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MSc Program
Renewable Energy in Central and Eastern Europe

Impact of wind speed forecast errors on the financial profit of an existing wind park project in Hungary

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
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Vienna, March 20, 2012

Affidavit

I, **Dipl.-Ing. Christian Wolfgang Weiser**, hereby declare

1. that I am the sole author of the present Master Thesis, “Impact of wind speed forecast errors on the financial profit of an existing wind park project in Hungary",
   83 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master Thesis as an examination paper in any form in Austria or abroad.

Vienna, ________________ ______________________________

Date Signature

Abstract

The target of this master thesis is to establish a model of calculating the economic impact of wind speed forecast and real data differences on a projected wind park in the area of Mosonmagyaróvár in Hungary.

The Hungarian law prescribes to producers of REN energy a supply forecast, which has to be sent regularly to the grid operator. Based on the forecasted energy delivery and the real delivery a penalty system is applied which leads to certain losses for the owner of the wind park.

Based on forecast data from the Hungarian Meteorological Service a model is established which calculates an energy delivery forecast. The real energy production also needs to be simulated but with the wind speed data from the tower.

Based on the differences of forecasted and “real” energy delivery the respective fine is calculated and introduced into the economic model of the wind park.

As economic model the structure of a net present value calculation over the projects life-time is applied. The technical and financial data are from an existing project of Energiepark Bruck an der Leitha. The paper will show that the direct usage of the received forecast data is resulting to a high power prediction error and therefore also a high fine to be paid. The impact of this fine to the economics of the wind park is rather significant. It is therefore proposed to further fine tune the received forecast data locally before establishing a power forecast to the grid operator.

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Abbreviations used:

ALADIN	European Consortium for Short Range Weather Forecasts
ECMWF	European Center for Medium Range Weather Forecasts
Ft	Hungarian Forint
HUF	Hungarian Forint
KAM	(Kötelező Átvételi Rendszer Management) Feed In Tarif Management
KAT	(Kötelező Átvételi Rendszer) Feed In Tarif
Kft	(Korlátozott Felelőségű Társaság) Ltd
MAVIR	(Magyar Villamosenergia-ipari Átviteli Rendszerirányító) Hungarian Grid Operator
NPV	Net Present Value
NWP	Numeric Weather Prediction
OMSZ	(Országos Meteorológiai Szolgálat) Hungarian Meteorology Service
REN	Renewable Energy
SRNWP	Short Range Numeric Weather Prediction
WACC	Weighted Average Cost of Capital
WMO	World Meteorology Organization

1 Introduction

The deployment of wind energy in various countries is always a reflection of the actual political and economic situation in the respective country. The specific Hungarian law for a forecast system has certainly an impact on the deployment of wind energy in Hungary. Based on a model of simulating this impact for a specific project gives us an idea of the general influence on the further deployment.

1.1 Motivation

Living in Hungary as an Austrian for more than 10 years and being confronted with the different approaches of renewable energy support and introduction in both countries I am curious into what extent the specific Hungarian forecast and penalty model is influencing the profitability of a wind park in Hungary. Speaking fluently Hungarian the access to Hungarian literature, which in most of the cases is not available in English language will facilitate my work.

1.2 What is the core objective / the core question?

The objective of this paper is to introduce a calculation model for the economic impact of forecast penalty on an existing wind park project. Based on this model it shall be shown if this system leads to significant losses to the wind park owners.

1.3 Method of approach

The specific Hungarian law situation regarding the forecast obligation will be shown.
The wind park project will be presented in form of a business plan.
As available data the forecast of the Hungarian Meteorological Service for August 2011 will be used. The methods of generating numerical based forecasts in Europe and Hungary will be introduced briefly. Based on this data and the planned technical setup of the project an energy delivery forecast will be established. The real measurement data from a wind mast on the site of the project will be transformed into the “real” energy delivery. Taking into account the existing laws out of the

difference in forecast and reality a theoretical penalty will be calculated. Based on the total economic model of this wind park, the penalties impact to the financial result will be analyzed. Conclusions regarding the usage of pure wind forecast data to make a power forecast will be drawn.

1.4 Structure of work

1. Introduction into the legal situation of the Hungarian Forecast Obligation
2. Introduction of the wind park project in Mosonmagyaróvár - Hungary
3. Introduction of the Hungarian Meteorological Service
4. Establishment of a transfer model wind data to energy delivery
5. Applying the model to the forecast data
6. Applying the model to the real data
7. Establishment of an comparison model including penalty calculation
8. Calculation of deviations and respective penalties with above data
9. Introduction of the economic model of the wind park
10. Calculating the economic impact of the penalties
11. Conclusions and Recommendations

2 The legal situation of wind energy grid connection in Hungary:

The legal background of the Hungarian Feed In Tariff System is the Electricity law from 2007-LXXXVI (VET) and especially the decree 109/2007 (Feed In Tariff and Process) and the decree 389/2007 (Fee for rebalancing energy in case of forecast deviations). The decrees have been modified in the last years. (20/2010 and 287/2008). There is so far no dedicated renewable energy law in Hungary.

2.1 Electricity law 2007 LXXXVI

(H. Government, 2007. évi LXXXVI. törvény 2007):

The electricity law (VET) is dealing with the production, distribution, trade, consummation and sales of electrical energy and the realization, operation and dismantling of electrical installations and connections.

§9-13 deals with renewable energy. The obligatory taking over is defined, which depends on energy source, efficiency and production processes, cost efficiency and depreciation of the power plants.

§10/3 For wind power stations the energy take over obligation is limited with respect to available balancing systems.

§11 is defining the price building for the Feed In tariff with the criteria of the take over obligation

§171 is defining the maximum Feed In Tariff: k*24,71 Ft/kWh with k as index factor of the consumer price index in relation to the previous year. Every year the k value is again to be calculated and multiplied. (Indexation [1])

2.2 Decree 109/2007 modified by 20/2010

(H. Government, 109/2007. (XII. 23.) GKM rendelet 2007), (H. Government, MAGYAR KÖZLÖNY • 2010.évi185.szám 20/2010 2010):

This decree is dealing with the process of the distribution of the Feed In Tariffs and the price building.

§2 describes the obligation of the producer to provide forecast data:

- The producer needs to provide every month at the 7th working day a rolling forecast for the next 12 months, split in months and tariff types (peak, low, deep).
- The producer needs to provide every month at the 7th working day a monthly forecast for the next following month to the grid operator.
- The producer has the right, every 3rd weekday up to 11.30 to provide a weekly forecast for the next week and from the 8th working day to the 7. working day of the following month to provide a daily forecast. The daily forecast can be modified for any of the following days of the actual month.
- The grid operator is calculating based on the monthly forecast data the summarized energy production quantity, which is falling into the Feed In Tariff.

1

consumer price index (%,yearly average)	2007	2008	2009	2010	2011
(Részvénytársaság 2012)	8,0	6,1	4,2	4,9	3,9

2.3 Decree 389/2007 (XII.23.) modified by decree 287/2008

(H. Government 2007), (H. Government, A kórmány 287/2008 (XI.28.) rendelete 2008)

§1 The validity area of this decree is for electrical energy out of renewable energy (detailed list)

…

(5) Wind power stations

which are built according the §7(2) VET LXXXVI 2007 and according the in the VET extra defined tenders and the energy out of wind power stations which is conform with the rules of the tender (especially: time frame, number, take over price,..) and which is entitled to sell into the Feed In Tariff System.

…

§2 Definitions

…

Grid-balancing Fee: The fee, which has to be paid from the producer to the grid operator in case of forecast deviation.

Change Fee: In case of deviation of the monthly summarized forecast and the electrical energy delivery. Fee to be paid based on the difference of the monthly-summarized forecast and the actual delivery from the producer to the grid operator. (Not for wind power stations)

Planning fee: (From the customer to pay)

…

§7 Rules for the take over obligation:

(1) Permits the sales of electrical energy from renewable sources according the law at fixed quantities within the agreed time period at the agreed tariff.

(4) The producer needs to provide to the grid operator according a separate decree the within the trading regulations and contracts of the grid operator defined forecast data on a monthly base. If the producer does not provide or

not according the regulations or too late provide the forecast he has to pay to the grid operator a grid-balancing fee of 7 Ft/kWh.

(7) If the actual delivered energy from a wind power station, photovoltaic station or a hydro power station <5MW -which is obliged to provide a forecast- on the given day is deviating from the last actual forecast of this day by more than +/-50% (daily summary) the producer has to pay for every kWh over 50% of the forecast a grid-balancing fee of 5Ft.

(8) In case of combined forecast the nominated representative is responsible. He is liable together with the producer to pay for the grid-balancing fee. In case of electricity from different sources the strictest regulation is applied.

(9) The invoicing of the grid-balancing fee can be dispensed if the producer can prove that he was restricted in his grid access due to technical failures or crisis in the distribution and delivery network. The relevant time frame must not be taken into account into the calculation of the fee.

(10) Wind power stations and bio gas stations <5MW are exempt from the payment of the grid balance fee for the first 6 months if they provide their forecast during this time properly.

3 Introduction of the wind park project in Mosonmagyaróvár:

For the evaluation of the forecast error it is necessary to have available a certain model of a wind park as base for the technical and financial calculations. For this purpose within this paper an existing project of the company Bakony Wind Kft. is used. The real location of the projected wind park of this company will not be disclosed within this paper. A different place (Mosonmagyaróvár) has been selected, as for this area the necessary wind data and forecast data is available. The general findings of this paper however can be a base for the treatment of the wind forecast even for other regions. For better understanding of the wind park model the project is presented in form of the executive summary of a business plan (The complete business plan of Bakony Wind Kft can be found in the Annex):

3.1 Executive summary

3.1.1 Business Purpose of Bakony Wind Kft:

The project company Bakony Wind Kft has been established in 2010 with the target to establish a wind park in Hungary.

The objective of the company is to realize the wind park from the specification and planning phase, the achievement of the necessary permissions, the power purchase agreement, the supervision of the building activities up to the implementation and the start of the energy delivery and operation of the wind park.

3.1.2 Project Description:

The project is consisting of two groups of wind turbines with a total installed power of 51 MW in Hungary. The turbines will be located close to Mosonmagyaróvár. Very close nearby (500m – 3 km) is a 120kV and a 400kV power line located. It is planned to connect the wind farm to the 120kV power line.

3.1.3 Company:

As legal form of the project company the Hungarian KFT (Ltd) has been chosen. Management:

Bakony Wind Kft was founded in 2008.

One owner has already leaded successfully various wind projects in Austria. He is very experienced in the technical background of wind projects like wind measurements and turbine technology, the other owner has been doing business in Hungary since 1989 and family roots to Hungary. Being very familiar with local authorities and Hungarian regulations he is very experienced in legal project management and Hungarian financials.

3.1.4 Key Financials:

- Yearly turnover of 12 Mio €
- Operating result of 3.3 Mio € in the first year
- EBT becomes positive already after 4 years

The total investment is financed with a registered capital of 20.5 Mio € and a long-term depth of 82 Mio €.

The Currency Risk has been taken into account by model scenarios, which show that the project can even in worst case assure the payback of the bank loan.

4 Introduction of the Hungarian Meteorological Service OMSZ:

4.1 History:

(O. M. Szolgálat 2012)

The first official Hungarian Meteorological Service has been established in 1870. The official name was Hungarian Kings Central Institute for Meteorology and Earth Magnetics. Its major purpose was to provide meteorological measurements, develop the measurement stations and analyze the measurement results and to describe the Hungarian climatological situation. The office was in Budapest's Real-school and 3 people were working on these topics. One year later the office's address changed to a house in the castle of Budapest and then in 1872 to the Novák Villa in the Lovas street.

1873 the first yearbook with the measurement data of 1871 was published. In the year 1890 a new department was founded: the prediction department. From June15th 1891 onwards a daily map with important weather situations was published. In 1900 already 765 meteorological measurement stations worked on the Hungarian territory, of which 146 3 times daily were taking measurements.
In1911 from 1426 stations 208 provided three times a day measurement data. After the First World War very few developments was done and only at the end of the years of 1920 the growing interest in flight meteorology and the storm warning for Lake Balaton induced new developments.
1925 the Hungarian Meteorological Society was established.

During world-war 2 not only a lot of the measurement stations but also the main building was severely damaged. After the rebuilding new tasks were included into the portfolio such as the civil aviation's needs for meteorological predictions.
In 1947 Hungary joined the first international meteorological institute World Meteorological Organization (WMO).

After 1950 the institute got under the responsibility of the ministry of defense and the earth magnetic department left the institute. The name therefore changed again into National Meteorological Institute.

After 1970 the actual name National Meteorological Service was introduced. The institute consisted at that time of 3 major departments:

- The Central Forecasting Institute: Forecasting, Agro-meteorology and Aviation-meteorology.
- The Central Meteorological Institute: Measurements and the needed measurement networks development. Also the database setup and maintenance was part of their tasks.
- The Central Atmosphere Physics Institute: Research of Agro-meteorology, Clouds physics and Air pollution.

1976 started the ice rain defense with rockets in the county of Baranya.
At that time almost 1000 employees worked for the institute. Due to economic reasons the ice rain defense program had to be stopped and the number of employees dropped significantly.

In 1992 a new law (12/1992.(IV.23) KTM directive) was imposed which gave the institute a complete new structure. The 3 departments were discontinued and a modernization program was started with the target to bring the IT infrastructure up to date and to integrate the OMSZ into the European and international meteorological institutions.

Currently the directive 277/2005 (XII.20) is regulating the institute's structure and tasks. The OMSZ remains within the traditional mission of data and information collection but tended within the last years to become more an information service.

4.2 The major tasks of the OMSZ:

(O. M. Szolgálat 2012)

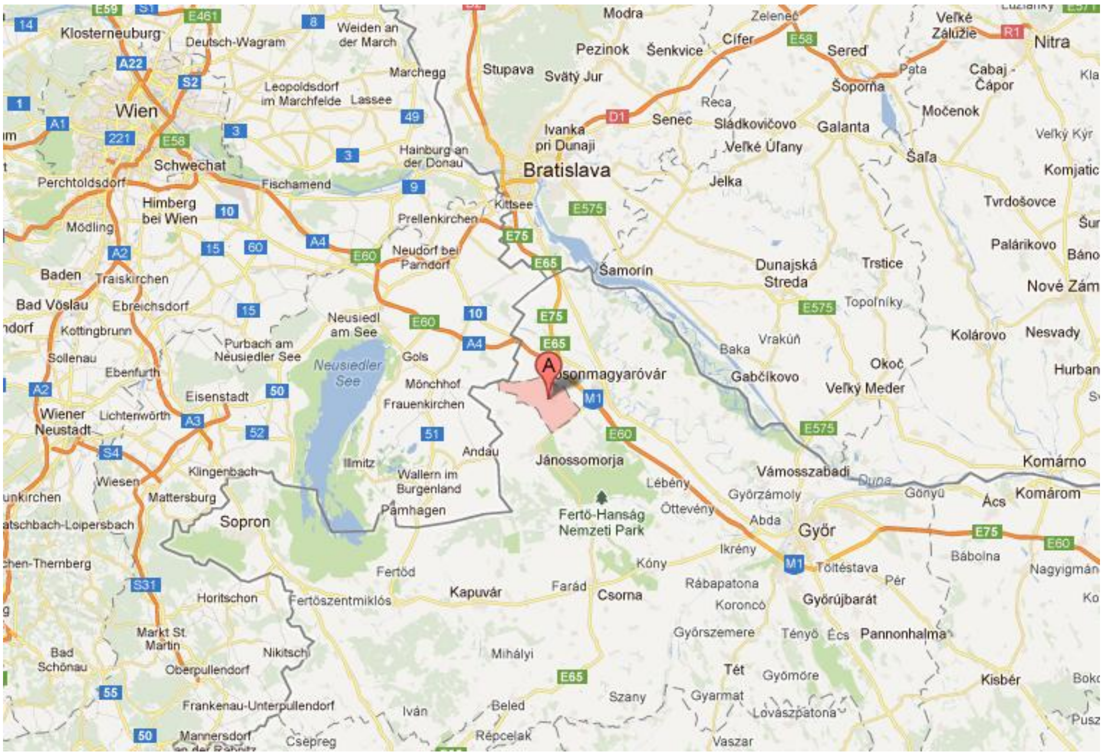
- Operate a connected measurement network on the territory of Hungary.

- Operate measurements of radio probes within the higher atmosphere, a radar network and a flash locating system.
- All these systems are operated, maintained, their data collected, analyzed and uploaded into the databases.
- Provide weather reports and forecasts for which international databases and national models are used.
- Operate and develop the Hungarian part of the telecommunication channels, which are coordinated by the International WMO and the International Citizen Aviation Institute.
- Upload of Hungarian data to the international databases, the download and processing of Hungary related data.
- Life and property defense: Forecast of weather and catastrophic events, storm forecast for the Hungarian lakes and forecast of nuclear wasted air distribution.
- The data is used also by civil aviation, ministry of water affairs and by the catastrophe defense institutions.
- Part of the work is also to do business with the available data.
- Provide the necessary data and documentation about the greenhouse gas emissions for the authorities.

5 Forecast data from Hungarian Meteorological Service:

For the purpose of this master thesis I received old sets of forecast data for the month of August 2011. The data is the original forecast data for a wind energy production site located close to Mosonszolnok.

Table 1: Location of Mosonszolnok



The data is provided on a daily base with a forecast range of 40 hours. It consists of wind speed and wind direction data. The forecast is given for a height of 80m.
The data is given in 15 minutes intervals.

The data is calculated out of the European ECMWF weather forecast data model and fine-tuned with the local ALADIN/HU model to a precision of 5km.

5.1 Numerical Weather Prediction Systems (Explanation of ECMWF and ALADIN):

National wind forecasts typically build up on international wide range forecasting systems, which are used as input for so called short-range prediction systems.
In any case the method used is the Numeric Weather Prediction (NWP).
Based on a wide range of input data and historical data numerical weather models are built up and run on very sophisticated computer systems. The next table shows an overview of international NWP systems (Giebel 2011):

Table 2: Overview of International NWP systems

Symbol Figure 29	Institution	model name	resolution/ model levels	approx. horiz. res.	Grid	Planned
ECMWF	European Center for Medium Range Weather Forecast	IFS	TL799/L91	~25km	Spectral	TL1279/L150 in 2009/10
METOF	Meteorological Office, UK	UM	0.375°x0.5625°/L 50	~40km	Gaussian grid	25km/L70 2009/10
MSC	Meterological Service of Canada	GEM	0.3°x0.45°/L58	~30km	Gaussian grid	Global 20-25 km uniform resolution, 90 levels, <2015
NCEP	National Center for Environmental Prediction, USA	GFS	TL382/L64	~50km	Spectral	
METFR	Meteo France	ARPEGE	TL538/L60	~ 15km over France	Spectral + gaussian grid with stretching factor	TL798/L70 2009/10
DWD	Deutscher Wetterdienst, Germany	GME	40km/L40	40km	Icosaeder	new model ICON (>2010)
AUSBM	Bureau of Meteorology, Australia	GASP	TL239/L29	~80km	Spectral	
JMA	Japan Meteorological Agency	JMA-GSM	TL319/L40	~60km	Spectral	
KMA	Korea Meteorological Agency	GDAPS	TL426/L40	~45km	Spectral	

For the data received from OMSZ as base the ECMWF has been used.

5.1.1 European Center for Medium Range Weather Forecasts (ECMWF):

The ECMWF has been founded by a number of European states with the target of cooperation in medium range weather forecasting. Hungary has a cooperation agreement with the ECMWF.

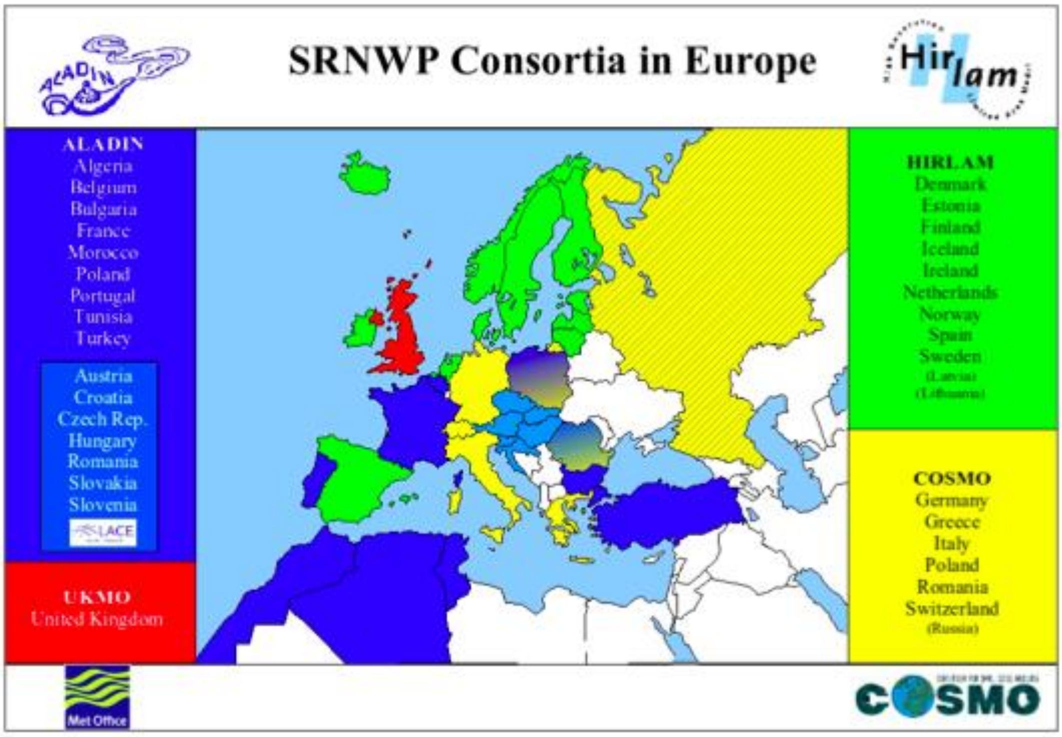
The main objectives of the Center are (ECMWF 2011)**:**

- development and operation of global models and data-assimilation systems for the dynamics, thermodynamics and composition of the Earth's fluid envelope and interacting parts of the Earth-system, with a view to:
  - preparing forecasts by means of numerical methods;
  - providing initial conditions for the forecasts; and
  - contributing to monitoring the relevant parts of the Earth-system;
- carrying out scientific and technical research directed towards improving the quality of these forecasts;
- collection and storage of appropriate data.

The ECMWF data is in best case available with a precision of 25km. That would by far not be enough for a local forecast in Hungary. Therefore the data needs to be modeled further with a short-range prediction system or limited area model.

The next table shows the limited area models in use in Europe (EUMETNET 2011):

Table 3: Limited Area Models used in Europe



5.1.2 The ALADIN consortium:

Hungary is part of the so-called ALADIN consortium. Other consortium operating in Europe are LACE, HIRLAM and COSMO.

The ALADIN was initiated by Météo-France and in October 1993 the SRNWP (Short Range Weather Prediction) consortia joined a common platform. (srnwp.met.hu)

Within this platform the data exchange and the further development of prediction models is coordinated.

OMSZ is using a Short Range Prediction Method of the ALADIN consortium (Consortium 1993) called ALADIN/HU. The data for this paper is derived from this model.

6 Forecast and measurement data preparation:

The forecast data is always used from the next day 9:00 a.m. to the day after up to 9:00 a.m.. The rest of the forecast is always skipped and the relevant newer data is used. This simulates the situation in reality where it is possible to adjust the forecast to MAVIR everyday up to 11.30 a.m. for the next day.

The data interval of the forecast data fits to the requirement of MAVIR to provide a power supply forecast in 15 min intervals.

6.1 The measurement data from Mosonmagyaróvár:

As the available forecast data is calculated for a site close to Mosonmagyaróvár wind measurement data from that city has been provided for the same time interval.
The data consists of wind speed and wind direction information from a pole with 18m height. The data is given in 10min intervals.

6.1.1 Data preparation for the comparison:

As the data sets don't match with their intervals both data sets have been averaged to the half and full hour values.

Forecast data:
The xx:00 and the xx:15 values are averaged to the new xx:00 value
The xx:30 and the xx:45 values are averaged to the new xx:30 value

Measurement data:
The xx:00, xx:10 and xx:20 values are averaged to the new xx:00 value
The xx:30, xx:40 and xx:50 values are averaged to the new xx:30 value

The measurement data is from a height of 18m, which doesn't fit to the forecast data at 80m. It is therefore necessary to calculate the 80m values from the given 18m data. This can be done with the following calculation:

$$v_{80} = v_{18} * \frac{\ln(\frac{80}{z_0})}{\ln(\frac{18}{z_0})}$$

with z_0 as roughness length given by OMSZ with 0,05m

6.2 Forecast and Measurement Data comparison:

A first visual comparison of the data:

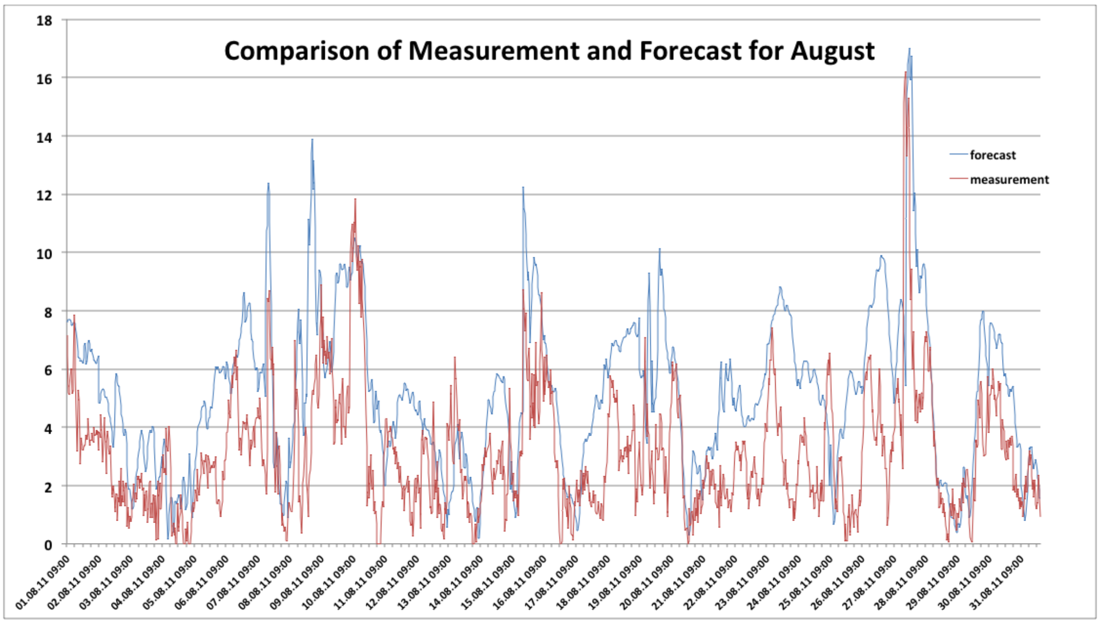


Figure 1: Comparison of measurement and forecast for 80m

For the whole month the comparison shows that the major wind events are forecasted correctly, however the forecast tends to be higher than the reality.

Deviation analyses:

The deviations on half hour averages can be expressed in mean and standard deviation if the errors are normal distributed.
A calculation of these values shows:

Mean: 2,04 m/s
Standard deviation: 2,11 m/s

The mean deviation is a further hint to the visual impression of too high forecast values.

In order to be allowed to use above values the deviations need to be normal distributed. A common method to prove for normal distribution is the Chi Square test

6.3 Explanation of the Chi Square test:

(Timischl 1995)

Chi Square test is a statistical test to prove if a certain sample is normal distributed. It is used for samples bigger than 50. For the test 2 hypothesis are made:

H_0: The sample is normal distributed

H_A: The sample is not normal distributed

Now the decision value needs to be calculated. The sample values need to be combined into classes.

k number of classes

n_j number of sample values in the j –class

v_j expected number of values in the j- class for normal distribution.

To come to the expected values the mean y and the variance have to be pre estimated (taking H_0 as the valid hypothesis).

The following preconditions have to be taken into account for the classification of the sample data:

1. All v_j need to be bigger than 1
2. Maximum 20% of v_j is less than 5

In case these preconditions are not fulfilled the number of classes needs to be reduced.

After having defined the number of classes the expected number of values for each class can be calculated by:

$$v_j = n * \left(G\left(\frac{b-\bar{x}}{s}\right) - G\left(\frac{a-\bar{x}}{s}\right) \right)$$

Equation 1: Expected number of classes

with:

a: upper border of j-class

b: lower border of j-class

n: sample size

G(x) normal distribution function

$\overline{x}$: mean value of samples

s: variance of samples

For the lowest class:

$$\nu_1 = n * G\left(\frac{b-\overline{x}}{s}\right)$$

For the highest class:

$$\nu_1 = n * \left[1 - G\left(\frac{a-\overline{x}}{s}\right)\right]$$

Based on the above the chi square test value is calculated as:

$$X_t^2 = \sum \frac{(sample - \text{expected})^2}{\text{expected}} = \sum_{j=1}^{k} \frac{(n_j - \upsilon_j)^2}{\upsilon_j}$$

Equation 2: Chi Square Test Value

The test value is giving an indication of the deviation of the sample values to the expected values. It needs to be evaluated versus the critical value $c^2_{k-3;1-a}$.

The critical value is depending on the allowed deviation in percent and the degree of freedom. The degree of freedom is the number of classes k-3.
The critical value for different degrees of freedom and deviations is given in statistical tables. For instance the critical value for 25 classes and 1% is 10,2 (Timischl 1995).

Having calculated the test value and found the critical value out of the table a decision can be taken:

$X_t^2 > X^2_{k-3,1-\alpha}$: H_0 has to be withdrawn – significant deviation to normal distribution

$X_t^2 \leq X^2_{k-3,1-\alpha}$: H_0 is valid, no systematic deviation to normal distribution

6.4 Application of the Chi Square Test on the data set:

The forecast data and the measurement data's deviation is expected to be normal distributed. We therefore setup

H_0 hypothesis: Normal distributed versus

H_A hypothesis: Significant deviation from normal distribution

The next step is to put the deviation values into classes. We have 1470 values, which we need to count into classes.

6.4.1 Calculation with 40 classes:

Taking the calculated mean value of $\overline{n}$=2,038 and the standard deviation s=2,109 we can define the expected number of counts according to < Equation 1: Expected number of classes >.

Table 4: Chi Square 40 classes

classes	expected frequency	Frequency
0	0	4
1	0	0
2	0	1
3	0	0
4	1	0
5	1	1
6	2	2
7	3	3
8	5	2
9	8	8
10	13	9
11	19	9
12	28	12
13	38	25
14	50	39
15	64	65
16	78	100
17	92	107
18	103	142
19	112	129
20	117	131
21	117	105
22	112	88
23	103	95
24	92	84
25	78	95
26	64	57
27	50	52
28	38	23
29	28	26
30	19	16
31	13	14
32	8	9
33	5	3
34	3	4
35	2	1
36	1	4
37	1	2
38	0	2
39	0	1
40	0	0

Before we continue we need to verify the preconditions of classifications (see above):

1. All v_j need to be bigger than 1 not ok
2. Maximum 20% of v_j is less than 5 17/40=42,5% not ok

The number of classes needs to be reduced!

6.4.2 Calculation with 25 classes:

Table 5: Chi Square 25 classes

classes	expected frequency	Frequency
0	2	6
1	2	2
2	4	4
3	8	7
4	14	9
5	22	11
6	34	15
7	50	33
8	69	65
9	89	99
10	108	136
11	125	163
12	136	158
13	140	136
14	136	127
15	125	106
16	108	107
17	89	98
18	69	65
19	50	39
20	34	28
21	22	21
22	14	14
23	8	6
24	4	4
25	4	2

We verify again the preconditions of classifications (see above).

1. All v_j need to be bigger than 1 ok
2. Maximum 20% of v_j is less than 5 4/25=16% ok

The number of classes is in conformity with the preconditions!

The picture shows the expected distribution versus the counts within the 25 classes:

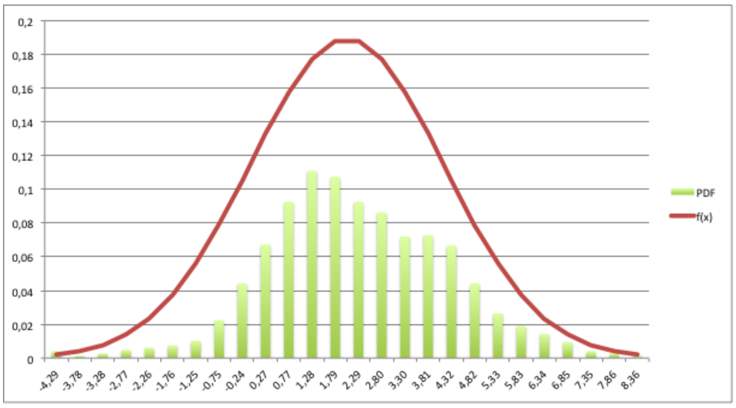


Figure 2: Normal distribution of forecast error at 80m

6.4.3 Comparing the test value with the critical value:

The test value X_t^2 is calculated according the < Equation 2: Chi Square Test Value> using the EXCEL function CHI.SQU:

X_t^2 =4,24

The critical value for 1% with a degree of freedom of 22 (k-3):

$X_{22,0,01}^2$ = 9,54 (Timischl 1995)

Decision:

As the test value X_t^2 is smaller than the critical value $X_{22,0,01}^2$ we can stay with H_0: The sample is normal distributed.

Conclusion:

The deviations are normal distributed. As the mean value is not 0 the forecast data should be corrected.

For the further calculations the data is not corrected.

7 The physical and technical background of wind energy usage:

7.1 Physical background of wind energy usage:

To use wind energy for the production of electrical energy it is necessary to know, what is the theoretical energy content of the wind and how it can be transformed into electrical energy. The power of the wind can be expressed as a function of the air mass transiting the propeller area of the wind power station and the velocity of the air. Splitting the air mass further into the density and the propelled area we get a function which shows the big impact of the velocity to the power input of a wind driven generator:

$$P = \frac{1}{2}\rho_a A_T v^3$$

Equation 3: Wind Power

The factor of wind velocity is the most prominent as it is in a cubic relationship to the power. Therefore a doubling of the wind speed gives 8 times higher power output. The inherent power of the wind cannot be transferred completely into mechanical torque power. The reason is that the wind velocity cannot be completely reduced to zero passing the rotor blades and hence transferring its complete energy into mechanical rotation energy. The relation between the power contained by the wind and the mechanical power on the rotor is called the theoretical power coefficient of the turbine. For the theoretical power coefficient there is a maximum limit called the Betz limit which is 16/27 or about 59%.

$$P_{T\,max} = \frac{1}{2}\rho_a A_T v^3 \frac{16}{27}$$

Equation 4: Maximum Wind Power

The real power curve of a rotor is less than the theoretical maximum and is also depending on the speed of the rotor.

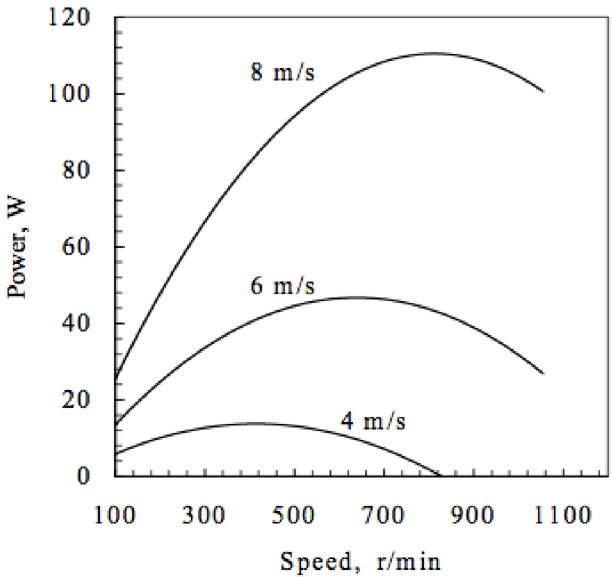


Figure 3: Power versus Rotor Speed

7.2 Wind energy conversion systems

(Mathew 2006)

In order to convert wind energy into electricity or mechanical work there are various possible forms of conversion technologies. The main differences are the orientation of the rotor axis (vertical, horizontal), the size and capacity of the system (a few watt to 5MW) and the location of the system (on shore, off shore).

For an on shore project like the task of this master thesis the typical application is a horizontal axis wind turbine with a capacity of around 2MW per unit. Such a system consists typically of the following components:

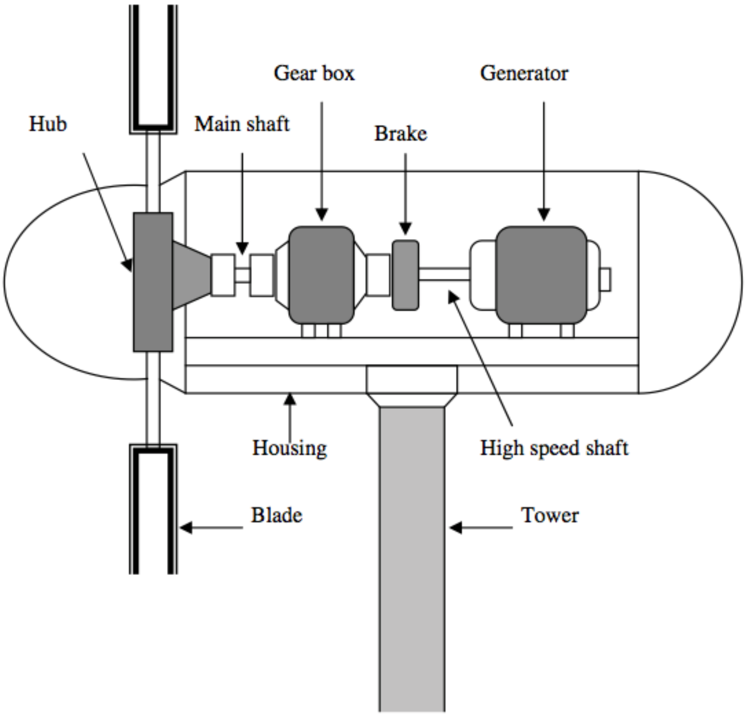


Figure 4: Horizontal Axis Wind Turbine

7.2.1 Rotor:

The basic parameters for the rotor design are:

- Number of blades
- Area of Rotor
- Tip speed
- Air attack angle
- Lift coefficient of the airfoil

The design of the rotor is depending on the requested capacity and on the wind regime in the area of usage. The maximum conversion efficiency, but also the price, size and the robustness of the rotor against heavy weather conditions are critical for the design. The blades are typically made of multi fiberglass eventually with carbon enforcement.

7.2.2 Tower:

The basic function of the tower is to hold the generating unit at the considered height and to allow the unit to follow the direction of the wind in order to get the maximum power. The height of the tower is very important as the wind speed increases with the height. With a simple calculation it is possible to find the wind speed at the hub height of a tower, knowing the wind speed at any other height:

$$\frac{v_{z_r}}{v_z} = \frac{\ln\left(\frac{z_r}{z_0}\right)}{\ln\left(\frac{z}{z_0}\right)}$$

Equation 5: wind speed conversion

z and z_r are the different heights and z_0 is the so called roughness height off the terrain (Typical 0,04 for grass lands).
Of course there is a higher cost for bigger towers not only in material and construction but also for transportation. The height can also be limited due to local laws.

7.2.3 Gearbox:

The typical speed of a generator, depending on the number of poles, is 1000 to 1500 r/min where the typical turning of the rotor is only 30 to 50 r/min. In order to convert these two velocities into each other a gearbox is needed. The gearbox however is a major source of losses due to friction and temperature increase. Also the maintenance of the gearbox is more difficult and expensive. By using generators with higher number of poles it is possible to omit the gearbox.

7.2.4 Safety brakes:

As the conversion unit is not able to operate at very high wind speed it is necessary to be able to bring the system to a complete stop in case of high wind speed. For safety reasons typically two independent brakes systems are installed.

7.2.5 Generator:

In most of the generation-units asynchronous generators are used. The operating speed of the generator is depending on the number of poles. A typical 4-pole application has a synchronous speed of 1500 r/min. Driving the unit with speeds higher than the synchronous speed it will act as a generator. This speed is only varying slightly when the torque from the rotor increases which makes the system very robust. To start the generator however, an external excitation is needed, which is not a problem for grid-operated designs. During wind speeds less than the minimum speed the generator is disconnected from the grid to avoid that it is behaving like a motor. As the generation of electricity in terms of waveform and frequency is depending on the operating speed of the generator, the resulting electricity cannot be fed directly into the grid. It needs to be rectified and converted by an inverter.

7.3 Current wind turbine market and suppliers

(Innovation 2009):

The market of wind turbines has been driving mainly into bigger and bigger designs as the larger sizes are considered to be more cost effective. Especially for off shore demand the increase in size will continue for the next years. For on shore applications the sizes are more limited due to local laws and also transportation bottlenecks and costs. The following picture gives an impression of the increase of size during the years.

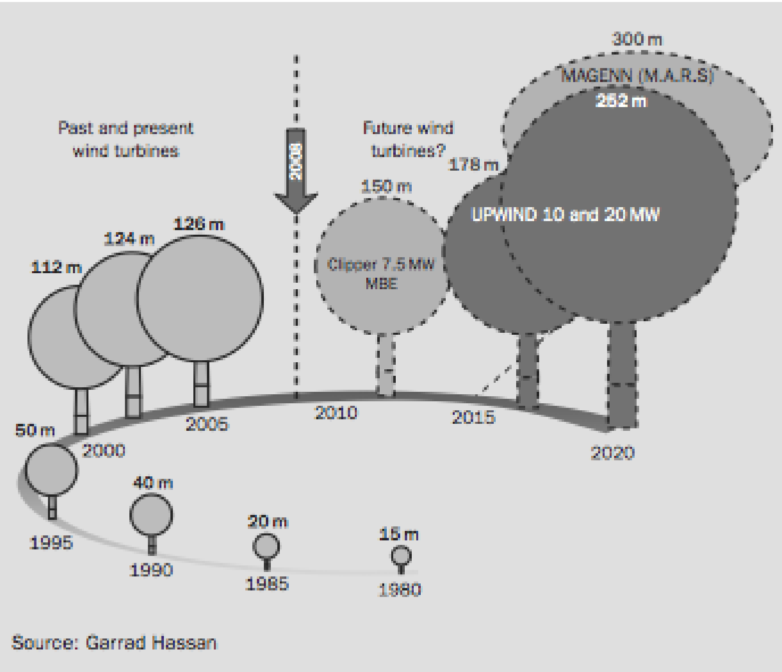


Figure 5: Development of Turbine Size

In terms of global market share (2008) the next table shows the 10 biggest suppliers of wind turbines:

Table 6: Major Wind Turbine Manufacturers

		Share (%)	Model	Drive train	Power rating (kW)	Diameter (m)	Tip speed (m/s)	Power conversion
1	Vestas	22.8	V90	Geared	3000	90	87	Asynchronous
2	GE Energy	16.6	2.5XL	Geared	2500	100	86	PMG converter
3	Gamesa	15.4	G90	Geared	2000	90	90	DFIG
4	Enercon	14.0	E82	Direct	2000	82	84	Synchronous
5	Suzlon	10.5	S88	Geared	2100	88	71	Asynchronous
6	Siemens	7.1	3.6 SWT	Geared	3600	107	73	Asynchronous
7	Acciona	4.4	AW-119/3000	Geared	3000	116	74.7	DFIG
8	Goldwind	4.2	REpower750	Geared	750	48	58	Induction
9	Nordex	3.4	N100	Geared	2500	99.8	78	DFIG
10	Sinovel	3.4	1500 (Windtec)	Geared	1500	70		

Source: Garrad Hassan

8 The power model for this paper:

The project consists of two groups of wind turbines with a total installed power of 57 MW. The turbines will be located in the area of Mosonmagyaróvár within grass-land.

Very close nearby (500m – 3 km) is a 120kV and a 400kV power line located. It is planned to connect the wind farm to the 120kV power line.

The produced electrical energy will be sold to the Hungarian grid operator MAVIR with whom a power purchase agreement will be established. The achievement of a power purchase agreement is subject to a tender with a limited available capacity.

The effective price for the energy sold (Feed in Tariff) is specified within the tender and is guaranteed for 12 years. The price is also yearly adapted according to the inflation rate in Hungary.

A rolling forecast of the prospective power supply to the grid needs to be sent to the grid operator.

8.1 Technical data:

Type of wind turbines:	Enercon E101
Number of installations:	19
Rated power of one turbine:	3 MW
Total power installed:	57 MW
Tower height:	130m

8.1.1 Technical data of the selected turbine:

(ENERCON 2010):

Table 7: Technical Data E101

Rated power:	3,000 kW
Rotor diameter:	101 m
Hub height:	99 m / 135 m
Wind zone (DiBt):	WZ III
Wind class (IEC):	IEC/NVN IIA
Turbine concept:	Gearless, variable speed, single blade adjustment
Rotor	
Type:	Upwind rotor with active pitch control
Rotational direction:	Clockwise
No. of blades:	3
Swept area:	8,012 m²
Blade material:	GRP (epoxy resin); integrated lightning protection
Rotational speed:	variable, 4 - 14.5 rpm
Pitch control:	ENERCON single blade pitch system, one independent pitch system per rotor blade with allocated emergency supply
Drive train with generator	
Hub:	Rigid
Main bearing:	Double-row tapered / cylindrical roller bearings
Generator:	ENERCON direct-drive annular generator
Grid feeding:	ENERCON inverter
Brake systems:	3 independent pitch control systems with emergency power supply, rotor brake, rotor lock
Yaw control:	Active via adjustment gears, load-dependent damping
Cut-out wind speed:	28 - 34 m/s (with ENERCON storm control)
Remote monitoring:	ENERCON SCADA

8.1.2 The Nacelle of the selected turbine:

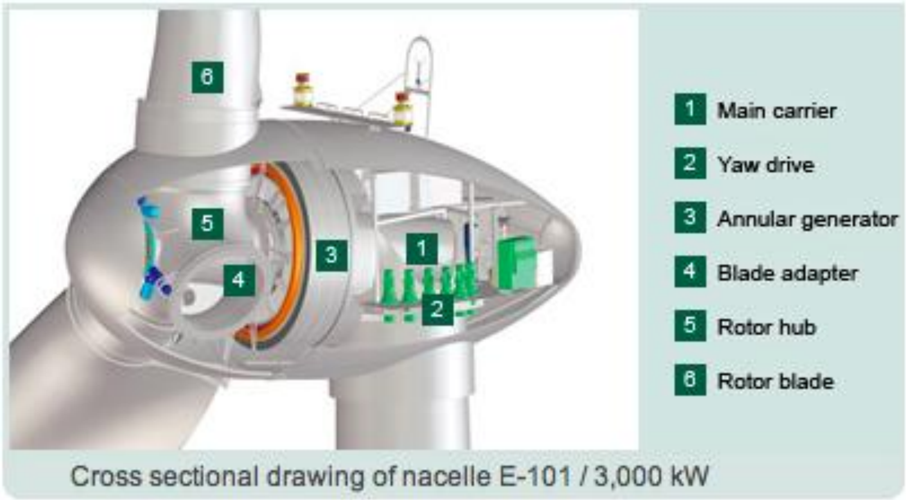


Figure 6: The Nacelle of E101

8.1.3 Power curve of the turbine

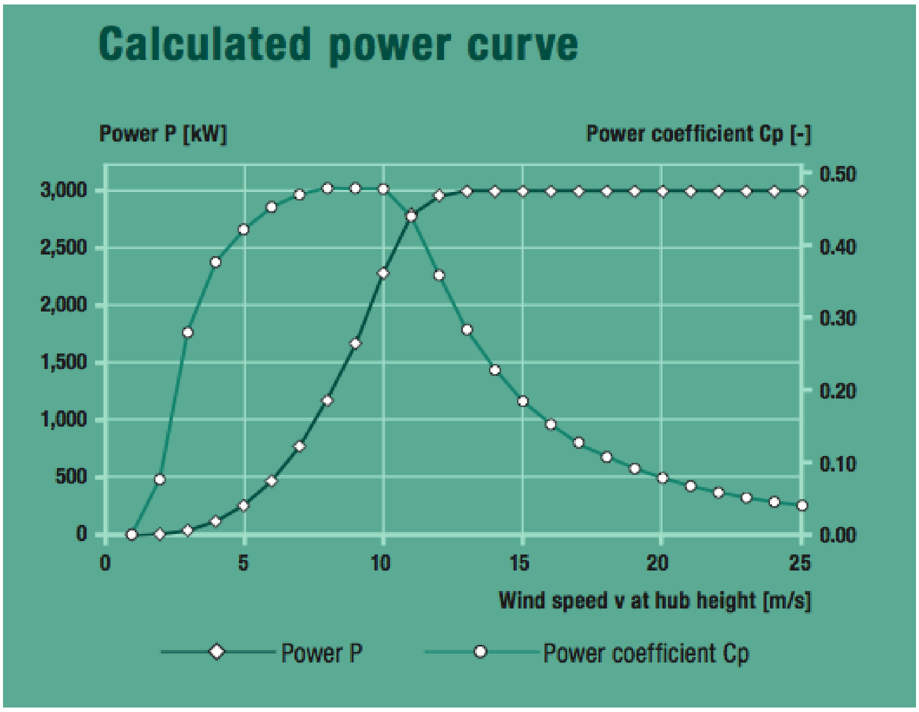


Figure 7: The Power Curve of E101

8.2 Energy Production:

In order to come from the given wind speeds to the energy production the power curve of the generator is used. This graph gives for different wind speeds the resulting energy production. Therefore for every point in time of the wind data an available power can be calculated. For the purpose of this paper we assume the power always as constant within the intervals of 15min, which need to be forecasted to MAVIR. The forecast data comes already in 15min rows. The measurement data with its 10min rows needs again to be averaged to the 15min grid.

8.2.1 The 15min averages of the measurement data:

$$\overline{v}_{0-15} = \frac{4v_0 + 7v_{10} + v_{20}}{12}$$

$$\overline{v}_{15-30} = \frac{v_{10} + 7v_{20} + 4v_{30}}{12}$$

$$\overline{v}_{30-45} = \frac{4v_{30} + 7v_{40} + v_{50}}{12}$$

$$\overline{v}_{45-60} = \frac{v_{40} + 7v_{50} + 4v_{60}}{12}$$

8.2.2 The correction of the height:

Both data is of different heights than the hub height of the Enercon 101 with 135m. Therefore both data needs to be corrected to this height. With above mentioned formula <Equation 5: wind speed >

$$\frac{v_{z_r}}{v_z} = \frac{\ln\left(\frac{z_r}{z_0}\right)}{\ln\left(\frac{z}{z_0}\right)}$$

this correction can be done. The roughness length for the site is 0,05m.

The next picture shows the two data sets for 135m.

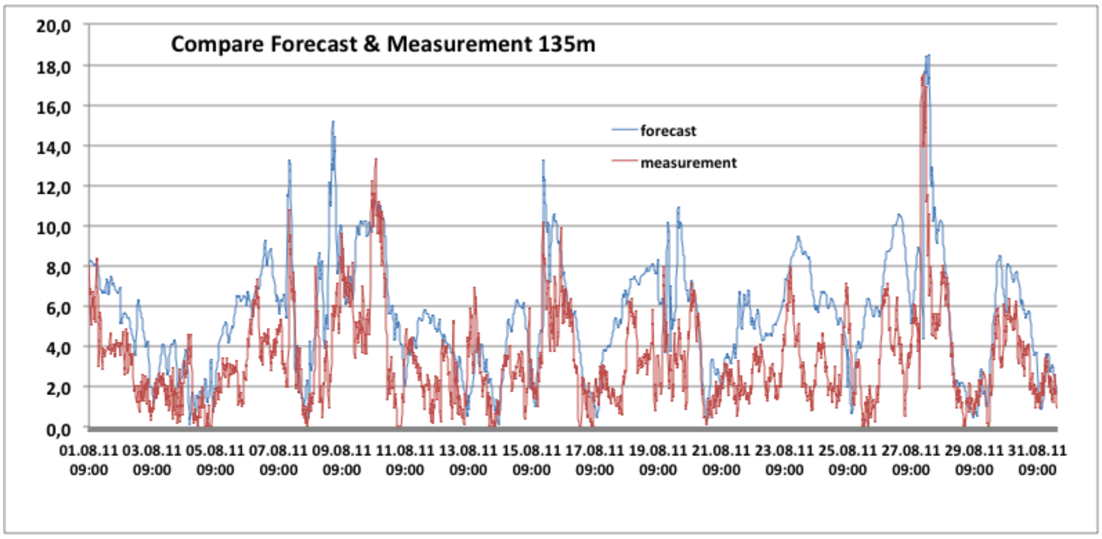


Figure 8: Comparison of forecast and measurement at 135m

8.2.3 Deviation analyses:

The deviations on 135m 15min averages can be expressed in mean and standard deviation if the errors are normal distributed.
A calculation of these values shows:

Mean: 2,2 m/s
Standard deviation: 2,28 m/s

This is an increase in both mean and standard deviation.

8.3 The power output of a single turbine:

Using the power curve of the turbine both data sets can be transferred into power outputs for every 15 minutes.

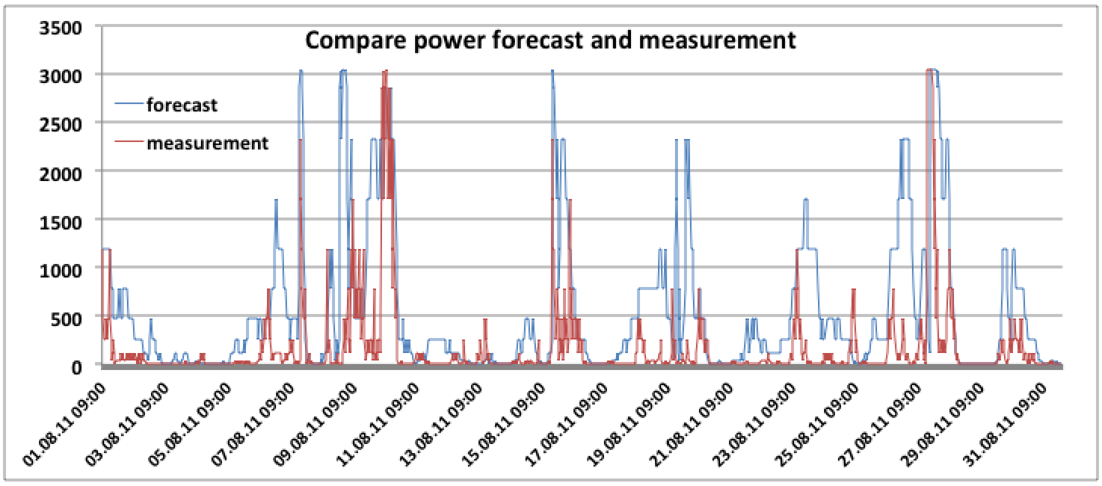


Figure 9: Comparison of forecasted and measured power output

Deviation analyses:

The deviations on 135m 15min averages can be expressed in mean and standard deviation if the errors are normal distributed.
A calculation of these values shows:

Mean:	373 kW
Standard deviation:	615 kW

8.4 Power production of the total wind park

The output of the single turbine needs to be multiplied by the number of turbines installed. The total output needs to be reduced due to the fact that the turbines in the park have some shadowing effects to each other. For this calculation a wind park efficiency of 90% is taken into account.

The wind park consists of 19 E101 turbines. Therefore the power output needs to be multiplied by 19 and by the efficiency of 0,9.

With this data the 15min power averages can be calculated out of the previous data and the forecast can be sent to MAVIR.

9 The forecast system of the Hungarian grid operator MAVIR

(M. M.-i. MAVIR 2011):

The Hungarian grid operator MAVIR is the take over partner for the delivery of electricity out of wind energy into the Hungarian grid. He is also responsible for the grid balancing and for the operation of the forecast system with the producers. For that reason MAVIR has put on its homepage an information system for the forecast handling. Also on the homepage you can find links to relevant laws and decrees and user manuals for the forecast system (only in Hungarian language)[2].

9.1 The KAM system:

The core of the forecast system is an XML based program, which can be entered on the homepage with user ID and password. (KAM system) There is a detailed description of the program (MEK rendszer Felhasználói kézikönyv) also only in Hungarian language.

[2] The homepage of MAVIR: www.mavir.hu

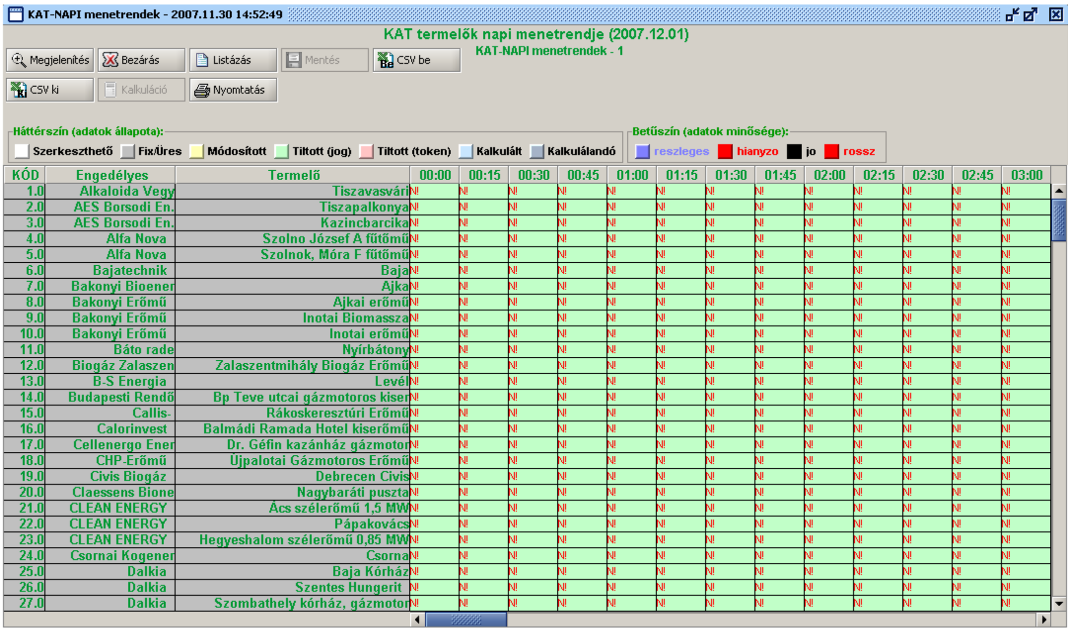


Figure 10: MAVIR KAM System Entry Page

Within this program the forecasts of producers and customers are processed and in different menus published.

The most important tools for the producers however are 4 Excel files with macros, which can be downloaded from the homepage:

1. Prognózis_sablon_201102-201201_mod.xls
2. KAT_sablon_Havi.xls
3. KAT_sablon_Heti.xls
4. KAT_sablon_Napi.xls

In order to use the Excel sheets an additional macro library needs to be uploaded on the PC:

OcxRegister.bat

Mscomct2.ocx

Again the user manual for these sheets is available only in Hungarian language, however within the Macro English names can be found.

9.1.1 Rolling Forecast:

According the previous mentioned laws every month at the 7th working day a rolling forecast for the next 12 months needs to be provided. Therefore the file "Prognózis_sablon_xxxxxx-xxxxxx_mod.xls" is used.

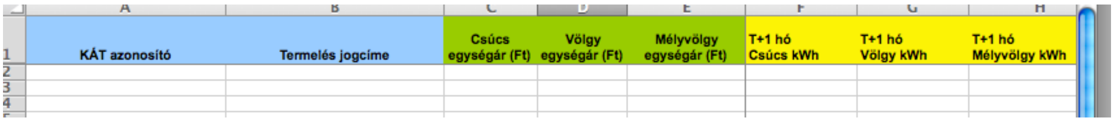


Figure 11: MAVIR Excel file for the running forecast

A producer code (KÁT azonosító) needs to be entered for identification. This code is distributed at the first registration to the system.
Besides that the renewable energy type (acc. the laws definition) needs to be specified. (for example: $4(2) B for power stations <20MW)

The next columns define the Feed in Tariff for the 3 different tariff zones (peak, low, deep)- (csúcs, völgy, mélyvölgy) in Forint/kWh.
The following columns are for the forecast (kWh/month) split into tariff zones. (T+1 hó = next month, T+2hó,…)

This file serves as orientation and allocation for the grid operator and is sent as Excel file to MAVIR.

9.1.2 Monthly forecast:

This has to be given also at the 7th working day of the month for the following month. The file to be used is the KAT_sablon_havi.xls.Opening the file you get the main menu:

Figure 12: Main Menu of MAVIR Excel File

Figure 13: Start date selection

With New schedule date the starting date of the forecast is entered:

In the menu "Edit schedule" you find a timeline for one month with lines for every 15 minutes. With "Add time series" a new series can be added.

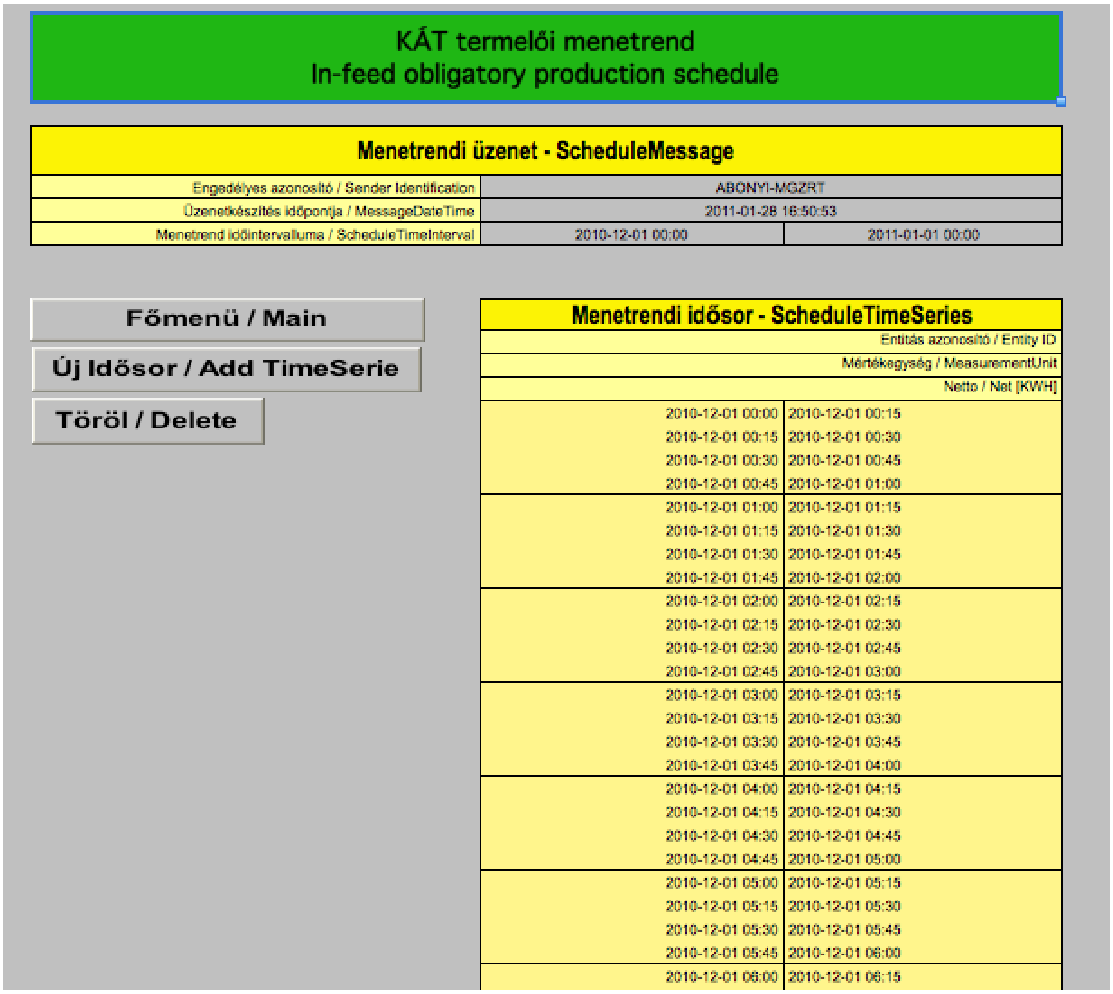


Figure 14: The Schedule Time Series Excel Sheet

Back in the main menu after input of the senders ID the data can be verified "Check Data" and then an XML file can be created.

When entering the sender ID also the directory for saving the XML file can be defined.

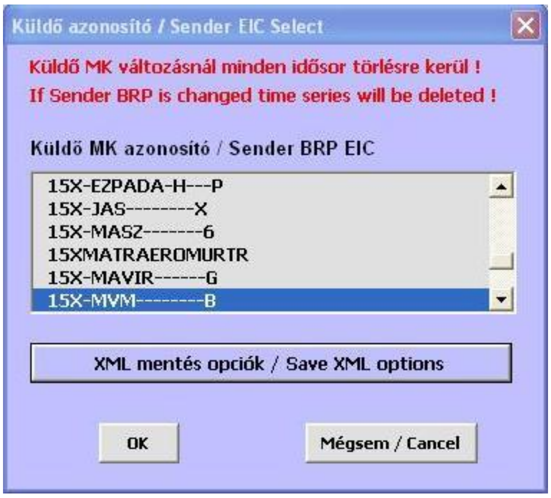


Figure 16: Selection of Senders ID

Figure 15: Selection of Storage Path

9.1.3 Weekly forecast:

According to the law at the 3rd day of the week up to 11.30 a weekly forecast for the next week can be given. This is done, by using the file: KAT_sablon_heti.xls (According to MAVIR (Toth 2011) seldom used)
The file creation is the same as the monthly one.

9.1.4 Daily forecast:

According to the law every day up to 11.30 the daily forecast for any of the following days of the month can be changed. From the 8th working day onwards a window for the 1st calendar day to the 8th working day is available as well.
For that forecast the file KAT-sablon_napi.xls is used.
The file creation is the same as the monthly one.

After login into the KAM system of MAVIR the files can be uploaded or they also can be sent by email.

9.2 Grid-balancing fee:

For wind power stations the law regulates the payment of a grid balance fee in case the actual delivered energy (one days summary) is 50% more or less than the indicated forecast. For every kWh above and below the 50% border a fee of 5Ft has to be paid.

According to MAVIR (Toth 2011) for example a wind park with 24MW had to pay for December 2010 a fee for 200.000 kWh while the total delivered energy was 6 GWh. This is equivalent to a forecast error of 3,5%, or 1 Mio Ft fee for the month December.

9.3 Group forecast:

The law offers the opportunity to calculate the forecast of more producers together into one group forecast. In this case still every producer needs to make his own forecast, but the grid balance fee is calculated by the combined forecast. The producers together are responsible for the payment of the grid-balancing fee, which is invoiced to a nominated representative of the group. According to MAVIR (Toth 2011) various such groups exist and there are also groups of wind power stations working.

Also producer of different renewable energy types can form a group. In that case however the tolerance for the forecast exceeding is the most rigorous of the different laws (mostly +/-5%) for the whole group. For that reason it doesn't make to much sense for wind power stations to join a group of other energy producers. Wind farms in different areas for sure have a benefit by joining a group.

9.4 General remarks:

By changing the law end of 2008 the very restrictive regulations for the grid-balancing fee have been eased. Therefore the number and the value of paid fees have been reduced. The fee now only has to be paid for the value exceeding the tolerance level – before that the whole delivery of every calculation period where there was one exceeding value was punished with the fee. Furthermore the calculation period for wind power stations has been changed from 15 minutes to full daily quantities.
The income for MAVIR due to the fees however is covering only about 5% of the cost of the net balancing.(MAVIR, KAT tanulmány 2010)

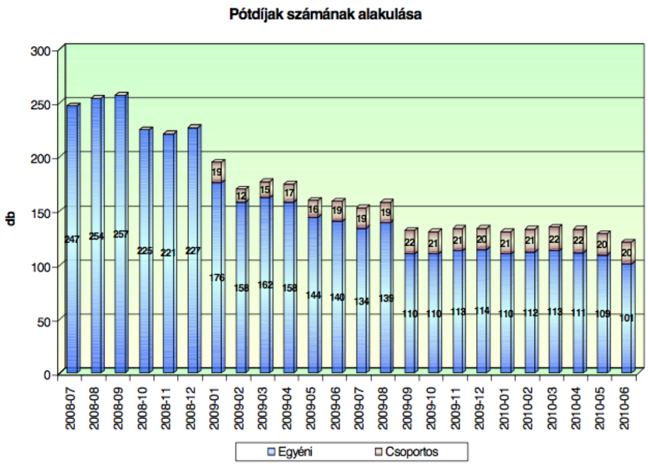


Figure 17: Number of grid balance fees invoiced (single and group)

10 Introducing the forecast data into the MAVIR Excel file

As we are using daily forecast data the so-called “CAT sablon napi” needs to be used. Having introduced the data into the Excel file with the menu point Balance the power production of each day can be seen in an overview:

Partner azonosító / Party ID	15X-K-MOV-R-H1-U	Vissza / Back
Dátum / Schedule Date	2011-08-06	

Period	Sum MW	Period	Sum MW	Period	Sum MW	Period	Sum MW
00:00	4,412	06:00	8,191	12:00	4,412	18:00	8,191
00:15	4,412	06:15	8,191	12:15	4,412	18:15	13,509
00:30	8,191	06:30	8,191	12:30	4,412	18:30	13,509
00:45	8,191	06:45	8,191	12:45	4,412	18:45	13,509
01:00	8,191	07:00	8,191	13:00	4,412	19:00	13,509
01:15	8,191	07:15	8,191	13:15	4,412	19:15	13,509
01:30	8,191	07:30	8,191	13:30	4,412	19:30	13,509
01:45	8,191	07:45	8,191	13:45	8,191	19:45	13,509
02:00	8,191	08:00	8,191	14:00	8,191	20:00	13,509
02:15	8,191	08:15	8,191	14:15	8,191	20:15	13,509
02:30	8,191	08:30	8,191	14:30	8,191	20:30	13,509
02:45	8,191	08:45	4,412	14:45	8,191	20:45	13,509
03:00	8,191	09:00	8,191	15:00	8,191	21:00	20,520
03:15	8,191	09:15	8,191	15:15	8,191	21:15	20,520
03:30	8,191	09:30	8,191	15:30	8,191	21:30	20,520
03:45	8,191	09:45	8,191	15:45	8,191	21:45	20,520
04:00	8,191	10:00	8,191	16:00	8,191	22:00	20,520
04:15	8,191	10:15	8,191	16:15	8,191	22:15	29,241
04:30	8,191	10:30	8,191	16:30	8,191	22:30	29,241
04:45	8,191	10:45	8,191	16:45	8,191	22:45	29,241
05:00	8,191	11:00	8,191	17:00	8,191	23:00	20,520
05:15	8,191	11:15	8,191	17:15	8,191	23:15	20,520
05:30	8,191	11:30	4,412	17:30	8,191	23:30	20,520
05:45	8,191	11:45	4,412	17:45	8,191	23:45	20,520
							0,000
							0,000
							0,000
							0,000

Total :	243,39713	MWh

Figure 18: The forecast data within the MAVIR Excel file

The picture shows the overview of August 6th.

The same procedure (only for the purpose of this paper) can be done with the measurement data. Then the daily power production forecast and measured can be compared.

Partner azonosító / Party ID	15X-K-MOV-R-H1-U	Vissza / Back
Dátum / Schedule Date	2011-08-06	

Period	Sum MW	Period	Sum MW	Period	Sum MW	Period	Sum MW
00:00	0,051	06:00	0,000	12:00	2,018	18:00	4,412
00:15	0,051	06:15	0,051	12:15	2,018	18:15	2,018
00:30	0,051	06:30	0,051	12:30	2,018	18:30	0,633
00:45	0,633	06:45	0,051	12:45	4,412	18:45	0,633
01:00	0,633	07:00	0,051	13:00	4,412	19:00	0,633
01:15	0,051	07:15	0,051	13:15	8,191	19:15	0,633
01:30	0,051	07:30	0,051	13:30	8,191	19:30	0,633
01:45	0,000	07:45	0,051	13:45	8,191	19:45	2,018
02:00	0,000	08:00	0,633	14:00	4,412	20:00	0,633
02:15	0,000	08:15	0,633	14:15	8,191	20:15	0,633
02:30	0,000	08:30	0,633	14:30	8,191	20:30	0,633
02:45	0,051	08:45	0,633	14:45	8,191	20:45	0,633
03:00	0,000	09:00	0,633	15:00	8,191	21:00	0,633
03:15	0,000	09:15	0,633	15:15	8,191	21:15	2,018
03:30	0,000	09:30	0,633	15:30	8,191	21:30	2,018
03:45	0,000	09:45	2,018	15:45	13,509	21:45	2,018
04:00	0,000	10:00	2,018	16:00	8,191	22:00	2,018
04:15	0,000	10:15	0,633	16:15	8,191	22:15	2,018
04:30	0,000	10:30	2,018	16:30	13,509	22:30	2,018
04:45	0,000	10:45	2,018	16:45	8,191	22:45	2,018
05:00	0,000	11:00	4,412	17:00	8,191	23:00	2,018
05:15	0,000	11:15	4,412	17:15	4,412	23:15	2,018
05:30	0,000	11:30	2,018	17:30	8,191	23:30	2,018
05:45	0,000	11:45	2,018	17:45	8,191	23:45	2,018
							0,000
							0,000
							0,000
							0,000

Total :	59,61915	MWh

Figure 19: The measurement data within the MAVIR Excel file

The picture shows the measured production for the same day out of the MAVIR EXCEL sheet.

10.1 Evaluation of forecast error:

To come to the base for calculating the penalties, a daily forecast-error needs to be calculated. Out of the sample pictures we can see already the daily energy production of the park including the park efficiency for 6.8.2011.

The deviation between forecast and measurement is 76% for this day's production.

10.2 Calculation of fees to be paid

According to the law (see above) a penalty (grid-balancing fee) of HUF 5,00 needs to be paid for all deviating kWh beyond the +/-50% margin.

For the example of 6.8.2011 this would be 62.079 kWh beyond the 50% level of 121.699 kWh.

Based on an exchange rate of 315 HUF/EUR for this day a penalty of 1.444€ needs to be paid.

For total August the following table shows the result:

Table 8: Daily Grid Balance Fee to be paid

	Forecast	Measurement	delta (%)	50% (MWh)	deviation > 50% (MWh)	penalty HUF	penalty EUR
	Values						
Row Labels	Sum of energy (MWh)	Sum of energy (MWh)2					
01.08.11	220,710	67,002	-70%	110,355	43,353	216.764	€ 1.008
02.08.11	151,459	21,576	-86%	75,729	54,154	270.768	€ 1.259
03.08.11	24,342	0,475	-98%	12,171	11,696	58.482	€ 272
04.08.11	8,058	4,681	-42%	4,029	0,000	-	€ 0
05.08.11	38,052	3,061	-92%	19,026	15,965	79.825	€ 371
06.08.11	243,397	59,619	-76%	121,699	62,079	310.397	€ 1.444
07.08.11	386,152	98,312	-75%	193,076	94,764	473.820	€ 2.204
08.08.11	151,553	19,246	-87%	75,777	56,530	282.652	€ 1.315
09.08.11	615,600	182,837	-70%	307,800	124,963	624.813	€ 2.906
10.08.11	730,358	442,847	-39%	365,179	0,000	-	€ 0
11.08.11	55,549	12,415	-78%	27,775	15,360	76.800	€ 357
12.08.11	60,867	9,089	-85%	30,434	21,345	106.725	€ 496
13.08.11	9,097	26,415	190%	4,549	12,769	63.847	€ 297
14.08.11	53,215	4,660	-91%	26,608	21,948	109.739	€ 510
15.08.11	265,289	95,807	-64%	132,645	36,838	184.188	€ 857
16.08.11	341,320	111,697	-67%	170,660	58,963	294.815	€ 1.371
17.08.11	13,992	0,808	-94%	6,996	6,188	30.940	€ 144
18.08.11	237,258	38,180	-84%	118,629	80,449	402.245	€ 1.871
19.08.11	296,151	31,785	-89%	148,075	116,291	581.453	€ 2.704
20.08.11	251,413	53,621	-79%	125,706	72,085	360.425	€ 1.676
21.08.11	27,082	1,120	-96%	13,541	12,421	62.105	€ 289
22.08.11	89,531	6,229	-93%	44,766	38,537	192.685	€ 896
23.08.11	355,146	75,326	-79%	177,573	102,247	511.237	€ 2.378
24.08.11	236,036	7,956	-97%	118,018	110,062	550.310	€ 2.560
25.08.11	56,139	37,889	-33%	28,070	0,000	-	€ 0
26.08.11	401,299	64,488	-84%	200,649	136,161	680.804	€ 3.167
27.08.11	631,969	364,345	-42%	315,984	0,000	-	€ 0
28.08.11	426,893	108,311	-75%	213,446	105,135	525.675	€ 2.445
29.08.11	7,105	1,603	-77%	3,553	1,949	9.747	€ 45
30.08.11	303,016	72,149	-76%	151,508	79,359	396.795	€ 1.846
31.08.11	25,569	3,886	-85%	12,784	8,898	44.492	€ 207
Grand Total	**6713,618**	**2027,436**	**-70%**	**3356,809**	**1329,373**	**6.646.866**	**€ 30.916**

Overall result:

Taking the uncorrected forecast into account the overall grid balance fee to be paid for August 2011 would be 30.916€. The percentage of penalty MWh versus produced MWh for this sample month is: 66%

11 Financial impact on the project:

In order to evaluate the financial impact on the project with an economic model the Cash Flow situation including earnings from sales of energy and cost of operation needs to be simulated. For a simulation of the economic situation it is necessary to build a model with generation over one full year and expand it to the life-time of the project. As a starting point the grid balance fee is set to zero in order to know the results without the impact of this penalty.

Also the wind situation over a full year needs to be estimated. Besides the detailed measurement data from August also some more general data about the wind situation in Mosonmagyaróvár is available:

11.1 Wind regime at the site:

As for the region of Mosonmagyaróvár no monthly wind speed data was available I considered the same wind situation as in Parndorf. This assumption was justified by the management of Energiepark Bruck an der Leitha. However there was some detailed wind speed distribution data available for Mosonmagyaróvár for the height of 65m and 113m (Wendl 2009). This data was used mainly to find a matching Weibull distribution.

11.1.1 Wind profile for Mosonmagyaróvár:

(Wendl 2009)

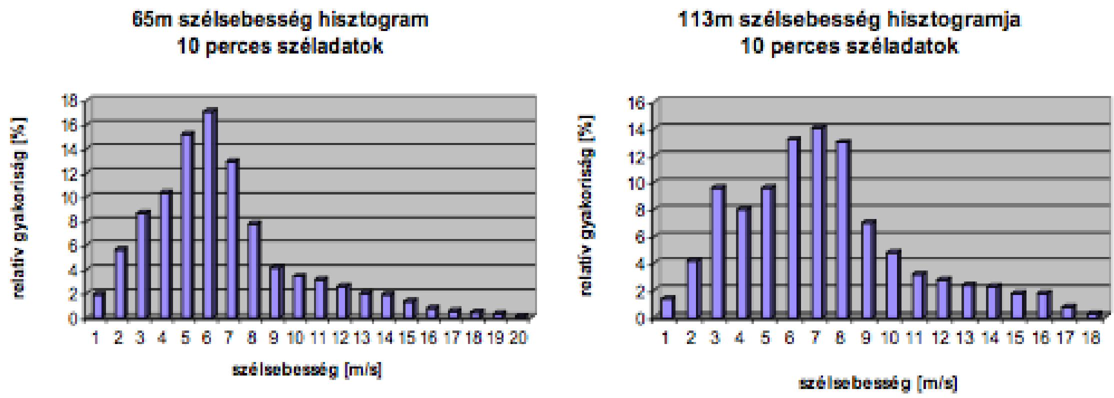


Figure 20: Wind Speed Distribution Mosonmagyaróvár at 65m and 113m

11.1.2 Establishing the Weibull Distribution:

On a graphical basis a matching Weibull distribution has been generated, of which the shape factor has been used for the further calculations while the scale factor will be deducted from the mean wind speed:

Weibull distribution for 65m:

Shape: 2,2

Scale: 6,8

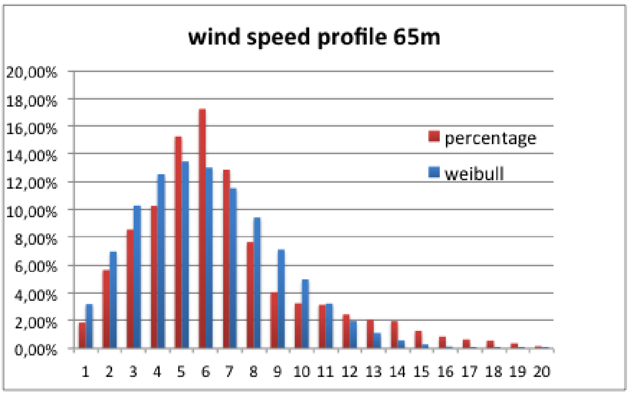


Figure 21: Wind Speed Profile and Weibull Approximation 65m

Weibull distribution for 113m:

Shape: k=2,4

Scale: c=7,7

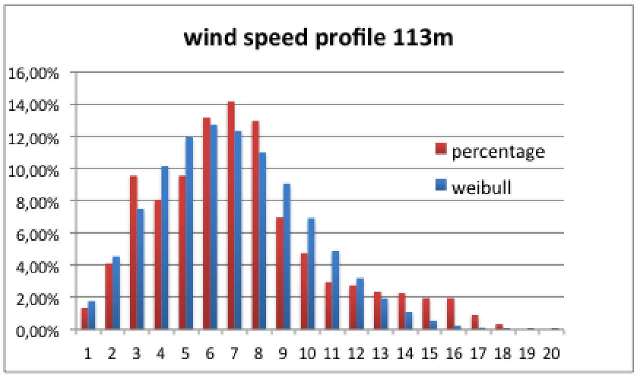


Figure 22: Wind Speed Profile and Weibull Approximation 113m

The formula used for the Weibull distribution is the following:

$$f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} e^{\left[-\left(\frac{v}{c}\right)^{k}\right]}$$

Equation 6: Weibull Distribution

k is the shape parameter and c the scale parameter.

For the further calculations the shape parameter is considered to be 2,4 out of the 113m Weibull Distribution.

11.1.3 Average monthly wind speed for Bruck an der Leitha:

For the wind park of Bruck an der Leitha there was monthly average wind data available for the height of 70m (Pschill 2011):

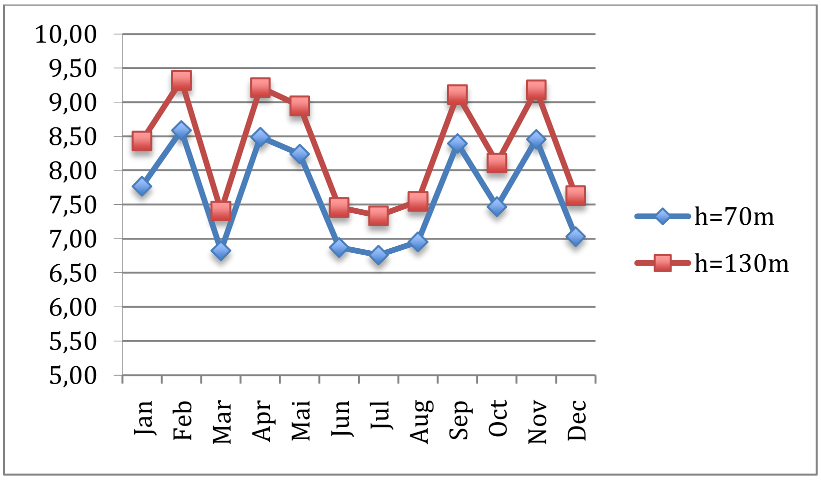


Figure 23: Average monthly wind speed in Bruck an der Leitha

As for our further calculations the wind speed in 130m is necessary, this was calculated by using the following formula <Equation 5: wind speed >:

$$\left(\frac{v}{v_0}\right) = \frac{\ln\left(\frac{H}{z}\right)}{\ln\left(\frac{H_0}{z}\right)}$$

H_0 = 70m and H = 130m. For the roughness length z=0,05m was considered according to MAVIR. See also the following table (Masters 2004):

Table 9: Typical roughness lengths

Roughness Class	Description	Roughness Length $z(m)$
0	Water surface	0.0002
1	Open areas with a few windbreaks	0.03
2	Farm land with some windbreaks more than 1 km apart	0.1
3	Urban districts and farm land with many windbreaks	0.4
4	Dense urban or forest	1.6

Having calculated the average wind speed at 130m for the whole year it is possible to calculate the Weibull scale parameter out of the average wind speed (Masters 2004):

$$c = \frac{2}{\sqrt{\pi}}\bar{v} \cong 1.128\bar{v}$$

Equation 7: Weibull Scale Parameter

As result we get for every month according to the average wind speed in 130m a Weibull wind speed distribution with the shape parameter k=2,4 and the scale parameter c according the average wind speed. As example here the result for January:

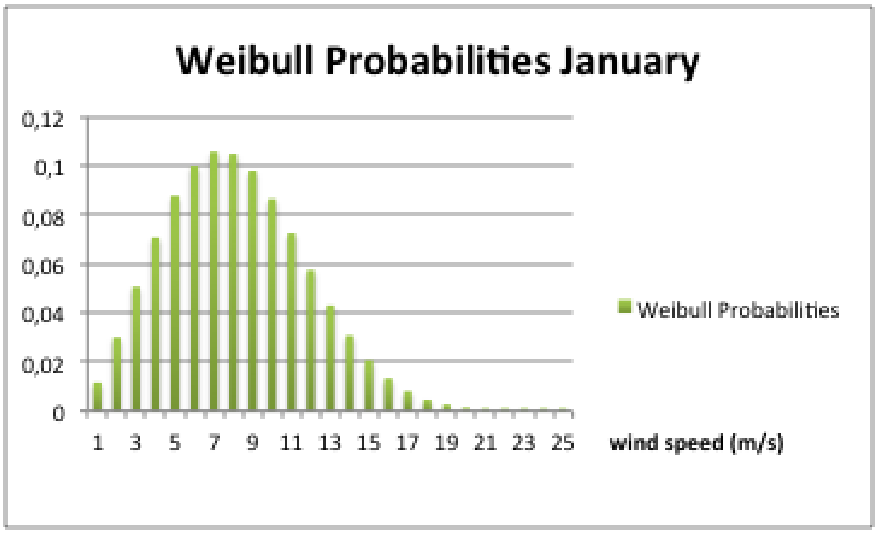


Figure 24: Average wind speed in January Weibull distributed

11.2 The resulting power generation:

11.2.1 The Power Curve:

In order to come from the wind speed distribution to the resulting energy output we need to apply the power curve of the wind turbine, which is part of the specification (ENERCON 2010):

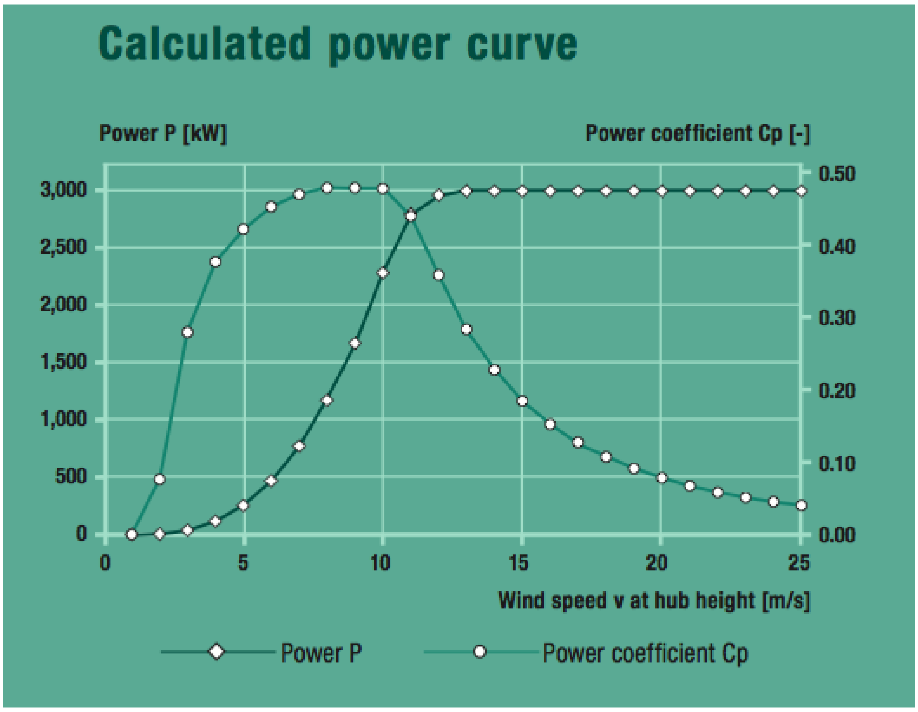


Figure 25: Enercon E101 Power Curve

11.2.2 The Power Output Weibull Distributed:

By combining the wind speed distribution with the power curve and multiplying with the hours per month we can calculate the resulting energy per month (Robert Gasch 2005):

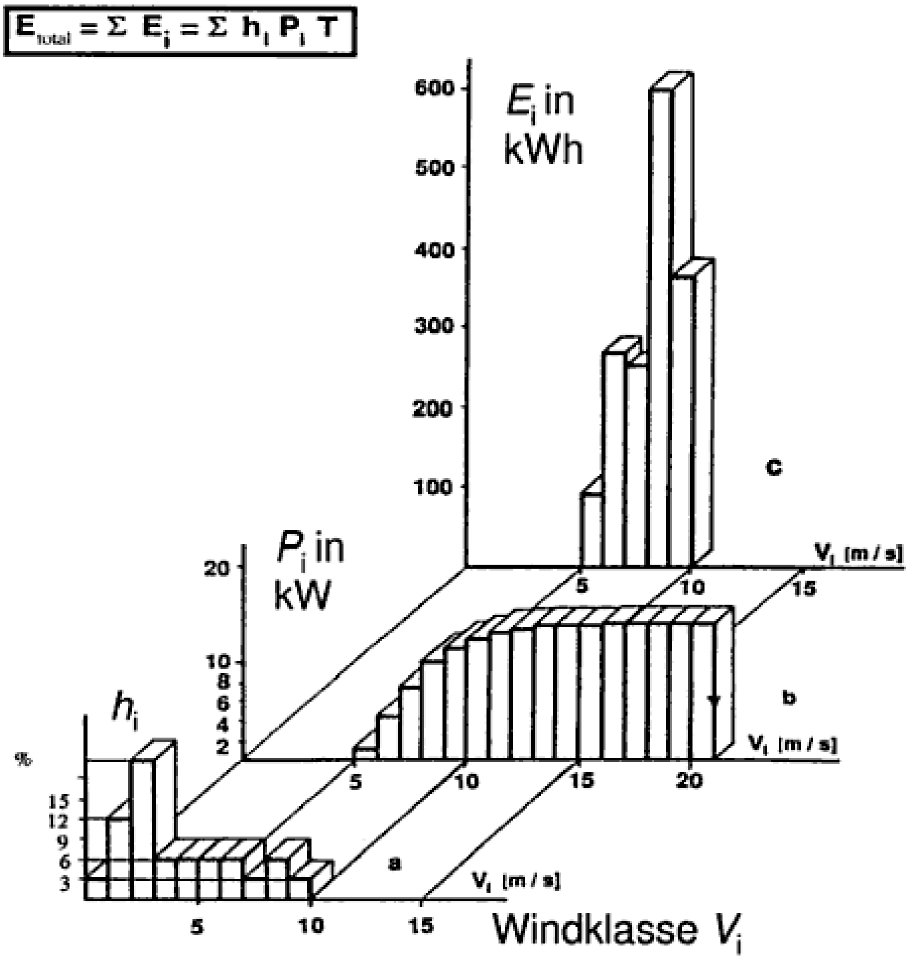


Figure 26: Converting Wind Speed Distribution into Power Production

As result we get the produced energy for the respective month at certain wind speeds, Weibull distributed:

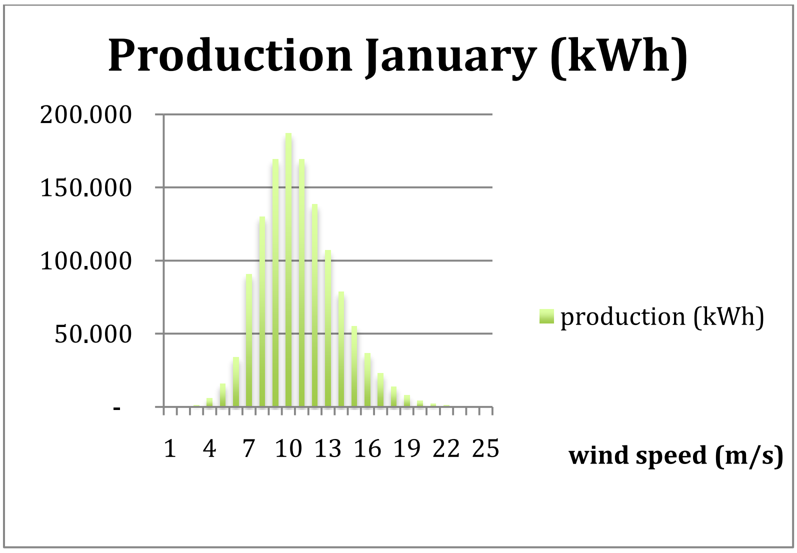


Figure 27: Resulting January Power Production Weibull distributed

11.2.3 The Power Output Summary per Turbine:

Summing up all the generated energy we get the monthly production estimate. By doing so for all months of the year we have the basis generation output for our capacity and economics calculation. In order to be on the save side regarding the wind data, which is only from one year, we reduce the calculated power to 75% and take a turbine availability of 97% into account:

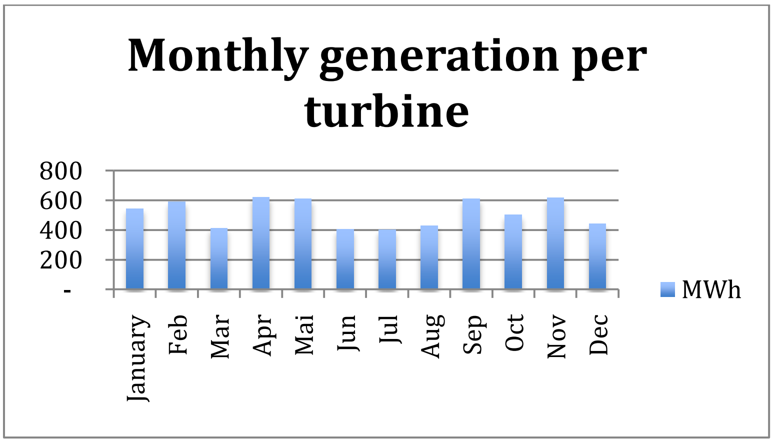


Figure 28: The summarised power production per month for E101

With the assumptions above therefore we can expect per Enercon 101 turbine:

Capacity:	3000 kW
Energy production:	6,2 GWh / year
Resulting full load hours:	2347h

According to the management of Energiepark Bruck an der Leitha 2300 full load hours are a realistic result.

For our wind park model 19 turbines are calculated.

11.3 The energy sales with the Feed In Tariff:

For the economic analysis of the wind project it is necessary to explain the actual law background for the feeding of electricity out of wind energy to the grid:

11.3.1 The guaranteed Feed In Tariff:

In Hungary similar to Austria a Feed In Tariff system is in place. The feed in tariff is different for the different periods of the day (high, low, deep low) and is linked to the consumer price index. The feed in tariff is guaranteed for 12 years. For the different forms of renewable energy different tariffs apply. In case of wind energy however this system is limited with respect to the capability of the grid. The announced feed in tariff for wind energy is only valid for power plants already in operation. New wind projects get the permission for the feed into the grid only via a tender procedure.

11.3.2 The Feed In Tariff via the Wind Energy Tender:

In 2009 a tender has been opened for a total of 410MW capacity. For this tender a total of 1118MW capacity of 68 applicants has been announced. In order to share the capacity of 410MW between the applicants the following system should have been used:

Tender evaluation:

Every applicant shall announce a price proposal for the electricity out of his wind park for the 3 different periods and with an indexation for 12 years. In order to compare the offers the net present value of the difference between the price offer and an estimated generation cost of 12Ft based on 0,6% of monthly interest rate and rated to the installed capacity should be used:

$$B_i = \frac{(P_i - P_p) * \frac{Q_i}{12}}{C_i} * \sum_{t=1}^{N_i} \frac{1[month]}{(1+r)^{t-1}}$$

Equation 8: NPV for Wind Tender

B_i is the net present value of the total support per installed capacity (Ft/kW)

P_i the average (high, low, very low) feed in tariff requested by the applicant

P_p the estimated generation cost of wind energy (12Ft/kWh)

Q_i the feed in quantity of electrical energy in MWh/year

C_i the installed capacity

N_i the requested duration of the Feed In Tariff in months

r the discount rate (0,6% per month)

With this system the capacity would have been given to the cheapest offers exclusively.

On top of that the applicants had to open an account at a specified bank and had to make a deposit of 60.000€ per MW capacity to be installed.
The tender has been withdrawn in summer 2010 and has not been reopened yet. Currently it is therefore not possible to get any feed in permission to the grid and all wind projects are on hold.

11.3.3 The Feed In Tariff calculation:

A standard NPV calculation with the theoretical Feed In Tariff of 2011 for old plants (30,46 HUF) was the starting point. The Exchange Rate was introduced with the value of 315 HUF/EUR. Based on the Investment cost (see below) and the financing structure (WACC=5,8% see below) I made a goal seek analyses and put the NPV value to zero by varying the feed in tariff.

The following data was the base of the calculation:

Investment:

Table 10: Wind Park Investment per kW

Investment cost	*€/kW*	*Source*
turbine	1400	
foundation	160	
electric installation	33	wind energy the facts
grid connection	160	estimation
control systems	10	estimation
consultancy	10	estimation
Land	8	8 mio Ft / turbine (2.000 - 2500m2) actual price for a hungarian project
Pre Financial costs	4	60.000 €/MW deposit for 2 years
Road	13	estimation
Total	***1798***	

In order to make a NPV calculation an estimation of investment cost was necessary. The cost estimation is based on information from Energiepark Bruck an der Leitha (Pschill 2011):

Financing:

Table 11: The Financing Structure of the Wind Park

WACC			
equity	20%	20.503	k€
debth	80%	82.010	k€
equity return	10%		
depth interest	6%		
corp. Tax	20%		
total investment	100%	102.513	k€
WACC	5,84%		

For the financing of the wind park an equity share of 20% was assumed with an expected return of 10%.

Setup:

Table 12: The NPV calculation setup parameters

capacity electrical per unit	3,0	MW	
number of units installed	19		
Full load hours		h/year	
Fuel Input price		€/t	
Fuel price increase		per year	
Efficiency Electrical			
heating value		MWh/t	
feed in tariff	85,79	€/MWh	
market tariff estimation	60,32	€/MWh	after 12 years
FI tariff increase	3%	per year	
income heat		€/MWh	
Investment costs	1798	€/kW	
subsidies	0%	of investment	
grid connection		part of investment cost	
WACC	5,8%		
Depreciation time	15	years	
Maintenance cost yearly	1,20	ct/kWh	
own electricity demand	0,15%	of production	not calculated
Labour cost yearly	20000	€/person	
Personal	4		
Wage increase	3%	per year	

The depreciation period has been set to the duration of the feed in tariff (12 years) plus 3 years at estimated market tariff. The market tariff of 19 Ft in 2010 has been adjusted by 3% per year into the future.

Result:

The resulting Feed In Tariff of 8,6 €ct/kWh seems to be competitive. (27 Ft). The guaranteed Feed In Tariff for old installations for 2011 is 30,46 Ft.

Table 13: The Feed In Tariff for old installations in 2011

Feed In Tariff			daily hours	
Peak	34,31	HUF	16	h
Low	30,71	HUF	4,5	h
Very Low	12,53	HUF	3,5	h
Average	*30,46*	*HUF*	*calculated*	
HUF EUR conversion	315			
Feed in Tariff	96,70	EUR/MWh		

11.4 The impact of the grid balance fee:

Out of our previous calculation we have found that for about 65% of the produced energy a penalty of 5Ft/kWh needs to be paid. We introduce this amount into the economic model as additional cost and calculate again with the goal seek function the needed Feed In Tariff for NPV=0 and WACC=5,84%.

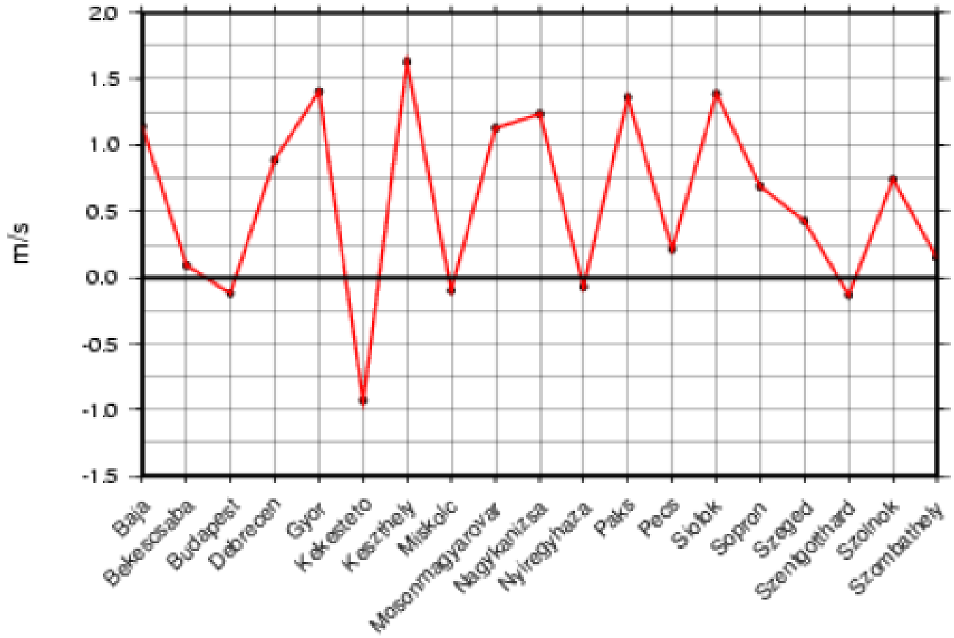
The resulting Feed In Tariff would be 30,36Ft, which is almost the same than the guaranteed Feed In Tariff for old installations.

It is very unlikely, that a tender could be won with this tariff, therefore the forecast inaccuracy would lead to a stop of the project before it even started operation.

12 Conclusions:

The received forecast data from OMSZ is covering only the period of one month. To come to general conclusions on the usage of this data a longer period should be observed. OMSZ itself made an analyzes of their forecast model with historical data where they found different deviations for different places in Hungary at a height of 10m (Kertész 2008):

Table 14: Computed and observed average 10 m wind speed 1992 to 2001



In that diagram Mosonmagyaróvár is also mentioned with a typical deviation of 1,2 m/s. Our monthly sample shows a higher deviation but in the same direction.
The used model seems in general to overestimate the wind speed.

Due to the non-linearity of the power curve the forecast error is even worse on the power prediction.

A possible error cause is also the given roughness length, which should be verified with the local circumstances of the project site. As the data available is quite in a distance of the actual height of the projected turbines (10m, 80m instead of 130m) this can have a big influence.

Another interesting point would be to analyze the deviation in relation to the wind speed. Out of these findings a dynamic error correction could be calculated.

The power production calculation is currently done by using the standard air density given for the power curve from Enercon. The air density however is depending not only on the height, but also from the temperature and the humidity of the air. If these data is also available as forecast data, the calculation of the resulting power could be corrected accordingly.

Both the analyzes of OMSZ and the outcome of this paper are highly recommending to fine tune the wind forecast data with a local model of the wind park based on measurement data and forecast data for a longer period of time. A self-learning model is recommended.

According to the Hungarian law, for the first half year of operation of a wind park there is no grid balance fee to be paid. This time is minimum necessary to develop such a local model.
However well this model can be established, a certain forecast error is always to be taken into the economic calculation of a wind park.

13 Acknowledgements:

I would like to thank my supervisor Dr. Gábor Milics from the University of Western Hungary for his support and contributions.

The work would have been much more difficult without the help of Gottfried Pschill from the Energiepark Bruck an der Leitha.

Also I would like to thank OMSZ for the forecast and measurement data which are the base of this thesis.

Especially I am very grateful for the patience of my wife and my four kids during the time it took to work on this Master Thesis.

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Annex:

Introduction of the Bakony Wind Kft:

The project company Bakony Wind Kft has been established in 2010 with the target to establish a wind park in Hungary.

The objective of the company is to realize the wind park from the specification and planning phase, the achievement of the necessary permissions, the power purchase agreement, the supervision of the building activities up to the implementation and the start of the energy delivery and operation of the wind park.

The founders experience with similar wind park projects in Austria and the specific legal situation in Hungary is the key success factor for the successful realization of the project.

For the detailed negotiations of the permissions and the building activities local subcontractors will be used.

As main technical partner a European wind turbine producer has been selected. 10 years of cooperation experience within a similar project in Austria and an excellent technical track record has been the base for this decision.

The partner for the technical grid access realization will be assigned together with the Hungarian grid operator MAVIR who is at the same time also the counterpart of the power purchasing agreement.

After successful start up of the wind park for strategic reason it is an option to sell part of the unit to a customer.

Detailed description of the project Wind Park Mosonmagyaróvár

General Information:

The project consists of two groups of wind turbines with a total installed power of 51 MW in Hungary. The turbines will be located at Mosonmagyaróvár. Very close nearby (500m – 3 km) is a 120kV and a 400kV power line located. It is planned to connect the wind farm to the 120kV power line.

The produced electrical energy of approximately 134 GWh / year will be sold to the Hungarian grid operator MAVIR with whom a power purchase agreement will be established. The achievement of a power purchase agreement is subject to a tender with a limited available capacity.

The effective price for the energy sold (Feed in Tariff) is specified within the tender and is guaranteed for 12 years. The price is also yearly adapted according to the inflation rate in Hungary.

A rolling forecast of the prospective power supply to the grid needs to be sent to the grid operator.

Technical data of the wind park:

Type of wind turbines:	E101
Number of installations:	19
Rated power of one turbine:	3 MW
Total power installed:	57 MW
Expected electricity generation:	134 GWh/year
Tower height:	130m

Investment:

Price of turbine incl. tower:	1400€/kW
Foundation, buildings, roads and grid access:	400€/kW
Total investment per MW:	1800€/kW
Total investment:	102,6 Mio €

Project schedule:

The project has been started in November 2007 and the start of energy delivery is scheduled for November 2013.
The achievement of the environmental permission is expected for September 2011, the building permission for December 2011.
The result of the Tender will be available in March 2012
The permission for the grid access is planned for October 2012.
Road works and foundations are planned to be finished in August 2012.
The finalization of the power station for the grid access is planned for March 2013.

Founder and Management

Mr. G. P. and Mr. P. M founded the Bakony Wind Kft in 2008.
Mr. G.P. has already leaded successfully various wind projects in Austria. He is very experienced in the technical background of wind projects like wind measurements and turbine technology, Mr. P.M. has been doing business in Hungary since 1989 and family roots to Hungary. Being very familiar with local authorities and Hungarian regulations he is very experienced in legal project management and Hungarian financials.
For the achievement of the necessary permissions external companies will be used, as this is common sense in Hungary.
The equity background is secured by a number of investors in Austria who have already long experience with similar investments in Austria.

Opportunities and risks

Opportunities:

1. Beneficial Feed In Tariff:
   The existing Feed In Tariff System in Hungary offers a very interesting tariff/kWh for existing Wind parks (January 2012). It is split into 3 different time zones:
   Peak (16h): 35,65 HUF/kWh
   Low (4,5h): 31,91 HUF/kWh
   Very Low (3,5h): 13,03 HUF/kWh
   In case of average distribution of energy generation during 24h the mean of the tariff is 30,46 HUF/kWh. At an exchange rate of 315 HUF/EUR, that would be 96,70 €/MWh.
2. Good wind situation in selected region:
   Hungarian Wind cards and own measurements show an average wind speed of 8,3 m/s in a height of 130m, which is the specified hub height of the turbines. Based on this data we can expect Full Load Hours of more than 2.300.
3. Mature technologies:
   The used technology of gearless wind turbines has been practically approved during the last ten years as well internationally as also within own projects at other sites. The used turbines have a very low maintenance time, which is covered by a maintenance agreement with the supplier.
4. REN part currently still very low in Hungary:
   Estimations from the Hungarian Wind Association show a technical potential of 2.000 MW of wind energy in Hungary up to 2020. So far (Sept. 2011) only 330 MW have been realized.

Risks:

- Currency Risk:
  Hungary is not part of the EURO Zone and the Forint has been already victim of speculations and is usually swinging within a band of +/- 10%. As

the Feed In Tariff is contracted in Forint and there is no regulation to follow the EUR the currency risk must be compensated by a calculation based on best and worst case scenarios. (See also attachment)

- Legal and Political risk:
  Although the Feed In Tariff is contracted with the grid operator MAVIR resent political changes show the tendency to overrule signed contracts by changing laws with a 2/3 majority of the ruling party. Most likely these changes will be subject of appeals to the European Court, however the duration of such an appeal is to be expected very long.

Key drivers of the business:

The most important decision for the success of the business is the selection of the correct place for the wind park. Mainly the wind regime is the guideline, however other circumstances can also have a big impact in time and cost: The regional and local area planning and certain areas of environmental protection need to be taken into account. Of course also the legal, economical and political situation in the respective country has a great impact on the success.

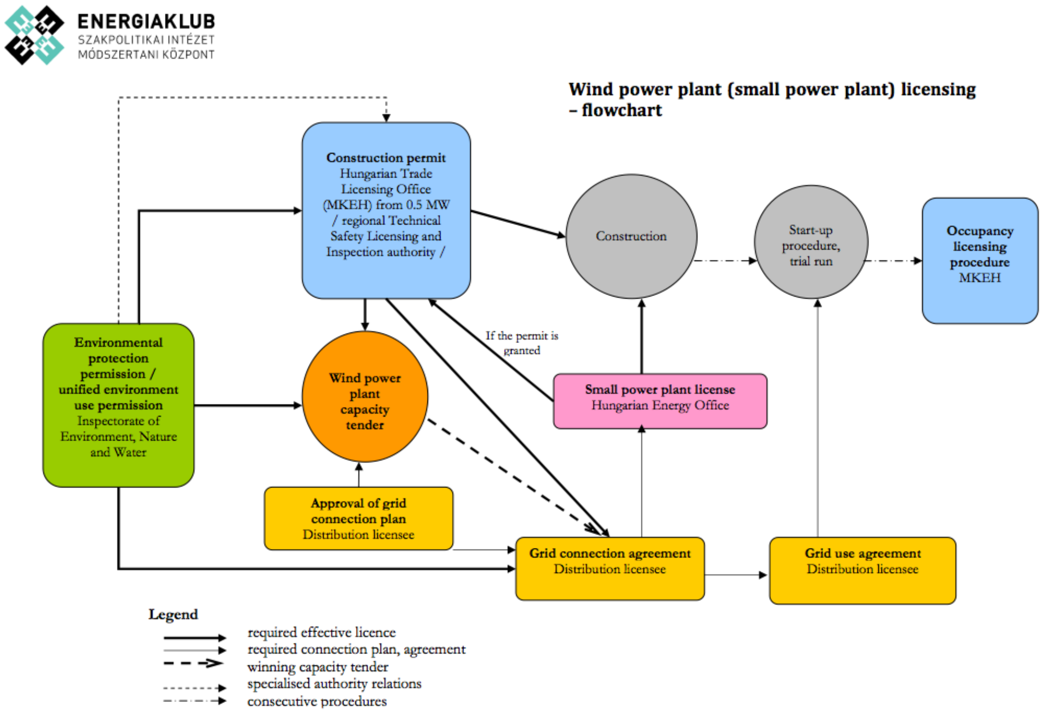
A second very important decision is the technology used and the supplier selection. A stable technology with low investment cost and maintenance cost is the backbone of the financial profitability.

For the construction works the selection of the right general contractor is crucial for the timely implementation and the guarantee of smooth start up of the energy generation.

Schedule of necessary permissions incl. tender:

In order to come into construction and operation phase of the wind park it is necessary to obtain different permissions, which partly depend on each other. The major milestones for this phase are the following

Table 15: Licensing Flowchart Wind Energy

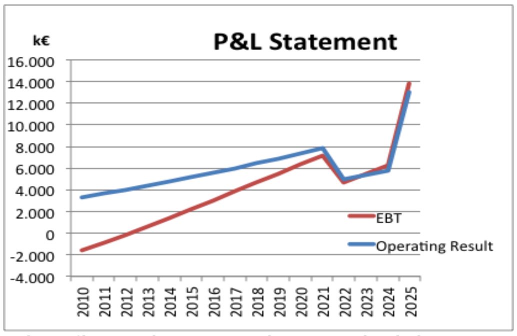


- Environmental Permission:

  As the wind park is not planned within an area of protection only a standard environmental impact examination with aspects of noise, visibility, bird-routes… have to be achieved. A new legislation with certain preferred areas for wind energy is under investigation and it is planned to nominate the respective building area to reduce the effort for the environmental permission.
- Building permission:
- Grid connection permission:

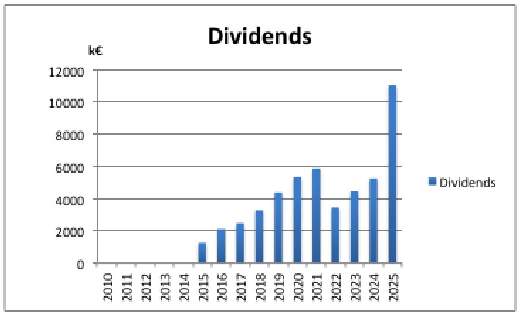
  After the proposal of a connection point by the wind park technical specifications are given by the grid operator, who also indicates the accredited companies, which are allowed to build the grid access. The cost of the grid access bears the wind park. The equipment will be owned and maintained by the grid operator after the start of the energy delivery

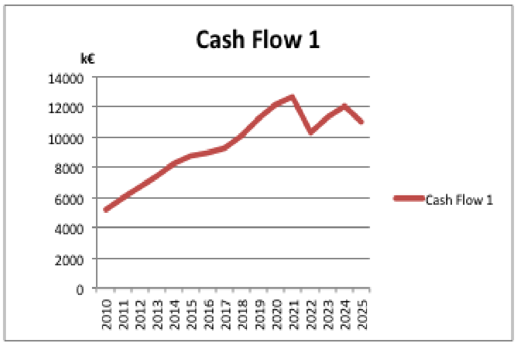
- Tender:
  In order to receive an energy sales agreement with the grid operator it is necessary to obtain the capacity allowances and the price agreement via a wind tender. The last tender of 2009 is currently on hold and a new tender is expected only by end of 2011. The ranking to win the tender has been depending on the requested Feed In Tariff and the guarantee time.



Financial Planning

The financial planning period is covering 15 years. Out of the P&L statement a yearly turnover of 12 Mio € indexed with 3% (Consumer Price Index Estimation) is assumed. The Turnover comes from the fixed Feed In Tariff paid by the Hungarian grid operator MAVIR.





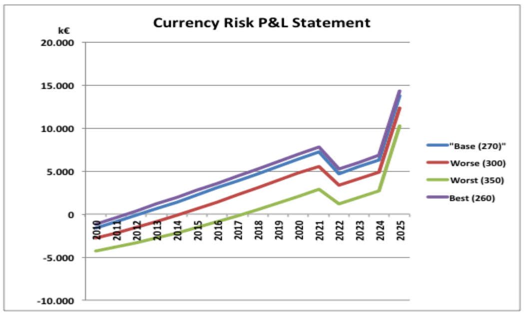
The yearly cost of 1.7 Mio € is mainly the running maintenance cost for the turbines acc. to the maintenance contract with the supplier.

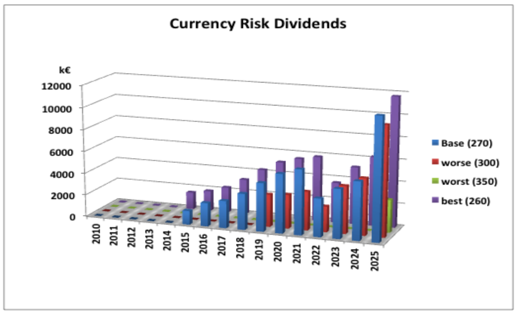
The asset depreciation is calculated over 15 years with an annual value of 6.8 Mio €.

Based on this structure already in the first year there is a positive operating result of 3 Mio €.

The EBT becomes positive already after 4 years leading to a cumulated positive Profit Before Tax in year 6.

Due to the high Turnover the Cash Flow is with 5.6 Mio € positive already in the first year.





The total investment is financed with a registered capital of 20.5 Mio € and a long-term depth of 82 Mio €. The depth has a payback time of 15 years with constant yearly repayment rates and a fixed interest rate of 6%.

The Currency Risk has been taken into account by model scenarios, which show that the project can even in worst case assure the payback of the bank loan.