length. According to the literature this means the height where the wind speed is zero. In the spreadsheet computation table 21 the mean wind speeds at 35 m and 83 m heights are measured. With equations 5.4 and 5.5 α and z_0 values are selected so that calculated and measured values are the same at the 83 m height. α will obtain in this terrain a typical iterated value of 0,290 and z_0 1,69 m. With values α, z_0 and the measured mean wind speed for the whole year at 35 m 5.6 m/s the wind speed at the hub height is calculated. The result of the mean value is 6.57 m/s at 60 m height.

Table 21. Two measuring places and two different methods to calculate hub height wind speed.

1.	h (m) height	V (m/s) measur.	v (m/s) yearly measured		**3.**			v (m/s) calculat.	V (m/s) measur.
h_3	60	x					ln (h_2/z_0)		
h_2	83	7.065			v (h_z) =	V (h_1)	--------------		
h_1	35	5.498	5.6				ln (h_1/z_0)		
zo	1.69 m						3.8941121		
alfa	0.290				v(83) =	5.498	---------------	7.065	7.065
2.		Alfa					3.0306195		
v(h_z) =	v(h_1)*(h/h_1)		v (m/s) calculat.	V (m/s) measur.					
							3.5696160		
v(83) =	5.498	1.285	7.065	7.065	v(60) =	5.6	---------------	6.60	
							3.0306195		
v(60) =	5.6	1.1694	6.55						

In Table 21 the measured average wind speed is at 83 m height 7.065 m/s at the top of the pylon and at 35 m height it 5.498 m/s at the top of the mast (picture 1 in table 16). The exponent α and z_0 values will be spreadsheet iterated so that the iterated and measured wind speed at the 83 m height level are the same. With these α (picture 2 in table 14) and z_0 values (picture 3) the wind speed at 60 m height will be calculated. It gives wind speeds of 6,55 and 6,60 m/s and the mean speed 6.57 m/s. The values for calculation came from the matrix ”Fjä Rai Both”.

Comparison to the measurements on Fjärdskäret island 5.9.1997–31.10.1998 (8860 h) at the same place and with the same mast at 35 and 20 m heights gives by the same calculation a wind speed at the 60 m height of 6.52 m/s (Rinta-Jouppi 1999a, in that Appendix 18). On the reference measuring place the measured and calculated wind speed is 6.57 m/s. The measuring mast gives after calculation 6.52 m/s. The difference is only 0.05 m/s (0.8 %).

Next was converted, with iterated α value and measured wind speeds at 35 m and 83 m height, every wind speed to the hub heights of 60 and 67 m. The computer spreadsheet will choose power values at different wind speeds (Appendix 9). These wind speed / power values are given by the wind turbine manufacturer. These power values are summed up for the whole measuring period time to energy. The same time measured wind speeds at the 35 m height will also be converted into energy. This short time (1002 h) energy ratio has been multiplied by the whole year’s 8860 h energy production (from NRG standard report) at the 35 m height (for example Appendix 11&12 in Rinta-Jouppi 1999b).

The additional measurement is an assumption of short term wind conditions but the energy ratio gives a more reliable calculation base. Multiplied by a more representative sample of wind speed data (the whole year) the difference with the calculation from the measuring mast (Rinta-Jouppi 1999a: 15) in this case is only 0.2 % .

Table 22. Wind power plant production at Fjärdskäret.

Place	Turbine	Hub height (m)	Wind speed over 4 (m/s)	Capacity factor C_f	Nominal power operation time (h / a)	Produced energy (MWh / a)
Fjärdskäret / Raippaluoto	BONUS 1 MW	60	7.23	0.27	2400	2400
	NEC Micon 1.5.MW	60	7.23	0.25	2193	3290
	Nordex 1.3 MW	60	7.23	0.26	2258	2936
	Vestas V66-1650	67	7.47	0.26	2263	3735

In Table 22 the planned wind power station at Fjärdskäret is featured. The wind turbine hub heights and wind mean speeds over 4 m/s are calculated. In addition there is the capacity factor, which be obtained by dividing the produced energy by the turbine nominal power and the year's hours. The nominal power hours will be obtained by dividing the produced energy by the nominal power, and finally the produced energy at the hub height. The values are from the matrix (Fjä Rai Energy).

In Figure 39 wind speed differences are measured at Raippaluoto at 83 m and Fjärdskäret at 35 m. The energy difference calculated with exponent α is 0.29 at Raippaluoto at 60 m and Fjärdskäret at 35 m height. Although the wind speed difference is smallest in the westerly direction, the energy difference is biggest because wind speeds are biggest from the west. The values came from the matrix (Fjä Rai Energy) 1201 rows, 19 columns, 23 000 elements such as date, hour, ws_{83}, $ws_{60}(\alpha\ 0.29)$, ws_i, E_{60}, _, _, wd_{83}, _, ws_{35}, δ_{35}, ws_i, E_{35}, wd_{35}, wd_{20}, _, Δ ws, Δ E.

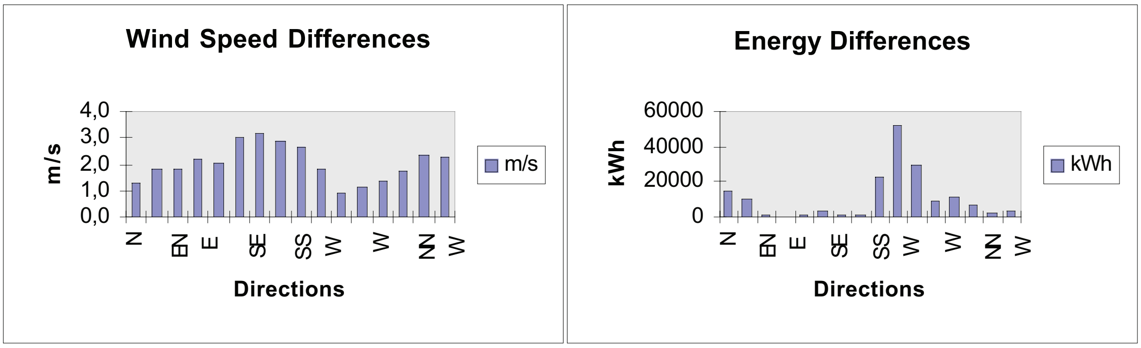


Figure 39. Wind direction analysis.

5.4 Empirical Measurement on a Distant Island and Comparison to the Measurement on the Measuring Mast onshore

5.4.1 Wind Measurements

The measurements are from fixed automatic station from the Finnish Meteorological Institute located at Strömmingsbåda-island, about 19 km west of the Bergö measuring mast (Appendix 5). The automatic measuring station gives, for example, a report with place code, observation time, hourly mean wind speed and direction during the same time period as the reference mast measurements. The anemometer and wind direction finder is at a height of 14 meters on the beacon island. The sensors are remote-controlled and heated if needed. Wind obstacles are the pilot house and beacon to the north. The direction from south-east to north-west is open. The other directions are hindered by islands (Appendix 10).

The reference measuring mast was located on Bergö island about 30 km south-west of Vaasa (Appendix 5). The island is connected to the mainland by a ferry connection. The measuring period was 21.11.1997–26.11.1998 (8876 h) with a 40 meter NRG measuring mast. The mast was equipped with anemometers at 40, 30 and 20 meters and the wind direction vane at 40 and 30 meters. In addition there was a thermometer at a height of about 3 meters. The measuring logging unit takes a sample every second and calculates the hourly mean value.

In Table 23 the mean wind speeds are measured on Strömmingsbåda island and Bergö island fish harbour at different height levels at the same moment. 1.5 % of the total data (9000 h) from Bergö and 0.6 % from Strömmingsbåda are rejected because of freezing of the gauges during winter time. The values came from the matrix Bergö.B.60 and Strömmingsbåda.G.40/60. Energy calculations were made by 1 MW power plant wind speed/power curve.

Table 23. Mean wind speed on Strömmingsbåda and Bergö island**.**

Place and measuring time 22.11.97–26.11.1998	Measured mean wind speeds on Bergö island				Measured and calculated Mean wind Speeds on Strömmingsbåda		
Heights (m)	20	30	40	60	14	40	60
Speeds (m/s)	5.63	6.16	6.80	7.95	6.82	8.33	9.01
Energy (MWh)	-	-	2563	3428	-	3687	4148

5.4.2 Sector Analysis

The energy production calculation for separate wind turbines will be made first by selecting the comparable wind sectors (on equal terrain) in both Bergö and Strömmingsbåda. Strömmingsbåda is open from south–east to north–west. Bergö is open from south to south–west. Table 24 describes the calculation of selected sector α values. The result has been calculated first by converting single hourly measures (8733 items) to the desired height (from 40 m to 60 m) and then the average has been calculated. The check column has been calculated from the average of single measures (8733 items) and converted to the desired height.

Table 24. Wind direction analysis operation table.

Item		Spreadsheet Calculation Operator	Result	Check
1	Date			
2	Hour			
3	Ws40		6.80	6.80
4	d40			
5	Ws30		6.16	6.16
6	d30			
7	Ws20		5.63	5.63
8	d20			
9	Wd40			
10	Wd30			
11	T		4.30	
12	Calc40	ws30(40/30)^(lg(ws30/ws20)/lg(30/20))	6.60	6.56
13	Calc60	ws40(60/40)^(lg(ws40/ws30)/lg(40/30))	7.95	7.83
14	Ws integer60		7.94	
15	α (360°)	lg(ws30/ws20)/lg(30/20)	0.29	0.22
16	% (180-225°)		1676	19.2 %
17	Ws40	(if(wd40>180;ws40:0)*if(wd40<225;ws40;0)^(1/2)	8.66	8.66
18	Ws30	(if(wd40>180;ws30:0)*if(wd40<225;ws30;0)^(1/2)	8.13	8.13
19	Ws20	(if(wd40>180;ws20:0)*if(wd40<225;ws20;0)^(1/2)	7.71	7.71
20	Number check		1676	
21	Calc40	if(ws30=0;0;ws30(40/30)^(lg(ws30/ws20)/lg(30/20))	8.46	8.45
22	Calc60	if(ws40=0;0;ws40(60/40)^(lg(ws40/ws30)/lg(40/30))	9.50	9.47
23	Ws integer60		9.48	
24	α (180-225°)	if(ws30=0;0;lg(ws30/ws20)/lg(30/20)	0.16	0.13
25	% (225-315°)		1497	17.1 %
26	Ws40	(if(wd40>225;ws40:0)*if(wd40<315;ws40;0)^(1/2)	7.30	7.30
27	Ws30	(if(wd40>225;ws30:0)*if(wd40<315;ws30;0)^(1/2)	6.71	6.71
28	Ws20	(if(wd40>225;ws20:0)*if(wd40<315;ws20;0)^(1/2)	6.29	6.29
29	Number check		1497	
30	Calc40	if(ws30=0;0;ws30(40/30)^(lg(ws30/ws20)/lg(30/20))	7.04	7.01
31	Calc60	if(ws40=0;0;ws40(60/40)^(lg(ws40/ws30)/lg(40/30))	8.28	8.23
32	Ws integer60		8.27	
33	α (225-315°)	if(ws30=0;0;lg(ws30/ws20)/lg(30/20)	0.19	0.16
34	% (315-22.5°)		1206	13.8 %
35	Ws40	(if(wd40>315;ws40:0)*if(wd40<22.5;ws40;0)^(1/2)	5.80	5.80
36	Ws30	(if(wd40>315;ws30:0)*if(wd30<22.5;ws40;0)^(1/2)	5.03	5.03
37	Ws20	(if(wd40>315;ws20:0)*if(wd20<22.5;ws40;0)^(1/2)	4.25	4.25
38	Number check		1206	
39	Calc40	if(ws30=0;0;ws30(40/30)^(lg(ws30/ws20)/lg(30/20))	5.73	5.68
40	Calc60	if(ws40=0;0;ws40(60/40)^(lg(ws40/ws30)/lg(40/30))	7.14	7.08
41	Ws integer60		7.13	
42	α (315-22.5°)	if(ws30=0;0;lg(ws30/ws20)/lg(30/20)	0.49	0.42

In Table 24 the measuring time was 8865 hours, 98.51 % 8733 h are acceptable hours. α values are calculated for directions 1–360°, 180–225°, 225–315° and 315–22.5°. Every incoming wind speed is handled with spreadsheet calculation operator and the average calculated for the whole group. Checking the averages is handled with the operator and can be compared to the result. The values came from matrix Bergö.B, 8733 rows 42 columns 366 000 elements.

Table 25. Calculated α values at Bergö and corresponding terrain sector at Strömb.

Terrain	α	Bergö	Strömmingsbåda
A	0.16	180–225°	135–337.5°
B	0.19	225–315°	22.5–135°
C	0.49	315–22.5°	337.5–22.5°

The exponent α in formula 5.4 will be calculated with a computer spreadsheet. The data from the Bergö measuring mast at 20 and 30 m heights give the base for exponent α calculation. For wind speeds on sector A) open sea to south to south-west (180–225 degrees) a figure of 0.16 is obtained for α (Appendix 10). The calculations for sector B) archipelago to south-west to north-west (225–315 degrees) gives 0,19 for α and sector C) building obstacles north-west to north-east (315–22.5 degrees) 0,49.

Table 25 shows the comparable directions (wind obstacles are the same, Appendix 10). The open sea at Strömmingsbåda is in direction A) south-east to north-north-west, α 0.16. B) is the archipelago north-north-east to south-east, α 0.19. C) is building obstacles in the direction north-north-west to north-north-east, α 0.49. (The α values came from matrix Bergö.B).

Table 26 exploits sector analysis of the Strömmingsbåda wind conditions. The measured values and calculations came from the matrix Strömmingsbåda.G, 8794 rows, 26 columns and 228 000 elements.

Table 26. Wind speed and energy calculation at Strömmingsbåda by obtained values.

Item		Spreadsheet Calculation Operator	Result	%
1	Date + hour			
2	Ws avg 14		6.82	
	Wd avg 14			
4	Ws60 α 0.38	=ws14*(60/14)^0,38	11.86	
5	1–360° h		8794	
6	135–330° h		4842	55 %
7	ws14	=(if(wd14>134,5;wd14;0)*if(wd14<330;ws14;0)) ^ (1/2)	7.29	
8	α		0.16	
9	ws60	=ws14*(60/14) ^ α	9.21	
10	15–135° h		3068	35 %
11	ws14	=(if(wd14>14,5;wd14;0)*if(wd14<135;ws14;0)) ^ (1/2)	6.52	
12	α		0.19	
13	ws60	=ws14*(60/14) ^ α	8.59	
14	330–15° h		884	10 %
15	ws14	=(if(wd14>329,5;wd14;0)*if(wd14<15;ws14;0)) ^ (1/2)	5.30	
16	α		0.39	
17	ws60	=ws14*(60/14) ^ α	9.34	
18	1–360° h		8794	100 %
19	ws60		9.01	
20	Ws integer60		9.00	
21	E (kWh)	=if(wsi60<4;0;PHAKU(wsi60;Appendix 5.2;2;0))	401566	
22	E (kWh)/month			
23	E (kWh)	=if(wsi60<4;0;PHAKU(wsi60;Appendix 5.2;2;0))	560047	
24	E (kWh)/month			
25	E (kWh)	=if(wsi60<4;0;PHAKU(wsi60;Appendix 5.2;2;0))	499726	
26	E (kWh)/month			

Table 27. The calculated wind speeds at 60 m on Strömmingsbåda island.

Directions (degrees)	15–135	135–330	330–15	1–360
Speed (m/s)	8.59	9.21	9.34	9.01

The wind speeds are calculated at the hub height of 60 m in different directions on Strömmingsbåda island (Table 27). The values came from matrix Strömmingsbåda.G

In the same Strömmingsbåda matrix the energy of different turbines is calculated at the hub height and with their own wind speed / power curve (Appendix 9). The energies in the above directions will be calculated together. The values will be converted from the measuring hours minus freezing time to the calendar hours of one year.

5.4.3 Energy Calculations

The values in the wind turbine power curve are stated normally at a 15 °C temperature and 1013,25 mbar air pressure. To change to the prevailing air density ρ the following formula is used (Walkers & Jenkins 1997: 11).

$$P = {}^{1}/_{2}\, c_p\, \rho\, A\, v^3, \text{ where } \rho = 1{,}225\ \left(\frac{288}{T(°K)} \times \frac{p(mbar)}{1013{,}25}\right) \qquad (5.6)$$

and c_p constant, p air pressure and T air temperature

The measured and converted values are calculated in the above equation with month mean air temperature and pressure. With new air density the measured energy is converted to the prevailing energy conditions.

Table 28. Measured energy converted to prevailing wind condition.

Month	Meas-ured Hours h	Temper-ature degrees	Air pressure mbar	Air densi- Kg/m^3	Meas-ured energy kWh	Air densi-ty Corrected KWh	Meas-Ured Energy KWh	Air densi-ty Corrected KWh	Meas-ured Energy kWh	Air densi-ty corrected kWh	Meas-ured energy kWh	Air densi-ty Corrected KWh
					Bonus	Bonus	Vestas	Vestas	Nordex	Nordex	NEGMico	NEGMico
Nov97	240	0.8	1015.8	1.292	203259	214339	222469	234596	240216	253310	129710	136780
Dec 97	741	-1.0	1013.6	1.298	733693	777120	776107	822044	890079	942762	495575	524908
Jan 98	744	-1.3	1008.0	1.292	874217	921862	921550	971775	1061416	1119264	596617	629133
Feb 98	631	-4.1	1001.9	1.297	738973	782597	777547	823448	898774	951831	505657	535507
Mar 98	741	-3.2	1012.7	1.307	763527	814590	809430	863563	923250	984995	517229	551820
Apr 98	707	0.5	1014.0	1.291	399441	420929	439275	462907	469721	494990	251708	265249
May 98	744	4.9	1014.1	1.271	486850	504967	528159	547814	578989	600535	323863	335915
Jun 98	714	9.8	1010.9	1.245	648459	658851	690477	701543	781043	793560	434672	441638
Jul 98	727	14.6	1003.3	1.215	467564	463616	508011	503722	557369	552663	309401	306789
Aug 98	744	13.9	1007.2	1.222	692026	690531	739373	737776	833595	831795	464090	463088
Sep 98	715	11.4	1014.8	1.242	702647	712630	752337	763026	843553	855538	461493	468050
Oct 98	744	7.1	1001.4	1.245	898719	913260	938358	953540	1099176	1116960	620185	630219
Nov98	602	0.4	1018.7	1.297	702678	744183	730990	774167	860967	911822	490279	519239
Altogether	8794				8312053	8619476	8834084	9159921	10038148	10410025	5600479	5808334
Years level	8760				8279916	8586151	8799929	9124506	9999338	10369777	5578826	5785878

The above energy values in Table 28 show the energy production on an open small island about 30 km from land. The energy production is calculated for separate wind turbines at 60 and 67 m hub heights. The wind conditions are nearly the same as with real offshore turbines with the needed wind obstacle corrections. Conversion from measured hours to calendar hours is made and from measured air conditions to wind speed / power curve condition. (The values came from the matrix Strömmingsbådan.G and Strömmingsbådan.V).

5.4.4 Tankar Continuous Measuring Station Assistance for Sector/Wind Speed Analysis

There were two measuring places in Larsmo commune, Ådö and Fränsvik (Appendix 16). The idea was to measure over half a year in both places and use the whole year continuous measuring data from the pilot house and fixed meteorological station Tankar. So it was possible to get a whole year or more of wind speed data from the target location, table 29 (Matrix Tankar.Ådö27Production).

The procedure: 1. A one hour average of wind speed, direction, air pressure and temperature from Tankar (27.5 km to north east from Ådö) was asked for. 2. Then were calculated on the same hour the wind speed differences by directions/speeds on Tankar (h=15m) and Ådö (h=40m) over about a half years period. 3. The differences were added to Tankar's wind speeds. 4. Then the calculated (Ådö 40m) and right wind speeds (Ådö 40m) were tested. 5. The measured differences was presented by a line which is an average of measured points. The lines were calibrated so that the measured and right wind speed differences by sector and speed class approaches zero. The same were done with wind energy calculations. 6. The coefficients of the lines (in this case) were used to calculate the wind speeds for the latter part of the year. In appendix 17 (matrix Tankar.Fränsvik) there is one example of measured differences and average line. Wind speeds from 40 m were converted to the hub height 60 m. 7. The wind speeds were converted through some turbine's wind speed / power values to energy values at the hub height of 60 m.

The same procedure with the measuring place Fränsvik (Tankar is 13.2 km to north east from Fränsvik) was made.

Table 29. Wind conditions at Larsmo Ådö and Fränsvik at 60 m hub height.

BONUS 1MW (d54m/h60m) energy production at Ådö

Month 2001	Measured Hours h	Month hours h	Mean Wind speed (m/s)	Measured Energy MWh	Month Energy MWh	Quarter Energy MWh	Cf
Jan	696	744	7.0	202.6	216.6	I/01	
Feb	653	672	6.1	143.9	148.1		
Mar	732	744	5.8	139.1	141.4	506.0	0.23
Apr	714	720	5.9	149.0	150.3	II/01	
May	741	744	5.6	125.7	126.2		
Jun	720	720	5.9	135.8	135.8	412.3	0.19
Jul	723	744	6.0	136.6	140.6	III/01	
Aug	724	744	5.9	146.2	150.2		
Sep	666	720	6.4	153.2	165.6	456.4	0.21
Oct	711	744	6.4	174.1	182.2	IV/01	
Nov	702	720	9.6	364.6	373.9		
Dec	729	744	7.1	224.5	229.1	785.2	0.36
Altogether	8511	8760	**6.5**	2095	2157	2160	**0.25**

BONUS 1MW (d54m/h60m) energy production at Fränsvik

Month 2001	Measured Hours h	Month hours h	Mean Wind Speed (m/s)	Measured Energy MWh	Month energy MWh	Quarter Energy MWh	Cf
Jan	696	744	6.6	173.0	184.9	I/01	
Feb	653	672	7.1	204.0	209.9		
Mar	732	744	5.6	126.5	128.6	523.4	0.24
Apr	714	720	5.6	136.4	137.5	II/01	
May	741	744	5.5	131.1	131.6		
Jun	720	720	5.6	123.4	123.4	392.6	0.18
Jul	723	744	5.6	120.9	124.4	III/01	
Aug	724	744	5.4	116.5	119.7		
Sep	666	720	5.7	109.2	118.1	362.2	0.16
Oct	710	744	6.1	154.1	161.5	IV/01	
Nov	701	720	9.2	327.1	336.0		
Dec	686	744	6.8	196.4	213.0	710.5	0.32
Altogether	8466	8760	**6.2**	1919	1985	1989	**0.23**

5.5 Offshore Wind Power Plant Investment Price, Example

5.5.1 General

A solution to reduce wind electric power price is to reduce the wind turbine foundation price. This means reducing the component, transportation and erection costs of offshore wind parks. The industrial problem is how to develop wind power offshore foundations, the transportation, erection and service of wind power plants**.** The economic problem is to reduce the wind energy component cost compared to present day solutions. The novel innovation WPOSFOLES (2000) is to develop a new steel foundation for power plants and new methods to transport, erect and service the new power plants.

The main construct includes a plant foundation and power plant transport. The erection goes, depending of the model of foundation, with an assisting modified barge or ship or sinking the foundation alone to the sea bottom. The new type of offshore wind power station and a modified barge facilitates the building of the wind power turbine and foundation completely on land, transportation to the site and erection the power station routinely. The whole idea is to make building, transportation, erection and maintenance work easy and robust for external conditions and therefore reduce the cost significantly.

A parallel plan is to use a telescopic tower instead of a modified barge or ship. The modified barge, ship or floating crane (Håkans 2000, Statements and Offers) keeps the floating foundation and tower with nacelle vertical during transportation and sinking. The telescopic tower is in a lower position (for example the nacelle at 40 m height) during transport and floating vertically without any help. When the foundation is sunk to the sea bottom the whole tower is lifted to the normal height.

This construct is a concept. Important questions are the strength of the combination against wind, waves, storms, sea bottom conditions, sea currents and possible ice etc. In realising the construct we need to examine:

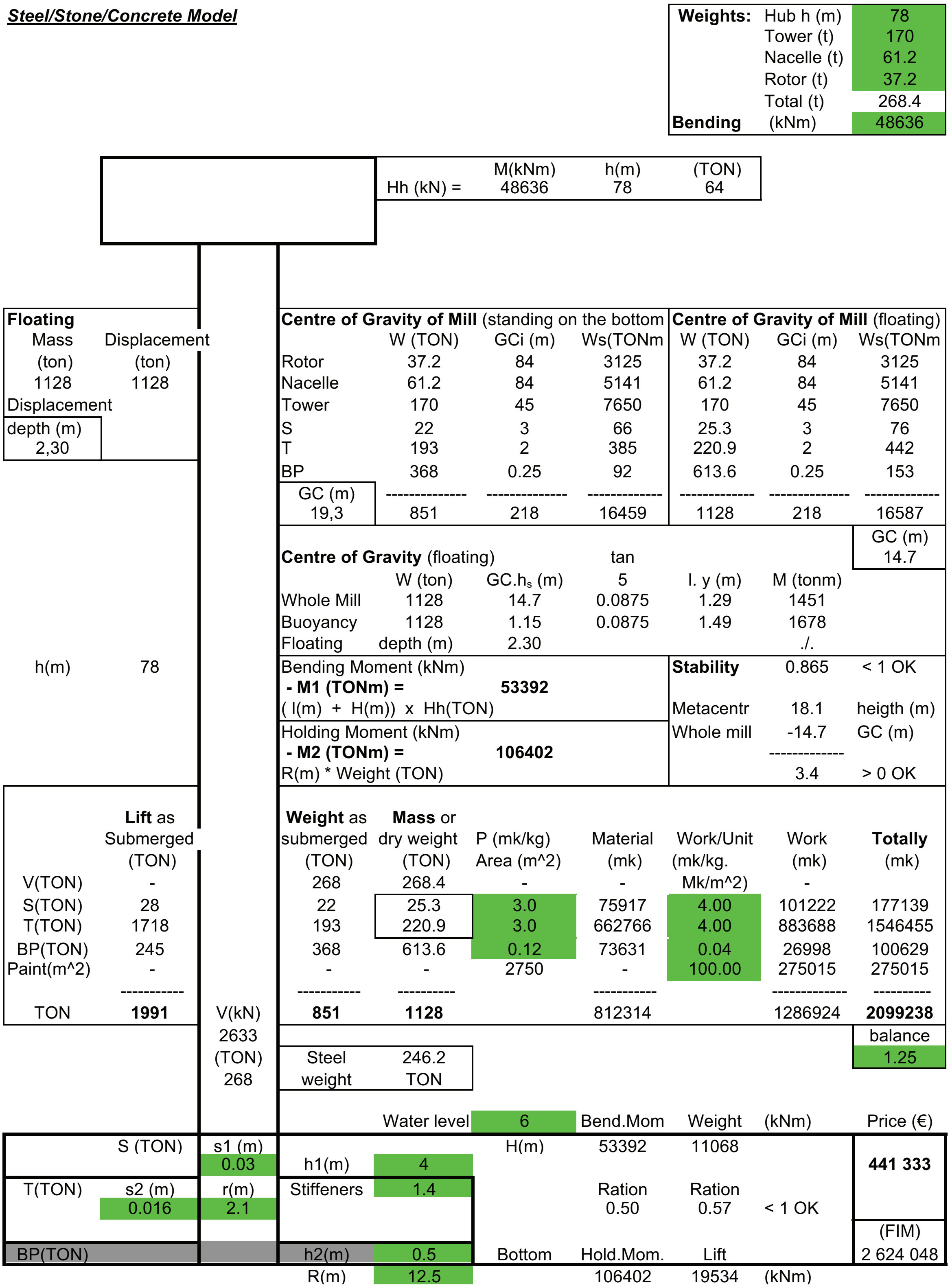
- static loads
- dynamic loads

- fatigue loads
- corrosion

In addition we need to measure the sea bottom bearing capacity, sea flow speed, wave height and length, possible ice effect, etc.

A weak market test for the whole construct is possible. The building of a steel foundation is also normal workshop work (Fagerström 2000, List of Statements and Offers). Transport and erection is normal offshore work (Håkans 2000, List of Statements and Offers). The prices for the construct are from the above offers. A weak market test was no longer the situation since a decision was made to start a product and production development (Hollming 2002, list of Statements and Offers). The positive comments from the offshore wind power market (Vestas -, NORDEX - and ENERGI E2 A/S *Interview and answer to inquiry form 2001*) strengthen the standpoint that this construct and product takes the own share of the present and future offshore foundation and erection market and plan for tomorrow in Denmark, Germany, Sweden, Holland, Belgium, Britain and Ireland (Appendix 14).

5.5.2 Foundation, calculation example



Steel/Stone/Concrete Model

Weights:	Hub h (m)	78
	Tower (t)	170
	Nacelle (t)	61.2
	Rotor (t)	37.2
	Total (t)	268.4
Bending	(kNm)	48636

	M(kNm)	h(m)	(TON)
Hh (kN) =	48636	78	64

Floating	
Mass (ton)	Displacement (ton)
1128	1128
Displacement depth (m)	
2,30	

	Centre of Gravity of Mill (standing on the bottom)			**Centre of Gravity of Mill** (floating)		
	W (TON)	GCi (m)	Ws(TONm	W (TON)	GCi (m)	Ws(TONm
Rotor	37.2	84	3125	37.2	84	3125
Nacelle	61.2	84	5141	61.2	84	5141
Tower	170	45	7650	170	45	7650
S	22	3	66	25.3	3	76
T	193	2	385	220.9	2	442
BP	368	0.25	92	613.6	0.25	153
	--------------	--------------	-------------	-------------	--------------	-------------
GC (m) 19,3	851	218	16459	1128	218	16587

GC (m) 14.7

Centre of Gravity (floating)	W (ton)	GC.h$_s$ (m)	tan 5	I. y (m)	M (tonm)
Whole Mill	1128	14.7	0.0875	1.29	1451
Buoyancy	1128	1.15	0.0875	1.49	1678
Floating	depth (m)	2.30			./.

h(m) 78

Bending Moment (kNm)
- M1 (TONm) = **53392**
(l(m) + H(m)) x Hh(TON)

Holding Moment (kNm)
- M2 (TONm) = **106402**
R(m) * Weight (TON)

Stability	0.865	< 1 OK
Metacentr	18.1	heigth (m)
Whole mill	-14.7	GC (m)

	3.4	> 0 OK

	Lift as Submerged (TON)	**Weight** as submerged (TON)	**Mass** or dry weight (TON)	P (mk/kg) Area (m^2)	Material (mk)	Work/Unit (mk/kg. Mk/m^2)	Work (mk)	**Totally** (mk)
V(TON)	-	268	268.4	-	-		-	
S(TON)	28	22	25.3	3.0	75917	4.00	101222	177139
T(TON)	1718	193	220.9	3.0	662766	4.00	883688	1546455
BP(TON)	245	368	613.6	0.12	73631	0.04	26998	100629
Paint(m^2)	-	-	-	2750	-	100.00	275015	275015
	-----------	-----------	----------		-----------		-------------	----------
TON	**1991**	**851**	**1128**		812314		1286924	**2099238**

V(kN) 2633 (TON) 268

balance 1.25

Steel weight 246.2 TON

			Water level	6	Bend.Mom	Weight	(kNm)	Price (€)
S (TON)		s1 (m) 0.03		H(m)	53392	11068		**441 333**
			h1(m)	4				
T(TON)	s2 (m) 0.016	r(m) 2.1	Stiffeners	1.4	Ration 0.50	Ration 0.57	< 1 OK	
								(FIM)
BP(TON)			h2(m)	0.5 Bottom	Hold.Mom.	Lift		2 624 048
			R(m)	12.5	106402	19534	(kNm)	

Figure 40. Spreadsheet computation simulation model for steel foundation.

Figure 29, 40 and Appendix 19 show the simulation model of steel/stone/concrete foundation. Stone and concrete are on the bottom of the foundation as ballast. The wind power plant model floats with the foundation. Foundation tanks filled with water sink it to the sea bed. The model calculates the costs. It can optimise the costs against bending moment (when bending moment / holding moment < 1), steel construct, stone/concrete ballast weight and floating/sinking conditions (when mass / lift ratio < 1).

The bending moment / holding moment calculates the effect round the right down corner of the foundation. It is dependent on the sea bottom bearing capacity where the right rotation point is. It is calculated in figures 29 f32, 35 and ratio in g56. The floating condition is calculated in figures 29 b47, e47, depth a21 and ratio in h56.

The centre of gravity of the mill standing on the bottom and floating is calculated in d15-j26. The centre of gravity of buoyancy is calculated in d29-i29. It is possible to select the inclination angle. A comparison between the whole mill moment and buoyancy moment is made in i31. For stability inspection the metacentre point is calculated and compared to whole mill gravity centre. This is made in zero wind speed but gives an estimation of what the dimensions of the foundation should be.

The dry and “wet” weights are in d38-e47 multiplied with the construction required stiffeners factor in e55.

Now we have the dimensions and can calculate the costs. In f42-45 are material costs and painting area, in h42-45 is the work price. H42 shows the foundation “under water tower” price, h43 the foundation price, the concrete ballast price is in h44 and the painting price in h45. The total price in j54 is the sum in j47 multiplied with the balance factor in j49.

The spreadsheet computation model needs 20 initial data from windmill manufacturers and sea – and sea bed conditions for defining the foundation size and characteristics. The foundation diameter addition (Beacon 2001) makes possible for the construction to float without any upright keeping auxiliary vessel or crane as in the original plan. This makes the foundation more costly but the erection is cheaper and more simple. The price of alternatives resolves the choice.

Figure 40 calculates in addition the centre of gravity for the whole power plant and the displacement of the floating construction and floating depth.

One example is the foundation itself. The foundations can be built in one place and then floated or transported with a half-submerged barge to the harbour or dock. There the whole power plant – the foundation, tower, nacelle, rotor and cabling and so on can be assembled totally ready. The whole power plant will be floated, for example, on the deck of a special half submerged barge (Håkans 2000, List of Statement and Offer). The barge will be towed to the site. There the windmill floats from the deck of the barge. Smaller floating or jack up type of cranes keep the windmill vertical during the submersing of the windmill down to the sea bed.

The foundation must be constructed to keep the wind power plant in place, vertical against wind, sea current, waves, bottom erosion and possible ice. The price of the foundation is depends on the version and in this example is € 441 333 / per unit, Figure 40.

5.5.3 Assembly, Transportation and Erection

One example is to build the foundations in Finland and transport them to Denmark, then assemble them ready in the dock or harbour, transport them to the site floating with a special barge, and sink the power plant on to the sea bed.

Table 30. The wind mill foundation transport and assembly costs.

a' (FIM)	Item	Tour, men	Days	FIM	Pieces	FIM/pc	€/pc
	Transport					38572	**6487**
45 000	Pori-Copenhagen	2	4	360 000	14	25714	4325
45 000	On loading Pori	1	2	90 000	14	6429	1081
45 000	Off l. Danish harbour	1	2	90 000	14	6429	1081
	Harbour					62343	**10485**
50 000	Harbour costs	1	2	100 000	14	7143	1201
4 000	Harbour crane	1	3	12 000	1	12000	2018
2 400	Assembly work	6	3	43 200	1	43200	7266
	Site					97143	**16338**
2 400	Site work	5	5	60 000	1	60000	10091
30 000	Material	1	1	30 000	1	30000	5046
50 000	Floating/Jack up crane	1	2	100 000	14	7143	1201
						----------	--------
	Altogether / unit					198058	**33310**

In the example in Table 30 the foundations are manufactured in Pori Finland. They are transported to Denmark harbour / dock with the assistance of a special half-submersible barge. They are assembled as ready power plants at the harbour. They are floated and erected at the site with the assistance of a small crane.

5.5.4 Cabling

In the example the wind power park is 20 km offshore and onshore there is a sufficiently strong 20 kV line. The cable and cable let down work costs € 40 / m (Rinta-Jouppi 1995: 25). The Tunö Knob park cable onto land 10 kV 6 km costs 1.5 M$. The local ring between turbines 10 kV 2,8 km costs 0.6 M$.(2.6 km land cable 0.4 M$). With exchange rate 1$ = 6.45 DKK and 1 € = 7,4288 DKK (14.2.2002) it costs 217 €/m, 186 €/m and 133 €/m (Morthorst et al. 1977: 203 and Madsen 1996: 5). 110 kV 3 km 3 MFIM amounts to 168 €/m (Holttinen et al. 1998: 109) On the sand bed it is possible to use a pressured water spray to get the cable into the sand bed. The cabling can be surprisingly expensive 11.47 M€ / 12.8 km makes 896 €/m (http://www.middelgrunden.dk/MG_UK/project_info/prestudy.htm 2000, p. 10).

The material and work costs of a 20 000 m cable is with item price 160 €/m 3.2 M€. If the distance between the 14 turbines is 300 m/each, it makes (13 x 300 m) 3900 m. Totally 23 900 m and with 160 €/m multiplied it makes 3.824 M€. For 14 turbines it makes <u>273 143</u> €/turbine. Every turbine has its own 20 kV transformer.

5.6 Operation and Maintenance Costs

The operation and maintenance costs include many different items, see Chapter 2.4.3. For older turbines the O&M cost can be 3 per cent and bigger turbines 1.5–2 % of the original turbine investment. Wear and tear on the turbine generally also increases with increased production. The used value for O&M is 0.01 $/kWh. The research centre ISET has analysed 250 MW wind power stations during 10 years. 500-600 kW plants costs are 30 DEM/kW. It makes 1,5 % of the investment price of 1000 €/kW. Finnish research states 5–10 FIMp/kWh (Tammelin et al. 2001). Morgan et al. (2001: 2–37) say as much as 30 % of energy cost and for 95 % availability £ 30 000 per turbine. Svenson et al. (1999: 298) use for the calculation <u>0.01 €/kWh</u>.

5.7 Offshore Wind Power Price, Example

As an assistance construct the price of electric power is calculated. As an example a wind power plant park 20 km from shore is used with a sufficiently strong 20 kV line. There are 14 turbines and the distance between the turbines is 300 m (Chapter 5.5.4, the cabling cost 3.824 M€). The transport barge takes the 14 turbine foundations and the same amount of ready assembled power plants to the site (Table 30, € 33 310 / pc). The year production comes from Chapter 5.4.3, Table 28 – energy calculations. The other information needed for the calculations comes from the literature, manufacturer's bid, foundation, steel construction, assembly, transport and erection, sea bed research and an interview. The operation and maintenance cost come from Chapter 5.6. The capital costs are calculated with 5 % real interest and the lifetime is 20 years. Tande (1994: 23) recommends levelled correction factors for annual power production during year t:

$K_{per,t}$	1.00	Performance factor (rain, dirt, etc.)
$K_{site,\ t}$	0.95	Site factor (obstacles)
$K_{ava,\ t}$	0.95	Technical availability factor (failure, service)
$K_{los,\ t}$	0.95	Electrical transmission losses factor
$K_{util,\ t}$	1.00	Utilisation factor
Total	0.86	

In Table 31 the energy price at Strömmingsbåda is calculated. There are turbine characteristics, onshore bid prices, offshore calculated prices, total investment costs, O&M cost, levelled years production and production cost. Depending on the turbine the kWh price varies from €c 3.60 to 4.70. (Table comes from matrix c€ per kWh.Strömmingsbåda).

The best kWh prices are between €c 3–4, depending on the wind turbine. Turbine B has over large bending moment and that effects large and expensive foundation. That is to seen in the kWh price. It is far higher than the old water power price, on the level of €c 1, but below new coal and nuclear power prices (Figure 17 OECD 1993 prices for separate production methods).

Table 31. Kilowatt price of different wind turbines.

Kilowatt Price with separate Power Plants

Measuring Periode on the Strömmingsbåda and Bergö Islands on 22.11.97 - 26.11.1998

Producer	**Turbine A**		**Turbine B**		**Turbine C**		**Turbine D**	
Rated Power (kW)	**2 000**		**1 500**		**2 500**		**2 000**	
Rotor D(m)	76		64		80		80	
Hub Height h(m)	80		60		80		78	
Weight (TON)	270		203		310		268	
Onshore Bid Prices	€		€		€		€	
Wind Turbine ex works	1 495 000	100 %	1 309 452	100 %	1 758	100 %	1 717 200	100 %
Transport to Dock	10 000	0.7 %	10 000	0.8 %	10 000	0.6 %	10 000	0.6 %
Transformer	30 000	2.0 %	30 000	2.3 %	30 000	1.7 %	Incl.	
Remote Control	3 500	0.2 %	2 528	0.2 %	Incl.		Incl.	
Training	incl.		incl.		10 226		11 500	
Accessory	40 000	2.7 %	incl.		98 398	5.6 %	6 100	0.4 %
Warranty Time's Service	40 000	2.7 %	11 840	0.9 %	incl.		Incl.	
Altogether	1 618 500	108 %	1 363 820	104 %	1 906	108 %	1 744 800	102 %
Currency Factor	1.00000		1.00000		1.00000		1.00000	
Turbine on Dock	**1 618 500**		**1 363 820**		**1 906**		**1 744 800**	
€ / kW	809		909		763		872	
Offshore Calculated Prices								
Steel Foundation	331 959	22.2 %	329 251	25.1 %	378 524	21.5 %	319 508	18.6 %
Transport	6 487	0.4 %	6 487	0.4 %	6 487	0.4 %	6 487	0.4 %
Harbour/Dock Assemblage	10 485	0.7 %	10 485	0.8 %	10 485	0.6 %	10 485	0.6 %
Site Work	16 338	1.1 %	16 338	1.2 %	16 338	0.9 %	16 338	1.0 %
Sea-bed Reseach	20 000	1.3 %	20 000	1.5 %	20 000	1.1 %	20 000	1.2 %
Cabling (20+3.9 km, 160€/m, 14	273 143	18.3 %	273 143	20.9 %	273 143	15.5 %	273 143	15.9 %
Planing	10 000	0.7 %	10 000	0.8 %	10 000	0.6 %	10 000	0.6 %
Additional Charge	10 000	0.7 %	10 000	0.8 %	10 000	0.6 %	10 000	0.6 %
Total Investment	**2 296 912**	153.6 %	**2 039 524**	155.8	**2 631**	149.7 %	**2 410 761**	140.4 %
€/kW	1 148		1 360		1 053		1 205	
Investment 0 %	0		0		0		0	
Net Investment	**2 296 912**	153.6 %	**2 039 524**	155.8	**2 631**	149.7 %	**2 410 761**	140.4 %
€/kW	1 148		1 360		1 053		1 205	
Operation and Maintenance (€/year)								
Operation and Maintenance	73 616	4.9 %	49 607	3.8 %	88 908	5.1 %	78 231	4.6 %
Insurance	15 000	1.0 %	15 000	1.1 %	15 000	0.9 %	15 000	0.9 %
Administration	5 000	0.3 %	5 000	0.4 %	5 000	0.3 %	5 000	0.3 %
Altogether (€/year)	**93 616**	6.3 %	**69 607**	5.3 %	**108 908**	6.2 %	**98 231**	5.7 %
O&M (€c/kWh)	1.27		1.40		1.22		1.26	
Year Production (kWh/a)	8 586 151		5 785 878		10 369		9 124 506	
Levelised Utilized Energy (0.86)	**7 361 551**		**4 960 667**		**8 890**		**7 823 123**	
Year Production per Swept Area	1 623		1 542		1 769		1 556	
Nominal Power Time (h/a)	3 681		3 307		3 556		3 912	
Capasity Factor (Cf)	0.42		0.38		0.41		0.45	
Production Cost (€c/kWh)	**3.78**		**4.70**		**3.60**		**3.73**	
Real Interest 5 %								
Refund Periode 20 Year	**2 000**		**1 500**		**2 500**		**2 000**	
Swept Area (m^2)	4 536		3 217		5 027		5 027	

5.8 Summary

The main and assistance construct is presented in chapter 3. It is tested with the method presented in Chapter 4 and the results are presented in Chapter 5.

The results are developed to obtain the electricity price in a model of a wind turbine park located some ten kilometres from shore (in this example, off Strömminsbåda). The main work is done with spreadsheet matrices and the results are presented in Chapter 5.

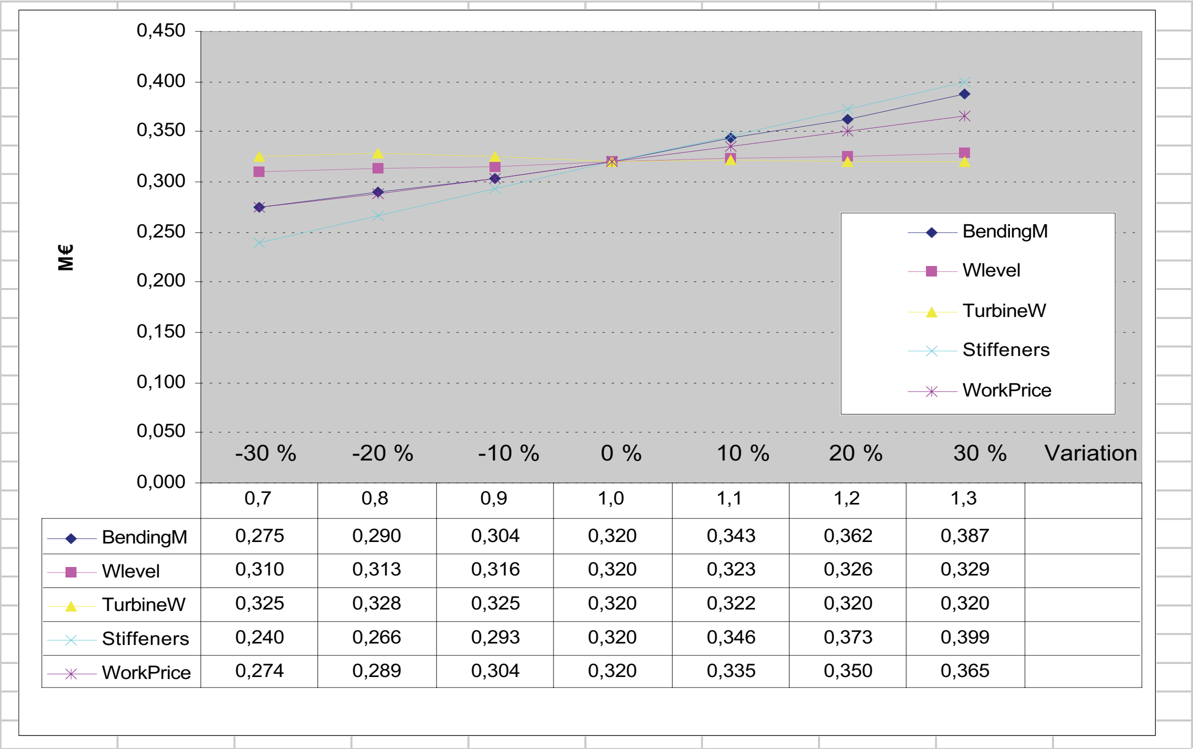
The construct example results are presented in Chapter 5.5.2. The spreadsheet calculation allows the feeding of all size turbine, tower height, water depth and to a certain extent the sort of sea bottom; in total 11 initial values concerning foundation features. These give:

- the foundation price
- sufficient bending / holding moment
- sufficient floating features
- centre of gravity
- centre of buoyancy

and possibly

- floating stability without external assistance (ship or barge) tower in the telescope mode

The assembly, transportation and erection example costs are presented in Table 30. The operation and maintenance costs are from the literature. In Table 31 all data are connected to the kilowatt price with separate wind turbines off Strömmingsbåda in a 14 turbine wind park.



	0,7	0,8	0,9	1,0	1,1	1,2	1,3	
◆ BendingM	0,275	0,290	0,304	0,320	0,343	0,362	0,387	
■ Wlevel	0,310	0,313	0,316	0,320	0,323	0,326	0,329	
▲ TurbineW	0,325	0,328	0,325	0,320	0,322	0,320	0,320	
× Stiffeners	0,240	0,266	0,293	0,320	0,346	0,373	0,399	
✳ WorkPrice	0,274	0,289	0,304	0,320	0,335	0,350	0,365	

Figure 41. Sensitivity analysis: The effectiveness of various cost components on foundation price. (Note decimal points commas not dots)

The sensitivity analysis (Figure 41 Matrix SensitiveAnalysis.Vestas2MW) tells that the most price increasing component is Stiffeners coefficient. It tells how much steel is needed to use for construction against static and dynamic (fatigue) load. The second most price increasing component is the wind turbine manufacturer stated bending moment. It describes wind conditions e.g. gust happening over 50 years. The construction shall tolerate these. The bending moment is depending e. g. on rotor diameter, wings form and how they can be turned to the wind direction. The work price has an effect on third place. Water depth and turbine weight do not affect much when the variation is between -30 – +30 %.

6. EVALUATION OF THE RESULTS AND RESEARCH METHODS

6.1 General

This study attempts to clarify the costs and cost structures of wind power production, especially the costs that are caused by the logistic factors of location and erection of offshore wind power stations, and proposes one possible solution.

Table 32. Evaluation of the costs of new construction and state-of-the art of technology (Table 8 and 9, Appendix 12, Middelgrunden 2000: 11,12 and Sörensen 2002).

Item	New Construct		State-of- the Art of Technology	
	(the Research)		(Middelgrunden 2000)	Sörensen (2002)
Foundation	Fig. 39	€ 331 959	€ 393 500	€ 496 000
Transport	Tab.25	€ 6 487		
Harbour	Tab. 25	€ 10 485		
Site	Tab.25	€ 16 338	€ 100 500	€ 134 500
Other costs	Tab. 26 A	€ 40 000	€ 60 000	€ 80 500
Sum	**Tab. 26 A**	**€ 405 269**	**€ 554 000**	**€ 711 500**

In Table 32 the prices of the two same kinds of foundations (gravity based) are compared. The cost of new logistic construction is calculated in Table 31. The right prices of state-of–the art–technology are most difficult to obtain – for understandable reasons – but in Appendix 12 the prices are calculated. Middelgrunden 2000 prices are budget prices but according to the tender. For example, total costs are in Middelgrunden 2000 m€ 46.95, Eskesen 2001 gives cost of m€ 49.2 and Sörensen m€ 44.9.

A typical saving for a 20 mill park could be m€ 2.97 – 6.12.

The foundation prices are on the same level. The new construct requires transport and harbour payment. The site work shows a difference. The main saving is to avoid the use of offshore cranes. Other costs are on the same level.

Benefits also come by another route. In summer months is possible to use offshore crane 50 % of the time and during the year 10 % of the time. The costs are round € 133 000 per day independent of sea conditions (Vestas 2001, Håkans 2000 list of statements). It makes the budgeting of costs very unstable, too.

The costs of offshore park size vary as follows: the turbine and cable between turbines stays on the same level between park size from 2 to 200 MW or more. The cable is e.g. 20 kV and the length between turbines 3–5 x rotor diameter. In the larger parks the turbines are in rows and the distance between rows is 5 – 9 x rotor diameter. The cable prices are in chapter 5.5.4. The total cabling price, however, depends very heavily on sea bottom conditions. According to Morgan & Jamieson (2001: 2–46) transmission price depends on three possible options:

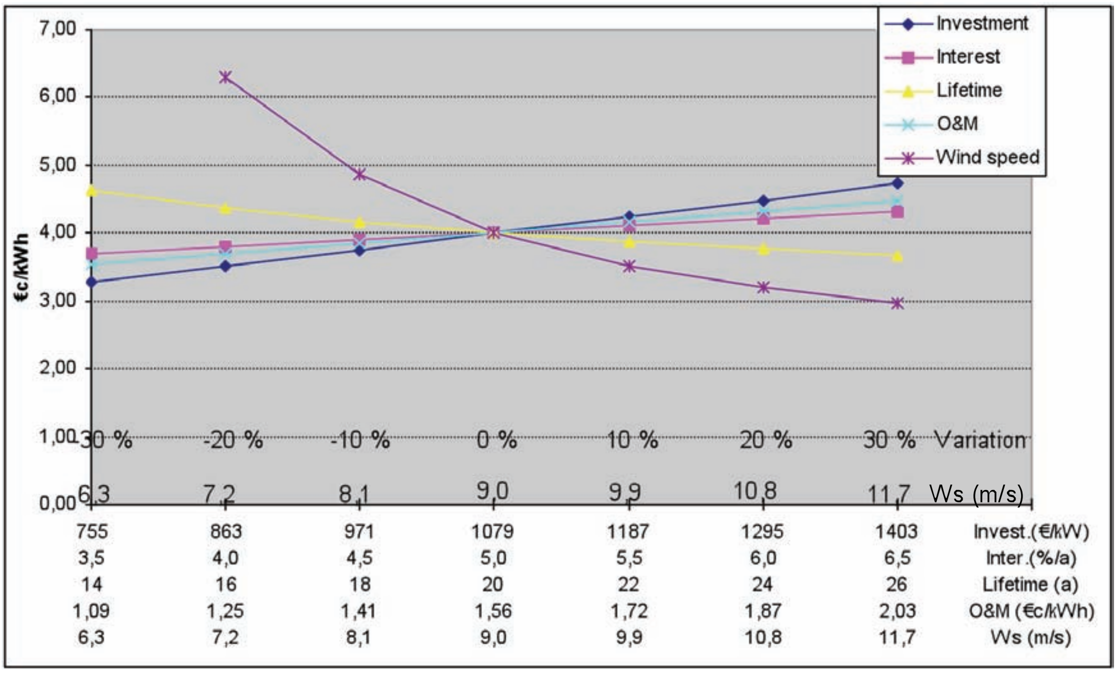
a) multiple medium voltage links (up to 35 kV) for parks some kilometres offshore and size less than 200 MW
b) single high-voltage link (100 to 200 kV) for longer distance offshore and larger wind parks
c) HVDC (High Voltage Direct Current) link for parks above 25 km offshore and power level more than 200 MW

In addition the shade effect of the park should be considered. There can be a 28% production loss in unidirectional wind with turbulence intensity of 0.05 and in omni directional case with turbulence intensity of 0.15 a 5 % production loss, depending on the distance of the turbines and rows with 10 rotor diameter (Lissaman 1998: 305).

The results will be appraised by clarifying the effectiveness of wind power electricity price against the cost and production components. In Figure 42 the components are calculated on Stömmingsbåda wind conditions at the 60 meter hub height with 1 MW turbine. In this example the wind turbine technical and commercial data are used to simulate turbine electricity production. The example uses a 14 wind mill turbine park at a 20 km distance from land and 3.9 km cables between the 1–1.65 MW turbines (Annex

12) and sandy sea bottom. The price consists of cost of investment (interest and lifetime) and operation & maintenance costs divided by electricity production. In this sensitivity analysis the parameter variation factors are 0.7, 0.8, 0.9. 1.0, 1.1, 1.2, 1.3.

In Appendix 11 (Matrix c€Sensitivity Analysis.Strömmingsbåda60m) one of the five cost factors changes and the other stays constant. For every varied cost factor the corresponding electricity price (€c/kWh) is calculated and can be seen in Figure 42.



755	863	971	1079	1187	1295	1403	Invest.(€/kW)
3,5	4,0	4,5	5,0	5,5	6,0	6,5	Inter.(%/a)
14	16	18	20	22	24	26	Lifetime (a)
1,09	1,25	1,41	1,56	1,72	1,87	2,03	O&M (€c/kWh)
6,3	7,2	8,1	9,0	9,9	10,8	11,7	Ws (m/s)

Figure 42. Sensitivity analysis: The effectiveness of various cost components on electricity price. (Note decimal points are commas not dots)

For varied wind speeds the wind turbine corresponding power is taken from the curve and calculated with a year's production. The total year's cost and the year's production are divided by cost per energy (€c/kWh). The same is as in figure 42 (Matrix Sensitivity Analysis.Strömmingsbåda60m), which shows the effectiveness of cost components with the electricity price. The variation for different components is shown in the graph.

It is clearly seen that the most important factor is the mean wind speed. Changes in wind speed measurement, calculations and estimates influences most on the energy price. The other components have an effect but are not as strong factors as wind speeds.

6.2 Validity

Validity refers to the ability of a measure to measure what it is intended to measure.

Internal validity establishes a causal relationship, whereby certain conditions are shown to lead to other conditions, as distinguished from spurious relationships. In this study such a measure is not applicable (Yin 1994: 35).

External validity considers to which domain the result or findings from a study can be generalised. The method handled in Chapter 6.3.1 could be generalised. If it is possible to find equal wind conditions in separate places, with this method it is possible to transfer the measurement results to another place. The foundation construct's validity depends on the sea bottom structure. If the bottom is solid and smooth the research construct is valid. In other cases other foundations come into question (such as mono pile) or levelling the sea bottom (for example concrete planes) (Yin 1994: 36).

6.2.1 Construct Validity

In term of construct validity, the question here is whether the research is constructed to produce the cheapest wind power? Other possibilities are, for example, wind turbines located high in the mountains. There wind speeds are favourable. On the other hand transport to the site can be difficult and at the height of clouds there is freezing on the blades at air temperature below zero Celsius. Ice on the blades can be avoided by using a heating system. This research in any case is evaluating the lowest possible price at sea. The selected construct is right if it leads to the result wanted.

6.2.2 Wind Speed

The sensitivity analysis in figure 42 shows the most important components of the wind power price. According to Lange & Höjstrup (1999: 1166) and Rinta-Jouppi (1995 in there appendix 17.2 and 17.3), the wind speed accelerates away from the shore and 10 km away from the shore is 1–2 m/s more than on the coastline at the same height. The measurement on Bergö and measurement of Finnish Meteorological Institute data from Strömmingsbåda (Table 23) shows that the measured mean wind speed already on Strömmingsbåda at a 14 m height (6.82 m/s) is higher than on the coastline at a 40 m height (6.80 m/s). The figures from Strömmingsbåda (8.33 m/s) island, 30 km from the coastline and 19 km from Bergö (6.80 m/s) show a calculated 1.53 m/s higher wind speed than both at the same 40 m height level. The conclusion is that at sea the wind blows more than at the coastline. Kühl (1999: 47) has collected the statistics from different wind parks, wind speed by separate hub height and distance from land (Table 33). The wind speeds above are in line with statistics collected from the North sea and the Baltic sea.

Table 33. Wind speed at different hub heights and the distance from the shore.

Name of Project or Study	Wind speed(m/s)	Hub Height (m)	From Shore(km)
Vindeby, Baltic, DK, P-91	7.5	37.5	1.5
Lely,North Sea, UK, P-94	7.7	41.5	1.0
Tunö Knob,Baltic, DK, P-95	7.5	43.0	6.0
Horns Rev, NS, DK, S-97	9.2	55.0	15.0
Bockstiegen-Valar, B, SE P-97	8.0	41.5	4.0

6.2.3 Investment

According to Table 31 the investment price depends on the turbine, transport to the dock, the transformer, remote control, training, accessories, warranty, steel foundation, transports, harbour/dock assemblage, site work, sea-bed research and cabling, etc. With planning and additional charges it costs, depending on the turbine, 1.05–1.36 M€ / MW. Svenson & Olsen (1999: 299) and Appendix 12, have studied parks at Rödsand, Omö and Dedser using steel foundations with olivine ballast and calculated with 1.5 MW x 96 turbine parks per each site. They decided the total investment to be 1.46–1.65 M€ / MW.

This research calculates the foundation is at a 6 meter water depth. The cost of foundation depends on turbine weight, bending moment, hub height, water depth, diameter and height of tower and foundation, steel thickness, stone/concrete ballast, painting and stiffeners. In total 11 starting values for spreadsheet computation define the outer and inner measures of the foundation and construct (Figure 40). The cost of foundation (Table 31) in these four calculation examples are 331 959, 329 251, 378 524 and 319 508 €. The Svenson & Ohlsen (1999: 297) research gives for steel construction at a 5–11 meter water depth a price of 265 000–318 000 € for 1.5 MW turbines (Appendix 12).

6.2.4 Interest and Lifetime

The practice of using 5 % real interest and 20 year life time makes comparison easier with different cost figures in references. 5 % interest is in practise very near reality because when the interest on bank loans is higher than 5 %, inflation starts to increase and the real interest is again 5 %. A 20 year lifetime is an economical lifetime. Modern wind turbines have not yet reached a 20 year lifetime, so it is not possible to say how long the construct lifetime actually is.

However, if wind turbine production costs and electricity selling prices rise equally as much (Table 34) it is possible to use real interest in the calculations. Statistical yearbook 1999 shows the rise of production and electricity prices. From 1980 to 1998 the rise for all the index is about double. The wholesale electricity price follows the rise quite exactly since in 1979 the index was 575, rising after a year to 737.

Table 34. Statistical yearbook; electricity selling and production prices.

Year	392.31b Wholesale price index; gas, electricity and heat	392.7 Wholesale price index; machinery and transport equipment	393.7 Production price index; machinery and transport equipment
1980	737	971	810
1998	1228	1899	1655

The conclusion is that inflation has caused a doubling of electric power price and the same rise in wind turbine production price during the same period (Table 34) and if the rise in future follows the same track, we can generally use real interest. It means that bank interest minus general inflation stays constant and in this special branch earning and costs follow each other. By using real interest the calculation becomes notably easier because it is not necessary to discount future development of earnings and costs to this day. The established real interest by wind power calculations is 5 %/a. In Finland during 1989-1998 the average rates of interest on advancing minus cost of living index change was on average during that time 6.337 %/a. At the same time the average rates of interest on advancing minus wholesale price index change was an average 7.25 %/a (Statistical Yearbook 1999: 250 and 387).

6.2.5 Operation and Maintenance

In the literature the figure for O & M costs including operation, maintenance, insurance and administration is 0.01 $ / kWh (Chapter 2.4.3). The research of Svenson & Olsen (1999: 299) uses 0.011 € / kWh. Earlier some percentage of the total investment price was used, then some percentage of turbine investment. Now the figure is calculated from produced energy, which may best reflect use and wear and therefore future costs also. Offshore O&M costs are higher than onshore wind turbines. Offshore windmills are difficult to reach because of waves, sea current and wind compared to the O&M of windmills on land. There the service vehicles can drive right up to and beside the windmill.

Verbruggen et al. (2001) calculate the following values for offshore wind farms operation and maintenance costs. These figures in Table 35 are very near to the earlier presented figures.

Table 35. Operation & Maintenance costs.

Type of maintenance	**Annual cost (€/kWh)**
Preventive maintenance	0.005–0.012
Corrective maintenance	0.010–0.019

6.3 Reliability

Reliability refers to the consistency of measurement results, including such characteristics as accuracy and precision. Reliability demonstrates that the operations of the study such as the test data collection procedures can be repeated, with the same results (Olkkonen 1994: 38).

Validity focuses on the meaning and meaningfulness of data. Reliability focuses on the consistency of results (Sykes 1991: 309).

6.3.1 Wind speed

The most reliable wind speed is possible to obtain only by measuring with a mast at hub height with a heated anemometer. For example on Strömmingsbåda island the measuring gauges on the mast must be at the windmill hub height at 60 m. Using computer simulating methods and measurements with lower masts makes the research more uncertain. The calibration of the anemometers and different wind years must be taken into consideration, too. In this research the wind speed measuring has been completed from Bergö island reached by car with a 40 meter mast and at the same time 19 km to the west with a time series at 14 meters. The results have been converted to 60 meter hub height.

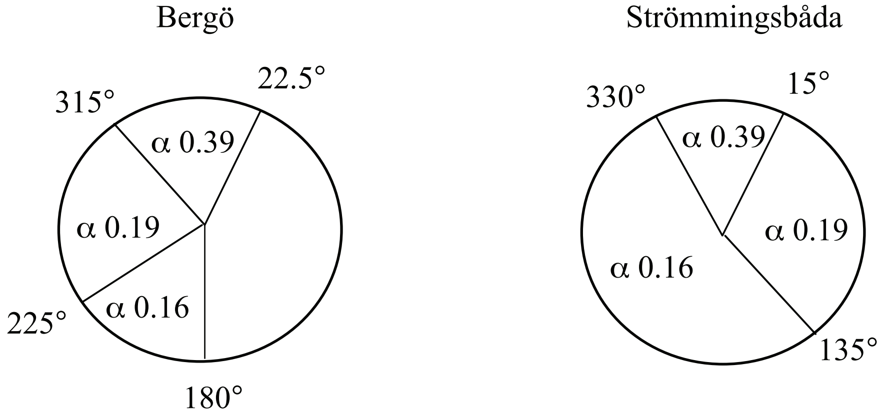


Figure 43. The same α values in different places and sectors.

According to the literature the wind speed accelerates when the height increases according to the formula (4.1). The Bergö 40 meter mast has anemometers at heights of 20, 30 and 40 meters. In the above formula potency α will be calculated at the above directions. The selected wind directions on Bergö correspond to wind obstacles on Strömmingsbåda island. With corresponding α values in Figure 43 the 14 meter height statistics are converted to 60 meter wind speed. The directions 15º–135º–330º–15º will be calculated. The corresponding mean wind speeds are 8.59, 9.21, 9.34 m/s and for all directions the mean speed is 9.01 m/s (Table 27). The energy calculations are made in the same manner selecting from the whole 8794 hours statistics with the same wind speeds at the above directions and taking the corresponding power values of the wind turbine and adding to the energy of the above directions. The obtained energy from the selected directions will be added together for whole 360º energy.

The method is tested in Chapter 4.1.4 (Reference Measurements on Height Direction) by using the top of the bridge pylon for the anemometer. The distance between the two measuring places was one kilometre.

The anemometer calibrations are made in a wind tunnel defining the wind speed shown by the anemometer. If there is difference between the real and anemometer values, this is taken into consideration in the calculations.

Whether the measuring year has been a good or bad wind year it must be estimated for example, with statistics from the Finish Meteorological Institute of Valassaaret island, 53 km to the north east of Strömmingsbåda (Appendix 13). In the years 1961–1990 the mean wind speed has been 6.6 m/s and at the same place and in the same measurement environment. During the time of this research the wind speed has been 5.9 m/s (Rinta-Jouppi 1999a: 9). The conclusion is that the coming years will be more windy.

6.3.2 Investment

The investment example consists of a) onshore up dated bid prices (Table 31) and b) offshore calculated prices (Table 30).

The steel foundation cost consists of (Figure 40) materials such as steel, ballast stone/ concrete, paint and also work: the amount and price. The wind turbine manufacturer defines the data of the turbine consisting of tower, engine room and rotor weight, bending moment, diameter and plate thickness of tower, and so on.

Figure 40, which is at the same time a spreadsheet program, calculates with the given values the diameter, height and ballast of the foundation so that the whole wind turbine bending/holding moment is under 1. In the same manner the weight / lift will be under 1. This means that the whole construct floats when the water tank is empty and the version in Figure 40 floats alone without assistance of smaller crane to keep the turbine on a vertical position (List of Statement and Offer: Beacon 2001). With ballast the turbine stays vertical against wind, sea current, waves and ice in the sea bottom. In the calculations the material and work amounts and prices used are inspected by an SME (Small and Medium size Enterprise) owner, who calculates and produces equal steel components (WPOSFOLES 2000, List of Statement and Offers: Fagerström 2000). The simulating program allows the combining of the measures and masses to find the lowest price for the foundation.

The transport consists of transport of the foundation to the assembly harbour or dock and the transport of the ready assembled windmill to the erection site. Table 30 shows the prices of towing, salvage, ice breaking, heavy transport and submarine work (List of Statement and Offers: Håkans 2000).

The sea-bed research costs come from an interview with a ground and sea-bed research company (List of Statement and Offers: Korpinen, GEO Engineers 2000). The cabling costs are from earlier research (Rinta-Jouppi 1995).

The investment price interest and lifetime will be chosen. It is important that it is comparable with other wind power plans and projects. Currently a 5% real interest rate and 20 year lifetime are used. The operation and maintenance costs used in the literature are 1 €c or 1 $c/kWh. In this research O&M costs are not measured.

6.4 Relevance

Relevance is concerned with the value and usefulness of the measurement results for the users of the measure. Figure 44 shows the constructive research approach (Kasanen & Lukka & Siitonen 1991: 306).

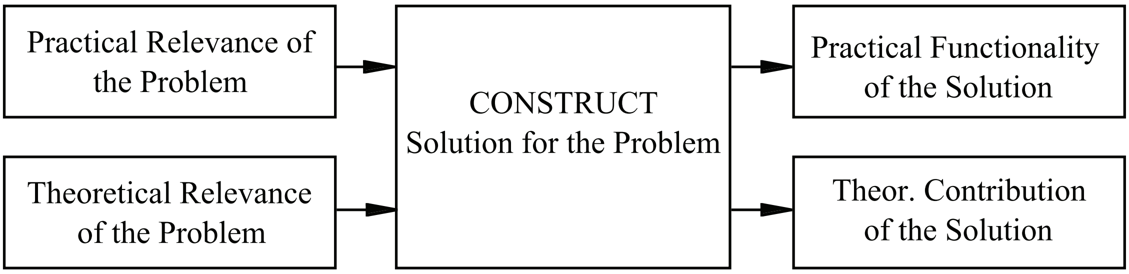


Figure 44. Constructive research approach.

The practical relevance could be wind measuring at the measuring points on the map, Appendix 5. The theoretical relevance could be the research of offshore windmill electricity prices, going far offshore as the planned wind parks are. Figure 34 and 42 show that wind speed is the most important component of the price. Therefore theoretical relevance is to take measurement at the site of a planned park with a measuring mast at a hub height over several years. Practical relevance gives the possibility of use: measuring with a 40 meter mast on land and converting FMI (Finnish Meteorological Institute) data from a beacon island from a 14 meter height to hub heights. The evaluation of whether the measuring year was a good or bad wind year can be done by comparing wind data over a 30 year period from a nearby measuring station.

The practical functionality of the solution of the whole construct is to develop competitive electric power. The wind speed and the other cost components define the whole construct competitiveness.

The theoretical contribution of the solution follows Porter's 1985 theory of reaching cost leader status. This means reaching a low cost level compared to competitors. The solutions in reaching low level costs are in going out to sea far enough, e.g. by more than 20 km from the shore and selecting the park location in shallow water from 5 to 15 meters in depth, ideally a place on the sea without ice, sea current, big waves and with a hard, smooth sandy sea bottom. To be a cost leader in electric power price the price of the foundation of the windmill should be on the limits shown in Figure 40 for steel foundation. The foundation prices in Table 31 are from 18.6 % to 25.1 % of the turbine price itself and the total investment is from 140.4 % to 155.8 % of the turbine (including tower) price (31,4 % foundation and 196 % total investment, Barthelmie et al. 2001: 6–3, 17.6 % foundation and 170 % total investment, Fuglsang & Thomsen 1998: 13). The electric power prices are shown in the same table. The comparison to other production methods is in Figure 1. and to other park locations in Appendix 12. This construct does not take into consideration investment support, return of taxes or other subsidies. It means that all figures are real costs without subsidies.

6.5 Practicality

The practicality is defined as the benefit-burden ratio of measurement. In other words, are the measurement results worth the effort needed for the implementation and the maintenance of the measurement. The measures are needed to get exact figures concerning wind power price components, the local wind speeds. The possibility to estimate wind speed by computer simulated program is too risky for big investments. To win cost leader status the foundation solution must include new ideas to obtain cheaper construction, transport and erection. Cost leader status includes the whole work practicality. If the whole working process is not practical, the process can not be a cost leader.

6.6 Summary

Does this research construct lead to the cheapest wind power electricity during the turbine life time? In this research we do not inspect possible mountain sites and wind speeds and wind power there. In this construct wind speeds are mapped offshore. Foundations suitable for offshore site, assembly, transport, cabling and erection on site are included in this research. The construct produces cheaper wind electricity but not yet at the same level as water power electricity. The best wind conditions and the cheapest foundation, transport, erection, cabling, and O&M leads to cost leader position.

7. CONCLUSION

7.1 Summary of Construct Created

The created construct brings new knowledge to the question of the direction in which the wind power plant industry and wind turbines should go. The computer simulated foundation model and also the small scale foundation with turbine model bring new knowledge to this branch of science. The unique computer simulated foundation model brings the right dimensions and solutions to the foundation in different conditions of sea and sea bottom and also to the different scales and types of wind turbines. A wind turbine foundation which floats and stays filled with water on the sea bottom leads the construct to cost leader position (Porter 1985) among the foundation structures. The example foundation used requires minimum values for foundation diameter 25 m, height 4 m, 0.5 m high concrete ballast and cost € 441 333. The typical saving can be 2.97 – 6.12 M€ for a park of 20 turbines). To sell the electric energy produced by windmills seems to be difficult if the produced energy is not at the same price level with other electricity production. The power plant produces wind electricity of 3.73 €c/kWh with cost of 1.2 M€/MW with wind speed of 9 m/s at 60m height.

This research construct helps in two ways to reach a lower wind electricity price level. The location of the windmill parks, in this case, are offshore, about 20 km from the coast. The wind speeds are significantly higher there than nearer the coast and on the coastline. A rough estimation is that the offshore wind speed level is 15 % higher than onshore winds. The theoretical power formula $P = {}^{1}/_{2}\rho A v^{3}$ promises 50 % more energy. The reason to go offshore is the better wind speed. It is measured in two places on Kaijakari 0.5 km from land on an island. The measured energy was 13.9 % better than onshore on a breakwater. The other case Strömmingsbåda is 19 km out to sea. The wind speed difference at 40 m height is 22.5 % and energy difference 43.8 %. At 60 m height the differences are for the wind speed 13.3 % and energy 21.0 %. This can be due to land effect; the forest does not so much affecting the wind speed at 60 m height.

Mean wind speed difference at 60 m height is 1.06 m/s Strömmingsbåda/Bergö. The formula (5.6) shows that the power increases by the potency of three when the wind speed increases by the first potency (In practice the potency is some decimals points above two). In practice often a half meter per second increase or decrease of wind speed at the planned turbine location decides if the place is good or bad for wind power production. This reason can result in a positive or negative cash flow for the wind electricity producer. Another reason to go offshore is practical. The lack of suitable places for wind turbines on shore is even worse in so called wind power countries.

The other solution to lead the construct into cost leader position is a unique logistical system to fabricate, transport, assemble and erect the foundation and the connection of windmill hull, engine room and rotor. The construct brings to the market a solution which significantly affects further constructs and price level. The whole construct brings wind electric power to a competitive position with other electric producer plants. For example with the operation time of 5000h/a the production costs are for peat 38.25 € / MWh, gas 29.63 € / MWh and coal 29.42 € / MWh and on Strömmingsbåga location for wind power 37.3 €/MWh.

7.2 Applicability of the Results

In the previous chapter we described the construct influencing the electric power price. The basis for competitive wind electricity price is the measurement of wind speeds on Bergö, Fjärdskäret and at the top of the Raippaluoto bridge pylon and also earlier measurements on Kaijakari (Chapter 5). Those data and analyses bring understanding of how the wind behaves on and offshore at separate heights and on different terrain. The most important cost component of wind power is the wind speed (20% smaller mean wind speed increases the wind electric price from 4.7 to 9.5 €c/kWh).

The unique test for the formula and spreadsheet applications is included in the calculation of wind speed at the hub height. The measuring mast measures wind speeds at heights of 30 and 20 m. On the basis of this data we can calculate the 60 m height speed. To control the result we use the pylon height of 82 m and 30 m data to calculate the 60 m speed. The results are very close. This formula can thus be used.

The other unique measuring and calculation is to convert the Strömmingsbåda island Finnish Meteorological Institute data from a 14 m height to 60 m height wind speed. On Bergö island, 20 km east, the measuring mast measured the wind speeds at 40, 30 and 20 m heights. From this data we can calculate in different directions with the formula (5.4) potency α factor. The potency factor always varies according to wind obstacles. Now we can select the same obstacle conditions for the measuring mast and conditions on Strömmingsbåda island: mainly sea, a similar archipelago and similar obstacle (building) by selecting the right sectors of a 360° circle. With this the potency factor α we calculated the wind speeds from 14 m data to 60 m data.

7.3 Contribution of the Research

The contribution to the science of this branch is a unique type of foundation for the offshore wind turbine. A new logistical system to fabricate, assemble, transport and erect offshore wind turbines is a contribution to the economy of wind electricity production. These measurements of wind speeds and calculations of offshore conditions will increase the internationally rather rare measurements and knowledge of wind speeds ten kilometres from the coast at the windmill hub height. All the results of this research lead to the goal of obtaining more competitive wind electric power compared with other power plants and for manufacturers to find more economic ways to produce, transport, assemble and erect wind parks in offshore locations For one foundation, turbine transportation and assembly in the harbour and floating to the site and assembly on the sea bottom cost € 33 310.

7.4 Need for Further Research

A need for further research would be for wind measuring masts directly at windmill hub height. Currently fabricated masts can be carried by hand on the terrain, and it is possible to erect them in places where no vehicle can go. They are also possible to erect and unload in a day or two. Today's portable measuring masts are 40 (50) m high and hub heights are 60 m and higher. It should be possible to erect on land or in the middle of sea at the hub height and the data could be read by radio signals.

In Ådö and Fränsvik (Chapter 5.4.4 Appendix 16, 17) the researcher attempts to continue the measuring after the measuring mast is taken down with the help of a fixed weather station nearby. The verification for method used is still missing.

There is still a great lack of wind energy measurements in inland Finland, on the sea coastline and offshore. Wind measurements have been made already for at least a hundred years but for the purpose of weather forecasts and warnings for sea navigators. These measurements serve badly in terms of wind energy data.

Still more questions arose during the research work. On the basis of earth surface friction the wind direction turns by rising to an upper level. Could the alteration of wind course be used to calculate the wind speed at an upper level?

If on any business branch there are some turnover figures, how much does it employ people with subcontract chains down to the excavation of raw material?

The foundation itself needs detailed planning, static and dynamic load calculations, drawings, verifying small scale analysis, status in the market, detailed price calculations and comparisons with comparable solutions in the market, as well as the mapping of subcontractors such as tug-boats, crane contractors and cabling.

Considering historical data over the range of machine sizes, the cubic scaling law regarding system masses and costs appears closer to a square law with ongoing technology development (Morgan & Jamieson 2001: 2–13).

In general we need to research what possibilities (offshore) wind power really offers in terms of replacing other electricity production in the whole country or part of it. What is the price of the replacement? To estimate the price in the future we need to take into consideration the super-fast development of wind power plants and wind power turbine manufacturing (from the eighties to the present the power of a single wind turbine has doubled during each 3 or 4 year period, from 30-40 kW to 2,5 MW).

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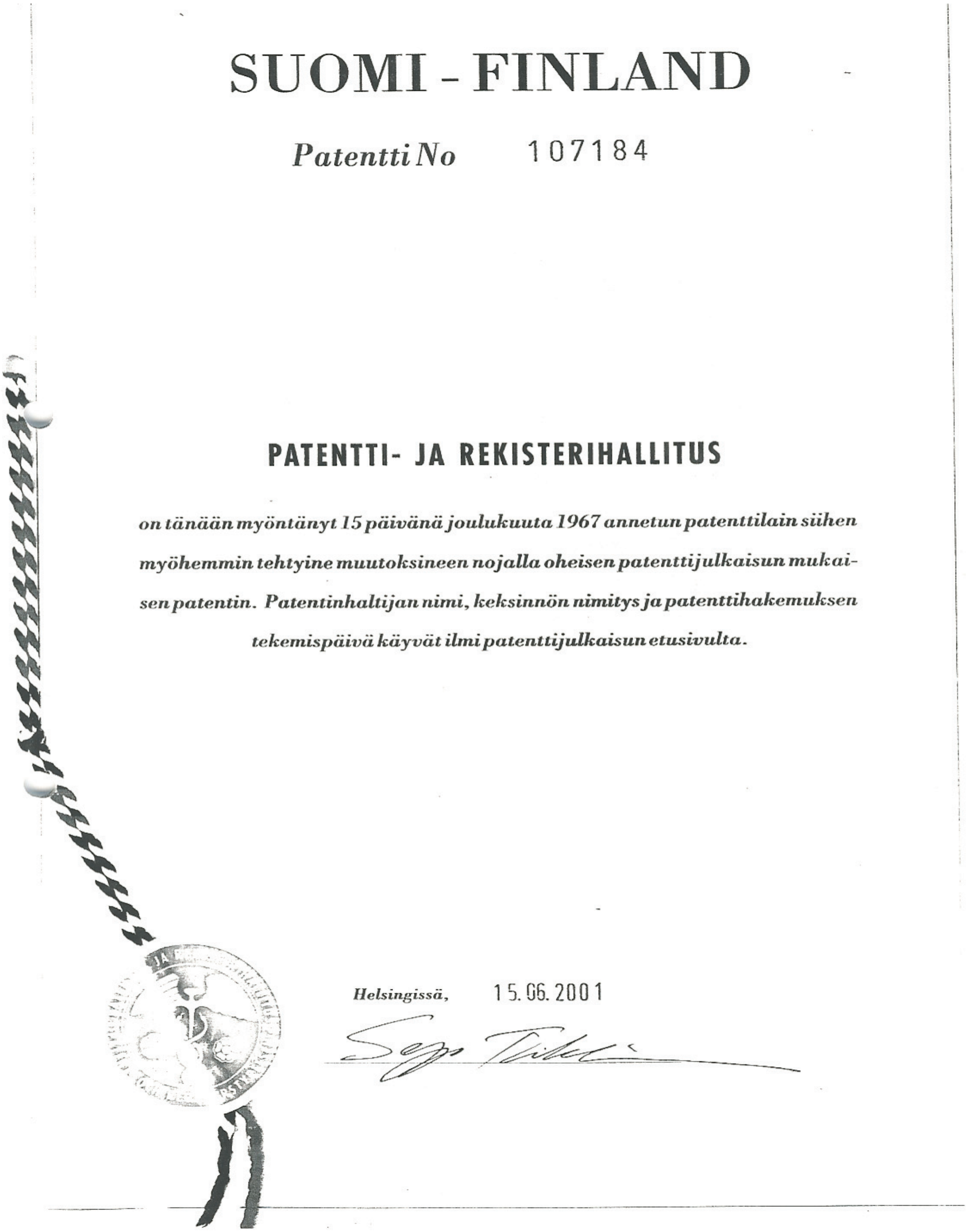
APPENDICES

Appendix 1. Patent number 107184 and PCT Application WO 01/34977 A1.



SUOMI - FINLAND

Patentti No 107184

PATENTTI- JA REKISTERIHALLITUS

on tänään myöntänyt 15 päivänä joulukuuta 1967 annetun patenttilain siihen myöhemmin tehtyine muutoksineen nojalla oheisen patenttijulkaisun mukaisen patentin. Patentinhaltijan nimi, keksinnön nimitys ja patenttihakemuksen tekemispäivä käyvät ilmi patenttijulkaisun etusivulta.

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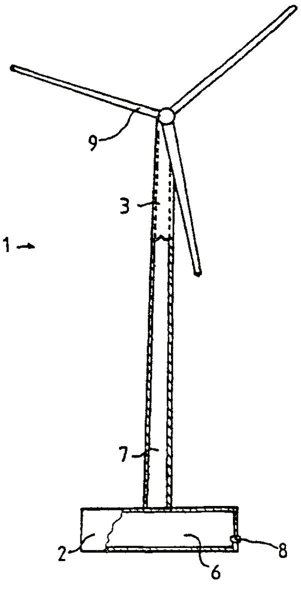
(54) Title: METHOD AND SYSTEM FOR INSTALLING AND TRANSPORTING AN OFFSHORE WIND POWER STATION AT SEA



(57) Abstract: A method and a system for installing an offshore wind power station (1) at sea and/or transporting one from sea e.g. for maintenance, said wind power station comprising a base (2) to be set on the sea bottom, and a tower (3) attached to the base, which wind power station is transported to a place of installation at sea by means of a transport vessel (4) and lowered to the sea bottom and/or lifted off the sea bottom and transported to land/ashore by means of a transport vessel. The wind power station is lowered by adding ballast water into a ballast water tank (6, 7) provided in the wind power station, and raised by reducing the amount of ballast water in the ballast water tank. The wind power station comprises a ballast water tank (6, 7).

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METHOD AND SYSTEM FOR INSTALLING AN OFFSHORE WIND POWER STATION AT SEA AND/OR TRANSPORTING ONE FROM SEA, AND AN OFFSHORE WIND POWER STATION

The present invention relates to a method as defined in the preamble of claim 1. Moreover, the invention relates to a system as defined in the preamble of claim 7. In addition, the invention relates to an offshore wind power station as defined in the preamble of claim 11.

In prior art, a method for installing an off- shore wind power station at sea is known from specification GB 2327440. The wind power station comprises a wide base and a tower extending vertically from the base and carrying a wind rotor mounted on its top. In the installation method presented in the above-mentioned specification, the tower and the base of the wind power station are transported as a single assembly by using a floating frame, e.g. barges, fastening the base to the bottom surface of the barge, transporting it to the place of installation and then lowering it to the sea bottom using means provided on the floating frame, such as chains, wire cables, a lever jack or the like. The floating frame can then be used for the installation of other corresponding base tower combinations.

A problem with this prior-art method is that the load capacity of the floating frame used for installation has to be so designed that it will bear the weight of the base and tower in addition to its own weight. The resulting floating frame is very bulky and expensive. Besides, this specification completely neglects the occasional need to raise the wind power station from the sea bottom and transport it to land/ashore for servicing. .With equipment built according to the specification, this would be difficult if not impossible because the base, which may be made of concrete or steel, must be very heavy to resist the stress exerted on the wind power station by the wind, sea currents, waves and ice. Therefore, the base is provided with ballast material of sand, stones or iron ore. Lifting such a load from the bottom requires very high external hoisting capacity. Therefore, special open sea crane ship would be needed for the hoisting operation.

The object of the invention is to eliminate the above-mentioned drawbacks.

A specific object of the invention is to disclose a method and system for the transportation of an offshore wind power station that will allow transportation without the transport vessel having to carry the weight of the wind power station at all.

A further object of the invention is to disclose a wind power station which can be easily transported back and forth between a place of installation and a place of maintenance and which can be raised and lowered independently in water without using any special hoisting equipment.

The features characteristic of the method, system and wind power station of the invention are presented in the claims below.

In the method of the invention, the wind power station is transported to a place of installation at sea by using a transport vessel and lowered to the sea bottom and/or raised from the sea bottom and transported to land/ashore by means of a transport vessel. According to the invention, the wind power station is lowered by adding ballast water into a ballast water tank provided in the wind power station- and the wind power station is raised by reducing the amount of ballast water in the ballast water tank.

In the system of the invention, the wind power station comprises a base to be mounted on the sea bottom, a tower attached to the base, and a transport vessel provided with a gripping device for gripping the wind power station and transporting the wind power station to a place of installation at sea and/or transporting it to land/ashore from the sea. According to the invention, the system comprises a ballast water tank disposed in the wind power station.

The offshore wind power station of the invention comprises a base to be mounted on the sea bottom, and a tower attached to the base. According to the invention, the wind power station comprises a ballast water tank.

Other preferred features and embodiments of the invention are presented in the sub claims below.

In the following, the invention will be de

scribed in detail by the aid of a few examples of its 15 embodiments

with reference to the attached drawing, wherein

Fig. 1 presents an embodiment of the wind power station of the invention in a diagrammatic side view and partly sectioned,

Fig. 2-7 present two different embodiments of the system of the invention and different stages in the procedure of the invention.

Fig. 1 presents a wind power station 1 according to the invention. It comprises a wide base 2 of e.g. a round slab-like shape, which can be set on the sea bottom. Further, the wind power station com- prises a tower 3 attached to the base and extending vertically from it. Mounted on the upper end of the tower 3 is a wind rotor 9. The box-like base 2, which may be made of concrete or steel, is of a hollow construction and the space inside it functions as a ballast water tank or container 6. The tower 3 is likewise of a hollow construction and the space inside it serves as a ballast water tank 7. The interior spaces of the ballast water tanks 6, 7 in the base 2 and tower 3 may be separate spaces or they may communicate with each other. Moreover, the wind power station 1 may comprise a pump or pumps 8, by means of which it is possible to pump sea water into and out of the ballast water tanks 6, 7. The pump 8 may also be disposed on a transport or service vessel 4, in which case the wind power station need not necessarily be provided with ballast water pumps.

The buoyancy of the wind power station in water is so designed that the station is able to float and carry its own weight in water when the ballast water tanks 6, 7 are empty. Correspondingly, when the ballast water tanks 6, 7 are partially or completely filled with water, the wind power station will sink to the bottom.

In Fig. 2, the base 2 and the tower 3 are assembled on land or ashore into a unitary whole by using a crane ashore. The base 2 can be floated separately to the place of installation and lowered onto a firm pedestal resting on the bottom by filling the ballast water tank 6 in the base. On the top of the base 2, a tower 3 is built from one or more parts. Water can also be pumped into the ballast water tank 7 in the tower to increase its firmness. Finally, a machine room and a wind rotor 9 are mounted on the end of the tower 3.

When the wind power station is to be transported to its place of installation at sea, as illustrated in Fig. 3 and 4, the amount of ballast water in the ballast water tanks 6 and 7 in the base 2 and in the tower 3 is so adjusted that the base 2 becomes buoyant and is lifted off the bottom. By adjusting the amount of ballast water in the tank 6, 7, the elevation and stability of the base in relation to the transport vessel 4 are adjusted to make them suitable for transportation. The tower 3 is gripped from a lateral direction from opposite sides by the gripping jaws 10 of a gripping device 5 mounted on the transport vessel, as illustrated in Fig. 4. The grip on the tower is preferably such that it permits movement of the tower in a vertical direction in relation to the transport vessel but not in other directions. The win- power station is then transported to its place of installation at sea.

Fig. 5 and 6 illustrate an alternative solution for implementing the transport vessel in Fig. 3 and 4. In Fig. 5 and 6, the transport vessel 4 used is a barge 4 having a forked frame with a through slot 11 extending from its middle to the edge, allowing the tower 3 to go through the slot. For transportation, the base 2 can be fastened in a substantially fixed manner to the barge 4. The upper surface of the base 2 lies against the bottom of the barge 4 and is fastened to it by suitable fastening elements 12, such as wire cables chains, threaded bolts or the like.

Fig. 7 presents a phase in the procedure at which the wind power station has been brought to the place of installation and an amount of water sufficient to increase the weight so as to allow the base 2 to sink to the sea bottom has been pumped into the ballast water tank 6 of the base 2 and into the ballast water tank 7 of the tower 3.

Substantially the entire inside space of the tower 3 constituting the ballast water tank 7 can be filled with water. Providing a ballast water tank in the tower 3 in addition to the base 2, together with an appropriate design, enables the weight of the wind power station to be increased so that it can rest very firmly on the bottom and the wind power station is able to receive the loads generated by wind, sea cur rents, sea roll and ice, which tend to upset or move the wind power station. Furthermore, providing a ballast water tank 7 in the tower 3 makes it possible to use a base 2 of a relatively light and compact construction.

The base 2 can be provided with water jet equipment (not shown in the figures) , by means of which the bottom, if it is e.g. of a sandy nature, can be dredged after the base has sunk against the bottom thus making it possible to adjust the vertical alignment of the wind power station.

When the wind power station is to be brought ashore from the sea for maintenance, the procedure is naturally reverse to that for installation. The amount of water in the ballast water tanks 6, 7 of the wind power station 1 standing on the bottom is reduced until the buoyancy of the base 2 and tower 3 has lifted the station off the bottom and raised it to a level near the surface. Via the ballast water tank 6, 7, the elevation and stability of the wind power station are adjusted to make them suitable in relation to the transport vessel 4 used for transportation. The tower 3 is then gripped from opposite sides by the gripping device 5 of the transport vessel 4 and the wind power station is transported away from the place of installation to a place of maintenance.

The invention is not restricted to the examples of its embodiments described above; instead, many variations are possible within the scope of the inventive idea defined in the claims.

CLAIMS

1. Method for installing an offshore wind power station (1) at sea and/or transporting one from sea e.g. for maintenance, said wind power station comprising a base (2) to be mounted on the sea bottom. and a tower (3) attached to the base, which wind power station is transported to a place of installation at sea by means of a transport vessel (4) and lowered to the sea bottom and/or lifted off the sea bottom and transported to land/ashore by means of a transport vessel, characterized in that the wind powerstation is lowered by adding ballast water into a ballast water tank (6, 7) provided in the wind power station and that the wind power station is raised by reducing the amount of ballast water in the ballast water tank.

2. Method as defined in claim 1, characterized in that vertical motion of the wind power station (1) in relation to the transport vessel (4) is permitted during the transportation.

3. Method as defined in claim l or 2, characterized in that, to install the wind power station at sea, the wind power station is gripped by a gripping device (5) mounted on the transport vessel (4) ; the elevation and stability of the wind power station are adjusted by the aid of the ballast water tank (6, 7) to make them suitable with respect to the transport vessel; the wind power station is transported to the place of installation at sea and the wind power station is lowered at the place 0= installation to the sea bottom by filling the ballast water tank (6, 7).

4. Method as defined in claim l or 2, characterized in that, to transport the wind power station from sea, the amount of water in the ballast water tank (6, 7) is reduced until the wind power station has risen off the bottom to a level near the surface; using the ballast water tank (6,7), the elevation and stability of the wind power station are adjusted to make them suitable in relation to the transport vessel (4) ; the wind power station gripped by the gripping device (5) of the transport vessel (4) ; the wind power station is transported ashore from the place of installation, e.g. to a place of maintenance; and the wind power station is released from the grip of the transport vessel.

5. Method as defined in anyone of claims 1-4, characterized in that a ballast water tank (6) disposed in the base (2) of the wind power station is used, and/or that a ballast water tank (7) disposed in the tower (3) of the wind power station is used.

6. Method as defined in anyone of claims 1-5, characterized in that the tower (3) of the wind power station is gripped by the gripping device (5) of the transport vessel (4) from opposite sides.

7. System for installing an offshore wind power station (1) at sea and/or transporting one from the sea e.g. for maintenance, said wind power station comprising a base (2) to be set on the sea bottom, and a tower (3) attached to the base, and a transport vessel (4) provided with a gripping device (5) for grip- ping the wind power station to transport it to a place of installation at sea and/or from the sea to land/ashore, characterized in that the system comprises a ballast water tank (6, 7) disposed in the wind power station.

8. System as defined in claim 7, characterized in that the system comprises a pump (u; disposed on the vessel (4) 'or on the wind power station (1) for pumping ballast water into/out of the ballast water tank (6, 7)

9. System as defined in claim 7 or 8, characterized in that the base (2) is pro- vided with a ballast water tank (6) and/or that the tower (3) is provided with a ballast water tank (7).

10. System as defined in anyone of claims 7 - 9, characterized in that the gripping device (5) of the transport vessel comprises gripping jaws (8) for gripping the tower (3) from a lateral direction from its opposite sides, said gripping jaws being designed to allow vertical motion of the tower in relation to the transport vessel (4).

11. Offshore wind power station comprising a base to be set on the sea bottom and a tower (3) attached to the base, characterized in that the wind power station comprises a ballast water tank (6, 7).

12. Offshore wind power station as defined in claim 11, characterized in that the base (2) is provided with a ballast water tank (6) and/or that the tower (3) is provided with a ballast water tank (7).

13. Offshore wind power station as defined in claim 11 or 12, characterized in that the wind power station (1) comprises a pump (8) for pumping ballast water into/out of the ballast water tank (6, 7).

(57) ABSTRACT

A method and a system for installing an off- shore wind power station (1) at sea and/or transporting one from sea e.g. for maintenance, said wind power station comprising a base (2) to be set on the sea bottom, and a tower (3) attached to the base, which wind power station is transported to a place of installation at sea by means of a transport vessel (4) and lowered to the sea bottom and/or lifted off the sea bottom and transported to land/ashore by means of a transport vessel. The wind power station is lowered by adding ballast water into a ballast water tank (6, 7) provided in the wind power station, and raised by reducing the amount of ballast water in the ballast water tank. The wind power station comprises a ballast water tank (6, 7).

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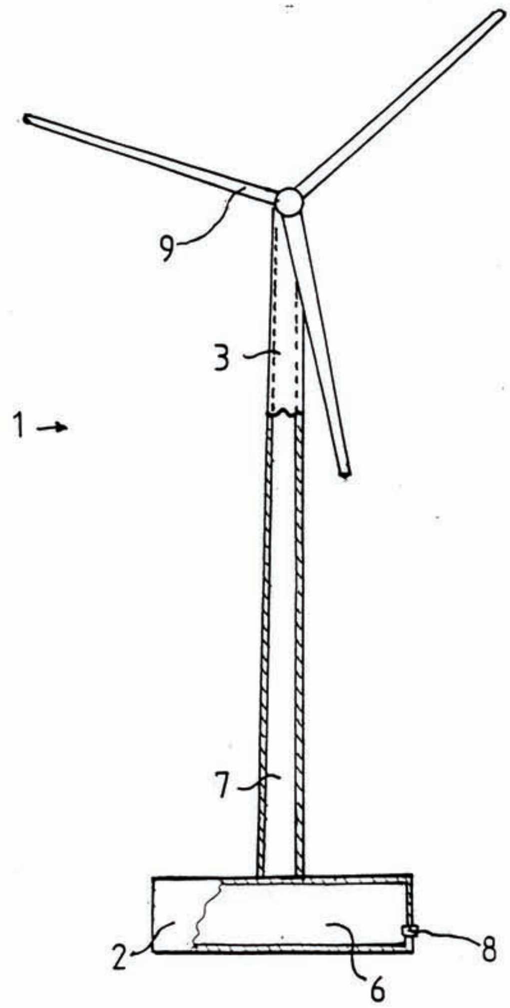


Fig 1

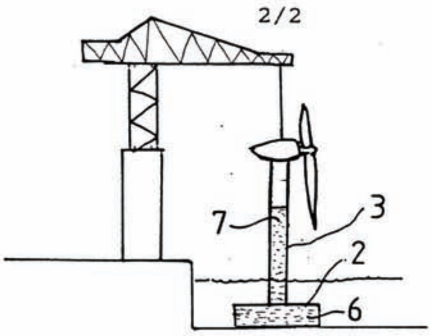


Fig 2

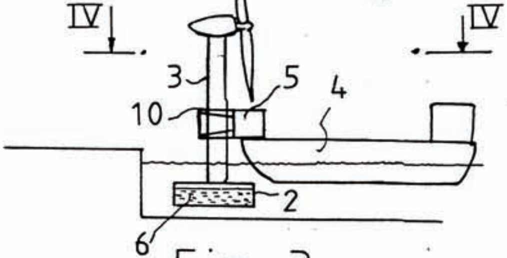


Fig 3

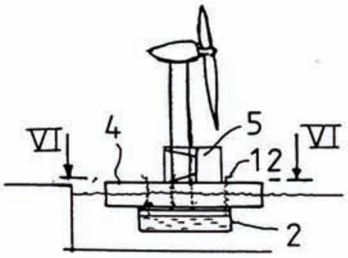


Fig 5

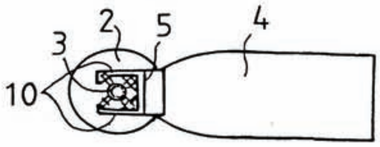


Fig 4

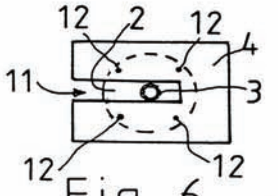


Fig 6

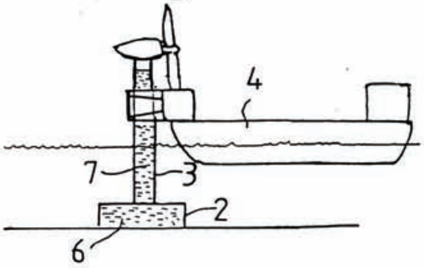
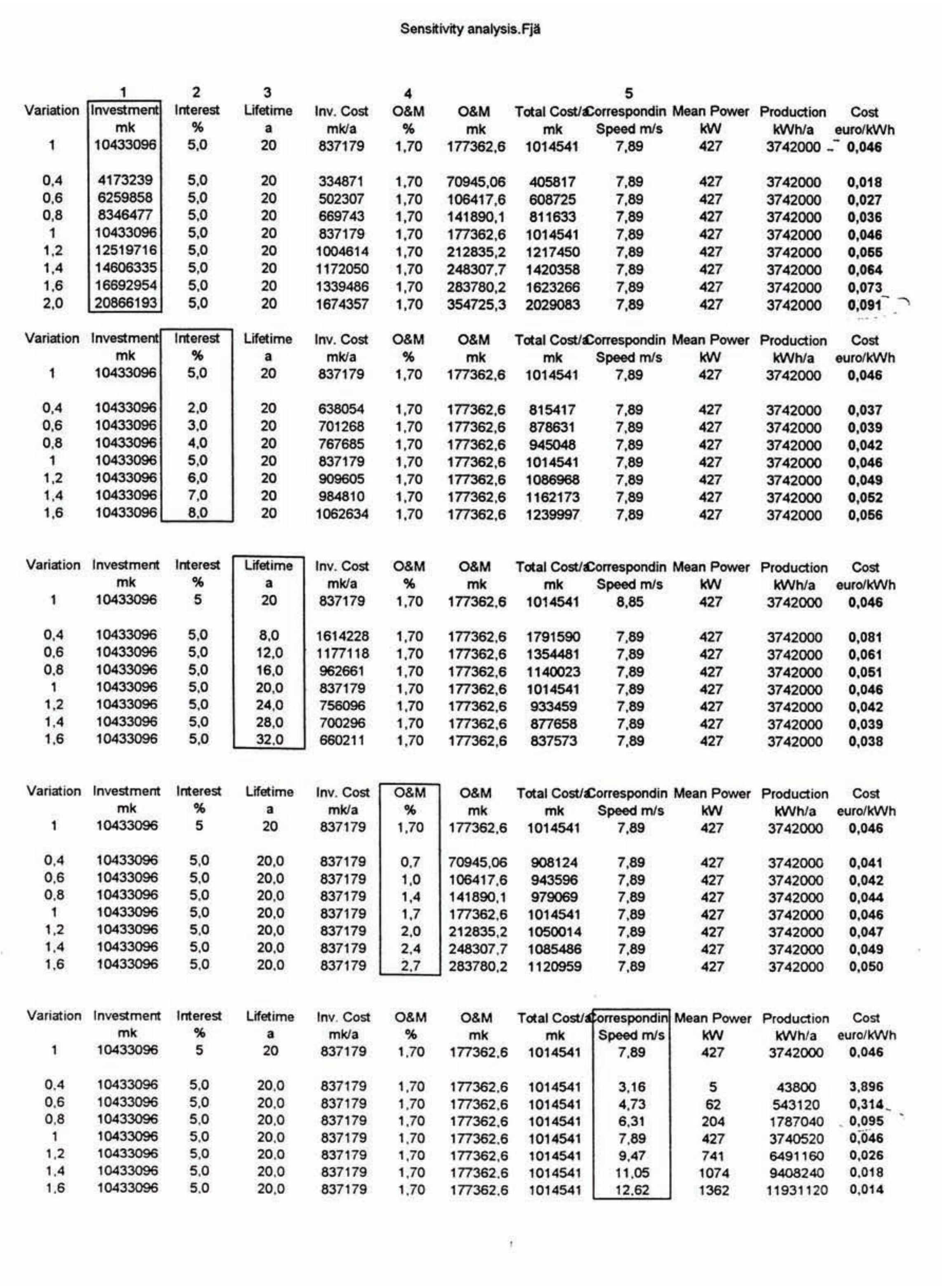


Fig 7

Appendix 2. Sensitivity Analysis on Fjärdskäret.



Sensitivity analysis.Fjä

Variation	1 Investment mk	2 Interest %	3 Lifetime a	Inv. Cost mk/a	4 O&M %	O&M mk	Total Cost/a mk	5 Correspondin Speed m/s	Mean Power kW	Production kWh/a	Cost euro/kWh
1	10433096	5,0	20	837179	1,70	177362,6	1014541	7,89	427	3742000	0,046
0,4	4173239	5,0	20	334871	1,70	70945,06	405817	7,89	427	3742000	0,018
0,6	6259858	5,0	20	502307	1,70	106417,6	608725	7,89	427	3742000	0,027
0,8	8346477	5,0	20	669743	1,70	141890,1	811633	7,89	427	3742000	0,036
1	10433096	5,0	20	837179	1,70	177362,6	1014541	7,89	427	3742000	0,046
1,2	12519716	5,0	20	1004614	1,70	212835,2	1217450	7,89	427	3742000	0,055
1,4	14606335	5,0	20	1172050	1,70	248307,7	1420358	7,89	427	3742000	0,064
1,6	16692954	5,0	20	1339486	1,70	283780,2	1623266	7,89	427	3742000	0,073
2,0	20866193	5,0	20	1674357	1,70	354725,3	2029083	7,89	427	3742000	0,091

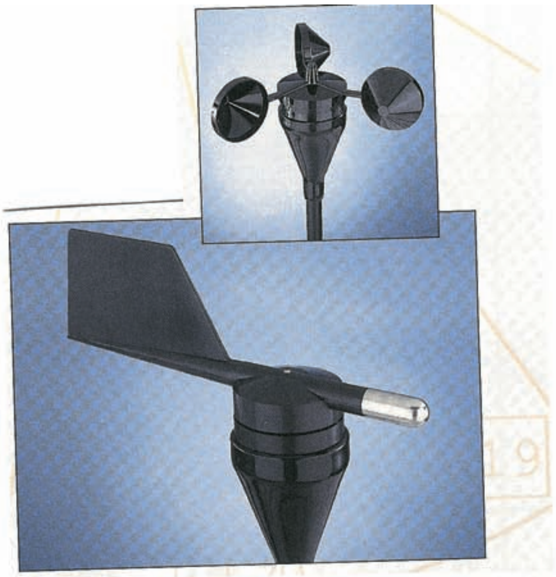
Variation	Investment mk	Interest %	Lifetime a	Inv. Cost mk/a	O&M %	O&M mk	Total Cost/a mk	Correspondin Speed m/s	Mean Power kW	Production kWh/a	Cost euro/kWh
1	10433096	5,0	20	837179	1,70	177362,6	1014541	7,89	427	3742000	0,046
0,4	10433096	2,0	20	638054	1,70	177362,6	815417	7,89	427	3742000	0,037
0,6	10433096	3,0	20	701268	1,70	177362,6	878631	7,89	427	3742000	0,039
0,8	10433096	4,0	20	767685	1,70	177362,6	945048	7,89	427	3742000	0,042
1	10433096	5,0	20	837179	1,70	177362,6	1014541	7,89	427	3742000	0,046
1,2	10433096	6,0	20	909605	1,70	177362,6	1086968	7,89	427	3742000	0,049
1,4	10433096	7,0	20	984810	1,70	177362,6	1162173	7,89	427	3742000	0,052
1,6	10433096	8,0	20	1062634	1,70	177362,6	1239997	7,89	427	3742000	0,056

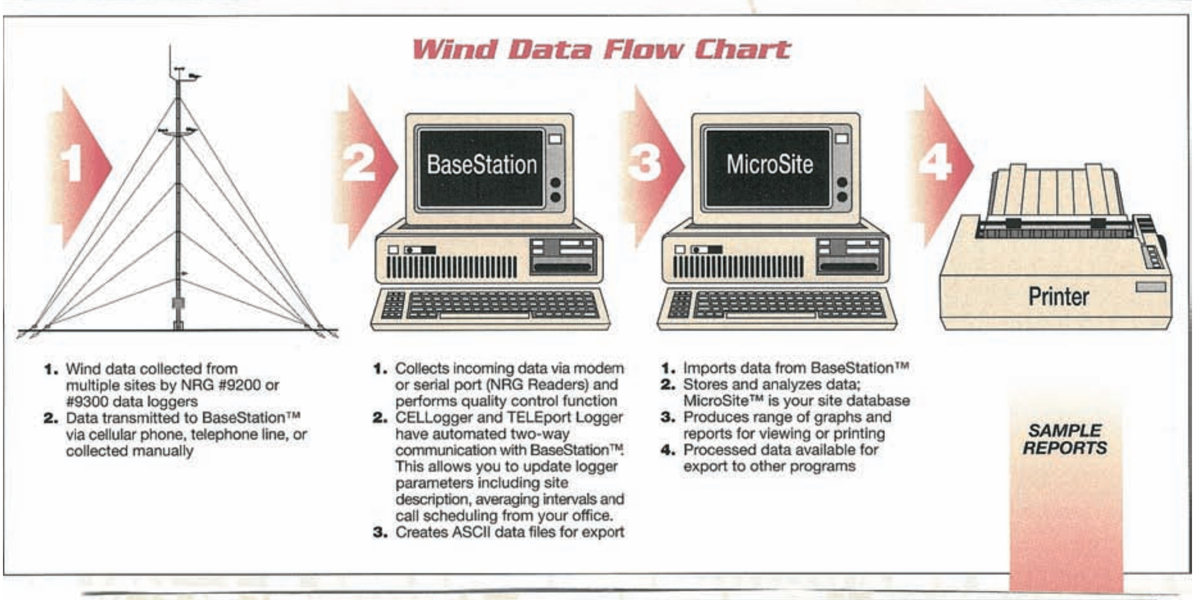
Variation	Investment mk	Interest %	Lifetime a	Inv. Cost mk/a	O&M %	O&M mk	Total Cost/a mk	Correspondin Speed m/s	Mean Power kW	Production kWh/a	Cost euro/kWh
1	10433096	5	20	837179	1,70	177362,6	1014541	8,85	427	3742000	0,046
0,4	10433096	5,0	8,0	1614228	1,70	177362,6	1791590	7,89	427	3742000	0,081
0,6	10433096	5,0	12,0	1177118	1,70	177362,6	1354481	7,89	427	3742000	0,061
0,8	10433096	5,0	16,0	962661	1,70	177362,6	1140023	7,89	427	3742000	0,051
1	10433096	5,0	20,0	837179	1,70	177362,6	1014541	7,89	427	3742000	0,046
1,2	10433096	5,0	24,0	756096	1,70	177362,6	933459	7,89	427	3742000	0,042
1,4	10433096	5,0	28,0	700296	1,70	177362,6	877658	7,89	427	3742000	0,039
1,6	10433096	5,0	32,0	660211	1,70	177362,6	837573	7,89	427	3742000	0,038

Variation	Investment mk	Interest %	Lifetime a	Inv. Cost mk/a	O&M %	O&M mk	Total Cost/a mk	Correspondin Speed m/s	Mean Power kW	Production kWh/a	Cost euro/kWh
1	10433096	5	20	837179	1,70	177362,6	1014541	7,89	427	3742000	0,046
0,4	10433096	5,0	20,0	837179	0,7	70945,06	908124	7,89	427	3742000	0,041
0,6	10433096	5,0	20,0	837179	1,0	106417,6	943596	7,89	427	3742000	0,042
0,8	10433096	5,0	20,0	837179	1,4	141890,1	979069	7,89	427	3742000	0,044
1	10433096	5,0	20,0	837179	1,7	177362,6	1014541	7,89	427	3742000	0,046
1,2	10433096	5,0	20,0	837179	2,0	212835,2	1050014	7,89	427	3742000	0,047
1,4	10433096	5,0	20,0	837179	2,4	248307,7	1085486	7,89	427	3742000	0,049
1,6	10433096	5,0	20,0	837179	2,7	283780,2	1120959	7,89	427	3742000	0,050

Variation	Investment mk	Interest %	Lifetime a	Inv. Cost mk/a	O&M %	O&M mk	Total Cost/a mk	Correspondin Speed m/s	Mean Power kW	Production kWh/a	Cost euro/kWh
1	10433096	5	20	837179	1,70	177362,6	1014541	7,89	427	3742000	0,046
0,4	10433096	5,0	20,0	837179	1,70	177362,6	1014541	3,16	5	43800	3,896
0,6	10433096	5,0	20,0	837179	1,70	177362,6	1014541	4,73	62	543120	0,314
0,8	10433096	5,0	20,0	837179	1,70	177362,6	1014541	6,31	204	1787040	0,095
1	10433096	5,0	20,0	837179	1,70	177362,6	1014541	7,89	427	3740520	0,046
1,2	10433096	5,0	20,0	837179	1,70	177362,6	1014541	9,47	741	6491160	0,026
1,4	10433096	5,0	20,0	837179	1,70	177362,6	1014541	11,05	1074	9408240	0,018
1,6	10433096	5,0	20,0	837179	1,70	177362,6	1014541	12,62	1362	11931120	0,014

Appendix 3. Wind Measuring and Analysis Equipment.





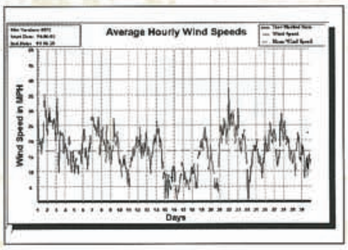
Wind Data Flow Chart

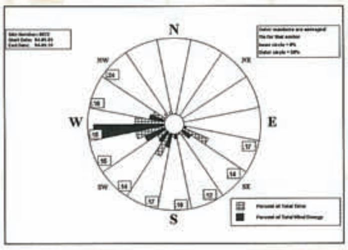
1. Wind data collected from multiple sites by NRG #9200 or #9300 data loggers
2. Data transmitted to BaseStation™ via cellular phone, telephone line, or collected manually

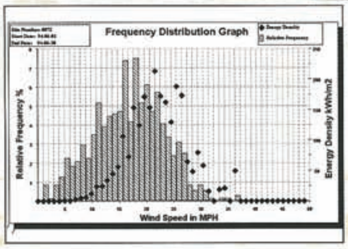
1. Collects incoming data via modem or serial port (NRG Readers) and performs quality control function
2. CELLogger and TELEport Logger have automated two-way communication with BaseStation™. This allows you to update logger parameters including site description, averaging intervals and call scheduling from your office.
3. Creates ASCII data files for export

1. Imports data from BaseStation™
2. Stores and analyzes data; MicroSite™ is your site database
3. Produces range of graphs and reports for viewing or printing
4. Processed data available for export to other programs

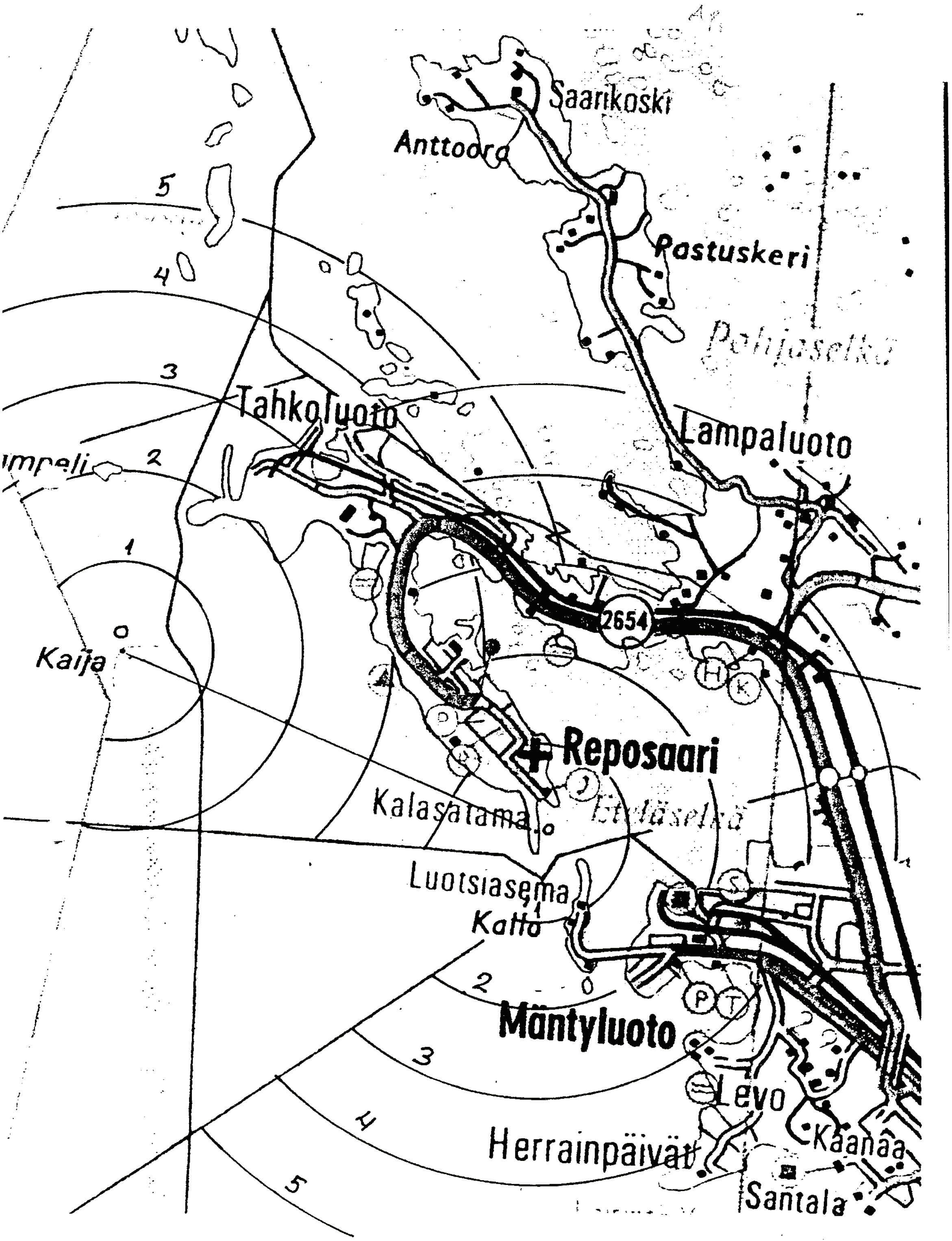
SAMPLE REPORTS





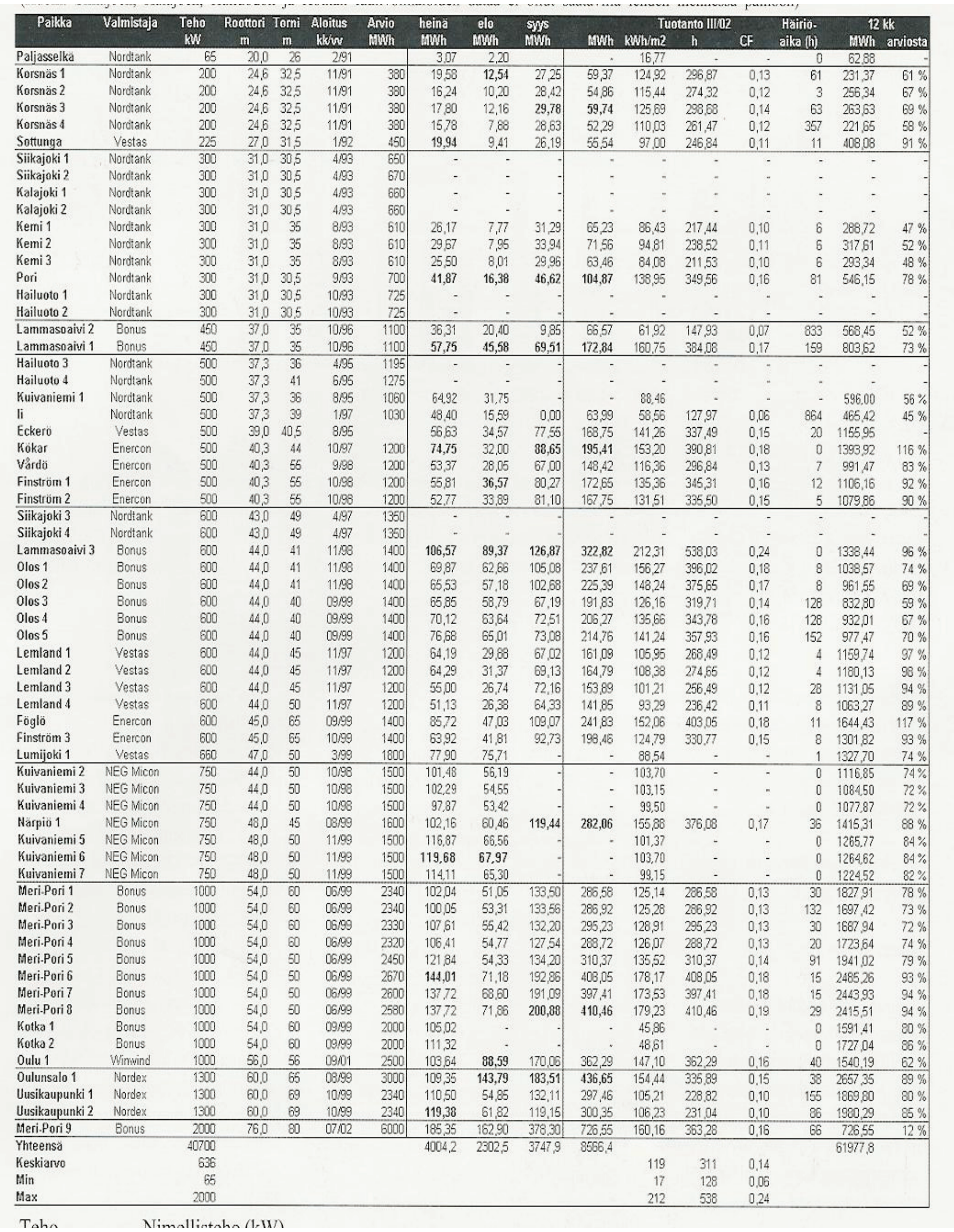


Appendix 4. Pori Kaijakari Measuring Locations.



Appendix 5. Measuring Places Strömmingsbåda, Bergö, Fjärdskäret and Valassaaret.

Appendix 6. Production statistics at different places in Finland during the measuring time (Tuulensilmä nr 4/2002).



Paikka	Valmistaja	Teho kW	Roottori m	Torni m	Aloitus kk/vv	Arvio MWh	heinä MWh	elo MWh	syys MWh	Tuotanto III/02				Häiriö-aika (h)	12 kk	
										MWh	kWh/m2	h	CF		MWh	arviosta
Paljasselkä	Nordtank	65	20,0	26	2/91		3,07	2,20		-	16,77	-	-	0	62,88	-
Korsnäs 1	Nordtank	200	24,6	32,5	11/91	380	19,58	**12,54**	27,25	59,37	124,92	296,87	0,13	61	231,37	61 %
Korsnäs 2	Nordtank	200	24,6	32,5	11/91	380	16,24	10,20	28,42	54,86	115,44	274,32	0,12	3	256,34	67 %
Korsnäs 3	Nordtank	200	24,6	32,5	11/91	380	17,80	12,16	**29,78**	**59,74**	125,69	298,68	0,14	63	263,63	69 %
Korsnäs 4	Nordtank	200	24,6	32,5	11/91	380	15,78	7,88	28,63	52,29	110,03	261,47	0,12	357	221,65	58 %
Sottunga	Vestas	225	27,0	31,5	1/92	450	**19,94**	9,41	26,19	55,54	97,00	246,84	0,11	11	408,08	91 %
Siikajoki 1	Nordtank	300	31,0	30,5	4/93	650	-	-	-	-	-	-	-	-	-	-
Siikajoki 2	Nordtank	300	31,0	30,5	4/93	670	-	-	-	-	-	-	-	-	-	-
Kalajoki 1	Nordtank	300	31,0	30,5	4/93	660	-	-	-	-	-	-	-	-	-	-
Kalajoki 2	Nordtank	300	31,0	30,5	4/93	660	-	-	-	-	-	-	-	-	-	-
Kemi 1	Nordtank	300	31,0	35	8/93	610	26,17	7,77	31,29	65,23	86,43	217,44	0,10	6	288,72	47 %
Kemi 2	Nordtank	300	31,0	35	8/93	610	29,67	7,95	33,94	71,56	94,81	238,52	0,11	6	317,61	52 %
Kemi 3	Nordtank	300	31,0	35	8/93	610	25,50	8,01	29,96	63,46	84,08	211,53	0,10	6	293,34	48 %
Pori	Nordtank	300	31,0	30,5	9/93	700	**41,87**	**16,38**	**46,62**	**104,87**	138,95	349,56	0,16	81	546,15	78 %
Hailuoto 1	Nordtank	300	31,0	30,5	10/93	725	-	-	-	-	-	-	-	-	-	-
Hailuoto 2	Nordtank	300	31,0	30,5	10/93	725	-	-	-	-	-	-	-	-	-	-
Lammasoaivi 2	Bonus	450	37,0	35	10/96	1100	36,31	20,40	9,85	66,57	61,92	147,93	0,07	833	568,45	52 %
Lammasoaivi 1	Bonus	450	37,0	35	10/96	1100	**57,75**	**45,58**	**69,51**	**172,84**	160,75	384,08	0,17	159	803,62	73 %
Hailuoto 3	Nordtank	500	37,3	36	4/95	1195	-	-	-	-	-	-	-	-	-	-
Hailuoto 4	Nordtank	500	37,3	41	6/95	1275	-	-	-	-	-	-	-	-	-	-
Kuivaniemi 1	Nordtank	500	37,3	36	8/95	1060	64,92	31,75	-	-	88,46	-	-	-	596,00	56 %
Ii	Nordtank	500	37,3	39	1/97	1030	48,40	15,59	0,00	63,99	58,56	127,97	0,06	864	465,42	45 %
Eckerö	Vestas	500	39,0	40,5	8/95		56,63	34,57	77,55	168,75	141,26	337,49	0,15	20	1155,95	-
Kökar	Enercon	500	40,3	44	10/97	1200	**74,75**	32,00	**88,65**	**195,41**	153,20	390,81	0,18	0	1393,92	116 %
Vårdö	Enercon	500	40,3	55	9/98	1200	53,37	28,05	67,00	148,42	116,36	296,84	0,13	7	991,47	83 %
Finström 1	Enercon	500	40,3	55	10/98	1200	55,81	**36,57**	80,27	172,65	135,36	345,31	0,16	12	1106,16	92 %
Finström 2	Enercon	500	40,3	55	10/98	1200	52,77	33,89	81,10	167,75	131,51	335,50	0,15	5	1079,86	90 %
Siikajoki 3	Nordtank	600	43,0	49	4/97	1350	-	-	-	-	-	-	-	-	-	-
Siikajoki 4	Nordtank	600	43,0	49	4/97	1350	-	-	-	-	-	-	-	-	-	-
Lammasoaivi 3	Bonus	600	44,0	41	11/98	1400	**106,57**	**89,37**	**126,87**	**322,82**	212,31	538,03	0,24	0	1338,44	96 %
Olos 1	Bonus	600	44,0	41	11/98	1400	69,87	62,66	105,08	237,61	156,27	396,02	0,18	8	1038,57	74 %
Olos 2	Bonus	600	44,0	41	11/98	1400	65,53	57,18	102,68	225,39	148,24	375,65	0,17	8	961,55	69 %
Olos 3	Bonus	600	44,0	40	09/99	1400	65,85	58,79	67,19	191,83	126,16	319,71	0,14	128	832,80	59 %
Olos 4	Bonus	600	44,0	40	09/99	1400	70,12	63,64	72,51	206,27	135,66	343,78	0,16	128	932,01	67 %
Olos 5	Bonus	600	44,0	40	09/99	1400	76,68	65,01	73,08	214,76	141,24	357,93	0,16	152	977,47	70 %
Lemland 1	Vestas	600	44,0	45	11/97	1200	64,19	29,88	67,02	161,09	105,95	268,49	0,12	4	1159,74	97 %
Lemland 2	Vestas	600	44,0	45	11/97	1200	64,29	31,37	69,13	164,79	108,38	274,65	0,12	4	1180,13	98 %
Lemland 3	Vestas	600	44,0	45	11/97	1200	55,00	26,74	72,16	153,89	101,21	256,49	0,12	28	1131,05	94 %
Lemland 4	Vestas	600	44,0	50	11/97	1200	51,13	26,38	64,33	141,85	93,29	236,42	0,11	8	1063,27	89 %
Föglö	Enercon	600	45,0	65	09/99	1400	85,72	47,03	109,07	241,83	152,06	403,05	0,18	11	1644,43	117 %
Finström 3	Enercon	600	45,0	65	10/99	1400	63,92	41,81	92,73	198,46	124,79	330,77	0,15	8	1301,82	93 %
Lumijoki 1	Vestas	660	47,0	50	3/99	1800	77,90	75,71	-	-	88,54	-	-	1	1327,70	74 %
Kuivaniemi 2	NEG Micon	750	44,0	50	10/98	1500	101,48	56,19	-	-	103,70	-	-	0	1116,85	74 %
Kuivaniemi 3	NEG Micon	750	44,0	50	10/98	1500	102,29	54,55	-	-	103,15	-	-	0	1084,50	72 %
Kuivaniemi 4	NEG Micon	750	44,0	50	10/98	1500	97,87	53,42	-	-	99,50	-	-	0	1077,87	72 %
Närpiö 1	NEG Micon	750	48,0	45	08/99	1600	102,16	60,46	**119,44**	**282,06**	155,88	376,08	0,17	36	1415,31	88 %
Kuivaniemi 5	NEG Micon	750	48,0	50	11/99	1500	116,87	66,56	-	-	101,37	-	-	0	1265,77	84 %
Kuivaniemi 6	NEG Micon	750	48,0	50	11/99	1500	**119,68**	**67,97**	-	-	103,70	-	-	0	1264,62	84 %
Kuivaniemi 7	NEG Micon	750	48,0	50	11/99	1500	114,11	65,30	-	-	99,15	-	-	0	1224,52	82 %
Meri-Pori 1	Bonus	1000	54,0	60	06/99	2340	102,04	51,05	133,50	286,58	125,14	286,58	0,13	30	1827,91	78 %
Meri-Pori 2	Bonus	1000	54,0	60	06/99	2340	100,05	53,31	133,56	286,92	125,28	286,92	0,13	132	1697,42	73 %
Meri-Pori 3	Bonus	1000	54,0	60	06/99	2330	107,61	55,42	132,20	295,23	128,91	295,23	0,13	30	1687,94	72 %
Meri-Pori 4	Bonus	1000	54,0	60	06/99	2320	106,41	54,77	127,54	288,72	126,07	288,72	0,13	20	1723,64	74 %
Meri-Pori 5	Bonus	1000	54,0	50	06/99	2450	121,84	54,33	134,20	310,37	135,52	310,37	0,14	91	1941,02	79 %
Meri-Pori 6	Bonus	1000	54,0	50	06/99	2670	**144,01**	71,18	192,86	408,05	178,17	408,05	0,18	15	2485,26	93 %
Meri-Pori 7	Bonus	1000	54,0	50	06/99	2600	137,72	68,60	191,09	397,41	173,53	397,41	0,18	15	2443,93	94 %
Meri-Pori 8	Bonus	1000	54,0	50	06/99	2580	137,72	71,86	**200,88**	**410,46**	179,23	410,46	0,19	29	2415,51	94 %
Kotka 1	Bonus	1000	54,0	60	09/99	2000	105,02	-	-	-	45,86	-	-	0	1591,41	80 %
Kotka 2	Bonus	1000	54,0	60	09/99	2000	111,32	-	-	-	48,61	-	-	0	1727,04	86 %
Oulu 1	Winwind	1000	56,0	56	09/01	2500	103,64	**88,59**	170,06	362,29	147,10	362,29	0,16	40	1540,19	62 %
Oulunsalo 1	Nordex	1300	60,0	65	08/99	3000	109,35	**143,79**	**183,51**	**436,65**	154,44	335,89	0,15	38	2657,35	89 %
Uusikaupunki 1	Nordex	1300	60,0	69	10/99	2340	110,50	54,85	132,11	297,46	105,21	228,82	0,10	155	1869,80	80 %
Uusikaupunki 2	Nordex	1300	60,0	69	10/99	2340	**119,38**	61,82	119,15	300,35	106,23	231,04	0,10	86	1980,29	85 %
Meri-Pori 9	Bonus	2000	76,0	80	07/02	6000	185,35	162,90	378,30	726,55	160,16	363,28	0,16	66	726,55	12 %
Yhteensä		40700					4004,2	2302,5	3747,9	8566,4					61977,8	
Keskiarvo		636									119	311	0,14			
Min		65									17	128	0,06			
Max		2000									212	538	0,24			

Teho Nimellisteho (kW)

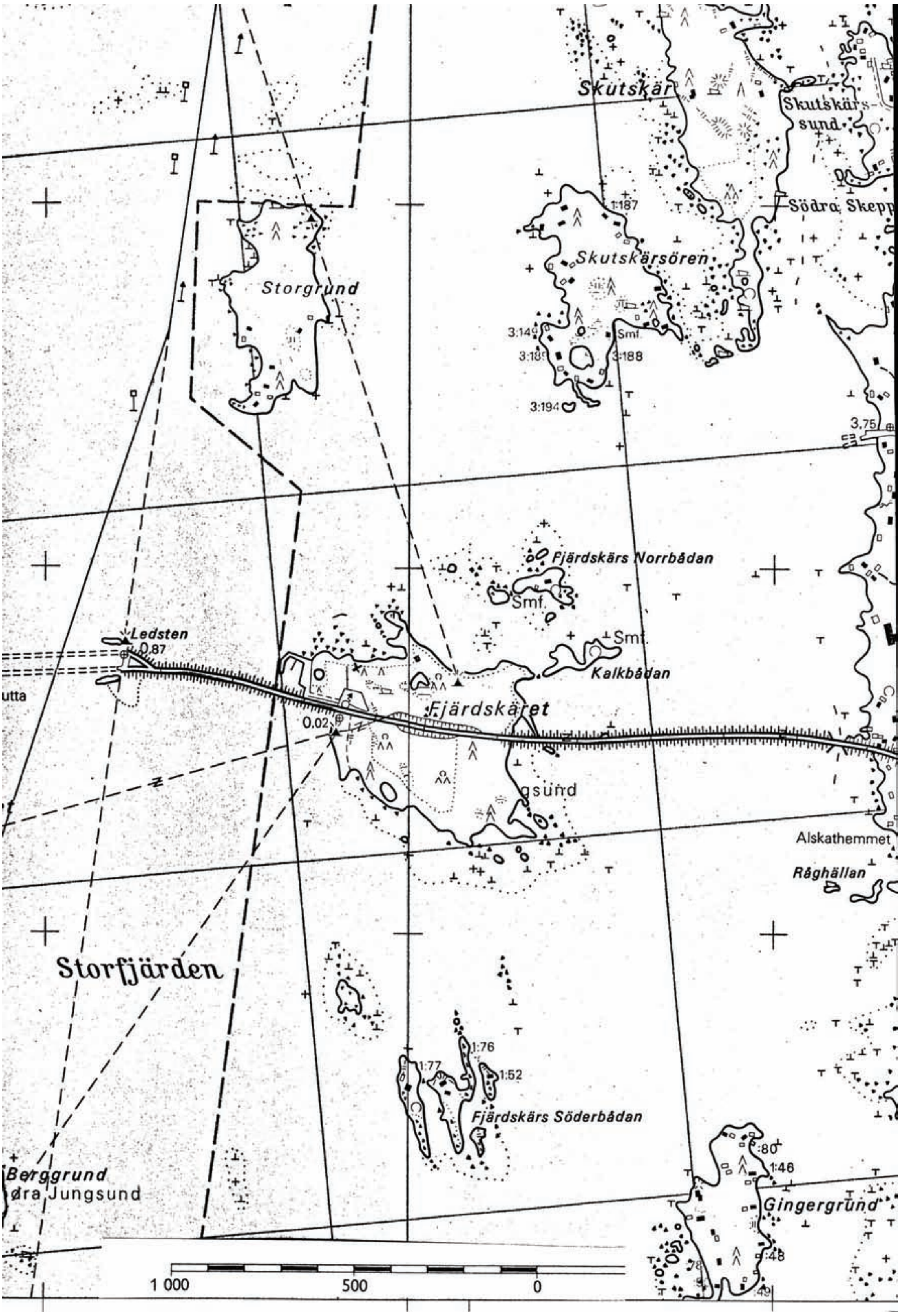
Appendix 7. Calculation Example with Turbine Power 1–1.65 MW.

Kilowatt Price with separate Power Plants

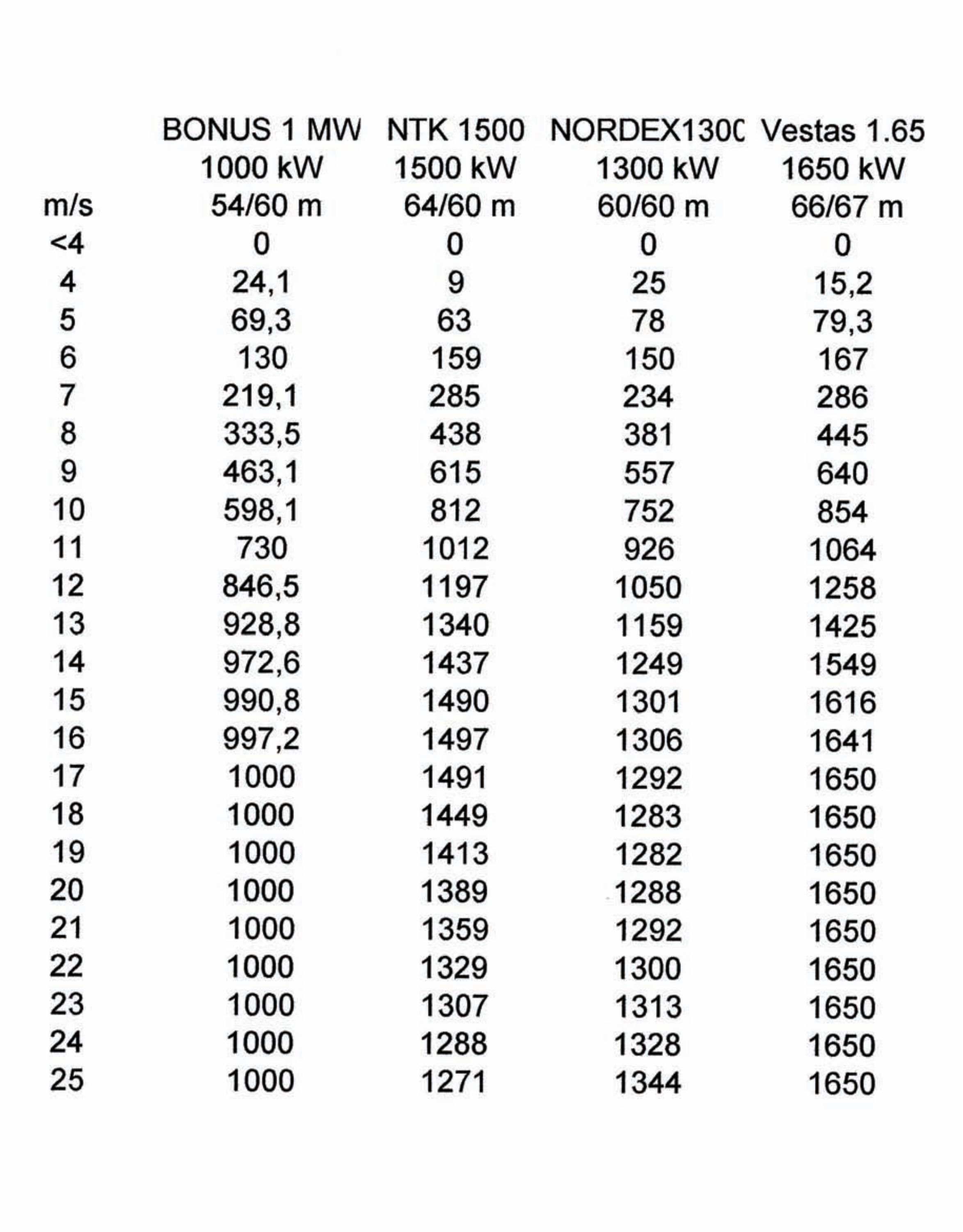
Measuring Periode on the Strömmingsbåda and Bergö Islands on 22.11.97 - 26.11.1998

Producer		**Bonus**		**NECMicon**		**NORDEX**		**Vestas**	
Rated Power (kW)		**1 000**		**1 500**		**1 300**		**1 650**	
Rotor D(m)		54		64		60		66	
Hub Height h(m)		60		60		60		67	
Weight (TON)		125		203		152		180	
Bending Moment (kNm)		27 795		44 700				27 800	
Onshore Bid Prices									
Wind Turbine		4 288 000	100 %	7 785 651	100 %	7 330 000	100 %	11 718 995	100 %
Transport to Dock		50 000	1,2 %	50 000	0,6 %	62 500	0,9 %	62 770	0,5 %
Transformer		100 000	2,3 %	150 000	1,9 %	187 594	2,6 %	incl.	
Remote Control		15 000	0,3 %	15 029	0,2 %	15 000	0,2 %	incl.	
Training		incl.		incl.		incl.		incl.	
Accessory		59 375	1,4 %	incl.		102 077	1,4 %	12 554	0,1 %
Warranty Time's Service		96 750	2,3 %	70 399	0,9 %	incl.		incl.	
Altogether		4 609 125	107 %	8 071 079	104 %	7 697 171	105 %	11 794 319	101 %
Currency Factor		1,00000		1,00000		0,79980		0,79980	
Turbine on Dock		**4 609 125**		**8 071 079**		**6 156 197**		**9 433 096**	
FIM / kW		4 609		5 381		4 736		5 717	
Offshore Calculated Prices									
Steel Foundation		965 226	22,5 %	1 060 731	13,6 %	1 019 513	11,1 %	850 662	5,8 %
Transport		38 572	0,9 %	38 572	45 715	38 572	0,4 %	38 572	0,3 %
Harbour/Dock Assemblage		62 343	1,5 %	62 343	0,8 %	62 343	0,7 %	62 343	0,4 %
Site Work		97 143	2,3 %	97 143	1,2 %	97 143	1,1 %	97 143	0,7 %
Sea-bed Reseach		50 000	1,2 %	50 000	0,6 %	50 000	0,5 %	50 000	0,3 %
Cabling (20+3.6 km, 14 turbines park)		400 912	9,3 %	400 912	5,1 %	400 912	4,4 %	400 912	2,7 %
Planing		50 000	1,2 %	50 000	0,6 %	50 000	0,5 %	50 000	0,3 %
Additional Charge		50 000	1,2 %	50 000	0,6 %	50 000	0,5 %	50 000	0,3 %
Total Investment (FIM)		**6 323 321**	147 %	**9 880 780**	127 %	**7 924 680**	135 %	**11 032 728**	118 %
FIM/kW		6 323		6 587		6 096		6 687	
Investment Support	0 %	0		0		0		0	
Net Investment (FIM)		**6 323 321**	147 %	**9 880 780**	127 %	**7 924 680**	135 %	**11 032 728**	118 %
FIM/kW		6 323		6 587		6 096		6 687	
Operation and Maintenance (FIM/year)									
Operation and Maintenance (FIM)		85 760	2,0 %	155 713	2,0 %	117 251	2,0 %	187 457	2,0 %
Insurance(FIM)		50 000	0,8 %	82 500	0,8 %	60 000	0,8 %	82 500	0,7 %
Administration (FIM)		30 000	0,5 %	30 000	0,3 %	30 000	0,4 %	30 000	0,3 %
Altogether (FIM/year)		**165 760**	2,6 %	**268 213**	2,7 %	**207 251**	2,6 %	**299 957**	2,7 %
O&M FIM (p/kWh)		4,66		5,41		4,68		5,47	
Year Production (kWh/a)		4 148 176		5 785 878		5 162 570		6 390 907	
Levelised Utilized Energy (0,86) (kWh/a)		**3 556 542**		**4 960 667**		**4 426 258**		**5 479 404**	
Year Production per Swept Area (kWh/m^2)		1 541		1 542		1 565		1 602	
Nominal Power Time (h/a)		3 557		3 307		3 405		3 321	
Capasity Factor (Cf)		0,41		0,38		0,39		0,38	
Production Cost FIM (p/kWh)		**18,93**		**21,39**		**19,05**		**21,63**	
Production Cost (€c/kWh)		**3,18**		**3,60**		**3,20**		**3,64**	
Real Interest	5 %	**Bonus**		**NECMicon**		**NORDEX**		**Vestas**	
Refund Periode	20 year	**1 000**		**1 500**		**1 300**		**1 650**	
Swept Area (m^2)		2 307		3 217		2 827		3 421	

Appendix 8. Fjärdskäret Measuring Location.

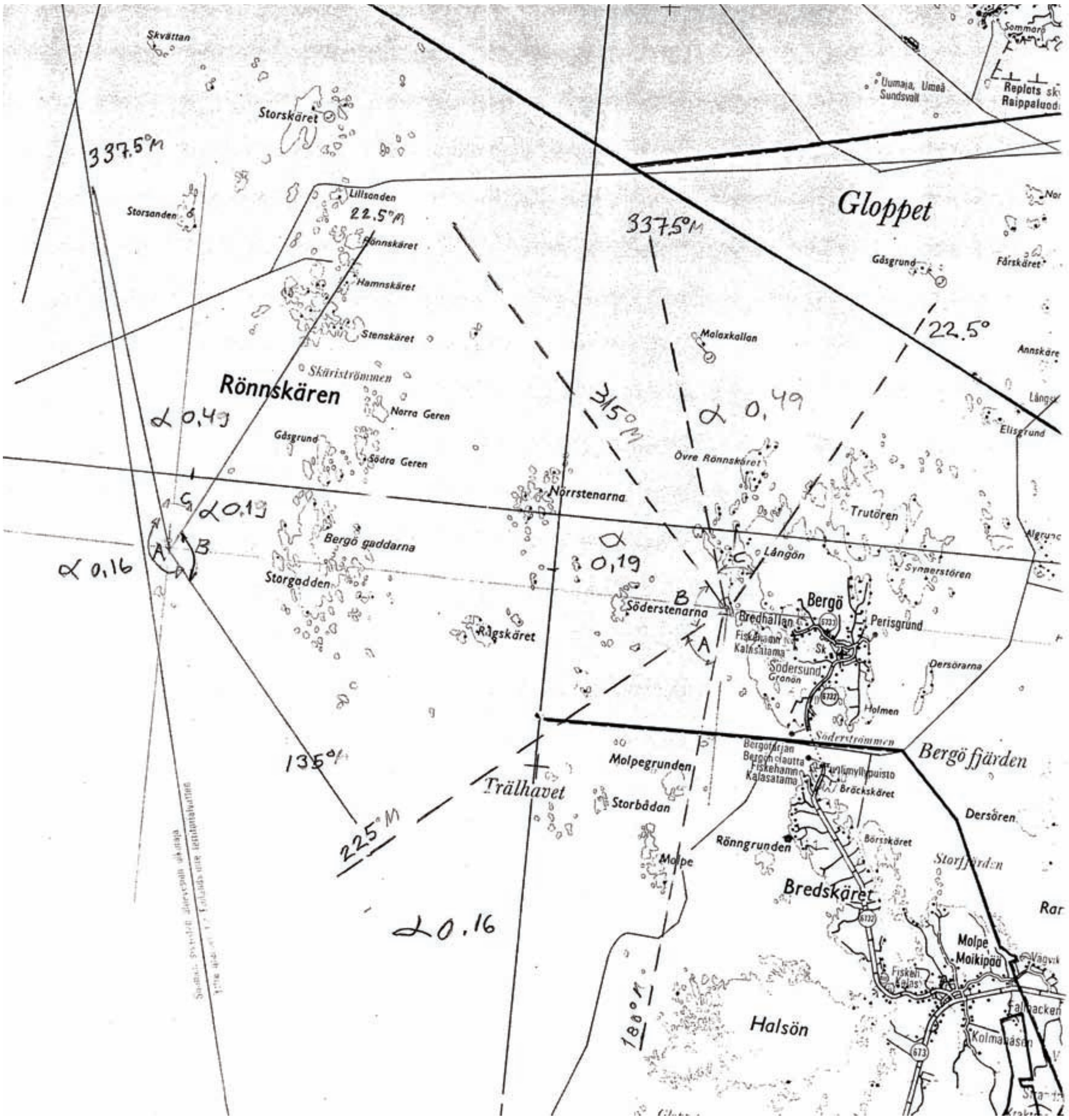


Appendix 9. Wind speed / Power values for different Turbines.



m/s	BONUS 1 MW 1000 kW 54/60 m	NTK 1500 1500 kW 64/60 m	NORDEX1300 1300 kW 60/60 m	Vestas 1.65 1650 kW 66/67 m
<4	0	0	0	0
4	24,1	9	25	15,2
5	69,3	63	78	79,3
6	130	159	150	167
7	219,1	285	234	286
8	333,5	438	381	445
9	463,1	615	557	640
10	598,1	812	752	854
11	730	1012	926	1064
12	846,5	1197	1050	1258
13	928,8	1340	1159	1425
14	972,6	1437	1249	1549
15	990,8	1490	1301	1616
16	997,2	1497	1306	1641
17	1000	1491	1292	1650
18	1000	1449	1283	1650
19	1000	1413	1282	1650
20	1000	1389	1288	1650
21	1000	1359	1292	1650
22	1000	1329	1300	1650
23	1000	1307	1313	1650
24	1000	1288	1328	1650
25	1000	1271	1344	1650

Appendix 10. Measured α values at Bergö and corresponding values at Strömmingsbåda.



Appendix 11. Sensitivity Analysis for 2 MW turbine in Strömmingsbåda Wind Conditions.

	1	2	3		4			5		Levelised	
Variation	Investment	Interest	Lifetime	Inv. Cost	O&M	O&M	Total Cost/a	orrespondir	Mean Powe	Production	Cost
	€	%	a	€/a	€c/kWh	€/a	€/a	Speed m/s	kW	kWh/a	€c/kWh
1	1079134	5,0	20	86593	1,56	55565	142158	9,01	472,1	3556542	**4,00**
0,7	755394	5,0	20	60615	1,56	55565	116180	9,01	472,1	3556542	**3,27**
0,8	863307	5,0	20	69274	1,56	55565	124839	9,01	472,1	3556542	**3,51**
0,9	971221	5,0	20	77933	1,56	55565	133499	9,01	472,1	3556542	**3,75**
1	1079134	5,0	20	86593	1,56	55565	142158	9,01	472,1	3556542	**4,00**
1,1	1187048	5,0	20	95252	1,56	55565	150817	9,01	472,1	3556542	**4,24**
1,2	1294961	5,0	20	103911	1,56	55565	159476	9,01	472,1	3556542	**4,48**
1,3	1402874	5,0	20	112570	1,56	55565	168136	9,01	472,1	3556542	**4,73**

Variation	Investment	Interest	Lifetime	Inv. Cost	O&M	O&M	Total Cost/a	orrespondir	Mean Powe	Production	Cost
	€	%	a	€/a	€c/kWh	€/a	€/a	Speed m/s	kW	kWh/a	€c/kWh
1	1079134	5,0	20	86593	1,56	55565	142158	9,01	472,1	3556542	**4,00**
0,7	1079134	3,5	20	75929	1,56	55565	131494	9,01	472,1	3556542	**3,70**
0,8	1079134	4,0	20	79405	1,56	55565	134970	9,01	472,1	3556542	**3,79**
0,9	1079134	4,5	20	82960	1,56	55565	138525	9,01	472,1	3556542	**3,89**
1	1079134	5,0	20	86593	1,56	55565	142158	9,01	472,1	3556542	**4,00**
1,1	1079134	5,5	20	90301	1,56	55565	145867	9,01	472,1	3556542	**4,10**
1,2	1079134	6,0	20	94084	1,56	55565	149649	9,01	472,1	3556542	**4,21**
1,3	1079134	6,5	20	97938	1,56	55565	153504	9,01	472,1	3556542	**4,32**

Variation	Investment	Interest	Lifetime	Inv. Cost	O&M	O&M	Total Cost/a	orrespondir	Mean Powe	Production	Cost
	€	%	a	€/a	€c/kWh	€/a	€/a	Speed m/s	kW	kWh/a	€c/kWh
1	1079134	5,0	20	86593	1,56	55565	142158	9,01	472,1	3556542	**4,00**
0,7	1079134	5,0	14	109018	1,56	55565	164584	9,01	472,1	3556542	**4,63**
0,8	1079134	5,0	16	99572	1,56	55565	155137	9,01	472,1	3556542	**4,36**
0,9	1079134	5,0	18	92316	1,56	55565	147881	9,01	472,1	3556542	**4,16**
1	1079134	5,0	20	86593	1,56	55565	142158	9,01	472,1	3556542	**4,00**
1,1	1079134	5,0	22	81982	1,56	55565	137548	9,01	472,1	3556542	**3,87**
1,2	1079134	5,0	24	78206	1,56	55565	133771	9,01	472,1	3556542	**3,76**
1,3	1079134	5,0	26	75069	1,56	55565	130635	9,01	472,1	3556542	**3,67**

Variation	Investment	Interest	Lifetime	Inv. Cost	O&M	O&M	Total Cost/a	orrespondir	Mean Powe	Production	Cost
	€	%	a	€/a	€c/kWh	€/a	€/a	Speed m/s	kW	kWh/a	€c/kWh
1	1079134	5,0	20	86593	1,56	55565	142158	9,01	472,1	3556542	**4,00**
0,7	1079134	5,0	20	86593	1,09	38896	125488	9,01	472,1	3556542	**3,53**
0,8	1079134	5,0	20	86593	1,25	44452	131045	9,01	472,1	3556542	**3,68**
0,9	1079134	5,0	20	86593	1,41	50009	136601	9,01	472,1	3556542	**3,84**
1	1079134	5,0	20	86593	1,56	55565	142158	9,01	472,1	3556542	**4,00**
1,1	1079134	5,0	20	86593	1,72	61122	147714	9,01	472,1	3556542	**4,15**
1,2	1079134	5,0	20	86593	1,87	66678	153271	9,01	472,1	3556542	**4,31**
1,3	1079134	5,0	20	86593	2,03	72235	158828	9,01	472,1	3556542	**4,47**

Variation	Investment	Interest	Lifetime	Inv. Cost	O&M	O&M	Total Cost/a	orrespondir	Mean Powe	Production	Cost
	€	%	a	€/a	€c/kWh	€/a	€/a	Speed m/s	kW	kWh/a	€c/kWh
1	1079134	5,0	20	86593	1,56	55565	142158	9,01	472,1	3556542	**4,00**
0,7	1079134	5,0	20	86593	1,56	18521	105113	6,31	157,4	1185440	**8,87**
0,8	1079134	5,0	20	86593	1,56	28589	115181	7,21	242,9	1829875	**6,29**
0,9	1079134	5,0	20	86593	1,56	40916	127508	8,11	347,6	2618878	**4,87**
1	1079134	5,0	20	86593	1,56	55565	142158	9,01	472,1	3556542	**4,00**
1,1	1079134	5,0	20	86593	1,56	68983	155575	9,91	586,1	4415330	**3,52**
1,2	1079134	5,0	20	86593	1,56	83003	169595	10,81	705,2	5312716	**3,19**
1,3	1079134	5,0	20	86593	1,56	95698	182291	11,71	813,1	6125303	**2,98**

Appendix 12. Production in Strömmingsbåda, Rödsand Omö and Gedser Wind Conditions.

Kilowatt Price with separate Power Plants

Measuring Periode on the Strömmingsbåda and Bergö Islands on 22.11.97 - 26.11.1998

Svenson, Jan & Olsen, Frank (1999)

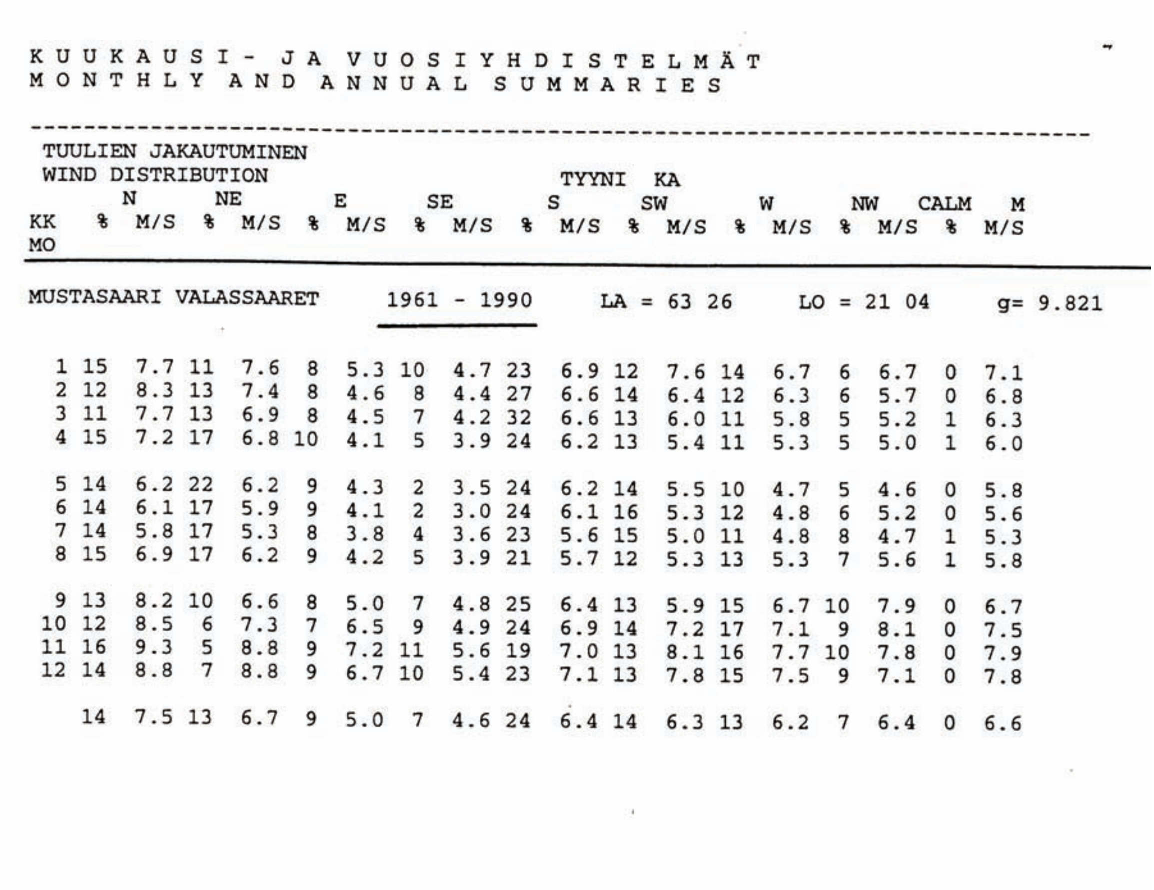
Producer	**Bonus**		**NECMicon**		**NORDEX**		**Vestas**		**Rödsand**		**Omö**		**Gedser**	
Rated Power (kW)	**1 000**		**1 500**		**1 300**		**1 650**		**1 500**		**1 500**		**1 500**	
Rotor D(m)	54		64		60		66		64		64		64	
Hub Height h(m)	60		60		60		67		55		55		55	
Weight (TON)	125		203		152		180							
Bending Moment (kNm)	27 795		44 700				27 800							
Onshore Bid Prices														
Wind Turbine	4 288 000	100 %	7 785 651	100 %	7 330 000	100 %	11 718 995	100 %	1 177 083	100 %	1 177 083	100 %	1 177 083	100 %
Transport to Dock	50 000	1,2 %	50 000	0,6 %	62 500	0,9 %	62 770	0,5 %		0,0 %		0,0 %		0,0 %
Transformer	100 000	2,3 %	150 000	1,9 %	187 594	2,6 %	incl.			0,0 %		0,0 %		
Remote Control	15 000	0,3 %	15 029	0,2 %	15 000	0,2 %	incl.			0,0 %		0,0 %		
Training	incl.		incl.		incl.		incl.							
Accessory	59 375	1,4 %	incl.		102 077	1,4 %	12 554	0,1 %	52 083		52 083	4,4 %	52 083	4,4 %
Warranty Time's Service	96 750	2,3 %	70 399	0,9 %	incl.		incl.		31 250	2,7 %	31 250		31 250	
Altogether	4 609 125	107 %	8 071 079	104 %	7 697 171	105 %	11 794 319	101 %	1 260 417	107 %	1 260 417	107 %	1 260 417	107 %
Currency Factor	5,94573		5,94573		7,43010		7,43010		1,00000		1,00000		1,00000	
Turbine on Dock	**775 199**		**1 357 458**		**1 035 944**		**1 587 370**		**1 260 417**		**1 260 417**		**1 260 417**	
€ / kW	775		905		797		962		840		840		840	
Offshore Calculated Prices														
Steel Foundation	162 339	22,5 %	178 402	13,6 %	171 470	17,4 %	143 071	9,1 %	375 000	31,9 %	375 000	31,9 %	375 000	31,9 %
Transport	6 487	0,9 %	6 487	0,5 %	6 487	0,7 %	6 487	0,4 %						
Harbour/Dock Assemblage	10 485	1,5 %	10 485	0,8 %	10 485	1,1 %	10 485	0,7 %						
Site Work	16 338	2,3 %	16 338	1,2 %	16 338	1,7 %	16 338	1,0 %						
Sea-bed Reseach	20 000	2,8 %	20 000	1,5 %	20 000	2,0 %	20 000	1,3 %						
Cabling (20+3.9 km, 40€/m, 14 turbines)	68 286	9,5 %	68 286	5,2 %	68 286	6,9 %	68 286	4,3 %	572 917	48,7 %	468 750	39,8 %	760 417	64,6 %
Planing	10 000	1,4 %	10 000	0,8 %	10 000	1,0 %	10 000	0,6 %	83 333	7,1 %	83 333	7,1 %	83 333	7,1 %
Additional Charge	10 000	1,4 %	10 000	0,8 %	10 000	1,0 %	10 000	0,6 %						
Total Offshore	303 935		319 998		313 066		284 667		1 031 250		927 083		1 218 750	
Total Investment	**1 079 134**	150 %	**1 677 456**	128 %	**1 349 010**	137 %	**1 872 037**	119 %	**2 291 667**	195 %	**2 187 500**	186 %	**2 479 167**	211 %
€/kW	1 079		1 118		1 038		1 135		1 528		1 458		1 653	
Investment Support 0 %	0		0		0		0		0		0		0	
Net Investment	**1 079 134**	150 %	**1 677 456**	128 %	**1 349 010**	137 %	**1 872 037**	119 %	**2 291 667**	195 %	**2 187 500**	186 %	**2 479 167**	211 %
€/kW	1 079		1 118		1 038		1 135		1 528		1 458		1 653	
Operation and Maintenance (€/year)														
Operation and Maintenance (0,01€/kWh)	35 565	4,9 %	49 607	3,8 %	44 263	4,5 %	54 794	3,5 %						
Insurance	15 000	2,1 %	15 000	1,1 %	15 000	1,5 %	15 000	1,0 %						
Administration	5 000	0,7 %	5 000	0,4 %	5 000	0,5 %	5 000	0,3 %						
Altogether (€/year)	**55 565**	7,7 %	**69 607**	5,3 %	**64 263**	6,5 %	**74 794**	4,7 %	**0**	0,0 %	**0**	0,0 %	**0**	0,0 %
O&M (€c/kWh)	1,56		1,40		1,45		1,37		0,00		0,00		0,00	
Year Production (kWh/a)	4 148 176		5 785 878		5 162 570		6 390 907		5 792 000		5 495 000		5 793 000	
Levelised Utilized Energy (0,86) (kWh/a)	**3 556 542**		**4 960 667**		**4 426 258**		**5 479 404**		**4 995 739**		**4 521 300**		**4 930 857**	
Year Production per Swept Area (kWh/m^2)	1 541		1 542		1 565		1 602		1 553		1 405		1 533	
Nominal Power Time (h/a)	3 557		3 307		3 405		3 321		3 330		3 014		3 287	
Capasity Factor (Cf)	0,41		0,38		0,39		0,38		0,38		0,34		0,38	
Production Cost (€c/kWh)	**4,00**		**4,12**		**3,90**		**4,11**		**3,68**		**3,88**		**4,03**	
Real Interest 5 %	**Bonus**		**NEGMicon**		**NORDEX**		**Vestas**		**Rödsand**		**Omö**		**Gedser**	
Refund Periode 20 year	**1 000**		**1 500**		**1 300**		**1 650**		**1 500**		**1 500**		**1 500**	
Swept Area (m^2)	2 307		3 217		2 827		3 421		3 217		3 217		3 217	

Production			1 pc		1 pc		1 pc
		Rödsand		Omö		Gedser	
Rated output	MW	144	1,5	144	1,5	144	1,5
Cf		0,44		0,42		0,44	
Gross production	MWh/y	556 000	5 792	527 500	5 495	556 100	5 793
Park efficiency	%	91,2		87,0		90,0	
Availability	%	97		97		97	
Transmission loss	%	2,5		2,5		2,5	
Net Production	MWh/y	479 563	4 995	434 028	4 521	473 338	4 931
Net full-load hours			3 330		3 014		3 287

pcs	96	1	Rödsand	€/pc	Omö	€/pc	Gedser	€/pc
Foundation		M€	36	375 000	36	375 000	36	375 000
Wind turbines		M€	113	1 177 083	113	1 177 083	113	1 177 083
Grid connection		M€	55	572 917	45	468 750	73	760 417
O&M facilities		M€	3	31 250	3	31 250	3	31 250
Project design		M€	8	83 333	8	83 333	8	83 333
Miscellaneous		M€	5	52 083	5	52 083	5	52 083
Total investment		M€	220	2 291 667	210	2 187 500	238	2 479 167
Investment per MW		M€	1,53		1,46		1,65	
Capital costs/kWh		€	0,037		0,039		0,040	
O&M costs/kWh		€	0,011		0,011		0,011	
Total costs / kWh		€	0,048		0,050		0,051	

Water level	1	5 m	€/pc	8 m	€/pc	11 m	€/pc
Structure		265 000	265 000	289 000	289 000	318 000	318 000
Installation		21 000	21 000	23 000	23 000	27 000	27 000
Access platform		33 000	33 000	33 000	33 000	33 000	33 000
Dismantling		11 000	11 000	13 000	13 000	17 000	17 000
Total		330 000	330 000	358 000	358 000	395 000	395 000

Appendix 13. Monthly and Annual Wind Speeds in Mustasaari Wind Conditions.



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KUUKAUSI- JA VUOSIYHDISTELMÄT
MONTHLY AND ANNUAL SUMMARIES

------------------------------------------------------------------------------
 TUULIEN JAKAUTUMINEN
 WIND DISTRIBUTION                       TYYNI  KA
      N      NE       E      SE       S      SW       W       NW    CALM   M
KK  %  M/S  %  M/S  %  M/S  %  M/S  %  M/S  %  M/S  %  M/S  %  M/S  %  M/S
MO
_______________________________________________________________________________

MUSTASAARI VALASSAARET     1961 - 1990     LA = 63 26     LO = 21 04     g= 9.821
                           ___________

   1 15  7.7 11  7.6  8  5.3 10  4.7 23  6.9 12  7.6 14  6.7  6  6.7  0  7.1
   2 12  8.3 13  7.4  8  4.6  8  4.4 27  6.6 14  6.4 12  6.3  6  5.7  0  6.8
   3 11  7.7 13  6.9  8  4.5  7  4.2 32  6.6 13  6.0 11  5.8  5  5.2  1  6.3
   4 15  7.2 17  6.8 10  4.1  5  3.9 24  6.2 13  5.4 11  5.3  5  5.0  1  6.0

   5 14  6.2 22  6.2  9  4.3  2  3.5 24  6.2 14  5.5 10  4.7  5  4.6  0  5.8
   6 14  6.1 17  5.9  9  4.1  2  3.0 24  6.1 16  5.3 12  4.8  6  5.2  0  5.6
   7 14  5.8 17  5.3  8  3.8  4  3.6 23  5.6 15  5.0 11  4.8  8  4.7  1  5.3
   8 15  6.9 17  6.2  9  4.2  5  3.9 21  5.7 12  5.3 13  5.3  7  5.6  1  5.8

   9 13  8.2 10  6.6  8  5.0  7  4.8 25  6.4 13  5.9 15  6.7 10  7.9  0  6.7
  10 12  8.5  6  7.3  7  6.5  9  4.9 24  6.9 14  7.2 17  7.1  9  8.1  0  7.5
  11 16  9.3  5  8.8  9  7.2 11  5.6 19  7.0 13  8.1 16  7.7 10  7.8  0  7.9
  12 14  8.8  7  8.8  9  6.7 10  5.4 23  7.1 13  7.8 15  7.5  9  7.1  0  7.8

     14  7.5 13  6.7  9  5.0  7  4.6 24  6.4 14  6.3 13  6.2  7  6.4  0  6.6
```

Appendix 14. Planned and tentative Wind Farms (Concerted Action on Offshore Wind Energy in Europe 2001: 9–26).

Table 9.2 Planned wind farms (Spring 2001):

Name	Turbines	Total MW	Year	Comments
Klasården	21 NEG MICON 2 MW	42	2001?	Gotland
Horns Rev, DK	80 Vestas 2 MW	160	2002	
Rødsand, DK	72 Bonus 2.1-2.2MW	151-158	2002	
Q7-WP, NL	Vestas	120	2002	> 12 miles
Breedt, FR		7.5	2002?	
Læsø Syd, DK		150	2003	
Nearshore Wind Farm, Egmond aan Zee, NL		100	2003	Receives subsidy of max. NLG 60 m for RTD programme
Omø Stålgrunde, DK		150	2004	
Gedser, DK		150	2006	10 km to coast, licence granted for monitoring Sep. 2000. ~ 27% more investment than onshore
Arklow Bank, EI		500		
Kish Bank, EI		250		Öresund
Lillegrund, SE	48 Enercon 1.5 MW	72		Public hearing June 1999. Tenders issued November 2001.
Samsø	10 2MW	20		
Total		1513		

Table 9.3 Tentative site exploration (Spring 2001).

Name	Total MW	Year	Comments
Knokke, BE	100	2002 or later	12-15 km from coast
Wenduine	100	2002 or later	5-11 km from coast
Pori, FI			
Kish Bank, EI	220-250		10 km from coast. Licence granted for monitoring Sep. 2000
Codling Bank, EI			Licence granted for monitoring Sep. 2000
Blackwater Bank, EI			Licence granted for monitoring Sep. 2000
Nord-Pas de Calais, FR			Study for local council or French Energy Agency (ADEME) 1998. 5 to 8 km from shore with water depth of 5 to 20 m. Estimated resource 775 MW giving 2.4 TWh/year.
Brittany, FR			Study for local council or ADEME 1999-2000. 3 to 10 km from shore in water dpeths 5 to 20 m. Estimated resource 2050 MW or 6.3 TWh/year.
Normandy, FR			Study for local council or ADEME 2000. Basse Normandie 5 to 10 km from shore in water depths 5 to 20 m. Resource estimated 3500 MW or 10.8 TWh /year.
Languedoc-Rousillon, FR			3.5 to 10 km from shore in water depths 20 to 30 m. Estimated resource 2800 MW 10.6TWh/year.
Cadiz, ES			Measurements underway.
Bialogóra, PL			Consents issued for 49-61 2 MW turbines
Karwia, PL			Consents issued for 50 2 MW turbines
Solway Firth, UK			Off Maryport, Cumbria 9.5 km from shore, Off Rock Cliffe, Dumfries & Galloway 8.5 km from shore. Preliminary consents for 60 turbines[1]
Barrow, UK			10 km from shore Off Walney Island, Cumbria. Preliminary consents for 30 turbines[1]
Shell Flat, Uk			Off Cleveleys, Lancashire, 7 km from shore. Preliminary consents for 90 turbines[1]
Southport, UK			Off Birkdale Merseyside, 10 km from shore. Preliminary consents for 30 turbines[1]
Burbo, UK			Off Crsoby, Merseyside 5.2 km from shore. Preliminary consents for 30 turbines[1]
North Hoyle/ Rhyl Flats, UK UK	60-90 for North Hoyle		Off Prestatyn, North Wales, 6km from shore and off Abergele, North Wales, 8 km from shore. Preliminary consents for 60 turbines[1]. The developers of North Hoyle, National Wind Power, report that the site has good wind resources and relatively low exposure in the predominant wind direction. Water depth is 12 m with a 9m tidal range. Plans are to install turbines of 2-3MW. The Delores of Rhyl Flats are Celtic Offshore Wind Ltd.
Scarweather Sands, UK		2004-2005	Off Porthcawl, South Wales, 9.5 km from shore.

			Preliminary consents for 30 turbines[1]. Developers are United Utilities .
Kentish Flats, UK		2004-2005	Off Whitstable Kent, 8 km from shore. Preliminary consents for 30 turbines[1]. The developers are Global Renewable Energy Partners UK, a subsidiary of NEG MICON. Turbines of 2-3MW will be installed on monopile foundations. Estimated production is 300 GWh/year.
Gunfleet, UK	100?		Off SE Clacton-on-Sea, Essex, 7 km from shore. Preliminary consents for 30 turbines[1]. Developers are Enron Wind Gunfleet Ltd.
Scroby Sands, UK	76	2003?	Off Caister, Norfolk, 2.3 km from shore. Preliminary consents for 30 turbines[1]. Developers are Powergen Renewables Offshore Wind Ltd. Plans exist to erect 38 2MW turbines.
Cromer, UK			Off Foulness, Norfolk, 6.5 km from shore. Preliminary consents for 30 turbines[1]
Lynn/ Inner Dowsing UK			Off Skegness /Off Ingoldmells, Lincolnshire, 5.2 km from shore. Preliminary consents for 60 turbines[1]. Developers of the Lynn Site are AMEC Offshore Wind Power Ltd. Earliest construction date is 2004. Developers of Inner Dowsing are Renewable Energy Systems and British Energy. Turbines are 2-3MW. Construction is anticipated in 2004.
Teeside, UK			Off NE Teesmouth, Middelsborough, 1.5 km from shore. Preliminary consents for 30 turbines[1]

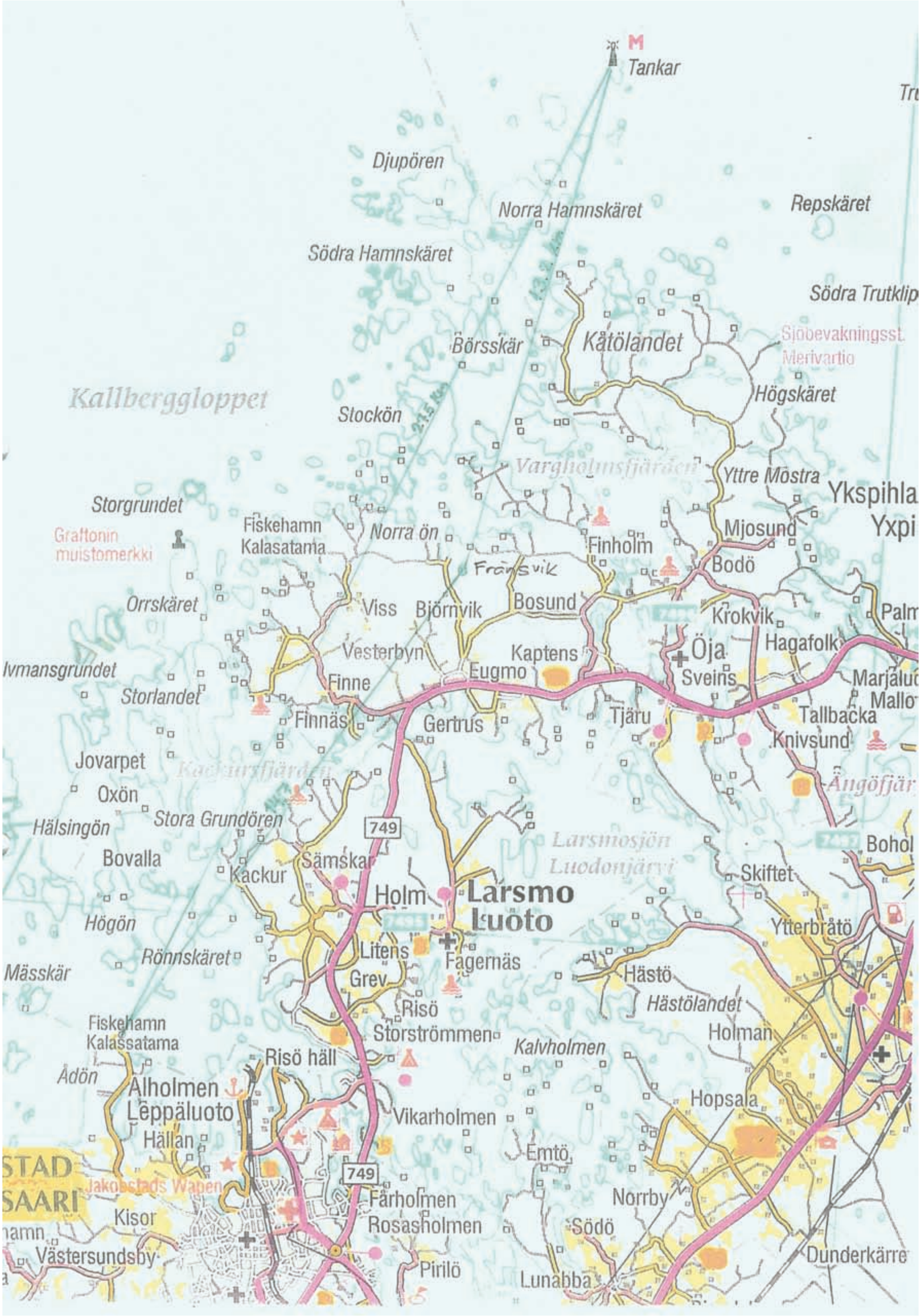
[1] The UK Crown Estate announced the sites and names of the eighteen wind farm developers who have successfully pre-qualified to obtain a lease of seabed for development of offshore windfarms (April 2000).

Appendix 15. Offshore Turbine Investment Cost by Components.

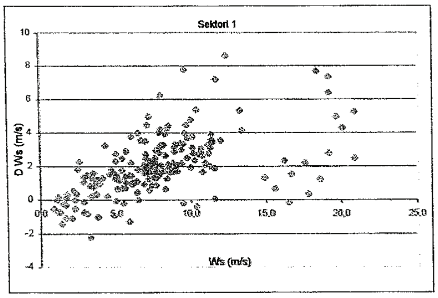
Offshore Wind Turbine Investment M€:

conversion coefficient	M€ 1,5	DKK 0,13459	M€ 1/96	M€ 1/96	M€ 1/96	M€ 1,5	M€ 1,5	M€ 1,5	M€ 1
References:	Kuhn et al. 1998 [13]	Fuglsang 1998 p.13	Svenson 1999p.299 Rödsand	Svenson 1999p.299 Omö	Svenson 1999p.299 Gedser	Hartnell et al. 2000 [10]	DEA/CAD-DET 2000 [5]	Barthelmie et al.2001 page 6-2	www.mid-delgrunden dk
Turbine size	1 MW	1,5 MW	1,5 MW	1,5 MW	1,5 MW	1 MW	1 MW	1 MW	2 MW
Turbine	0,675	1,390	1,177	1,177	1,177	0,765	0,765	0,495	1,207
Foundation	0,480	0,554	0,375	0,375	0,375	0,240	0,240	0,360	0,394
Grid connection	0,315	0,417	0,573	0,469	0,760	0,375	0,375	0,225	0,574
Management	0,030		0,083	0,083	0,083	0,060	0,060	0,030	
O&M facilities	0,000		0,031	0,031	0,031	0,030	0,030	0,345	
Miscellaneous	0,000		0,052	0,052	0,052	0,030	0,030	0,045	0,161
Total M€/pc	1,500	2,369	2,292	2,188	2,479	1,500	1,500	1,500	2,336
Turbine size	1 MW	1,5 MW	1,5 MW	1,5 MW	1,5 MW	1 MW	1 MW	1 MW	2 MW
Total M€ / 1 MW	1,500	1,579	1,528	1,458	1,653	1,500	1,500	1,500	1,168

Appendix 16. Measuring Arrangements in Larsmo Region.

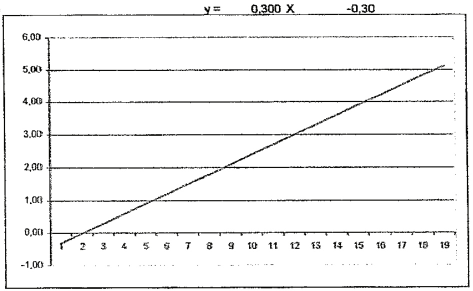


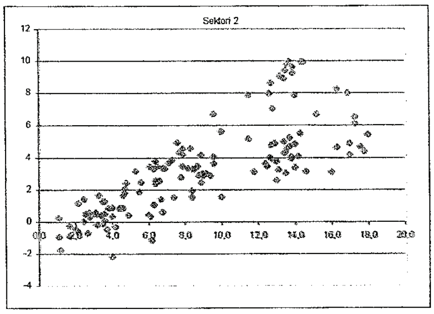
Appendix 17. Tankar and Fränsvik Wind Speed Differences by Wind Speeds and Wind Direction Sectors.



Ws (m/s)	DWs (m/s)
0	-0,30
1	0,00
2	0,30
3	0,60
4	0,90
5	1,20
6	1,50
7	1,80
8	2,10
9	2,40
10	2,70
11	3,00
12	3,30
13	3,60
14	3,90
15	4,20
16	4,50
17	4,80
18	5,10

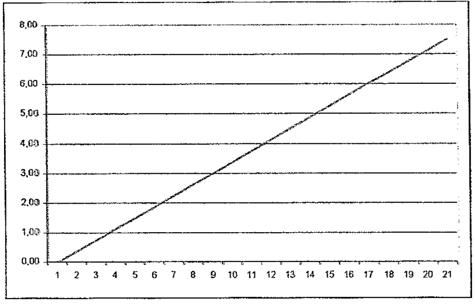
y = 0,300 X -0,30

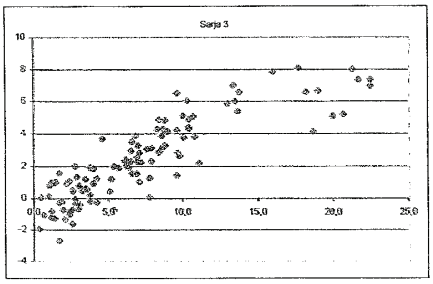




Ws (m/s)	DWs (m/s)
0	0,00
1	0,38
2	0,75
3	1,13
4	1,50
5	1,88
6	2,25
7	2,63
8	3,00
9	3,38
10	3,75
11	4,13
12	4,50
13	4,88
14	5,25
15	5,63
16	6,00
17	6,38
18	6,75
19	7,13
20	7,50

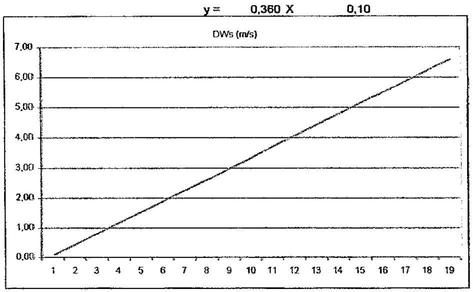
y = 0,375 X 0,00

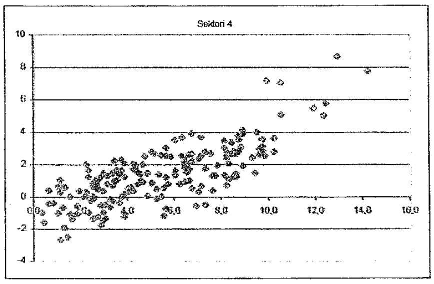




Ws (m/s)	DWs (m/s)
0	0,10
1	0,46
2	0,82
3	1,18
4	1,54
5	1,90
6	2,26
7	2,62
8	2,98
9	3,34
10	3,70
11	4,06
12	4,42
13	4,78
14	5,14
15	5,50
16	5,86
17	6,22
18	6,58

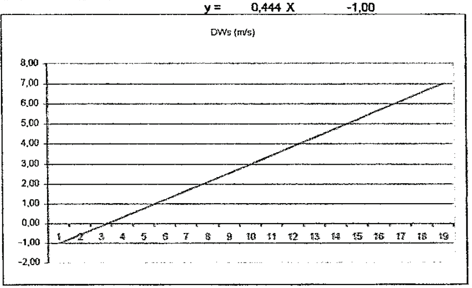
y = 0,360 X 0,10

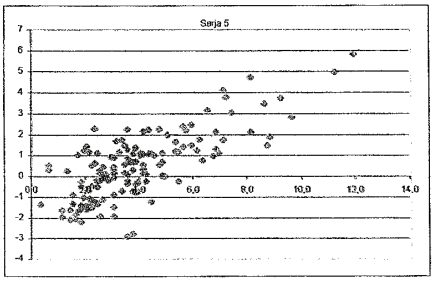




Ws (m/s)	DWs (m/s)
0	-1,00
1	-0,56
2	-0,11
3	0,33
4	0,78
5	1,22
6	1,66
7	2,11
8	2,55
9	3,00
10	3,44
11	3,88
12	4,33
13	4,77
14	5,22
15	5,66
16	6,10
17	6,55
18	6,99

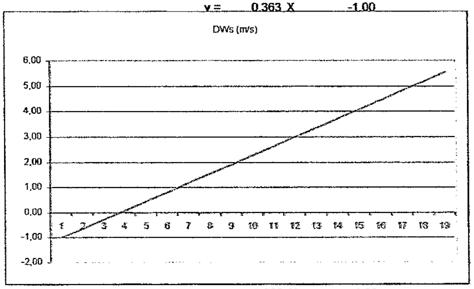
y = 0,444 X -1,00

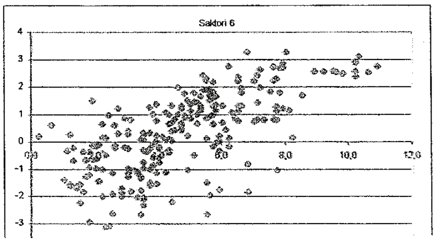




Ws (m/s)	DWs (m/s)
0	-1,00
1	-0,64
2	-0,27
3	0,09
4	0,45
5	0,82
6	1,18
7	1,54
8	1,90
9	2,27
10	2,63
11	2,99
12	3,36
13	3,72
14	4,08
15	4,45
16	4,81
17	5,17
18	5,53

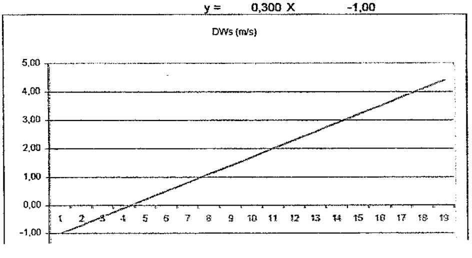
y = 0,363 X -1,00

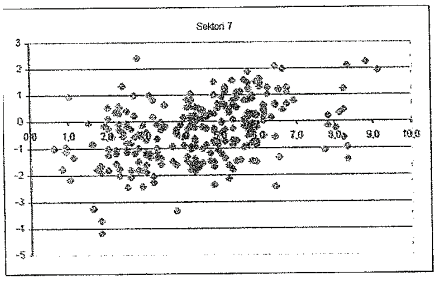




Ws (m/s)	DWs (m/s)
0	-1,00
1	-0,70
2	-0,40
3	-0,10
4	0,20
5	0,50
6	0,80
7	1,10
8	1,40
9	1,70
10	2,00
11	2,30
12	2,60
13	2,90
14	3,20
15	3,50

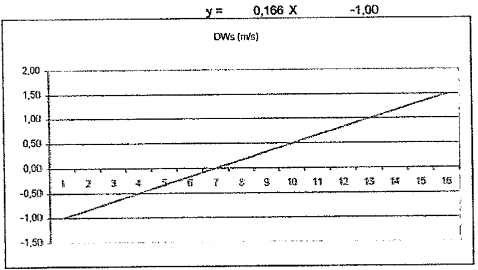
y = 0,300 X -1,00

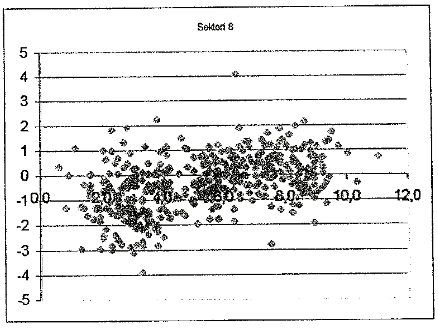




Ws (m/s)	DWs (m/s)
0	-1,00
1	-0,83
2	-0,67
3	-0,50
4	-0,34
5	-0,17
6	0,00
7	0,16
8	0,33
9	0,49
10	0,66
11	0,83
12	0,99
13	1,16
14	1,32
15	1,49

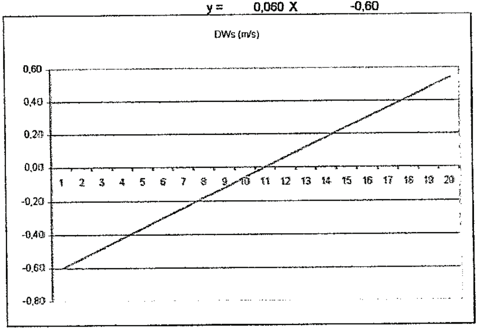
y = 0,166 X -1,00

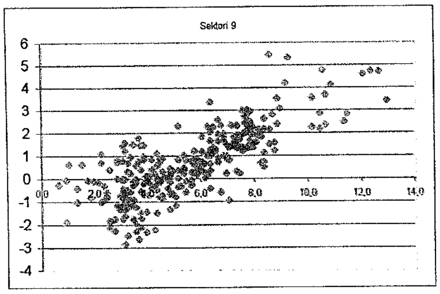




Ws (m/s)	DWs (m/s)
0	-0,60
1	-0,54
2	-0,48
3	-0,42
4	-0,36
5	-0,30
6	-0,24
7	-0,18
8	-0,12
9	-0,06
10	0,00
11	0,06
12	0,12
13	0,18
14	0,24
15	0,30
16	0,36
17	0,42
18	0,48
19	0,54

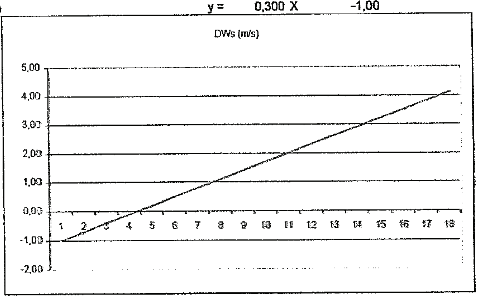
y = 0,060 X -0,60

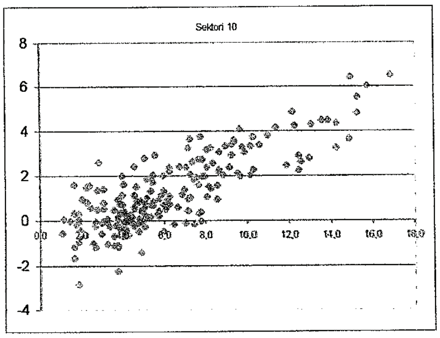




Ws (m/s)	DWs (m/s)
0	-1,00
1	-0,70
2	-0,40
3	-0,10
4	0,20
5	0,50
6	0,80
7	1,10
8	1,40
9	1,70
10	2,00
11	2,30
12	2,60
13	2,90
14	3,20
15	3,50
16	3,80
17	4,10

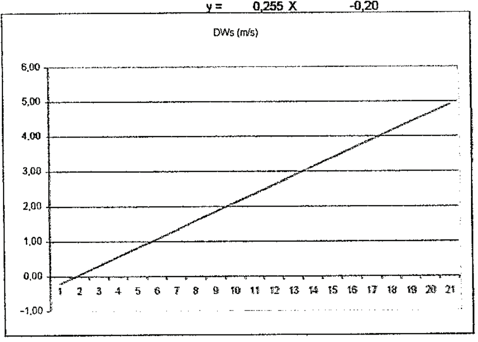
y = 0,300 X -1,00

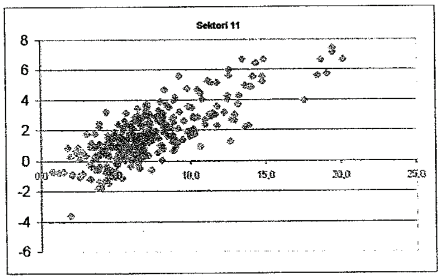




Ws (m/s)	DWs (m/s)
0	-0,20
1	0,06
2	0,31
3	0,57
4	0,82
5	1,08
6	1,33
7	1,59
8	1,84
9	2,10
10	2,35
11	2,61
12	2,86
13	3,12
14	3,37
15	3,63
16	3,88
17	4,14
18	4,39
19	4,65
20	4,90

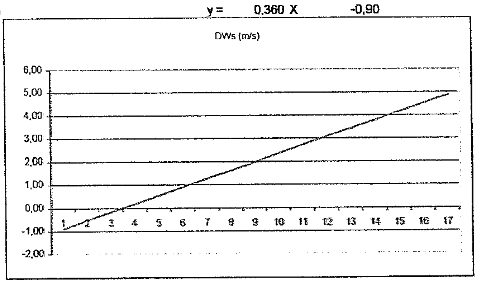
y = 0,255 X -0,20

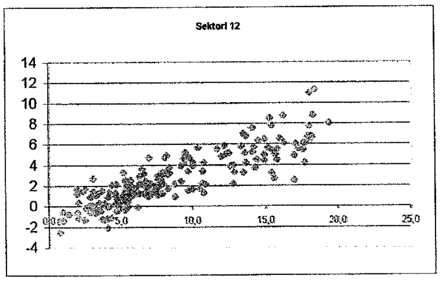




Ws (m/s)	DWs (m/s)
0	-0,90
1	-0,54
2	-0,18
3	0,18
4	0,54
5	0,90
6	1,26
7	1,62
8	1,98
9	2,34
10	2,70
11	3,06
12	3,42
13	3,78
14	4,14
15	4,50
16	4,86

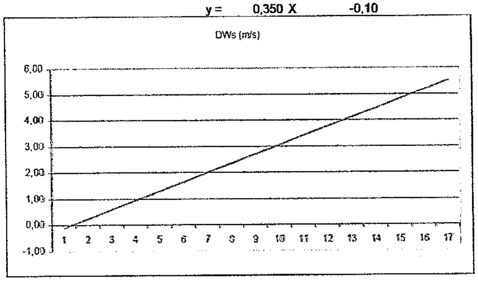
y = 0,360 X -0,90

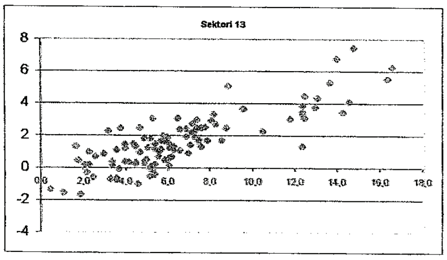




Ws (m/s)	DWs (m/s)
0	-0,10
1	0,25
2	0,60
3	0,95
4	1,30
5	1,65
6	2,00
7	2,35
8	2,70
9	3,05
10	3,40
11	3,75
12	4,10
13	4,45
14	4,80
15	5,15
16	5,50

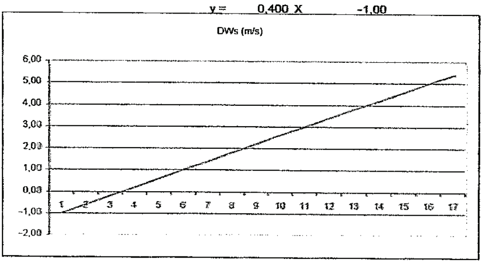
y = 0,350 X -0,10

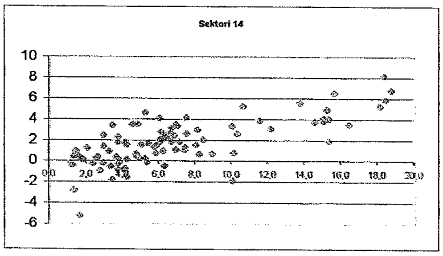




Ws (m/s)	DWs (m/s)
0	-1,00
1	-0,60
2	-0,20
3	0,20
4	0,60
5	1,00
6	1,40
7	1,80
8	2,20
9	2,60
10	3,00
11	3,40
12	3,80
13	4,20
14	4,60
15	5,00
16	5,40

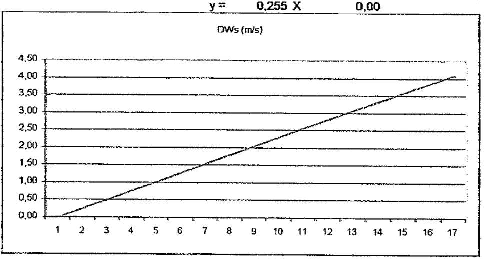
y = 0,400 X -1,00

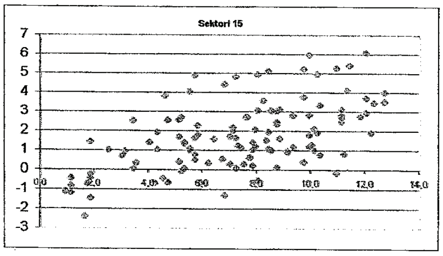




Ws (m/s)	DWs (m/s)
0	0,00
1	0,26
2	0,51
3	0,77
4	1,02
5	1,28
6	1,53
7	1,79
8	2,04
9	2,30
10	2,55
11	2,81
12	3,06
13	3,32
14	3,57
15	3,83
16	4,08

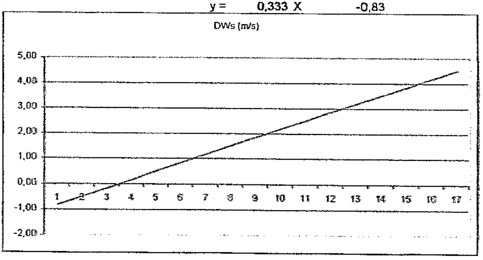
y = 0,255 X 0,00

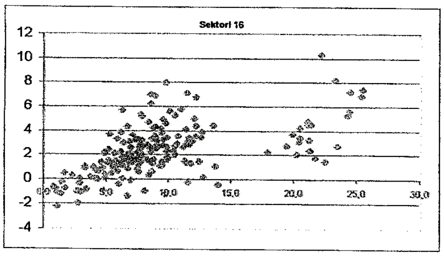




Ws (m/s)	DWs (m/s)
0	-0,83
1	-0,50
2	-0,16
3	0,17
4	0,50
5	0,84
6	1,17
7	1,50
8	1,83
9	2,17
10	2,50
11	2,83
12	3,17
13	3,50
14	3,83
15	4,17
16	4,50

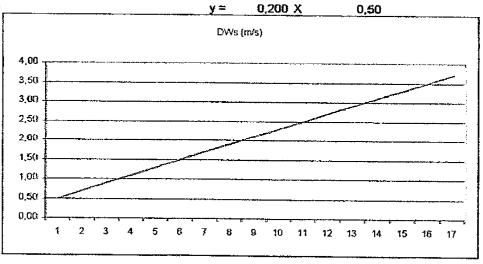
y = 0,333 X -0,83



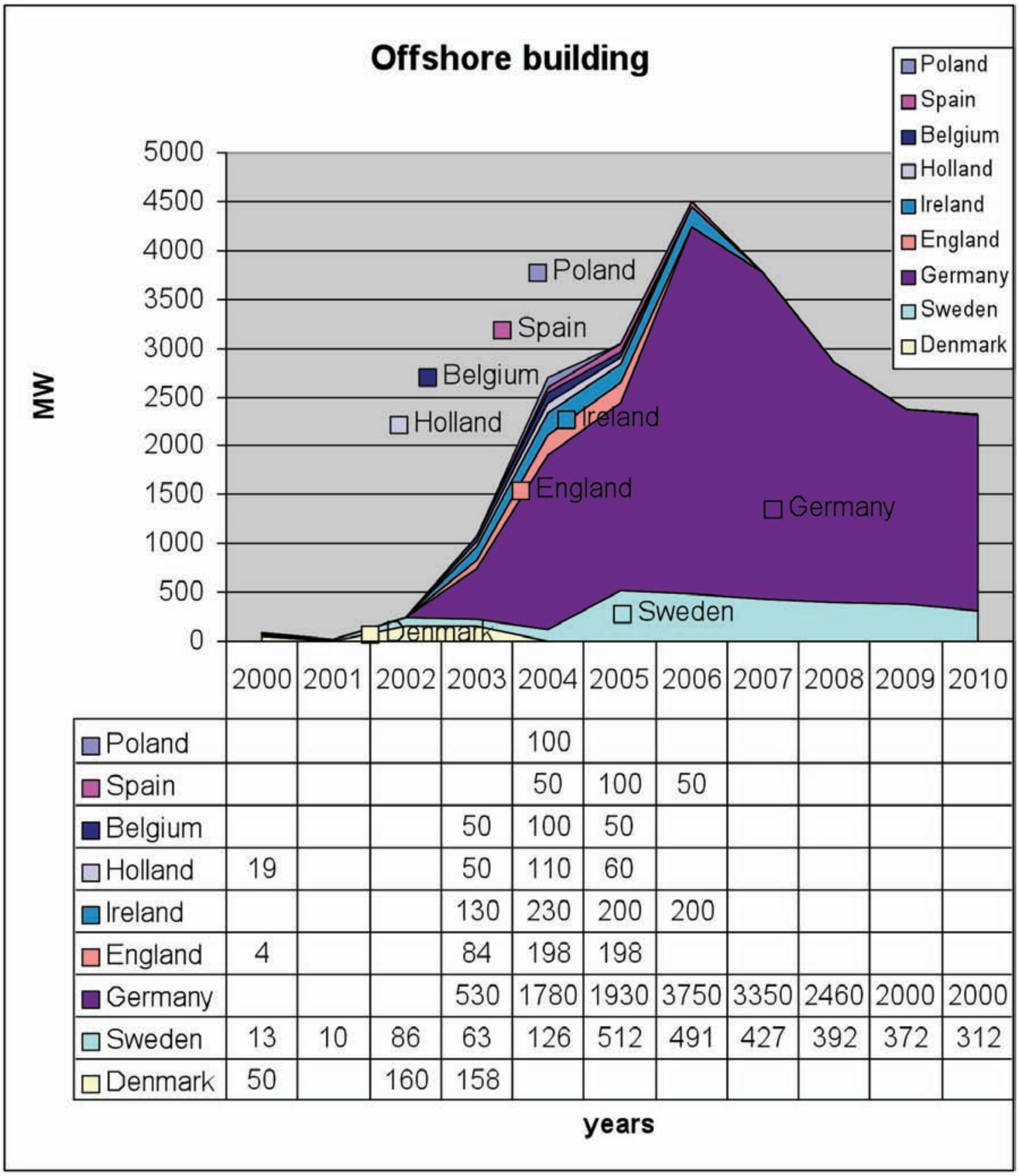


Ws (m/s)	DWs (m/s)
0	0,50
1	0,70
2	0,90
3	1,10
4	1,30
5	1,50
6	1,70
7	1,90
8	2,10
9	2,30
10	2,50
11	2,70
12	2,90
13	3,10
14	3,30
15	3,50
16	3,70

y = 0,200 X 0,50



Appendix 18. Offshore Market Plans for Years 2003 - 2010



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Poland					100						
Spain					50	100	50				
Belgium				50	100	50					
Holland	19			50	110	60					
Ireland				130	230	200	200				
England	4			84	198	198					
Germany				530	1780	1930	3750	3350	2460	2000	2000
Sweden	13	10	86	63	126	512	491	427	392	372	312
Denmark	50		160	158							

Source: Own reseach, BTM Consult A/S-March 2001, New Energy 2001-2, Concerted Action on Offshore Wind Energy in Europe 2001.

Appendix 19. Spreadsheet computation simulation model for steel foundation

Appendix 19 describes the simulation model. The input values of the turbine are given in Figure 40 in colour. The idea is to test how the turbine stays with water filled tanks on the sea bottom and floats with empty tanks, but only roughly for construction price estimation. The given circumstances are: given moment M_y GL-II/DIBt-III (Germanischer Lloyd-TypenklasseII / Deutscher Instituts für Bautechnik (DIBt)-WindzoneIII 2001:4,6,25), hub height, turbine weight, water depth, material thickness of under water tower, foundation height, estimated required stiffeners for foundation construction, thickness of foundation steel plate, radius of under water tower, height of concrete layer and radius of foundation.

The floating mass, displacement and depth are calculated. The lift of foundation, wet weight, dry weight, prices are given and areas are calculated, material cost, given work price, work cost and material and work cost summed (Fagerström, Asko 2000, List of Statement).

Bending moment and holding moment are calculated. The comparison ratio is calculated. The floating conditions are tested. The comparison ration is mentioned. The price for foundation painted steel construction is included and balance is 25% in this case.

In addition there are gravity centre calculations for a mill standing on the sea bottom. For floating condition in inspections are made. The centre of gravity is calculated. The stability in floating condition is made. The comparison is made for the whole mill and the buoyancy moment. A metacentre and the distance for whole mill centre of gravity are also calculated.

This construct gives a rough picture on how different input values affect the price. In addition those given 20 input values will be calculated. Thus it can be seen at once if construction is possible in reality.