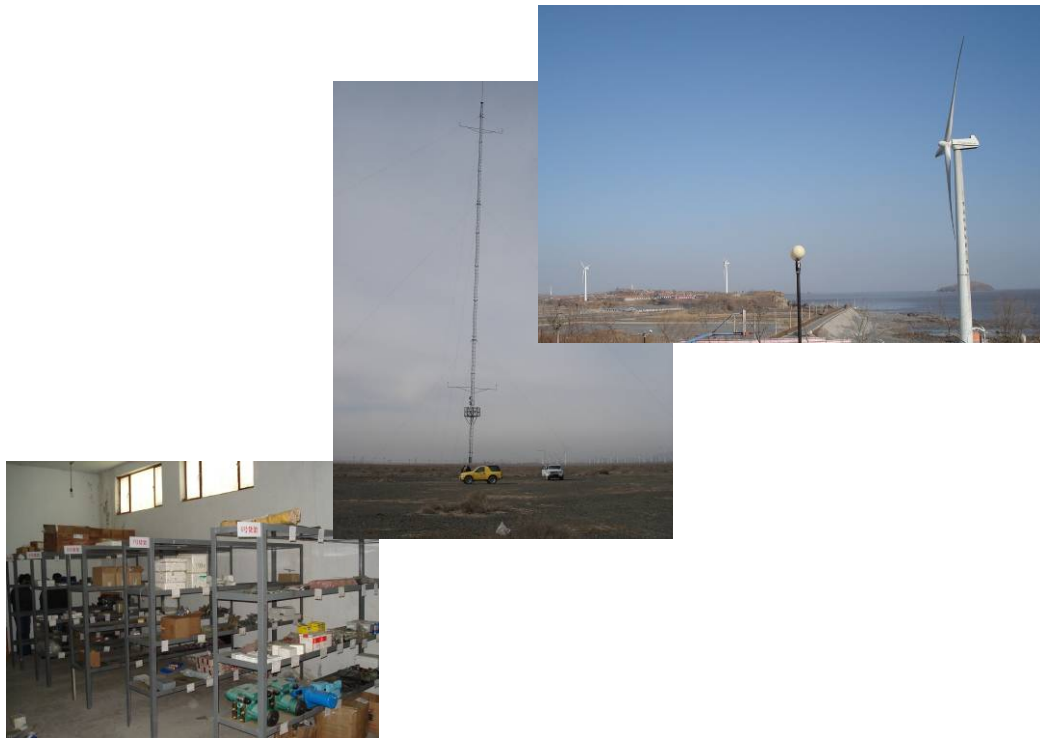


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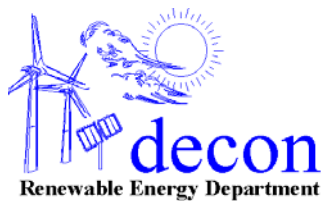
Wind Farm Performance Improvement Activity

Consultant to Collect and Interpret Data and  
Recommend Corrective Actions



Recommendation of Corrective Actions Report  
December 2008

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**Deutsche Energie-Consult  
Ingenieurgesellschaft mbH**  
Norsk-Data-Strasse 1  
D-61352 Bad Homburg v.d.H.,  
Germany



**CEPRI – Electric Power  
Research Institute**  
15 East Xiaoyin Road  
Qinghe Town, Beijing 10005  
P. R. of China



**Deutsche WindGuard GmbH**  
Oldenburger Strasse 65  
26316 Varel  
Germany

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## 1. Executive Summary

In the framework of the 2<sup>nd</sup> phase of the Wind Farm Performance Improvement Project data of 3 exemplary wind farms has been analysed in order to determine the performance level and to find out reasons for underperformance of individual machines or a complete wind farm. Based on these analyses then improvement measures have been identified that could help to increase the performance of the wind farms.

### Characteristics of the exemplary wind farms and available data

The 3 wind farms are situated in different regions of the country, all of them rather in the north and distributed over east, the centre and west. Two of the wind farms implement a variety of different machine types that have been installed over several years. The third wind farm only operates machine of one individual type.

The available data was on the one hand operational data of the machines and on the other hand meteorological data of met masts installed in the 3 wind farms in the first phase of the project. The operational data included monthly production data of each individual machine for up to 6 years back and further actual data has been collected in the run of the project (weekly data in April and monthly data from January to September). Furthermore fault data was collected for the most recent months in the run of the project. The meteorological data included wind speed and direction data as well as air temperature and air pressure.

An important problem was found with the meteorological data during the evaluation. It turned out that mainly for quite limited periods and for 1 to 2 years back in the past data was available. Furthermore the quality of the data was not the highest, there were some inconsistencies between redundant measurements and also some implausible relations between same parameters (in particular wind speed and direction) measured at different masts in one wind farm or in different heights of the same mast. The temperature and pressure data could not be used as the collected data seemed to be corrupted.

For the production data of the machines there were no real problems in the interpretation, but for the fault data it seemed that not all down-times of the machines had been registered correctly. The production data had been registered completely independent from the meteorological data and the data sets of both types had not been synchronized.

### Methodology of Data Analyses

Due to the limitations of the available meteorological data no sophisticated analyses could be carried out, in particular no verifications of the power curves of machines could be performed (due to no synchronized meteorological and production data) and no detailed wind potential maps for the wind farms could be calculated (due to reliable direction data existing only for individual months, but also due to missing terrain height data). Nevertheless the meteorological data could be used to verify and generally check the production data of individual machines. This comparison of theoretical yields with

the real production figures of good performing machines in the vicinity of the met mats showed that the chosen machines performed quite well. Thus it can be concluded that the production of these machines can be used as a reference to evaluate the production of other machines in the wind farm.

Resulting from the limited quality of the meteorological data and its availability only for certain time periods it was decided to choose a method to evaluate the production data mainly relative between machines, but rather not in absolute figures corresponding to the actual wind regime.

The production figures of all machines had been analysed and all (extreme) low productions in individual months had been identified. The criteria for such production were less than 15% of the production of neighbouring machines. In addition to the comparison of the data of two machines for a given month also the development of the production from the month before was evaluated. If one of the machines had a significant lower production while the other(s) had a significant increase in production, it was assumed that the machine with the decreasing production must have had a problem, also if its production was not less than 15% below the production of the other machine(s).

It was obvious that there are a quite big number of machines with heavy problems, i.e. significant lower production than the other machines over several months. But it was also obvious that in the wind farms there were machines with very good performance throughout years.

Only in one of the wind farms, in Dandong, the production figures showed nearly no signs of technical problems. But in this wind farm the production is very low because of the very low wind potential. These low wind speeds have been confirmed by the meteorological data.

The identified losses of production have then been used to estimate an availability of the machines. The availability in this regard was defined as the ratio of produced energy in comparison to the estimated potential of the machine in a given month. Of course the so calculated availability figure is not absolutely exact, but it gives a good indication of the lost energy. As production figures are compared, it is an energy based availability definition, which in general has advantages over a time based availability – a low availability period during high wind speeds results in higher energy losses than a period of the same duration and the same low availability during low wind speeds.

#### General Findings on the Past and Actual Performance of the Wind Farms

For the Xinjiang Dabancheng wind farm the weighted average availability over five years was found to be around 92.4% with the lowest values in 2003 (90.8%) and 2005 (91.8%) and a promising upwards trend from 2005 to 2007 where the availability increased by 1.8%. For the different machines in this wind farm the development over the years are different, in particular bad is it for the small 300 kW Bonus machines (the oldest type in the wind farm), whereas it is quite promising for the Vestas 660 kW machines (the type with the biggest installation numbers).

In the Inner Mongolia Huitengxile wind farm the development of the weighted average availability can be judged only with a certain limitation, as for the type with the biggest installation number (Micon 600 kW) only data for 1 year was made available. The weighted average availability stands at only 90 % in 2007. This is mainly influenced by the 89% availabilities of the Micon 600 kW and GE 1.5 MW machines. For the GE machines this figure is absolutely unsatisfying as the machines have still been



under maintenance of the manufacturer. But there are two types of machines that perform significantly better than the others, the Micon 900 kW and the Nordex 600 kW machines. The good performance could be related to the quite simple design of the machines.

For the Liaoning Dandong wind farm the availability has been very satisfying high during all the past 6 years. It has been nearly constantly at 97% or even higher.

The main reasons for down times in the Dabancheng and Huitengxile wind farms are found in an insufficient handling of repair measures. If there is a problem at a machine, it is mostly not fixed quickly, but the repair may take several attempts and may last over months. In some cases the availability of spare parts is found as the cause in the background, in other cases it is an incomplete repair that leads to new still stands after only few days or weeks of operation. It is assumed that also the maintenance of the machines can be improved, because several problems due to worn parts could be avoided by a timely replacement – and this can only be achieved by a good maintenance. During the site visits an exemplary machine was visually inspected in each of the wind farms. The found state of the machines (in particular they were extremely dirty and oil leakages have been found) underlines the assumption that the maintenance may be much improved.

At the Dandong wind farm the production losses are not caused by technical problems of the machines, but by the low wind potential in the area. In this case the feasibility study during the preparation of the project has been insufficient. This problem could have been avoided by a high quality measurement of the wind potential in conjunction with a long-time correlation of the measured data. It cannot be figured out at so long time after the preparation of the project what exact reasons have led to the wrong wind studies, but it is assumed that it was a mixture between measuring with low quality equipment in a period of quite high winds without a real long-term correlation. Additionally probably the involved people had been too optimistic and not careful enough in the evaluation.

#### Proposed Improvement Measures and Improvements during the Course of the Project

Some recommendations for improvement are given in this report. They may look as very simple or even too simple, but in fact it is such simple methods that can bring real high improvement in output of the wind farms. The recommendations have been developed under consideration of the found problems in the wind farms. And in the case of the Dabancheng and Huitengxile wind farms it is not a fine tuning or correction of control parameters in the machines or other sophisticated measures that would help most, but it is just the improvement of the basic operation and maintenance of the wind farms.

During the consulting activities nearly no improvement in the operation of the wind farms could be achieved, especially no direct and intentionally improvement. On the one hand this is due to the difficult and lengthy process of getting the actual production data, showing a quite difficult communication between the consulting team and the wind farm owners/operators. On the other hand the proposed improvement measures can be implemented only by changing the daily procedures in the wind farms and by improving the staff structure; and such measures take in general longer times than just implementing small technical improvements (like parameter setting in the WEC controllers).

### Experiences and General Recommendations concerning wind measurements

The work in this project has brought some insight in the performance of wind farms in China and typical problems. Apart from that the project has also shown (in the case of the Dandong wind farm) that low production figures may be the result of a low wind potential in the area of the wind farm. The latter leads to the conclusion that diligence in the preparation of a project and a high quality of wind studies in the forefront are a key factor to a successful realisation and operation of such kind of project. In order to prevent in the future negative experiences of this kind with wind farms, it is recommended to put much attention to the assessment of the wind potential. Connected to this assessment there should be a decision process that is open also to the possibility of not constructing a wind farm at an investigated site and to search for a more suitable site in some distance.

The work in the project has also shown the importance of high quality wind measurements in the framework of a wind farm post evaluation during the operation time. In the best case, wind measurements would be carried out all the time from the initial steps for a wind farm at the same site. This would give data for a sufficient long time for evaluating also differences in the wind potential between the preparation and the operation phases of a project. High quality wind measurements include not only high quality equipment but at the same importance also high quality in data collection, evaluation and maintenance of the equipment.

In the case of this specific consulting project, the separation of the contracts between the installation of the measurement masts and the evaluation of the data has turned out to be problematic. For the 3 exemplary investigated wind farms, it could be a good idea to equip the existing met masts with new sensors fixed appropriate to the mast and to continue the data collection and evaluation.

## 2. Introduction

The CRESP – China Renewable Energy Scale-up Program is a project in cooperation of the Government of China (GOC), the World Bank (WB) and the Global Environment Facility (GEF) with the aim to promote the development of the renewable energy sector in China.

In the framework of CRESP one activity is the Wind Farm Performance Improvement Activity. The purpose of the activity is to assess and demonstrate improvements to the technical and commercial performance of a limited number of existing wind farms in China. In the first phase of this activity meteorological wind measurement equipment has been installed in three wind farms in order to collect representative wind data that can be used as base for evaluation of the available wind energy potential and can support the performance analysis of the wind farms.

Actually the second phase of the activity is in progress.

In this phase the collection and evaluation of operational data of the wind farms and of the meteorological data as well as the identification of faults and underperformance and development of improvement measures is carried out.

As Consultant for this phase DECON – Deutsche Energieconsult Ingenieurgesellschaft mbH from Germany in cooperation with CEPRI – China Electric Power Research Institute and with Deutsche Windguard GmbH has been selected via an international tender.

In this report information is given on the current performance of the 3 wind farms and actions are proposed which could help to improve the operational results.

### 3. Methodology

In the following the methodology used in evaluation of the data of the wind farms is explained. The available data is split in general in two types:

1. Operational data of the WECs, i.e. production figures and failure lists
2. Meteorological data measured at the met masts, i.e. wind speed, direction, air temperature and pressure

There exist different possibilities to work with this data and to use them in relation to each others. Some methods are rather simple and others are rather sophisticated. The sophisticated procedures can bring the most detailed results, but they also require very detailed and exact input data. Without an adequate quality of input data the sophisticated procedures will not bring very exact results, but very detailed figures that are only of low importance or even rubbish.

In the actual project the first analysis of the available data revealed the following limitations:

- Production data of the machines was available only as monthly values but not for 10 minutes time series synchronized with the meteorological measured data
- Meteorological data was available not for the total periods with production data, but in general only for roughly one complete year; in particular nearly no actual measured data was available
- The meteorological data showed a number of deficiencies:
  - o Some anemometers seem to have bearing problems in the later months and give not accurate results for all months with data
  - o No calibration certificates for the anemometers were made available
  - o The wind vane booms often were not fixed correctly and moved with the wind, so that the measured direction data contains a high uncertainty
  - o The wind speeds and directions measured on the same mast in different heights or even in the same height, did sometimes not show plausible relations between them.
  - o The wind speeds and directions measured on different masts in the same wind farm and in quite short distance to each other did sometimes not show plausible relations.

Due to the deficiencies in the available data, it was not possible to apply the following sophisticated analyses, which could have brought some additional more detailed results about the performance of the machines:

- evaluation of power curves of individual WECs – this would have required synchronized high resolution production data
- calculation of wind potential maps for the wind farms - this would have required accurate direction data and additionally good terrain data (height levels)

Despite the deficiencies of the data some WASP calculations have been carried out to check what quality and level of results can be achieved. These calculations have confirmed the conclusions drawn from evaluating only the production data.

Nevertheless, the following simpler procedures could be applied:

- Comparison of production data of neighbouring machines for identical periods
- Comparison of production data for a machine between two adjacent periods
- Calculation of a rough theoretical electricity production of machines based on the measured wind data
- Calculation of a rough technical availability for the machines in the wind farms
- Evaluation of the accuracy and level of details of failure lists

The most work in the consulting services has been concentrated on the processing of the meteorological data and of the evaluation of the production figures. The aim in processing of the meteorological data was to extract the most possible information out of it. The work included also search and evaluation of long-term measurement stations that could supplement the data measured directly in the wind farms. This would help to evaluate the production figures also for periods where no data was measured in the wind farm.

Although, it might at first give a bad impression that the aforementioned sophisticated procedures could not be used, it is in fact no major problem. The comparison of the theoretical yields calculated from the met data with the real production figures showed that in the wind farms in the relevant period a considerable number of machines have performed well. The production of these machines can be used as a reference for evaluating the performance of the other machines also.

Additionally the production data showed clearly very heavy production deficits – some machines producing 0 or less than half than other machines in a given month – which can be evaluated to a good extent and with sufficient accuracy also without the sophisticated procedures.

#### Calculation of an estimated technical availability

It was tried to identify in the wind farms for all WEC types machines that showed constantly high production over longer times and where in the best case also the production could be verified with the available meteorological data. By referencing the production of neighbouring machines to this production, their production losses can be estimated and furthermore the achieved production can be used to estimate a technical availability of the machine. The availability in this regard is defined as the ratio of produced energy in comparison to the estimated potential of the machine in a given month.

The calculation shall be demonstrated by an example:

1. A machine 1 has produced 83.000 kWh in the respective month
2. A neighbouring machine 2 of the same type has produced 100.000 kWh in the same month,
3. It is assumed that the machine 2 has produced nearly the theoretical optimum (confirmed by plausibility tests or in the best case also by meteorological data); to account for possible unidentified problems that nevertheless have effected the production of this machine, not a 100% technical availability, but only a value of 97% is assigned to this machine.

4. The technical availability of the machine 1 is now calculated by the relation of the two productions, multiplied by the assumed availability of the machine 2, i.e.

$$83.000 / 100.000 \times 97\% = 80.51\%$$

Of course the so calculated availability figure is not absolutely exact, but it gives a good indication of the lost energy. As production figures are compared, it is an energy based availability definition, which in general has advantages over a time based availability – a low availability period during high wind speeds results in higher energy losses than a period of the same duration and the same low availability during low wind speeds.

The setting of 97% technical availability for the well performing machine is not objective, but a pragmatic approach. The assumed 3% unavailability is meaning roughly 1 day of accumulated unidentified losses of this machine during the month. It might be that the real technical availability of this machine in the month have even been 100% or it might have been lower than 95%. The chosen 97% is to be seen as an intermediate value that could for several months represent as well the months with 95-97% availability as also the months with 97-100%.

Assigning a lower value than 97% seems not to be plausible. If choosing instead, for example 95% this would mean that in average over several months also months with availabilities down to 90% would be included. But the experience of the consultant team with many other projects has shown that in the long run energy based availabilities of machines are either rather close to 100% or below 90%. The reason is that with small and single problems the availability is influenced not very much, but with bigger or repeated problems down-times increase very quick. This means either a problem is solved easily and quickly within less than 1 day (and remains a small and single problem) or it needs intensive research of the cause and/or delivery time for a spare part and/or it is not solved in the first attempt (and clearly this is a bigger and/or repeated problem).

The production data of the machines in the examined wind farms show these patterns also: there are a big number of machines with values in a quite narrow band (those with no or only minor problems) and a limited number of machines with significantly lower production (those with the major problems).

#### Benchmarking approach

As it is a requirement of the consulting project, also to benchmark the performance of the wind farm during the project and in the future, it was thought about an appropriate method. The method leading to the exactest results would be the use of high quality meteorological data. In principal this method can be applied in the wind farms, but it needs a thorough management of the existing meteorological masts, a regular data collection and plausibility check of the registered data. Then it needs additionally the regular calculation of the theoretical energy yield for the different types of machines in the wind farm. In total this procedure is quite sophisticated.

The experience during rendering the consulting services showed that it is difficult to only collect regularly the registered data. Considering that additionally the accuracy of the data is questionable after in the mean time at least 3 years operation of the sensors, it seemed not very promising to implement this sophisticated approach.

Instead, a much simpler procedure is proposed. This procedure relies only on the monthly production data of the machines. The idea is to evaluate the distribution of all machines of the same type in a wind farm over a given matrix of 4 classes:

- (1) best performing machines,
- (2) slightly better than average machines,
- (3) machines slightly below the average and
- (4) machines significantly below the average (including the machines with zero production).

According to these classes, in a good performing wind farm there should be a distribution with most of the machines in classes 2 and 3 (around the average) and only a few numbers in the best and worst classes. The machines in class 4 are the machines that should be absolutely in the focus of activities aiming at improving the performance.

The method might look too simple and not objective, and it has obviously some limitations.

So, it is not giving significant results, if the number of machines of a type is small – the number should be at least 8. Then it would not give relevant results, if even the best performing machine would be far below the theoretical potential. And finally, it is giving a too good impression with too many machines above the average, if the production data of the machines are equally distributed over a broad range.

However, it is a method that can be applied very easily and it is working well for wind farms, where only a limited number of machines is performing very bad – and the latter is the case in the Dabancheng and Huitengxile wind farms for most of the machine types.

There is a flexibility in applying the approach, as the thresholds for the definition of the classes may be varied. It is proposed to use a range of  $\pm 10\%$  around the average of all identical machines for defining the limits of the classes. As many machines in the wind farms tend to have either no (0-10%) or real important losses ( $>35\%$ ), modified thresholds would not change the distribution of the machines very much. Choosing  $\pm 5\%$  instead of the proposed  $\pm 10\%$  would cause more machines to fall in the “extreme” classes 1 and 4, but the sum of machines either above or below the average (sums of classes 1/2 and 3/4) would remain the same. With the proposed  $-10\%$  threshold between classes 3 and 4 the number of machines that should be the target of performance improvement is clearly shown.

## 4. Current and past performance of the wind farms

The evaluation of the historical data is aimed at getting a first understanding of the development of electricity production and problems in the 3 wind farms. This evaluation will reveal if there is a general trend in production, reliability and fault events in the wind farm. Furthermore the evaluation can give hints at the distribution of problems throughout the different machines and types within the wind farm, i.e. are some machines more effected by failures than others.

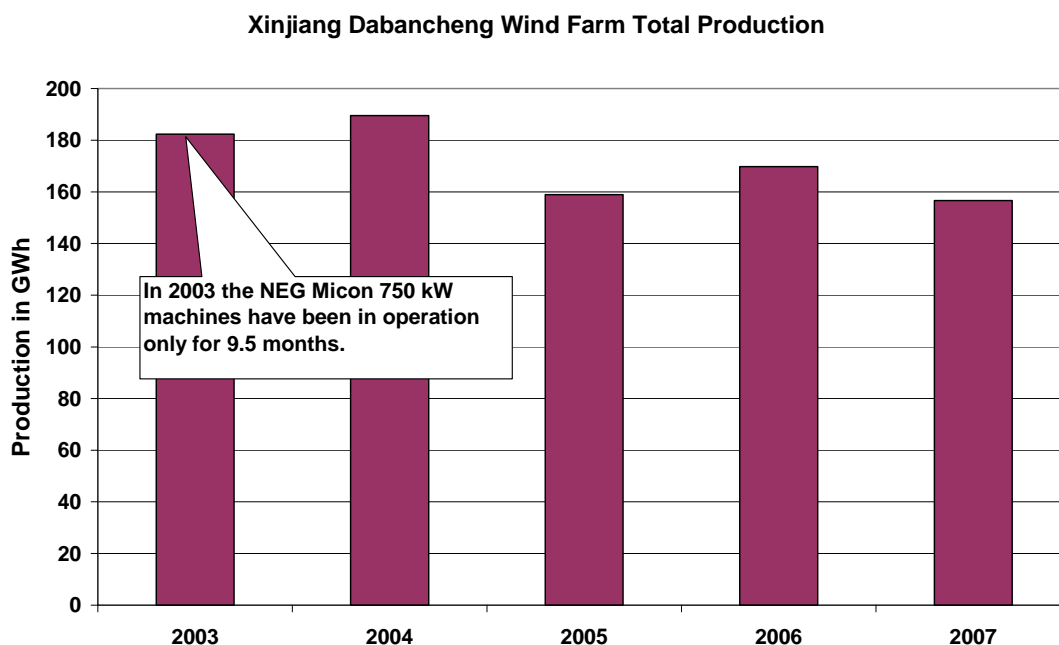
However, this evaluation cannot reveal all of the reasons for under-production, as the analysis of data from the past is always limited to the availability of stored production and fault data. It is not possible to further investigate found problems. This could only be done for periods in the present and future when immediately after the occurrence of an fault the analysis will be started. This deeper analysis of reasons for the faults will be done in the next stage of the project.

### 4.1 Evaluation of data from the Xinjiang Dabancheng Wind Farm

#### 4.1.1 Global Production data of the Wind Farm

As a first step the total production of the wind farm throughout 5 years is analyzed. It is shown in Figure 1.

Figure 1: Total production of the Dabancheng Wind Farm over 5 years



The annual total wind farm production has been around 160 to 190 GWh, with the highest in 2004. Considering that in March 2003 the newest 10 machines (type: NEG Micon 750 kW) have been commissioned and thus have not been in operation for the complete year, this production can not be



compared directly to the production of the following years. The theoretical production of these 10 machines in their first 3 months of 2003 is 5 GWh, meaning that the total annual production could have been the same as in 2004.

This first graph indicates a tendency of the production to decrease slightly from year to year. But it is questionable whether this tendency is valuable for the future also. It is necessary to analyze to what extent the wind potential in the different years has differed and whether the technical availability of the wind farm was always constant or at least within a certain range.

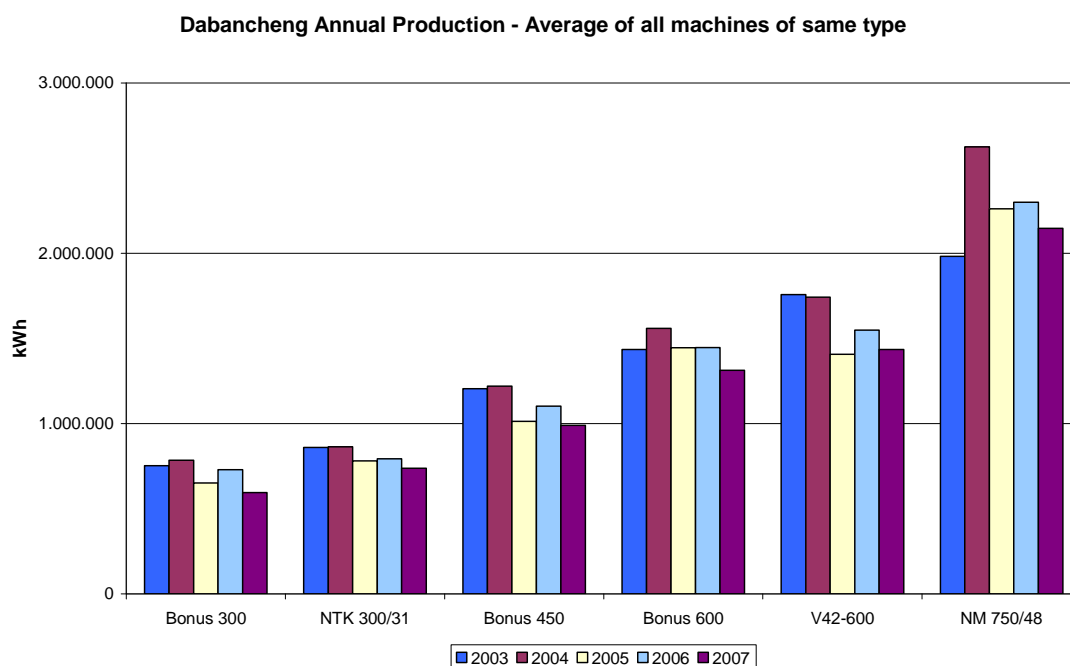
This analysis will be done in the following chapters.

#### 4.1.2 Production data of the different machine types over the past 5 years

In Figure 2 the average production for all machines of the same type over the past 5 years is shown. As in Figure 1 it can be seen that the production in 2003 and 2004 was significantly higher than in the 3 years thereafter.

However there are also differences between the individual machine types. For the Bonus 600 kW machines, it strikes that the production in 2003 was quite low. For the Bonus 600 kW and the Nordtank 300 kW machines there is nearly no difference between 2005 and 2006 whereas for the other machines (especially for the Bonus 450 kW and the Vestas 600 kW machines) the production in 2006 was higher than in 2005. Finally the difference between 2005 and 2007 is much more distinctive with the Bonus 300 kW, Bonus 600 kW and NEG Micon 750 kW machines than for the other types.

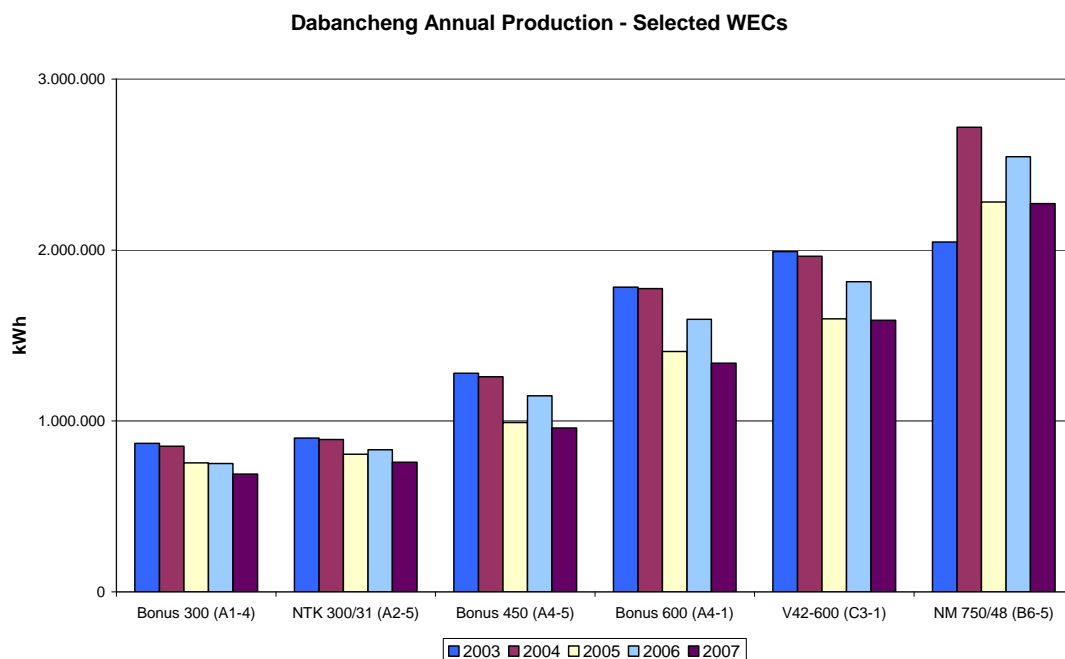
**Figure 2: Development of Production over time for different machine types**



These differences in the development over the time are a first indication on the different availability the machines of different types had in the individual years. If only the variation of the wind potential would have effected the production, this should have resulted in very similar patterns for all machine types and there should be no such big differences between the machine types.

In the following the production of individual machines of each type over the 5 years is analyzed. For the diagram in Figure 3 individual machines have been selected for which the production data over the 5 years showed no big losses in all of the months, i.e. for each type a machine with an apparently constant availability over the time has been chosen. It is not absolutely clear that the availability of these machines has been constant throughout all the time as the available historical data does not completely contain this information. But all the monthly production values show no significance for important losses so that it is assumed that these machines have performed always well.

**Figure 3: Development over time for individual machines of each type**



The development of annual production for these individual machines shows very similar patterns:

- 2003 was always the highest production (for the NEG Micon 750 kW machines it has to be taken into account that 2003 is not complete),
- 2004 always very similar to 2003
- 2006 for most of the machines better than 2005
- 2007 for most of the machines nearly the same as 2005

It has to be remarked that probably the selected Bonus 300 kW machine had a loss in 2006, the production should have been higher than in 2005 and 2007; but for the other 3 machines of this type

also the production of at least one of the years had been more affected by unavailability, so this machine is nevertheless the best reference.

From the patterns of individual machines with quite constant (and high) availability in conjunction with the patterns in Figure 2 some conclusions can be drawn for the average performance of all machines of one type:

- The Bonus 300 kW machines had on average in 2003 remarkable losses, but in the following years the performance was in principle well. However, for 2007 it is not absolutely clear and more detailed analyzes will have to show the extent of losses.
- The Nordtank 300 kW machines had on average remarkable losses in 2003 and 2006.
- The Bonus 450 kW machines also did not perform optimal in 2003.
- The Bonus 600 kW machines on average also did not perform optimal in 2003, 2006 and 2007, but they showed very well performance in 2005.
- The Vestas 600 kW machines on average performed better in 2007 than in 2005.
- The NEG Micon 750 kW machines performed not optimal in 2006 and 2007, the last year seems to be even worse than 2006, but this still has to be confirmed by more detailed analyzes of individual machines.

As a summary this means that in 2003 the performance of most of the machines was not very well, but had been improved in 2004. Then, in 2006 there had been losses due to low availability especially for the Nordtank 300 kW and Bonus 600 kW machines. For the Vestas machines it looks like a positive trend since 2005, whereas for the NEG Micon machines it looks like a negative trend.

Up to now the analyses has focused on the general behavior of all of the machines of the same type. In the following chapter, the production data of individual machines will be analyzed and discussed in more detail.

### 4.1.3 Production data of individual machines

#### 4.1.3.1 Bonus 300 kW

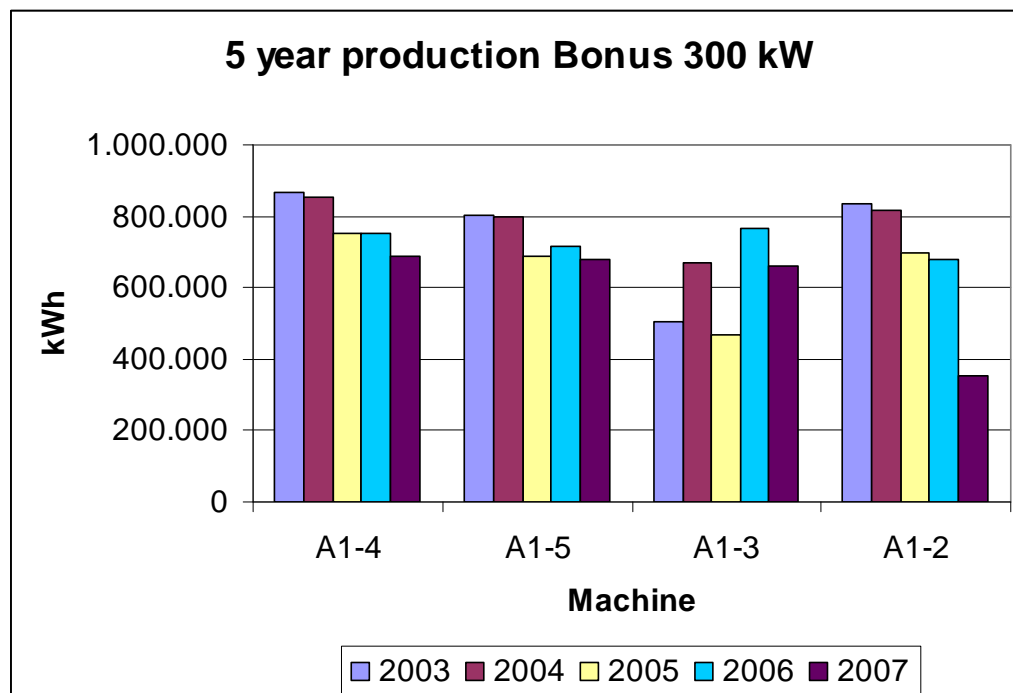
As only a small number of 4 machines of this type is operated in the wind farm, in the following the data of all machines is shown (Table 1 and Figure 4). The red marked cells in the table show individual annual results significant below the average performance of the group of machines. The green marked cells show the quite constant performance of the machine A1-4 (selected also in chapter 4.1.2 as reference machine).

**Table 1: Detailed production data of all Bonus 300 kW machines**

| Site | No. | Production (kWh) |         |         |         |         |           |                           |
|------|-----|------------------|---------|---------|---------|---------|-----------|---------------------------|
|      |     | 2003             | 2004    | 2005    | 2006    | 2007    | 5 yr avg. | 5 yr rel to group average |
| A1-4 | A3  | 868.545          | 851.827 | 754.283 | 750.231 | 688.226 | 782.622   | 111%                      |
| A1-5 | A4  | 804.161          | 799.419 | 688.158 | 717.354 | 678.555 | 737.529   | 105%                      |
| A1-3 | A2  | 504.678          | 670.470 | 466.564 | 766.600 | 660.164 | 613.695   | 87%                       |
| A1-2 | A1  | 835.806          | 816.106 | 699.397 | 680.667 | 351.527 | 676.701   | 96%                       |

The worst performing machine was the one at the site A1-3, in average over the 5 years it produced 13% less than the average of the group and still 10% less than the second worst machine at the site A1-2. However, the data shows also clearly that the problems existed only from 2003 to 2005. During the last two years the production of the machine was at a comparable level with the 2 best performing ones (A1-4 and A1-5), in 2006 this machine even showed the highest result.

For the second worst machine (A1-2) the production had been at good levels from 2003 to 2005, but the machine underperformed in 2006 and had heavy problems in 2007.

**Figure 4: 5 year production data of individual Bonus 300 kW machines**

By comparing the results in the red marked cells in Table 1 to the production data of other machines in the same year, an estimation of the loss of production for the respective machine in the year can be achieved. As it is not absolutely clear which of the other machines is most comparable in regard to the wind potential and wake effects, as a conservative approach the lowest production of one of the other machines can be used.

This leads to losses of approx. 11,000 kWh for the machine A1-5 in 2005, 300,000 + 130,000 + 233,000 kWh for the machine A1-3 in the years 2003 to 2005 and 310,000 kWh for machine A1-2 in 2007. By relating these losses to the achieved production values an indication of the availability of the machines can be calculated. For the data in the cells which are not highlighted an availability of 97% is assumed. This takes into account that for the machines in the respective years also some smaller down-times and losses of production have occurred. As a result the availability of this type of machines has been on average 90% throughout the last 5 years (cf. Table 2). The bad availability of 2007 is influenced only by one machine and should thus not be regarded as representative for a trend in development of the availability, but the problems with the machine A1-2 represent rather a singular event. In general the availability of the machines of this type is regarded as good for 2006 and 2007, for 3 machines it is even excellent.

**Table 2: Estimated availability of the Bonus 300 kW machines**

| Site    | No. | Availability (rough estimate) |      |      |      |      |         |
|---------|-----|-------------------------------|------|------|------|------|---------|
|         |     | 2003                          | 2004 | 2005 | 2006 | 2007 | Average |
| A1-4    | A3  | 97%                           | 97%  | 97%  | 97%  | 97%  | 97%     |
| A1-5    | A4  | 97%                           | 97%  | 95%  | 97%  | 97%  | 97%     |
| A1-3    | A2  | 61%                           | 81%  | 65%  | 97%  | 97%  | 80%     |
| A1-2    | A1  | 97%                           | 97%  | 97%  | 97%  | 52%  | 88%     |
| Average |     | 88%                           | 93%  | 89%  | 97%  | 86%  | 90%     |

#### 4.1.3.2 Nordtank 300 kW

In the wind farm there are 25 machines of this type operated. In the following only the data of some exemplary machines is discussed in detail.

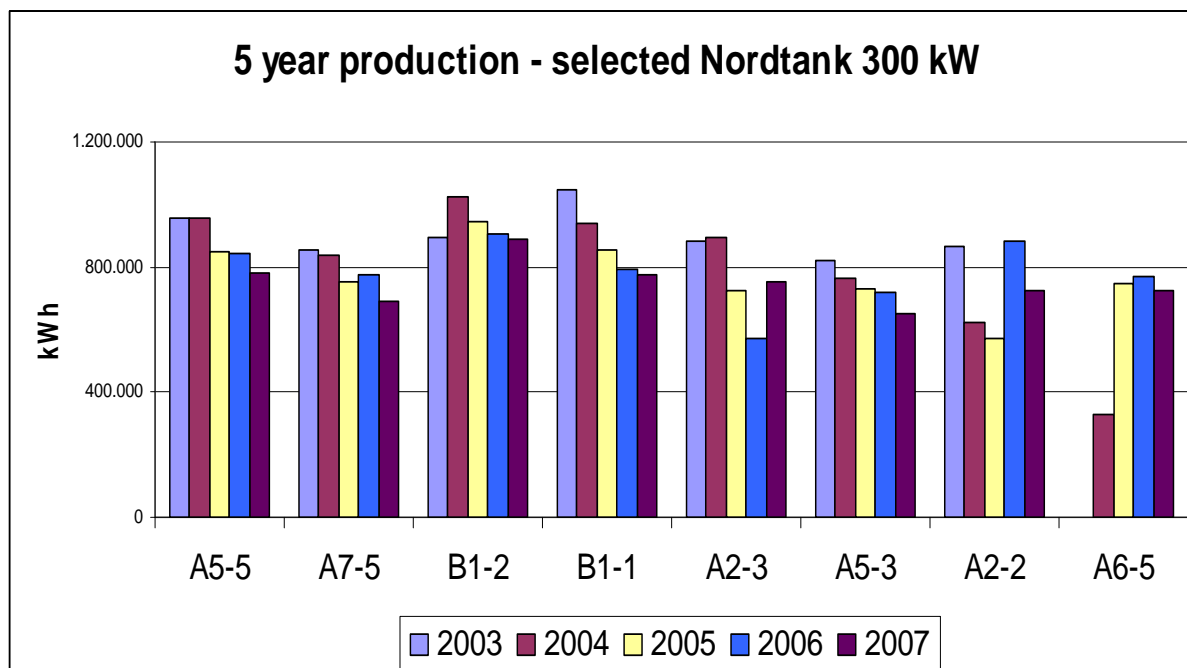
10 out of the machines, i.e. 40%, have shown quite good production data throughout the 5 years and it is concluded that they have produced at constant high availability. The average annual production of these machines for the 5 years was in the range of 780,000 to 880,000 kWh per machine.

3 of the machines, i.e. 7.5%, have shown very low production data with an average for the 5 years of 513,000 kWh, 735,000 kWh and 736,000 kWh.

The remaining 12 machines showed good performance during 2-4 years and bad performance during 1-3 years. Their average annual production is ranging from 764,000 kWh to 931,000 kWh. The production of 2 of these machines had been even higher than that of the 10 machines with quite constant availability throughout the time.

**Table 3: Production data of selected Nordtank 300 kW machines**

| Site | No. | Performance | Production (kWh) |           |         |         |         |           |                         |
|------|-----|-------------|------------------|-----------|---------|---------|---------|-----------|-------------------------|
|      |     |             | 2003             | 2004      | 2005    | 2006    | 2007    | 5 yr avg. | 5 yr rel. to group avg. |
| A5-5 | E4  | good        | 955.457          | 956.099   | 847.057 | 843.694 | 780.343 | 876.530   | 109%                    |
| A7-5 | G3  | good        | 854.772          | 839.283   | 752.156 | 778.123 | 691.511 | 783.169   | 97%                     |
| B1-2 | A6  | normal      | 896.217          | 1.024.666 | 943.923 | 906.220 | 886.149 | 931.435   | 115%                    |
| B1-1 | A5  | normal      | 1.045.430        | 940.653   | 856.450 | 791.986 | 777.298 | 882.363   | 109%                    |
| A2-3 | B2  | normal      | 883.243          | 894.472   | 721.751 | 573.257 | 750.077 | 764.560   | 95%                     |
| A5-3 | E2  | bad         | 820.174          | 764.102   | 728.236 | 719.062 | 650.864 | 736.488   | 91%                     |
| A2-2 | B1  | bad         | 868.725          | 624.898   | 572.589 | 881.478 | 726.203 | 734.779   | 91%                     |
| A6-5 | F4  | bad         | 0                | 325.935   | 746.127 | 768.820 | 726.227 | 513.422   | 64%                     |

**Figure 5: 5 year production of selected individual Nordtank 300 kW machines**

As the Table 3 and Figure 5 show, for the selected 3 machines with rather average performance and the 2 very bad ones, the production of individual machines differs significantly between different years. For the year 2007 in general the performance was better than the year before. The overall availability for the machines of this type (again assumed 97% for the machines with no obvious production losses in single years) and for the 3 worst performing ones is shown in Table 4. The calculation of losses and availability has been done in the same way as explained for the Bonus 300 kW machines in chapter 4.1.3.1.

**Table 4: Average annual availability (rough estimate) of the Nordtank 300 kW machines**

| Year                                 | 2003 | 2004 | 2005 | 2006 | 2007 | Average |
|--------------------------------------|------|------|------|------|------|---------|
| Average Availability of all machines | 91%  | 94%  | 95%  | 93%  | 96%  | 94%     |
| A6-5                                 | 0%   | 37%  | 97%  | 97%  | 97%  | 66%     |
| A2-2                                 | 97%  | 79%  | 76%  | 97%  | 97%  | 89%     |
| A8-5                                 | 88%  | 97%  | 97%  | 63%  | 97%  | 88%     |

As the losses for the worst performing machines are much more significant than with the Bonus 300 kW machines discussed in chapter 4.1.3.1, it shall be demonstrated a little better in which way these losses occur.

In Table 5 and Figure 6 the monthly data of 3 selected machines is shown. One machine was selected because of its good and constant performance throughout all the past 5 years, the 2 other because of their low production in 2007.

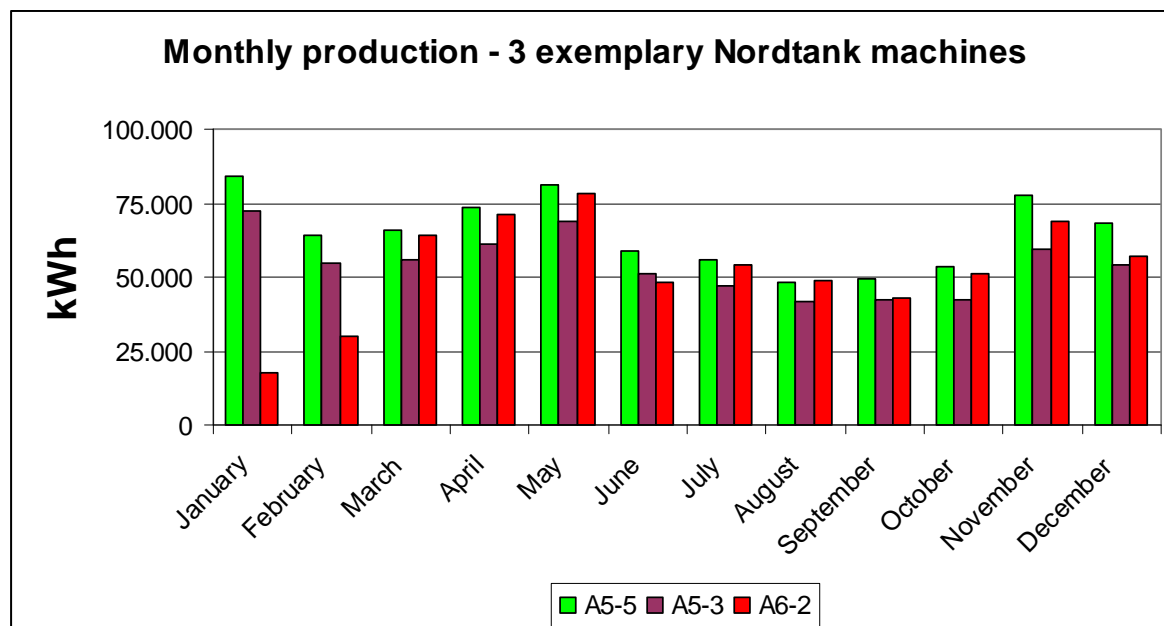
**Table 5: Monthly production data 2007 of selected Nordtank machines**

| Site        | A5-5    | A5-3      | A6-2    |
|-------------|---------|-----------|---------|
| Performance | good    | not clear | bad     |
| January     | 83.900  | 72.177    | 17.443  |
| February    | 64.202  | 54.972    | 30.156  |
| March       | 65.665  | 56.043    | 64.271  |
| April       | 73.697  | 60.936    | 71.372  |
| May         | 80.965  | 68.758    | 78.119  |
| June        | 58.972  | 50.908    | 48.522  |
| July        | 56.113  | 47.345    | 53.825  |
| August      | 48.233  | 41.677    | 48.809  |
| September   | 49.168  | 42.452    | 43.072  |
| October     | 53.741  | 42.312    | 51.296  |
| November    | 77.434  | 59.289    | 68.858  |
| December    | 68.253  | 53.995    | 57.068  |
| Total Year  | 780.343 | 650.864   | 632.810 |

For one of the machines with low production (A6-2) it is obvious that it is related to down-times in individual months (marked red in the table). It can easily be seen that there are some months with nearly the same production as the machine A5-5 and other months with significant losses. It is also obvious that faults last quite long (more than one month at the begin and at the end of the year).

For the machine with the second worst production in 2007 it is not absolutely clear whether this is related to bad performance or to a bad siting in the wind farm. For all months the production is lower than that of the good performing machine. However, the comparison with the bad performing machine shows exceptions for June and September; it is possible that in these months the bad performing machine has losses that could explain the small difference to the machine A5-3. This aspect might be analyzed in more detail later-on during the project.



**Figure 6: Diagram of monthly production data, Nordtank 300 kW**

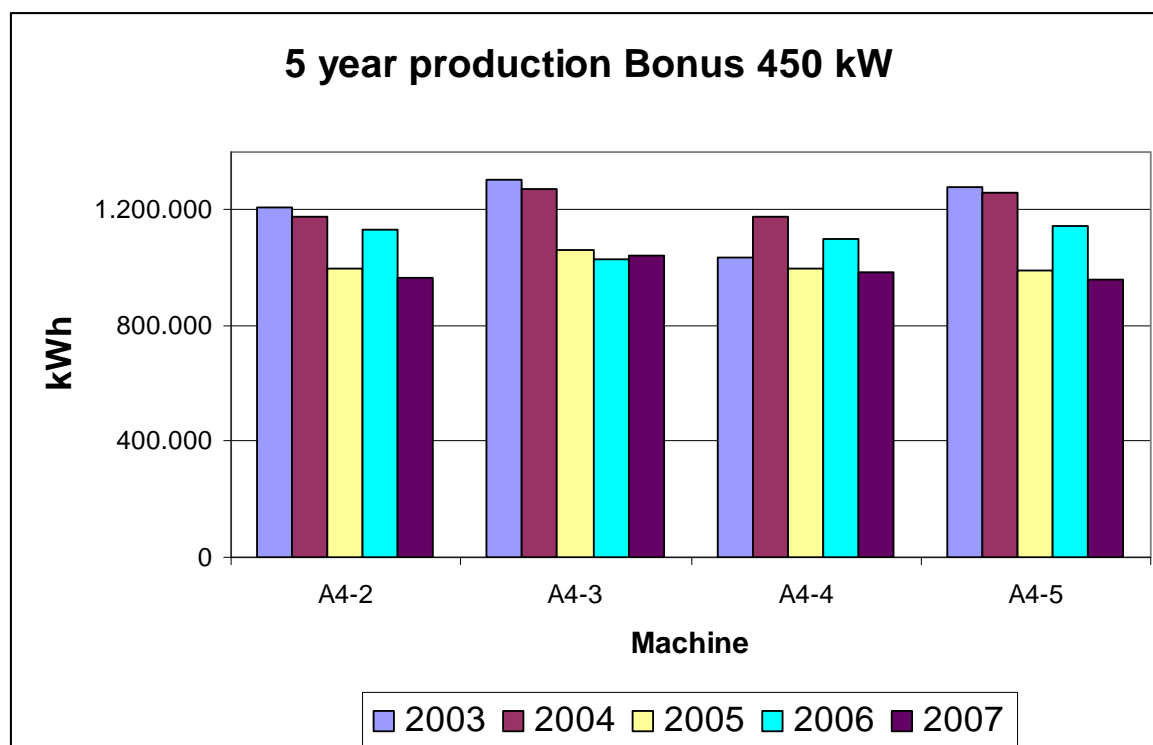
#### 4.1.3.3 Bonus 450 kW

As also of this type only a small number of 4 machines is existing in the wind farm, in the following again the data of all machines is shown (Table 6 and Figure 7). The red marked cells in the table show individual annual results significant below the average performance of the group of machines. The green marked cells show the quite constant performance of the machine A4-5 (selected also in chapter 4.1.2 as reference machine).

**Table 6: Detailed production data of all Bonus 450 kW machines**

| Site | No. | Production (kWh) |           |           |           |           |           | 5 yr relative to group average |
|------|-----|------------------|-----------|-----------|-----------|-----------|-----------|--------------------------------|
|      |     | 2003             | 2004      | 2005      | 2006      | 2007      | 5 yr avg. |                                |
| A4-2 | D1  | 1.205.135        | 1.174.628 | 998.899   | 1.133.266 | 966.137   | 1.095.613 | 99%                            |
| A4-3 | D2  | 1.301.420        | 1.270.705 | 1.060.733 | 1.030.518 | 1.044.073 | 1.141.490 | 103%                           |
| A4-4 | D3  | 1.035.734        | 1.176.335 | 998.953   | 1.099.756 | 987.313   | 1.059.618 | 96%                            |
| A4-5 | D4  | 1.278.848        | 1.258.413 | 991.232   | 1.146.589 | 958.927   | 1.126.802 | 102%                           |

The annual production data show not many important losses of the individual machines. Only for machine A4-3 in 2006 and A4-4 in 2003 there is a remarkable production deficit compared to the other machines. The production of the machine A4-5 seems to be quite good throughout all the years, comparing to a constant high availability. The annual average production of all the machines is quite similar with only deviations in the range of -4% to +3% for the individual machines in comparison to the group average.

**Figure 7: 5 year production data of individual Bonus 450 kW machines**

By comparing the results in the red marked cells in Table 6 to the production data of other machines in the same year, an estimation of the loss of production for the respective machine in the year can be achieved. The losses are estimated at 170,000 kWh for machine A4-4 in 2003 and at 70,000 kWh for machine A4-3 in 2006.

Again the availability for the machines of this type is estimated in the same way as for the other types (cf. chapter 4.1.3.1). The detailed values are shown in Table 7. As a result the availability of this type of machines has been on average a high 96% throughout the last 5 years and has been quite constant over the time (the losses of the individual machines as discussed before can be seen as single events that cannot be avoided).

**Table 7: Estimated availability of the Bonus 450 kW machines**

| Site    | No. | Availability (rough estimate) |      |      |      |      | Average |
|---------|-----|-------------------------------|------|------|------|------|---------|
|         |     | 2003                          | 2004 | 2005 | 2006 | 2007 |         |
| A4-2    | D1  | 97%                           | 97%  | 97%  | 97%  | 97%  | 97%     |
| A4-3    | D2  | 97%                           | 97%  | 97%  | 91%  | 97%  | 96%     |
| A4-4    | D3  | 83%                           | 97%  | 97%  | 97%  | 97%  | 94%     |
| A4-5    | D4  | 97%                           | 97%  | 97%  | 97%  | 97%  | 97%     |
| Average |     | 94%                           | 97%  | 97%  | 95%  | 97%  | 96%     |

#### 4.1.3.4 Bonus 600 kW

In the wind farm there are 12 machines of this type operated. In the following only the data of some exemplary machines is discussed in detail.

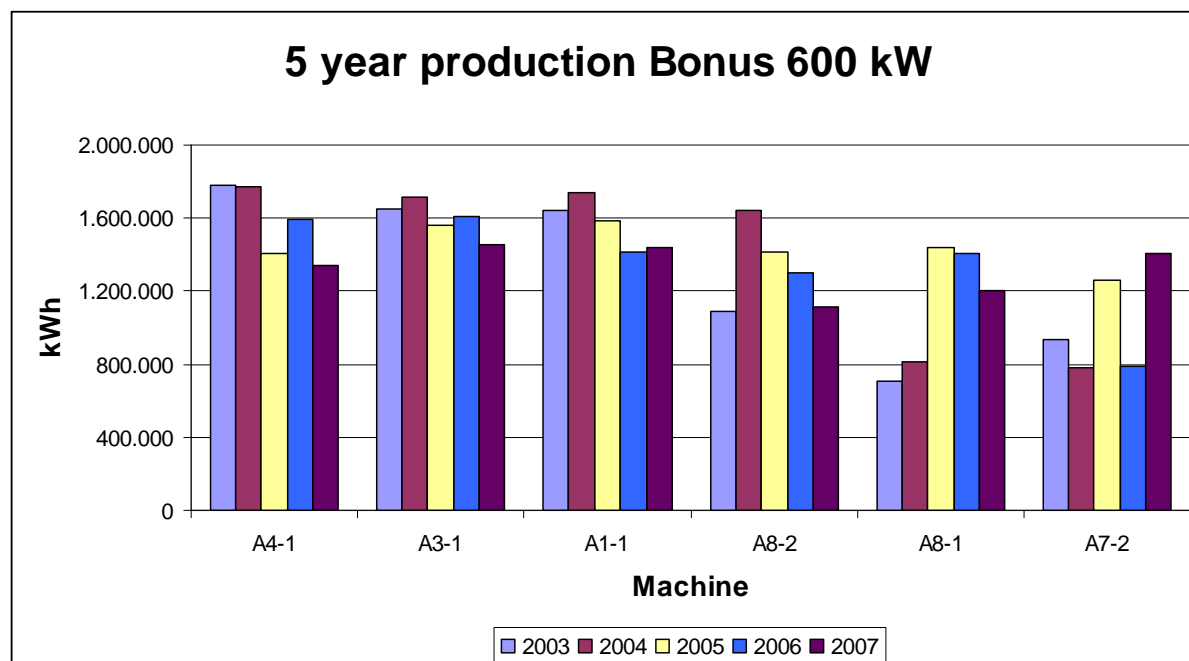
3 out of the machines, i.e. 25%, have shown quite good production data throughout the 5 years and it is concluded that they have produced at constant high availability. The average annual production of these machines for the 5 years was in the narrow range of 1,565,000 to 1,580,000 kWh per machine.

4 of the machines, i.e. 33%, have shown very low production data with an average for the 5 years of 1,033,000, 1,114,000, 1,312,000 and 1,363,000 kWh; this is equivalent to only approx. 66% to 87% of the production of the best performing machines.

The remaining 5 machines showed good performance during 1-4 years and bad performance during 1-4 years. Their average annual production is ranging from 1,508,000 kWh to 1,600,000 kWh, corresponding to 96% to 102% of the production of the machines with quite constant availability.

**Table 8: Production data of selected Bonus 600 kW machines**

| Site | No | Performance | Production (kWh) |           |           |           |           |           | 5 yr rel. to group avg. |
|------|----|-------------|------------------|-----------|-----------|-----------|-----------|-----------|-------------------------|
|      |    |             | 2003             | 2004      | 2005      | 2006      | 2007      | 5 yr avg. |                         |
| A4-1 | 4  | good        | 1.782.725        | 1.774.158 | 1.405.898 | 1.594.653 | 1.337.573 | 1.579.001 | 110%                    |
| A3-1 | 3  | normal      | 1.653.677        | 1.713.175 | 1.562.746 | 1.607.890 | 1.457.951 | 1.599.088 | 111%                    |
| A1-1 | 1  | normal      | 1.638.941        | 1.743.312 | 1.582.085 | 1.415.340 | 1.439.578 | 1.563.851 | 109%                    |
| A8-2 | 10 | bad         | 1.089.127        | 1.639.471 | 1.414.428 | 1.304.764 | 1.114.668 | 1.312.492 | 91%                     |
| A8-1 | 9  | bad         | 705.955          | 813.345   | 1.442.340 | 1.406.169 | 1.202.288 | 1.114.019 | 77%                     |
| A7-2 | 8  | bad         | 933.280          | 778.422   | 1.261.035 | 786.522   | 1.407.244 | 1.033.300 | 72%                     |

**Figure 8: 5 year production of selected individual Bonus 600 kW machines**

As seen with the other machine types, also for the Bonus 600 kW machines the Table 8 and Figure 8 show that the 2 machines with rather average performance and the 3 very bad ones have much varying production in different years. The losses of individual machines are significant and can be up to more than 50% of the annual theoretical production (for example for machine A8-1 in 2003 and 2004, also for machine A7-2 in 2004 and 2006). For the year 2007 in general the performance was similar to that of the year before and still worse than in the best year of the period, 2005.

The overall availability for all machines of this type (again assumed 97% for the machines with no obvious production losses in single years) and for the 3 worst performing ones is shown in Table 9. The calculation of losses and availability has been done in the same way as explained for the Bonus 300 kW machines in chapter 4.1.3.1.

**Table 9: Average availability (rough estimate) of selected Bonus 600 kW machines**

| Year                                 | 2003 | 2004 | 2005 | 2006 | 2007 | Average |
|--------------------------------------|------|------|------|------|------|---------|
| Average Availability of all machines | 80%  | 88%  | 96%  | 93%  | 93%  | 90%     |
| A8-2                                 | 62%  | 97%  | 97%  | 90%  | 81%  | 85%     |
| A8-1                                 | 40%  | 46%  | 97%  | 97%  | 81%  | 72%     |
| A7-2                                 | 53%  | 44%  | 88%  | 50%  | 97%  | 66%     |

As the losses for the worst performing machines of this type are also significant, it shall be demonstrated a little more detailed in which way these losses occur.

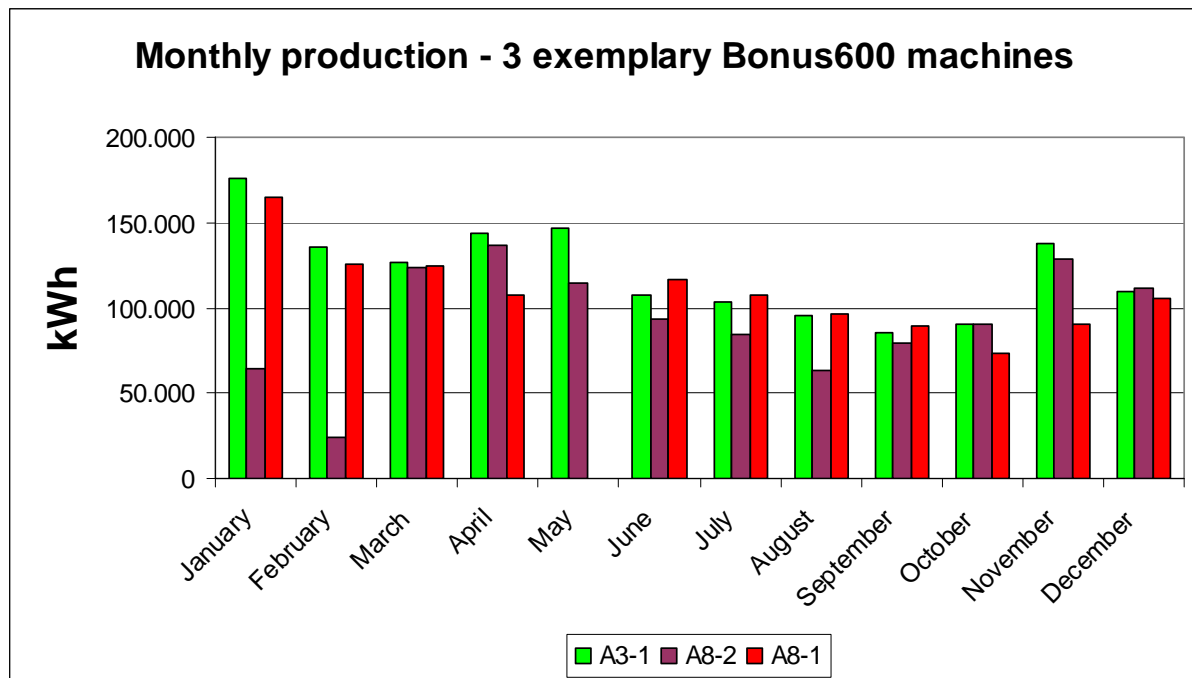
In Table 10 and Figure 9 the monthly data of 3 selected machines is shown. One machine was selected because of its good and constant performance throughout all the past 5 years, the 2 other because of their low production in 2007.

**Table 10: Monthly production data 2007 of selected Bonus 600 kW machines**

| Site        | A3-1      | A8-2      | A8-1      |
|-------------|-----------|-----------|-----------|
| Performance | good      | bad       | bad       |
| January     | 175.719   | 64.665    | 164.575   |
| February    | 135.386   | 23.768    | 125.695   |
| March       | 127.100   | 123.858   | 124.537   |
| April       | 143.295   | 136.694   | 107.300   |
| May         | 146.462   | 114.157   | 0         |
| June        | 107.155   | 93.738    | 116.783   |
| July        | 103.689   | 84.177    | 107.308   |
| August      | 95.640    | 63.574    | 96.306    |
| September   | 85.113    | 79.391    | 89.516    |
| October     | 90.591    | 90.295    | 73.565    |
| November    | 137.801   | 129.006   | 90.903    |
| December    | 110.000   | 111.345   | 105.801   |
| Total Year  | 1.457.951 | 1.114.668 | 1.202.288 |

As can be seen, the loss of production occurs either by long down times related to one problem (as for machine A8-1 in April and May) or it is related to erratic behaviour over longer time and with no distinctive long complete outage (as for machine A8-2). The latter effect is most probably related to not diligent research for failure reasons and working on repairing symptoms rather than the real fault reasons.

Nevertheless these worse machines may operate in single months very well, as seen in March and December where all 3 machines reach the same production levels.

**Figure 9: Diagram of monthly production data, Bonus 600 kW**

#### 4.1.3.5 Vestas 600 kW

The type of machines with most installations in the wind farm is Vestas V42. Of this type there are 66 machines. In the following only the data of some exemplary machines is discussed in detail.

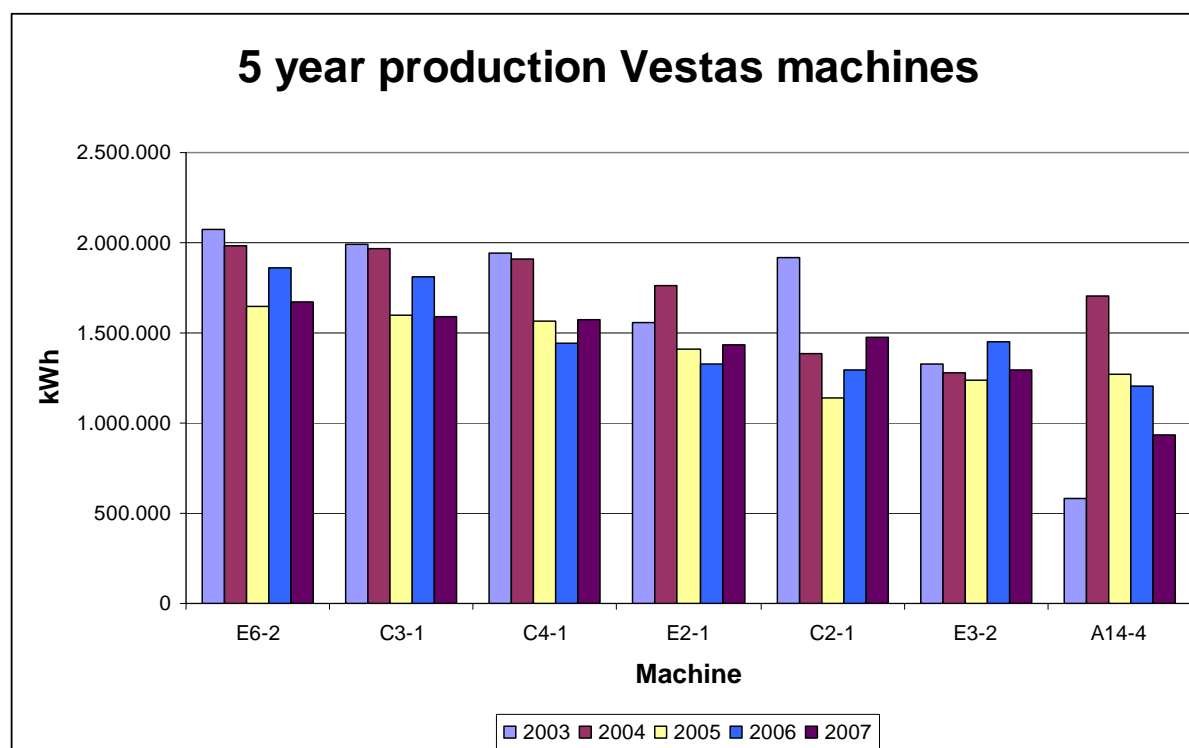
Only 12 out of the machines, i.e. 18%, have shown quite good production data throughout the 5 years and it is concluded that they have produced at constant high availability. The average annual production of these machines for the 5 years was in the range of 1,690,000 to 1,850,000 kWh per machine.

21 of the machines, i.e. 32%, have shown very low production data with an average for the 5 years between 1,140,000 kWh and 1,485,000 kWh, i.e. equivalent to only approx. 65% to 84% of the production of the best performing machines.

The remaining 33 machines, this is half of the total number of this type, showed good performance during 1-4 years and bad performance during 1-4 years. Their average annual production is ranging from 1,500,000 kWh to 1,750,000 kWh, corresponding to 85% to 99% of the production of the machines with quite constant availability.

**Table 11: Production data of selected Vestas 600 kW machines**

| Site  | No. | Performance | Production (kWh) |           |           |           |           | 5 yr avg. | 5 yr rel. to group avg. |
|-------|-----|-------------|------------------|-----------|-----------|-----------|-----------|-----------|-------------------------|
|       |     |             | 2003             | 2004      | 2005      | 2006      | 2007      |           |                         |
| E6-2  |     | good        | 2.077.398        | 1.980.651 | 1.647.406 | 1.861.792 | 1.671.513 | 1.847.752 | 117%                    |
| C3-1  |     | good        | 1.991.133        | 1.963.387 | 1.597.653 | 1.815.055 | 1.588.782 | 1.791.202 | 114%                    |
| C4-1  |     | normal      | 1.938.583        | 1.912.759 | 1.567.142 | 1.439.743 | 1.571.826 | 1.686.011 | 107%                    |
| E2-1  |     | normal      | 1.560.115        | 1.765.055 | 1.412.474 | 1.326.701 | 1.436.622 | 1.500.193 | 95%                     |
| C2-1  |     | bad         | 1.916.579        | 1.387.679 | 1.143.128 | 1.295.456 | 1.472.060 | 1.442.980 | 92%                     |
| E3-2  |     | bad         | 1.326.713        | 1.278.356 | 1.236.201 | 1.449.208 | 1.298.671 | 1.317.830 | 84%                     |
| A14-4 |     | bad         | 578.797          | 1.707.548 | 1.274.194 | 1.208.838 | 937.074   | 1.141.290 | 72%                     |

**Figure 10: 5 year production of selected individual Vestas 600 kW machines**

Again, as with the other machine types, also for the Vestas 600 kW machines the production of the average and bad performing machines varies much between different years (cf. Table 11 and Figure 10). The losses of individual machines are significant and can be far more than 50% of the annual theoretical production (for example for machine A14-4 in 2003). For the year 2007 in general the performance was slightly better than the two years before, but still worse than in the best year of the period, 2004.

The overall availability for all machines of this type (again assumed 97% for the machines with no obvious production losses in single years) and for the 3 worst performing ones is shown in Table 12. The calculation of losses and availability has been done in the same way as explained for the Bonus 300 kW machines in chapter 4.1.3.1.

**Table 12: Average availability (rough estimate) of selected Vestas 600 kW machines**

| Year                                 | 2003 | 2004 | 2005 | 2006 | 2007 | Average |
|--------------------------------------|------|------|------|------|------|---------|
| Average Availability of all machines | 92%  | 94%  | 89%  | 92%  | 93%  | 92%     |
| C2-1                                 | 97%  | 75%  | 73%  | 81%  | 97%  | 85%     |
| E3-2                                 | 75%  | 73%  | 83%  | 97%  | 97%  | 85%     |
| A14-4                                | 33%  | 97%  | 85%  | 82%  | 67%  | 73%     |

As also for this type of machine the losses for the worst performing machines are significant, it shall be demonstrated a little more detailed in which way these losses occur.

In Table 13 and Figure 11 the monthly data of 3 selected machines is shown. One machine was selected because of its good and constant performance throughout all the past 5 years, the 2 other because of their low production in 2007.

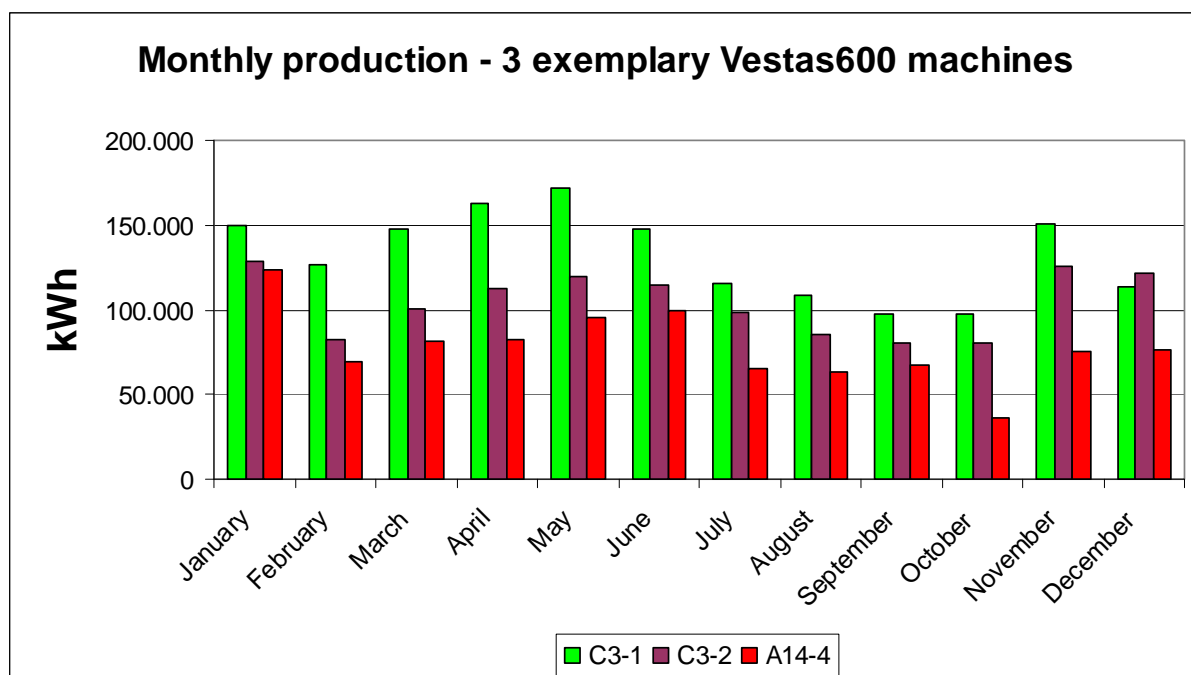
**Table 13: Monthly production data 2007 of selected Vestas 600 kW machines**

| Site        | C3-1      | C3-2      | A14-4   |
|-------------|-----------|-----------|---------|
| Performance | good      | bad       | bad     |
| January     | 149.511   | 128.981   | 123.735 |
| February    | 126.240   | 82.467    | 69.634  |
| March       | 147.782   | 100.049   | 81.529  |
| April       | 162.575   | 112.191   | 82.314  |
| May         | 171.420   | 119.547   | 95.889  |
| June        | 147.299   | 114.331   | 99.759  |
| July        | 115.245   | 98.945    | 65.357  |
| August      | 108.707   | 85.741    | 63.515  |
| September   | 97.957    | 80.450    | 67.133  |
| October     | 97.206    | 80.259    | 36.580  |
| November    | 150.797   | 125.847   | 75.136  |
| December    | 114.043   | 121.342   | 76.492  |
| Total Year  | 1.588.782 | 1.250.150 | 937.074 |



For the Vestas machines the loss of production occurs nearly always as an under production in a month, but rarely with a long complete outage (not shown here, but it exists for other machines of this type and other years).

**Figure 11: Diagram of monthly production data, Vestas 600 kW**



#### 4.1.3.6 NEG Micon 750 kW

The NEG Micon machines are in the Dabancheng wind farm the type with highest capacity and shortest operation time (commissioned in early 2003). There are 10 machines of this type. In the following only the data of some exemplary machines is discussed in detail.

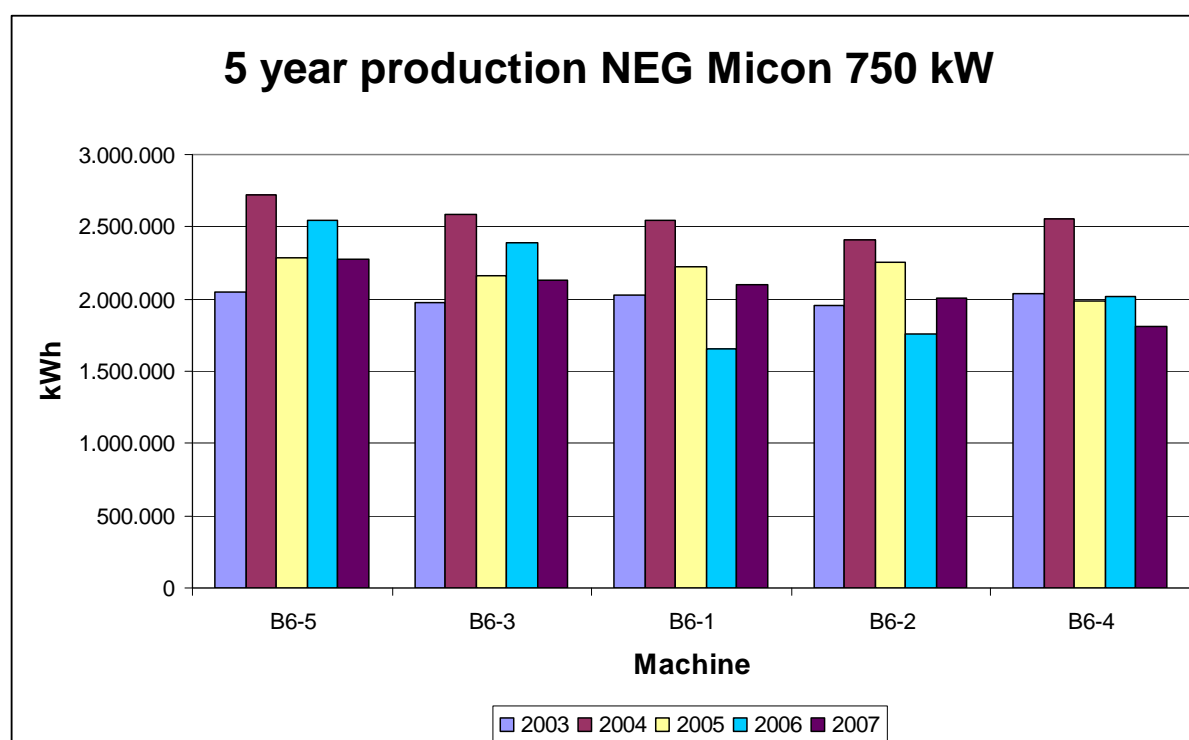
3 of the machines, i.e. 30%, have shown quite good production data throughout the nearly 5 years and it is concluded that they have produced at constant high availability. The average annual production of these machines for the 4 complete years 2004 – 2007 was in the range of 2,410,000 to 2,500,000 kWh per machine.

Also 3 of the machines (30%) have shown low production data with an average for the 4 years between 2,090,000 kWh and 2,130,000 kWh, i.e. equivalent to only approx. 86% of the production of the best performing machines.

The remaining 4 machines (40%) of this type, showed good performance during 2-4 years and bad performance during 1-3 years. Their average annual production is ranging from 2,280,000 kWh to 2,520,000 kWh, corresponding to 93% to 103% of the production of the machines with quite constant availability.

**Table 14: Production data of selected NEG Micon 750 kW machines**

| Site | No. | Performance | Production (kWh) |           |           |           |           | 5 yr avg. | 5 yr rel. to group avg. |
|------|-----|-------------|------------------|-----------|-----------|-----------|-----------|-----------|-------------------------|
|      |     |             | 2003             | 2004      | 2005      | 2006      | 2007      |           |                         |
| B6-5 |     | good        | 2,046,556        | 2,717,810 | 2,281,869 | 2,546,280 | 2,271,452 | 2,454,353 | 105%                    |
| B6-3 |     | normal      | 1,980,123        | 2,587,248 | 2,165,902 | 2,390,772 | 2,125,927 | 2,317,462 | 99%                     |
| B6-1 |     | bad         | 2,029,121        | 2,539,981 | 2,222,224 | 1,652,506 | 2,096,662 | 2,127,843 | 91%                     |
| B6-2 |     | bad         | 1,955,317        | 2,409,631 | 2,258,370 | 1,763,590 | 2,002,983 | 2,108,644 | 90%                     |
| B6-4 |     | bad         | 2,036,859        | 2,559,267 | 1,990,637 | 2,019,708 | 1,809,325 | 2,094,734 | 90%                     |

**Figure 12: 5 year production of selected individual NEG Micon 750 kW machines**

Again, the production of the average and bad performing machines differs in the different years very much from the production of the good machines (cf. Table 14 and Figure 12). The losses of individual machines are remarkable, but not as high as with the machines of other types in the wind farm.

The overall availability for all machines of this type (again assumed 97% for the machines with no obvious production losses in single years) and for the 3 worst performing ones is shown in Table 15. The calculation of losses and availability has been done in the same way as explained for the Bonus 300 kW machines in chapter 4.1.3.1.

**Table 15: Average availability (rough estimate) of selected NEG Micon 750 kW machines**

| Year                                 | 2003 | 2004 | 2005 | 2006 | 2007 | Average |
|--------------------------------------|------|------|------|------|------|---------|
| Average Availability of all machines | 97%  | 97%  | 96%  | 89%  | 94%  | 95%     |
| B6-1                                 | 97%  | 97%  | 97%  | 67%  | 97%  | 91%     |
| B6-2                                 | 97%  | 90%  | 97%  | 72%  | 91%  | 89%     |
| B6-4                                 | 97%  | 97%  | 89%  | 82%  | 83%  | 90%     |

For these machines, it strikes that during the first two years the availability of all machines was very good and then dropped extremely in the next two years. This is most probably related to the manufacturer being responsible for the maintenance during the warranty period (assumed to have been 1-3 years). In 2007 the availability reached a quite acceptable level again, maybe this is a result of the local operator staff acquiring more knowledge and improving the skills on the maintenance and repair works.

#### 4.1.4 Summary and overview on the availability and production of all machines

After analyzing and discussing the development of production and availability of the individual machines of the different types in the previous chapter, now some main findings shall be presented in an overview.

**Table 16: Overview on the availability of the machine types**

| Year                    | 2003         | 2004         | 2005         | 2006         | 2007         | Average      |
|-------------------------|--------------|--------------|--------------|--------------|--------------|--------------|
| Bonus 300 kW            | 88%          | 93%          | 89%          | 97%          | 86%          | <b>90%</b>   |
| Nordtank 300 kW         | 91%          | 94%          | 95%          | 93%          | 96%          | <b>94%</b>   |
| Bonus 450 kW            | 94%          | 97%          | 97%          | 95%          | 97%          | <b>96%</b>   |
| Bonus 600 kW            | 80%          | 88%          | 96%          | 93%          | 93%          | <b>90%</b>   |
| Vestas 600 kW           | 92%          | 94%          | 89%          | 92%          | 93%          | <b>92%</b>   |
| NEG Micon 750 kW        | 95%          | 96%          | 96%          | 89%          | 94%          | <b>94%</b>   |
| <b>Weighted Average</b> | <b>90.8%</b> | <b>93.7%</b> | <b>91.8%</b> | <b>92.3%</b> | <b>93.6%</b> | <b>92.4%</b> |

Table 16 shows the availability figures that had been presented for the different machine types in the chapters before. In order to get an impression on the availability of the total wind farm, the availability of the different types has been weighted with the number of machines of the same type in the wind

farm. For the complete wind farm the availability is rather low with on average 92.5% over the last 5 years, but the trend for only the last 3 years is promising.

**Table 17: Production overview for the wind farm**

| Type              | 2003               | 2004               | 2005               | 2006               | 2007               | Average            |
|-------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|
| <b>Bonus 300</b>  | 3.013.190          | 3.137.822          | 2.608.402          | 2.914.852          | 2.378.472          | <b>2.810.548</b>   |
| <b>Nordtank</b>   | 21.502.777         | 21.607.997         | 19.517.834         | 19.829.157         | 18.436.762         | <b>20.178.905</b>  |
| <b>Bonus 450</b>  | 4.821.137          | 4.880.081          | 4.049.817          | 4.410.129          | 3.956.449          | <b>4.423.523</b>   |
| <b>Bonus 600</b>  | 17.220.655         | 18.709.214         | 17.351.893         | 17.361.985         | 15.748.400         | <b>17.278.429</b>  |
| <b>Vestas 600</b> | 115.995.708        | 114.955.908        | 92.213.069         | 102.268.119        | 94.669.394         | <b>104.020.439</b> |
| <b>NEG 750</b>    | 19.815.118         | 26.250.778         | 22.615.123         | 23.003.332         | 21.464.887         | <b>23.333.530</b>  |
| <b>Total</b>      | <b>182.368.585</b> | <b>189.541.799</b> | <b>158.356.137</b> | <b>169.787.574</b> | <b>156.654.364</b> | <b>172.045.374</b> |

**Table 18: Estimated Losses for the wind farm**

| Type              | 2003              | 2004             | 2005             | 2006             | 2007             | Average          |
|-------------------|-------------------|------------------|------------------|------------------|------------------|------------------|
| <b>Bonus 300</b>  | 308.167           | 134.960          | 234.463          | 0                | 304.223          | <b>218.598</b>   |
| <b>Nordtank</b>   | 1.417.766         | 689.617          | 410.902          | 852.867          | 192.050          | <b>644.008</b>   |
| <b>Bonus 450</b>  | 153.866           | 0                | 0                | 92.845           | 0                | <b>46.078</b>    |
| <b>Bonus 600</b>  | 3.659.389         | 1.913.442        | 180.749          | 746.752          | 677.351          | <b>1.343.878</b> |
| <b>Vestas 600</b> | 6.304.115         | 3.668.806        | 8.288.815        | 5.558.050        | 4.071.802        | <b>5.653.285</b> |
| <b>NEG 750</b>    | 479.881           | 181.460          | 235.574          | 2.067.715        | 685.050          | <b>743.588</b>   |
| <b>Total</b>      | <b>12.323.184</b> | <b>6.588.285</b> | <b>9.350.503</b> | <b>9.318.229</b> | <b>5.930.475</b> | <b>8.649.434</b> |

In Table 17 an overview on the production of the complete wind farm and for all machines of the different types is given and Table 18 shows estimated losses. This loss estimation is done in a quite simple way and is intended as a first step towards an understanding of the potential for optimization in the wind farm. The background for the loss estimations are the real production and the estimated availabilities for all types of machines. Then an estimation of the theoretical potential production is calculated by assuming that all machines would have reached an availability of 97%. Finally the estimated loss is calculated as difference between this estimated theoretical and the registered real production.

As a result of the presented availability and loss figures it shall be pointed out that by far the highest part of the losses in 2007 was related to the machines of Vestas 600 kW type (68.7% of the estimated loss of the wind farm), the NEG Micon 750 kW type (11.6% of the estimated loss) and the Bonus 600 kW type (11.4% of the losses). For the Vestas type machines this can easily be understood because they are installed with the highest number in the wind farm. For the NEG Micon 750 kW machines it is mainly related to their high unit capacity and high production potential. For the Bonus 600 kW machines it is explained by a mixture of the low availability, the unit capacity and the number of machines in the wind farm.

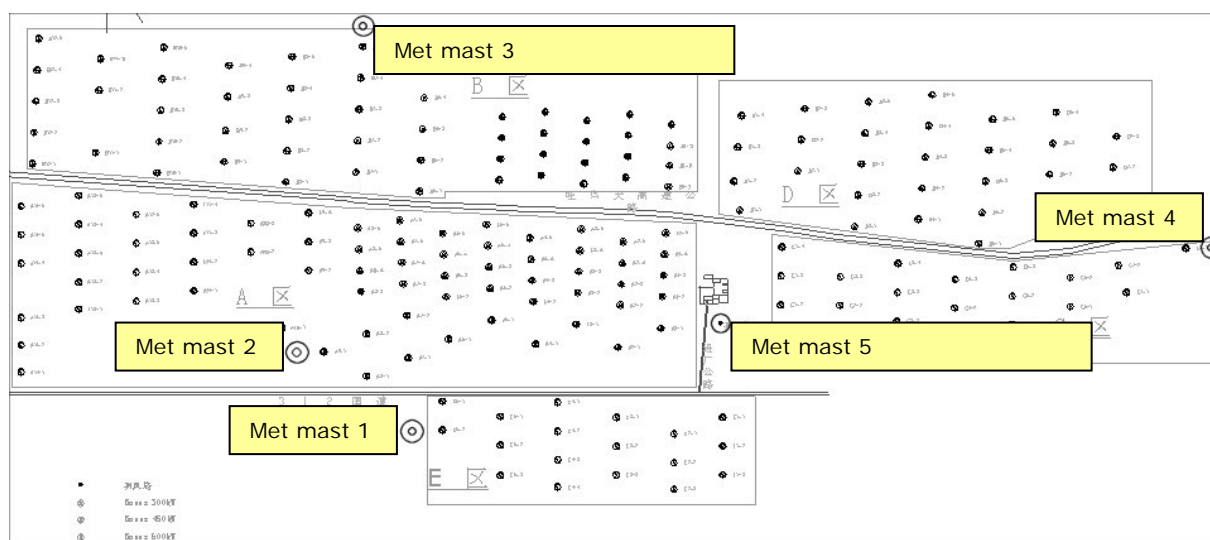
Concerning a strategy, it arises from the calculations that it would be worth to concentrate with improvement measures at highest priority on the Vestas machines in order to tap this very big potential for loss reduction.

#### 4.1.5 Comparison of production data with calculations based on measurements

In the first phase of the Performance Improvement Project measurement masts have been installed at the end of the year 2005 with the intention to verify the production in the wind farm in relation to the wind speeds and to check exemplary the power curve of individual turbines. The detailed evaluations of a power curve would need a substantial extended effort regarding operational data storage (10 minutes time series of the WEC production data and these synchronized to the met mast data) and analysis and have not been required explicitly in the current project.

Currently 5 met masts of different heights, with different measurement heights and for different measured parameters are installed in the wind farm. Their location is shown in Figure 13. In Table 19 the data coverage rate for the past months is shown. The months where more than 90% of the time is covered are marked green. The 90% threshold refers to the necessary data coverage for a reliable data evaluation.

**Figure 13: Location of the met masts in Dabancheng**



**Table 19: Availability of data of the individual met masts in Dabancheng**

| Period         | Xinjiang1 | Xinjiang2 | Xinjiang3 | Xinjiang4 | Xinjiang5 |
|----------------|-----------|-----------|-----------|-----------|-----------|
| May 2006       | 99%       | 100%      | 99%       | 99%       | 99%       |
| June 2006      | 100%      | 100%      | 100%      | 100%      | 100%      |
| July 2006      | 100%      | 100%      | 100%      | 100%      | 100%      |
| August 2006    | 100%      | 100%      | 100%      | 100%      | 100%      |
| September 2006 | 100%      | 100%      | 100%      | 100%      | 100%      |
| October 2006   | 100%      | 100%      | 100%      | 100%      | 100%      |
| November 2006  | 100%      | 100%      | 100%      | 100%      | 100%      |
| December 2006  | 100%      | 100%      | 100%      | 100%      | 100%      |
| January 2007   | 100%      | 100%      | 100%      | 100%      | 50%       |
| February 2007  | 100%      | 100%      | 100%      | 100%      | 0%        |
| March 2007     | 100%      | 100%      | 100%      | 100%      | 0%        |
| April 2007     | 100%      | 100%      | 100%      | 100%      | 0%        |
| May 2007       | 100%      | 100%      | 100%      | 100%      | 0%        |
| June 2007      | 1%        | 0%        | 1%        | 1%        | 62%       |
| July 2007      | 0%        | 0%        | 0%        | 0%        | 100%      |
| August 2007    | 0%        | 0%        | 0%        | 0%        | 100%      |
| September 2007 | 38%       | 0%        | 0%        | 0%        | 100%      |
| October 2007   | 100%      | 0%        | 0%        | 0%        | 100%      |
| November 2007  | 100%      | 0%        | 0%        | 0%        | 100%      |
| December 2007  | 100%      | 0%        | 0%        | 0%        | 100%      |
| January 2008   | 0%        | 75%       | 0%        | 0%        | 100%      |
| February 2008  | 0%        | 100%      | 0%        | 0%        | 100%      |
| March 2008     | 0%        | 100%      | 0%        | 0%        | 100%      |
| April 2008     | 0%        | 8%        | 0%        | 0%        | 8%        |
| May 2008       | 0%        | 100%      | 0%        | 0%        | 100%      |
| June 2008      | 0%        | 100%      | 0%        | 0%        | 100%      |
| July 2008      | 0%        | 0%        | 0%        | 0%        | 100%      |
| August 2008    | 0%        | 89%       | 0%        | 0%        | 89%       |
| September 2008 | 0%        | 100%      | 0%        | 0%        | 100%      |
| October 2008   | 0%        | 0%        | 0%        | 0%        | 0%        |

It can be seen that complete data of 4 masts is available for 13 consecutive months, and additionally data of a 5<sup>th</sup> mast is available for 8 months in parallel. The period is May 2006 to May 2007 for the 4 masts and May to December 2006 for the 5<sup>th</sup> one. Out of this data only the data for 12 months have been evaluated in detail, as the energy production of a one year period is regarded as the most interesting (the annual energy production is normally the base for economic analyses, etc.). Additionally some periods of 1 to 3 complete months is available for 4 masts and an additional period of 9 consecutive months for the 5<sup>th</sup> mast is existing. However a detailed analysis of these separate periods seems to be of not much interest.

A check of the provided data showed some noticeable problems for individual time periods, especially the following listed ones:

- At met mast 1 one of the two anemometers at 10 m height shows problems at starting-up, which may be caused by a bearing problem. The wind direction of this mast is not reliable, because it shows signs of the mounting boom sometimes moving under the force of high wind.
- At met mast 2 one of the two anemometers at 40 m height is not working at all. The wind direction at this mast is not reliable because the mounting boom is moving due to the force of high wind speeds.
- The wind direction at met mast 3 is not completely reliable. A considerable offset in comparison to the wind direction measurements at the other met masts has been found. Maybe the boom is misaligned. Additionally it seems that the mounting boom is moving horizontal due to high wind speed forces. At the site visit in February the met mast was out of order, probably because of a power supply breakdown. The local technician assumed that the battery was empty, but he was not able to change it. Furthermore the solar module was covered with dirt.
- At met mast 4 some short standstills of anemometers occurred, possibly caused by icing. It cannot be excluded that the mounting boom of the wind vane is moving and causing changes in direction offset. At the site visit also this met mast was out of order, probably because of a power supply breakdown. The technician assumed that the battery was empty, but he was not able to change it. Furthermore also this solar module was covered with dirt.
- At met mast 5 one of the two anemometers at 40 m height is out of order since March 2007. One of the two anemometers at 10 m height shows problems at starting-up, which may be caused by a bearing problem. The wind direction at 60 m is not reliable and it can be assumed that the corresponding mounting boom sometimes is moving under the force of high wind speeds. The recordings of air temperature, relative humidity and air pressure can not be used, because they are all complete out of a reasonable range. The number of the wind sensors at the met mast counted during the site visit in February is about the double number of sensors which are recorded and it was not possible to clarify which sensors are recorded.
- Considerable deviations have been found in the wind directions recorded at the same time at different met masts. This underlines that the mounting booms sometimes are turned by heavy wind forces and it could not be figured out, what wind direction recording was the most reliable or "correct" one.

No documentation of the met masts was made available. An exact allocation of the single sensors to the recorded data channels is not possible. It can not be stated if the anemometers have been calibrated and if the calibrations have been applied to the data recording. The used anemometer type NRG Max40 has a big uncertainty in complex terrain and tends to have an inappropriate long-term behavior.

No maintenance works are performed at the met masts. Not even the solar cells were cleaned from dust and dirt. No data checks to ensure liability of sensor function and recorded data could be undertaken.

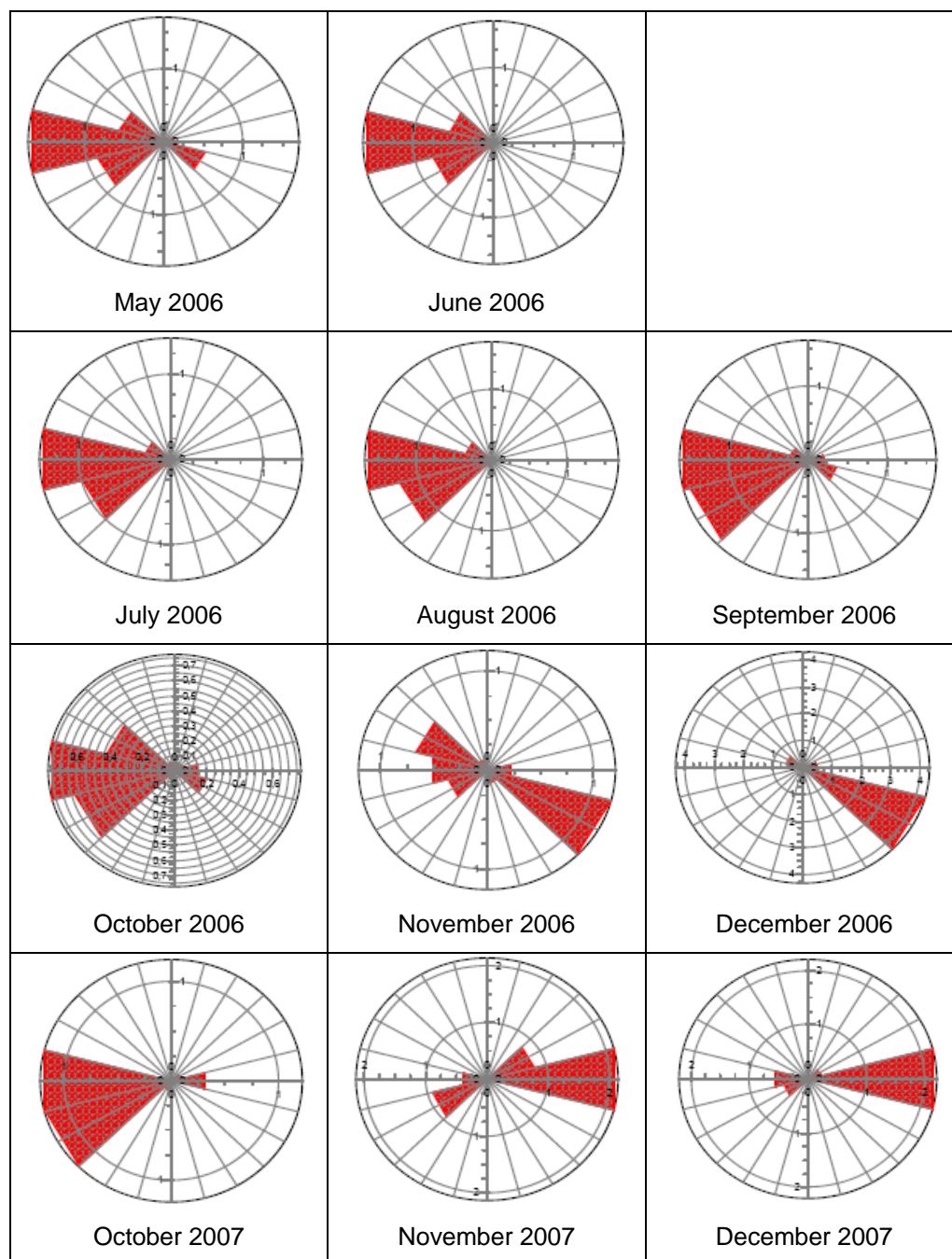
- At last, for one met mast different sets of data have been provided for the same time period. The allocation of the data to a certain met mast or the data treatment seems to be faulty.

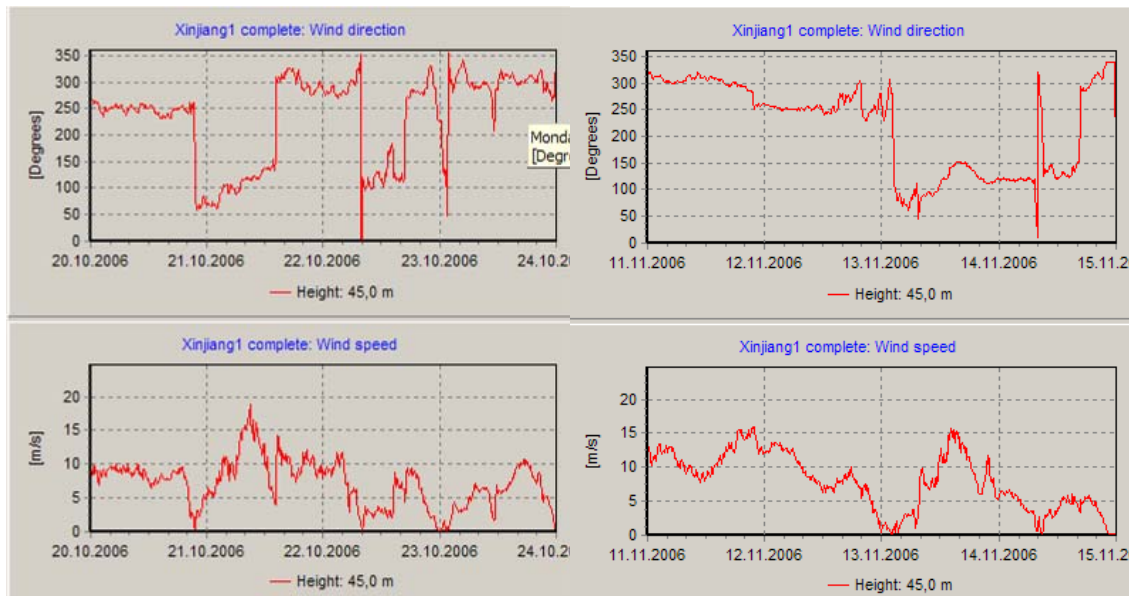
In the following some observations on the direction data shall be discussed. In Table 20 the wind energy roses calculated with the software package WAsP are shown for individual months. It can be seen that from May 2006 to October 2006 the prevailing winds from west tend to rotate a little bit to the south. Especially in September 2006 there is an important contribution from the south-western sector. As the wind regime in the Dabancheng wind farm is very much influenced by the mountain ranges in the south and the north, which create a sort of tunnel, it is doubted whether this observed rotation in the wind directions is real and it is assumed that it could be also due to a moving boom of the wind vane. Supported is this assumption by a similar effect seen in the last quarter of 2007. Compared with the same months of 2006 the wind directions seem to have rotated by approx. 30 degree counter-clockwise.

To investigate this assumption in detail, registered time series of wind speed and direction have been checked. In Figure 14 two sequences of 4 days length are shown. The first starts on 20.10.2006 with winds apparently from southwest (250 degree). In the evening the wind shifts to eastern directions – this is quite typical at this site that the wind shifts its direction and due to the mountain ranges in south and north, it is seen as plausible. However, the easterly winds seem to turn to the south – from approx. 50 degree in the evening of the 20.10. to approx. 150 degree in the afternoon of the next day. As this apparent rotation of the wind direction is absolutely in parallel to the increasing wind (from nearly 0 to more than 15 m/s), it is concluded that very probable the boom of the wind vane is turning here and thus giving false directions for a long time. As the wind shifts back to westerly direction in the evening of the 21.10. the new wind direction is also rotated by approx. 50 degree compared to the wind direction of two days before. Then there is a certain down trend in the wind direction, but probably due to the winds not very strong and the time not long enough, it is not going back the 50 degrees. But then, two weeks later, on the 12.11. (shown on the right) when the wind is getting to around 15 m/s at one moment, there is this change of the winds by nearly 50 degrees.

For other periods in the shown time series (22. to 23. October and 13. to 14. November) for the wind shifting to eastern directions the same phenomenon is observed. This observation of wind directions “shifting” by approx. 40-50 degrees is quite the same as seen in the energy roses; but in the energy roses the effect is a little bit absorbed by the sector width of 30 degrees.



**Table 20: Dabancheng: Energy roses for individual months**

**Figure 14: Dabancheng: Exemplary Time series of wind speed and direction**

In summary the data of the met masts cannot be trusted for the whole time. For the wind directions in principle, it would be possible to apply much effort to sort out which of the deviating values are the more logic ones for all time periods, but this would be very time consuming.

Furthermore the uncertainty of the measurements (amongst others due to not known calibrated sensor characteristics) is of an order which does not allow absolute evaluations and comparisons. It is possible to use the wind speed data in some degree for relative comparisons. Hence from the available wind speed data a theoretical monthly energy production was calculated and compared with the real observed production.

In the calculation of these energy yields the power curve of a Vestas 600 kW machine, the type of the biggest share of machines in the wind farm, was applied. Although some of the masts are adjacent to machines of other types (or adjacent to machines of different types), this single machine type was chosen in order to have also an indication of the differences in the wind potential throughout the wind farm.

The monthly theoretical energy yields have been calculated from time series of wind speeds under use of turbine type dependent (measured) power curve. For that purpose wind speed has been averaged and inter- or extrapolated from anemometers which were adjacent to the hub height of the related turbine type. Because of extreme variety of air density throughout the year at the site (which is caused by the extreme temperature differences) a different air density has to be considered for each month. Long-term data from proximate meteorological stations were used to calculate the air density and applied for the energy yield calculations.

These calculated theoretical yields are presented in Table 21. The average total of the 4 masts for a period of 12 months is roughly 1,890,000 kWh, with the 4 locations being between -8.1% and +12% of the average.

Same wind speeds in different months may result in different theoretical yields and the theoretical yield is regarded as a better parameter for understanding the wind potential. Nevertheless, as an indication for one of the masts the corresponding wind speed is shown in Table 22 (the wind speeds at the other masts are not so much different and are thus not shown).

**Table 21: Theoretical Yields for a Vestas 600 at the 5 met mast positions in Dabancheng**

| Month          | Yield 1 (kWh)    | Yield 2 (kWh)    | Yield 3 (kWh)    | Yield 4 (kWh)    | Yield 5 (kWh) |
|----------------|------------------|------------------|------------------|------------------|---------------|
| May 2006       | 178,858          | 174,629          | 204,825          | 199,486          | 172,469       |
| June 2006      | 138,154          | 127,493          | 152,349          | 158,543          | 124,791       |
| July 2006      | 134,367          | 124,504          | 145,970          | 141,168          | 122,233       |
| August 2006    | 149,657          | 142,496          | 157,060          | 146,323          | 135,877       |
| September 2006 | 171,022          | 176,486          | 208,428          | 166,765          | 173,460       |
| October 2006   | 107,134          | 102,616          | 121,985          | 96,297           | 105,048       |
| November 2006  | 136,564          | 139,457          | 213,299          | 187,747          | 170,374       |
| December 2006  | 140,893          | 138,485          | 194,763          | 181,691          | 167,656       |
| January 2007   | 186,831          | 178,359          | 226,893          | 208,101          |               |
| February 2007  | 127,167          | 125,495          | 157,033          | 135,769          |               |
| March 2007     | 166,964          | 164,336          | 163,032          | 155,743          |               |
| April 2007     | 138,236          | 137,612          | 167,906          | 146,431          |               |
| <b>Total</b>   | <b>1,775,847</b> | <b>1,731,968</b> | <b>2,113,541</b> | <b>1,924,064</b> |               |

**Table 22: Wind speed at Mast 2 (45 m height) in the Dabancheng wind farm**

| <b>Month</b>          | <b>Speed Mast 2 (m/s)</b> |
|-----------------------|---------------------------|
| <b>May 2006</b>       | 8.5                       |
| <b>June 2006</b>      | 7.7                       |
| <b>July 2006</b>      | 7.5                       |
| <b>August 2006</b>    | 7.7                       |
| <b>September 2006</b> | 8.6                       |
| <b>October 2006</b>   | 6.2                       |
| <b>November 2006</b>  | 7.2                       |
| <b>December 2006</b>  | 7.0                       |
| <b>January 2007</b>   | 8.3                       |
| <b>February 2007</b>  | 6.8                       |
| <b>March 2007</b>     | 7.6                       |
| <b>April 2007</b>     | 7.6                       |
| <b>Average</b>        | <b>7.5</b>                |

It has to be considered that wake effects in the wind farm have an influence on the wind measurements and that this influence is not absolutely comparable to a turbine which would be positioned at the position of the met mast. For the following it is, nevertheless, assumed that the influence would be the same.

Furthermore, the theoretical energy yields do not include production losses according the availability of the machines. To consider this effect, a deduction of 5% from the theoretical energy yield of a single machine is applied. This means that according to the wind data the machines should have reached an average production of 1,795,000 kWh (95% of the above mentioned 1,890,000 kWh average of the 4 masts).

The real average production of all the machines of Vestas 600 type in the relevant period has been 1,470,000 kWh, i.e. 81.9% of the average theoretical yield calculated with the measured wind data. However, if correcting the yields for all months with obviously high losses, then the average corrected production of all machines increases to 1,539,000 kWh, i.e. 85.7% of the average theoretical yield. Additionally, the best production of a single machine in the relevant period was 1,794,000 kWh and 7 further machines reached more than 1,700,000 kWh, i.e. the yield of those machines was quite close to the expectation according to the wind measurements, showing that the machines were in principle able to achieve the theoretical production and resulting in the conclusion that the power curve of these machines should have been according to the specifications.

Although there is a significant difference in the theoretical yields of mast M1 (south-west border) and M4 (east border, 8.3% higher theoretical production than for M1), the difference in the real production of the best neighboring machines in that period is less distinctive – approx. 1.73 million kWh for the machines E6-1 and E6-2 in the south-west corner and approx. 1.79 million kWh for the machines C7-1 and C7-2 in the east area, only 3% higher. Here, it has to be considered that the uncertainty in the meteorological data is quite high and that thus the appearing difference in the calculated theoretical yields may be misleading. Thus the smaller difference in the real production values is seen as acceptable.

In Table 23 the real production data of the closest machines to the masts 1 and 4 are shown in parallel to the theoretical production. It can be seen that the real data correlate very well with the theoretical yields. Some deviating data may be explained with not identical time periods or minor faults in data collection (for the machine E6-2 it is assumed that some production of November 06 is registered as being in December; i.e. the November value has been taken a few days before the end of the month). The most important deviations that are not explained in this way are found for the machine C7-1 in August 2006 (might be indication of a fault of the machines in that month) and for C7-1 and C7-2 in November 2006.

The comparison of the production data of the 4 machines with the data of other neighboring machines shows no significant under production for the 4 machines in the period and it is concluded that an assumption of 97-99% availability for this period is justified.

**Table 23: Theoretical and Real Yields for 2 met mast positions in Dabancheng**

| Month          | Mast 1<br>(kWh)  | E6-1<br>(kWh)    | E6-2<br>(kWh)    | Mast 4<br>(kWh)  | C7-1<br>(kWh)    | C7-2<br>(kWh)    |
|----------------|------------------|------------------|------------------|------------------|------------------|------------------|
| May 2006       | 178,858          | 165.509          | 168.794          | 199,486          | 182,644          | 181,835          |
| June 2006      | 138,154          | 127.214          | 133.487          | 158,543          | 138,063          | 144,391          |
| July 2006      | 134,367          | 120.404          | 116.999          | 141,168          | 130,101          | 131,475          |
| August 2006    | 149,657          | 122.281          | 121.007          | 146,323          | 98,565           | 119,620          |
| September 2006 | 171,022          | 162.097          | 169.062          | 166,765          | 165,372          | 153,781          |
| October 2006   | 107,134          | 111.322          | 114.132          | 96,297           | 105,655          | 92,653           |
| November 2006  | 136,564          | 138.294          | 123.397          | 187,747          | 148,570          | 149,696          |
| December 2006  | 140,893          | 150.295          | 167.866          | 181,691          | 177,794          | 177,038          |
| January 2007   | 186,831          | 176.768          | 166.741          | 208,101          | 181,270          | 193,547          |
| February 2007  | 127,167          | 127.923          | 125.621          | 135,769          | 134,587          | 130,295          |
| March 2007     | 166,964          | 160.987          | 161.537          | 155,743          | 151,555          | 151,440          |
| April 2007     | 138,236          | 161.944          | 166.219          | 146,431          | 167,025          | 168,177          |
| <b>Total</b>   | <b>1,775,847</b> | <b>1,725,038</b> | <b>1,734,862</b> | <b>1,924,064</b> | <b>1,781,201</b> | <b>1,793,948</b> |

With the comparison of the met mast and real production data, it is shown that the real production is acceptable and that the machines exploited the available wind resources. This is a positive result.

Although the measured wind data have the mentioned problems, especially with the wind directions, calculations based on the data have been carried out using the WAsP software package for a number of months. The detailed results of these months are included in the annex; for some exemplary machines the results for 4 months are shown in Table 24 and Table 25.

For the majority of the machines the WAsP simulations underestimate the real yields. For the different machine types there are significant differences in the level of deviation between the real and the calculated yields. To a certain extent this surely is related to the positions of the machines in the wind farms, as the smaller machines are completely surrounded by other machines and have no free wind flow and as on the other hand the 750 kW machines are located at quite undisturbed positions. A second factor of influence is found in the quality of the available power curve data for the machines, as for the smaller and older machines at their time of production not so much interest was put on an independent verification of the power curves. And finally some general aspects have an influence, amongst others some inexactness in the terrain description, not exact wind data or limitations of WAsP for big wind farms with a great number of parallel rows of machines.

For the first months covered with detailed wind data (i.e. May and June 2006) the calculation matches better the reality than for the later months (i.e. November 2006 and November 2007). This is related probably to the different main wind direction, but also to the above described deviations in the wind directions starting from at least October 2006.

**Table 24: Comparison of WASP Results with Reality for Selected Machines, Dabancheng (1)**

| Site  | WEC Type  | May 2006 |         |           | June 2006 |         |           |
|-------|-----------|----------|---------|-----------|-----------|---------|-----------|
|       |           | Calc     | Real    | Real:Calc | Calc      | Real    | Real:Calc |
| A1-4  | Bonus300  | 66.909   | 70.167  | 105%      | 50.064    | 53.154  | 106%      |
| A1-5  | Bonus300  | 66.191   | 80.197  | 121%      | 48.973    | 47.437  | 97%       |
| A7-5  | NTK300/31 | 67.200   | 70.377  | 105%      | 50.700    | 54.675  | 108%      |
| A7-6  | NTK300/31 | 65.818   | 80.134  | 122%      | 48.909    | 62.033  | 127%      |
| A8-4  | NTK300/31 | 65.582   | 74.831  | 114%      | 47.355    | 57.990  | 122%      |
| A8-5  | NTK300/31 | 68.273   | 76.428  | 112%      | 52.045    | 57.916  | 111%      |
| A4-2  | Bonus450  | 103.836  | 109.200 | 105%      | 79.118    | 84.942  | 107%      |
| A4-3  | Bonus450  | 104.573  | 109.377 | 105%      | 79.091    | 66.174  | 84%       |
| A1-1  | Bonus600  | 148.609  | 145.750 | 98%       | 112.591   | 109.440 | 97%       |
| A2-1  | Bonus600  | 150.636  | 158.853 | 105%      | 115.500   | 115.643 | 100%      |
| A3-1  | Bonus600  | 146.382  | 153.657 | 105%      | 111.400   | 105.108 | 94%       |
| A4-1  | Bonus600  | 151.009  | 152.884 | 101%      | 117.100   | 110.607 | 94%       |
| A12-1 | V42-600   | 150.427  | 115.126 | 77%       | 114.327   | 90.885  | 79%       |
| A12-2 | V42-600   | 147.136  | 143.444 | 97%       | 111.200   | 101.043 | 91%       |
| E06-1 | V42-600   | 157.373  | 165.509 | 105%      | 121.809   | 127.214 | 104%      |
| E06-2 | V42-600   | 156.691  | 168.794 | 108%      | 122.773   | 133.487 | 109%      |
| B6-1  | NM750/48  | 207.309  | 223.353 | 108%      | 156.736   | 148.560 | 95%       |
| B6-2  | NM750/48  | 207.555  | 225.256 | 109%      | 156.445   | 169.245 | 108%      |
| B7-4  | NM750/48  | 212.800  | 249.533 | 117%      | 165.609   | 194.672 | 118%      |
| B7-5  | NM750/48  | 216.627  | 240.745 | 111%      | 167.155   | 188.687 | 113%      |

**Table 25: Comparison of WAsP Results with Reality for Selected Machines, Dabancheng (2)**

| Site  | WEC Type  | Nov 06  |         |           | Nov 07  |         |           |
|-------|-----------|---------|---------|-----------|---------|---------|-----------|
|       |           | Calc    | Real    | Real:Calc | Calc    | Real    | Real:Calc |
| A1-4  | Bonus300  | 54.582  | 54.942  | 101%      | 59.191  | 65.698  | 111%      |
| A1-5  | Bonus300  | 55.245  | 61.748  | 112%      | 59.409  | 67.073  | 113%      |
| A7-5  | NTK300/31 | 51.000  | 61.809  | 121%      | 58.000  | 68.236  | 118%      |
| A7-6  | NTK300/31 | 51.018  | 71.370  | 140%      | 59.336  | 66.994  | 113%      |
| A8-4  | NTK300/31 | 53.591  | 63.457  | 118%      | 58.400  | 71.988  | 123%      |
| A8-5  | NTK300/31 | 51.145  | 61.370  | 120%      | 56.600  | 67.773  | 120%      |
| A4-2  | Bonus450  | 81.900  | 91.864  | 112%      | 87.600  | 99.720  | 114%      |
| A4-3  | Bonus450  | 82.055  | 96.095  | 117%      | 88.473  | 107.784 | 122%      |
| A1-1  | Bonus600  | 118.636 | 119.387 | 101%      | 122.791 | 128.872 | 105%      |
| A2-1  | Bonus600  | 119.145 | 119.978 | 101%      | 119.745 | 79.697  | 67%       |
| A3-1  | Bonus600  | 115.482 | 120.283 | 104%      | 119.445 | 137.801 | 115%      |
| A4-1  | Bonus600  | 116.027 | 113.063 | 97%       | 119.191 | 134.623 | 113%      |
| A12-1 | V42-600   | 115.655 | 103.735 | 90%       | 121.245 | 142.723 | 118%      |
| A12-2 | V42-600   | 114.127 | 122.520 | 107%      | 118.709 | 135.248 | 114%      |
| E06-1 | V42-600   | 119.927 | 138.294 | 115%      | 122.364 | 154.375 | 126%      |
| E06-2 | V42-600   | 116.709 | 123.397 | 106%      | 122.973 | 157.234 | 128%      |
| B6-1  | NM750/48  | 168.855 | 8.442   | 5%        | 166.882 | 213.276 | 128%      |
| B6-2  | NM750/48  | 169.536 | 209.599 | 124%      | 167.418 | 209.356 | 125%      |
| B7-4  | NM750/48  | 167.636 | 221.157 | 132%      | 169.564 | 231.653 | 137%      |
| B7-5  | NM750/48  | 174.527 | 221.306 | 127%      | 171.945 | 165.905 | 96%       |

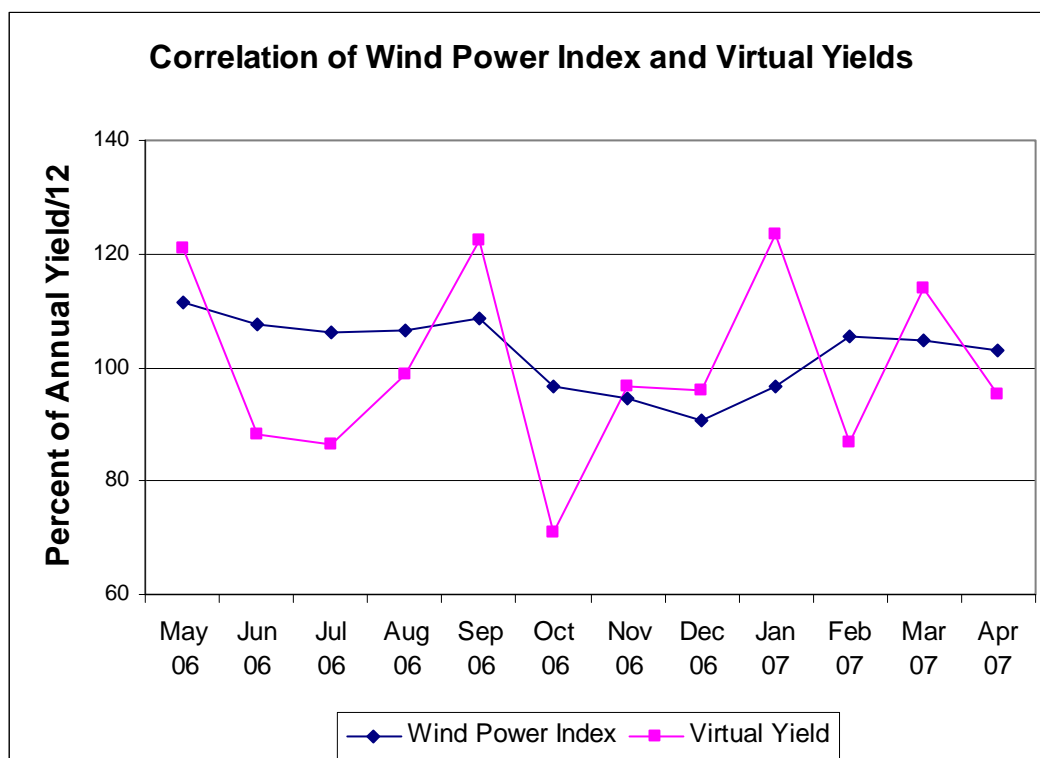
All in all there are a lot of machines with real yields above the calculated figures. And for most of the machines with real yields below the calculations, the WAsP calculation do not give new insights, as for the biggest part of these machines also without the WAsP calculations the clear under-performance could be identified.

As a result, the WAsP calculations support the conclusions that have been based on the analysis of only the production data, i.e. there are a limited number of bad performing machines and the rest is performing acceptable. However the WAsP calculations have limitations to absolutely calculate the lost production of each machine in detail.



In the next step it is tried to find additional long-term data that could be used to evaluate also the production data of further past periods in relation to the wind potential. One source for such long-term wind data is the World Wind Atlas<sup>1</sup>. As can be seen in Figure 15 there is nearly no correlation between the Index (based on the World Wind Atlas) and the Virtual Yields (calculated with the measured wind speeds). This means that these long-term data are not representative for the local wind regime and that these data cannot be used to evaluate the long-term development of wind speeds and energy yield in the wind farm. It was then researched what other long-term data of proximate meteorological stations is available. Unfortunately with all data of four near-by meteorological stations (Fukang, Wu Lu Mu Qi, Diwopu and Pau-Yang-Hu) also a sufficient correlation is not given.

**Figure 15: Correlation of Wind Power Index and Virtual Yields for Dabancheng**



This means that with the available and accessible data it is not possible to evaluate how the wind potential and theoretical energy yield have developed in the past.

<sup>1</sup> <http://www.worldwindatlas.com>, published by German company Energie Online GmbH

#### 4.1.6 Base for Benchmarking the Future Performance

The aim of the Consulting Services is to identify potential for improving the operation of the wind farms, to propose corresponding measures and to monitor and benchmark the performance.

Thus it is necessary to define a criterion for this benchmarking. This should be the availability of the machines at the priority. But in order to better understand how the performance of individual machines influences the availability and to give a brighter picture, additionally 4 classes of machines will be defined and it will be monitored monthly which part of the machines falls in the classes.

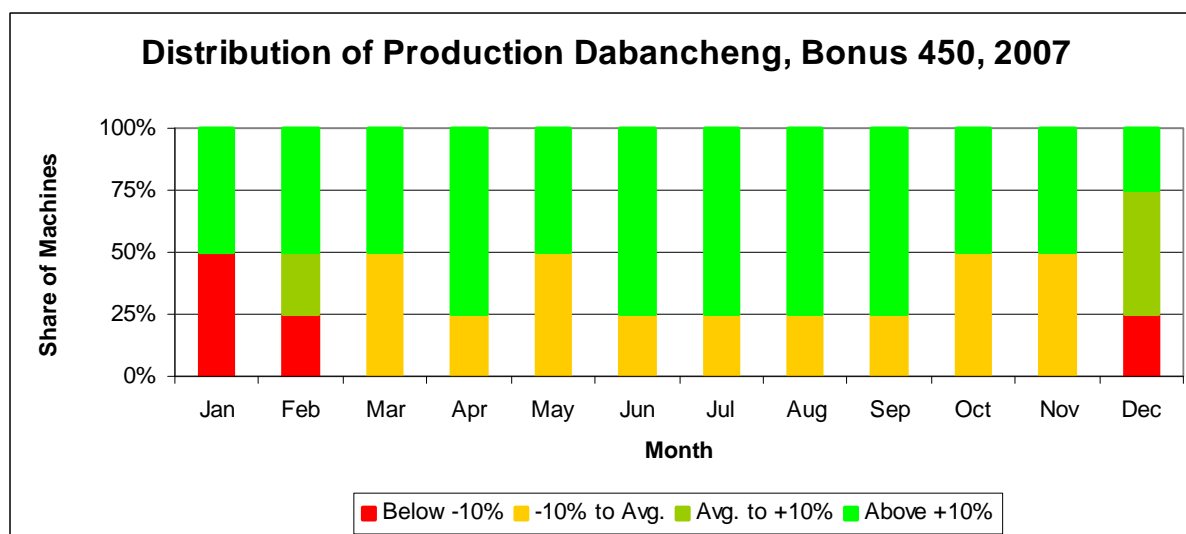
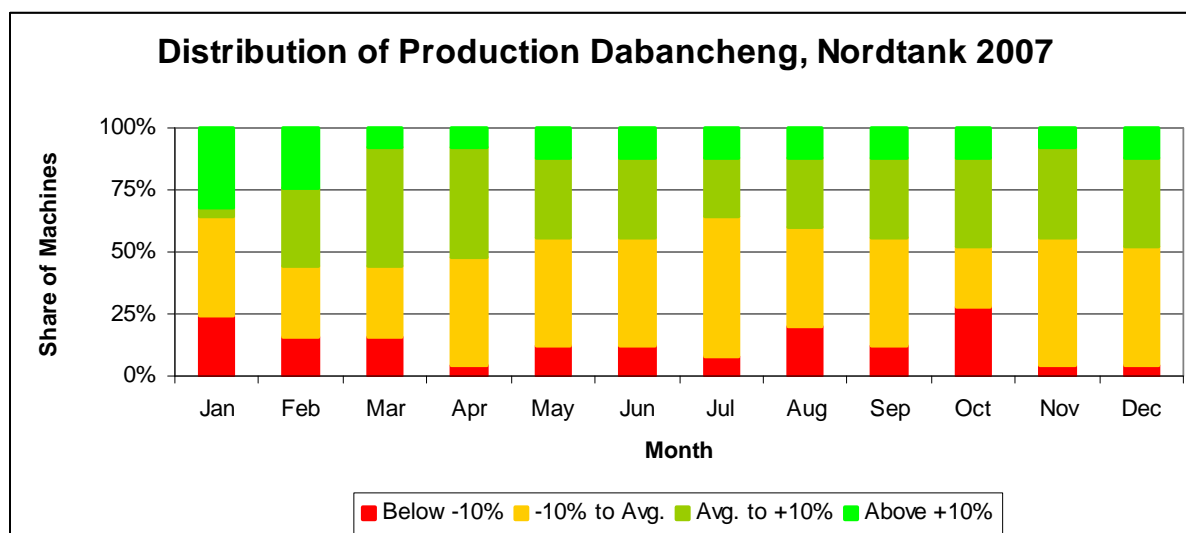
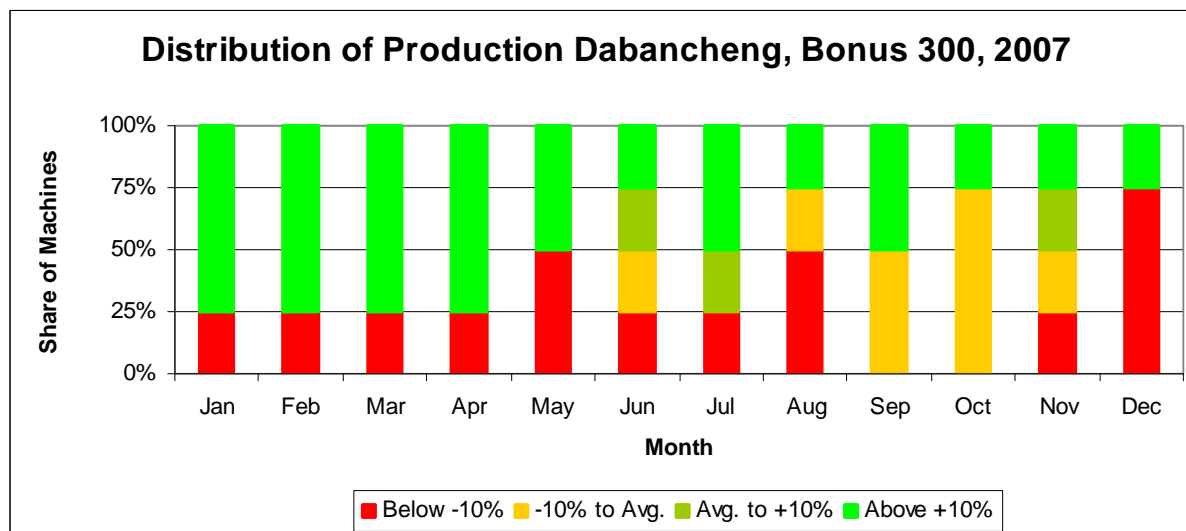
The 4 classes are the following:

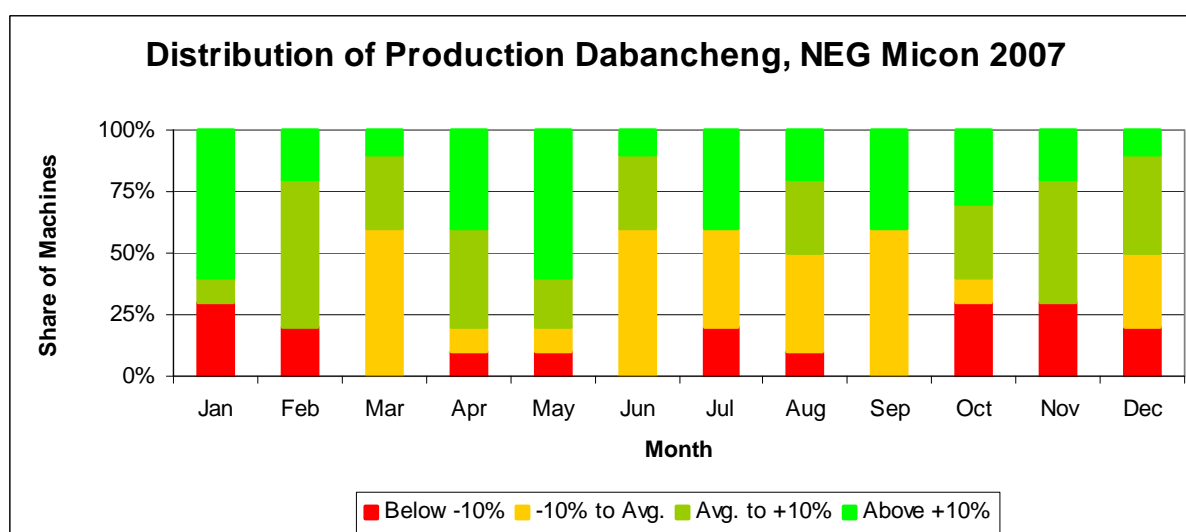
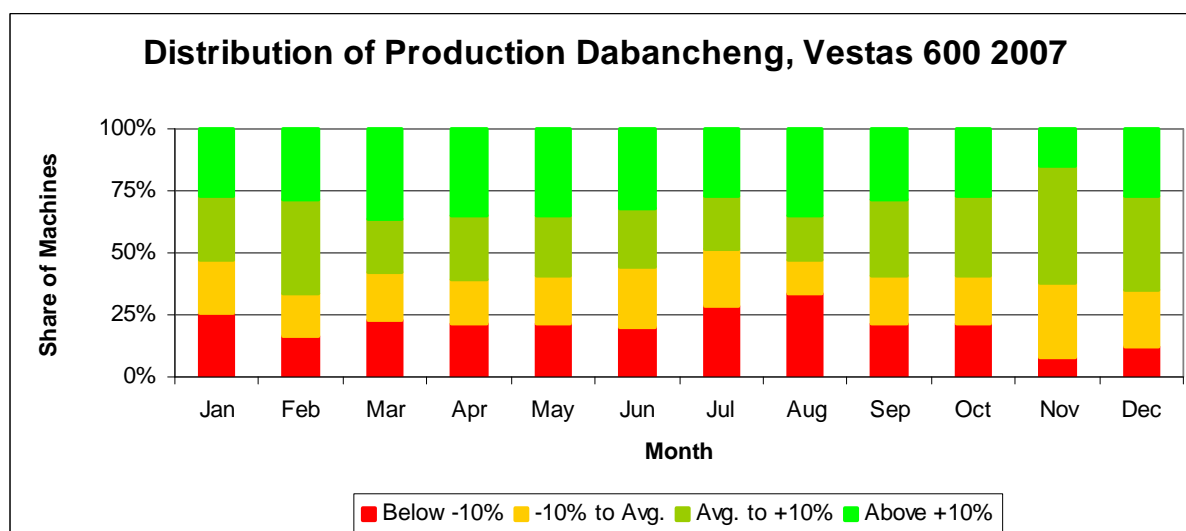
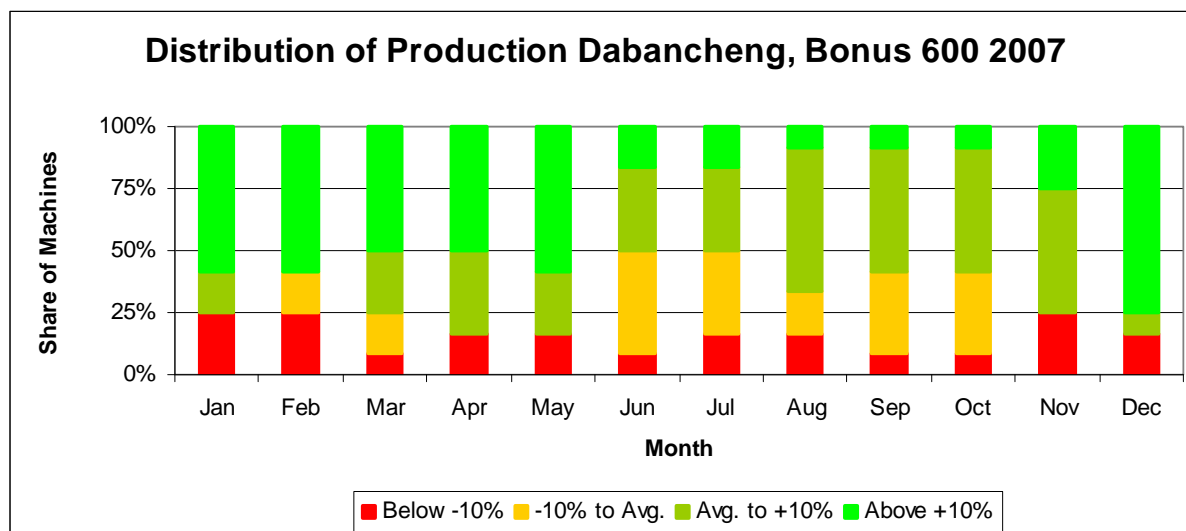
- 1) Worst performing machines, with a production below 10% of the average of all machines of the same type
- 2) Low performing machines, with a production between -10% and the average of all machines of the same type
- 3) High performing machines, with a production between the average of all machines of the same type and +10%
- 4) Best performing machines, with a production above +10% of the average of all machines of the same type

This classification allows a quick evaluation of the actual performance, of the improvement since begin of the project and of focus for the work.

In the best case all machines should perform around the average (classes 2 and 3) and only a small number should fall in the best and worst categories. An improvement of the performance is characterized by an increasing number in the higher classes in comparison to the month before.

In the following diagrams the share of the machines in the different classes is shown for the year 2007.



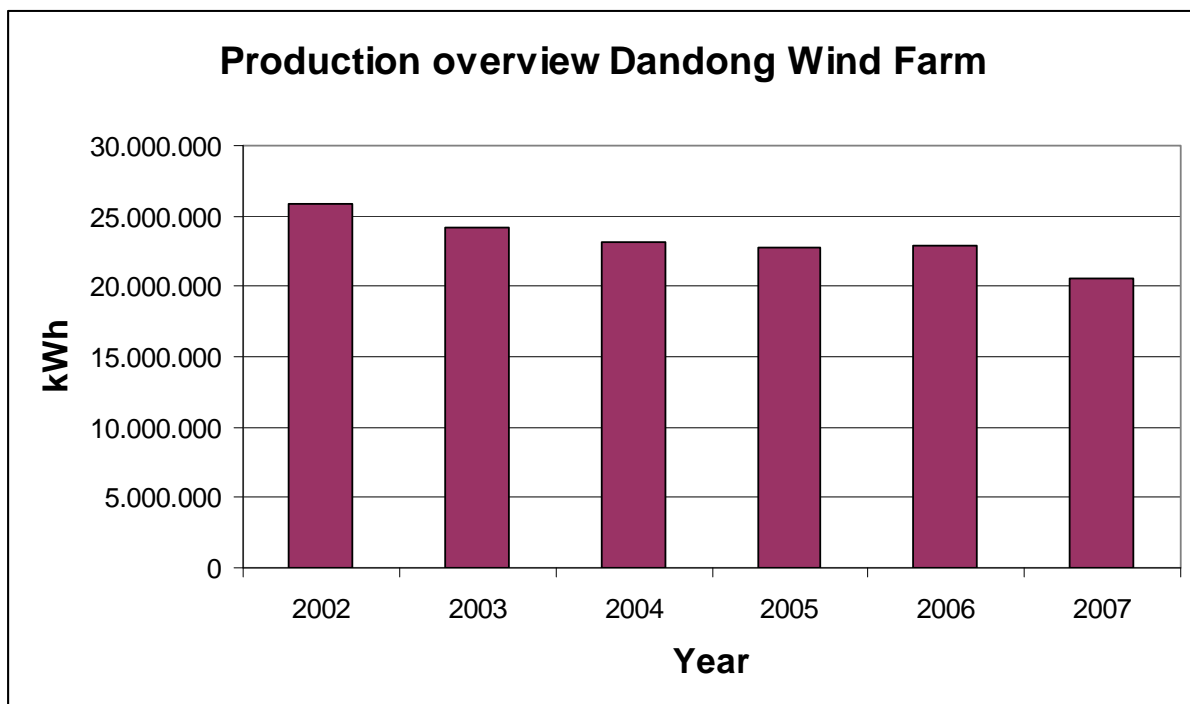


## 4.2 Evaluation of data from the Liaoning Dandong Wind Farm

### 4.2.1 Global production data of the wind farm

For the Dandong Wind Farm complete monthly data for the last 6 years is available. Figure 16 shows the data. The production shows a certain down trend with quite constant production for 2004 to 2006. This pattern deviates a little bit from the pattern found for the 2 other wind farms.

**Figure 16: Production Overview Dandong Wind Farm for 6 years**



### 4.2.2 Production data for individual machines

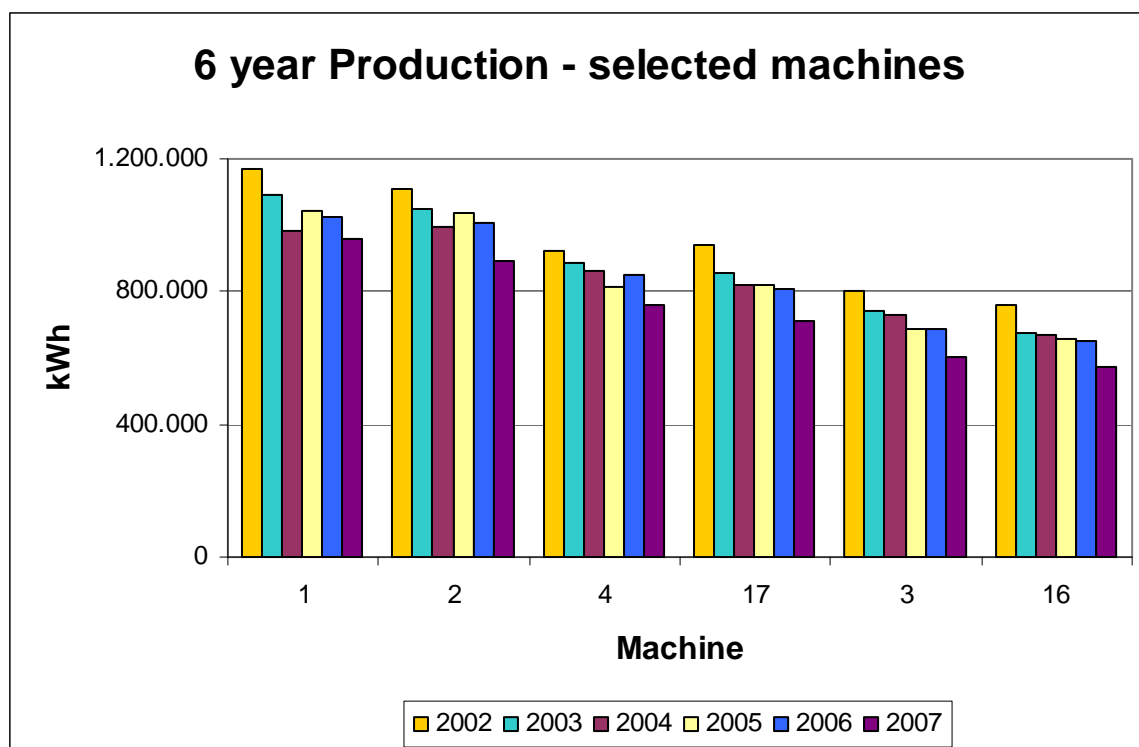
As in the Dandong wind farm only 1 type of machines exists, the detailed analysis of the production data can be done simple and quick.

There are 28 machines of the type NEG Micon 750 kW.

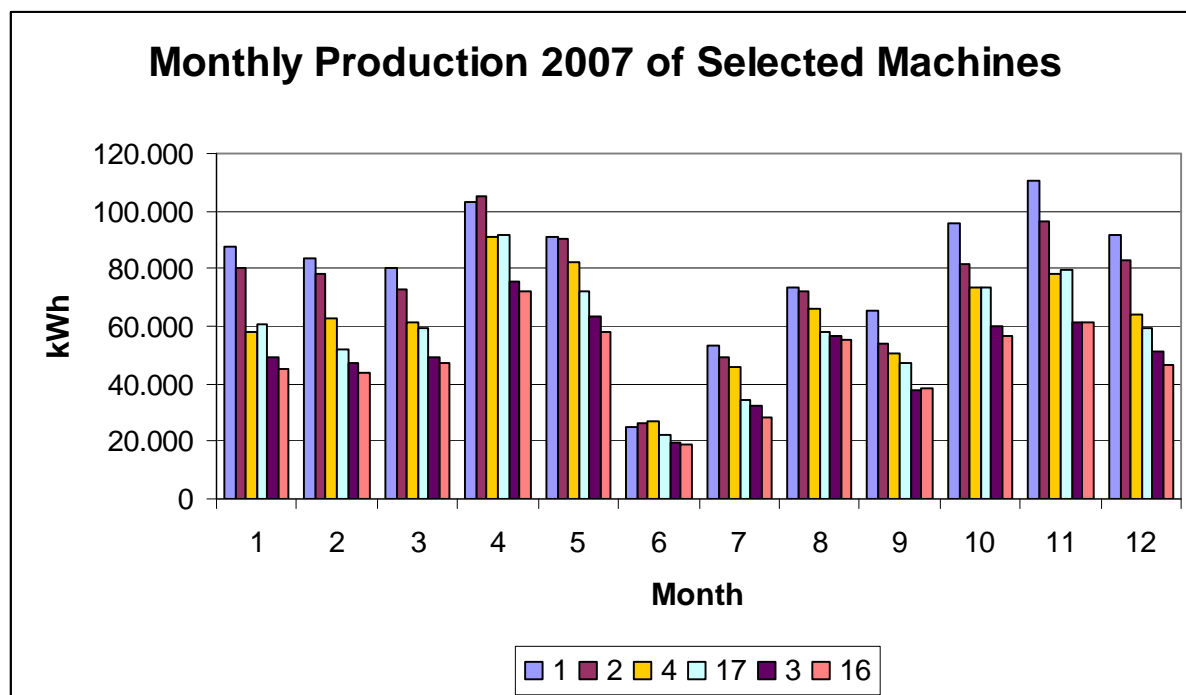
Of these machines 5 reached on average over 6 years a yield of 930,000 to 1,045,000 kWh and 11 produced only less than 800,000 kWh with the minimum at 664,000 kWh, i.e. 69 to 83% of the production of the best machines. All the production data are very low regarding the theoretical production of this machine type or production in general cases of wind farms (i.e. in principle wind farms are regarded as economic viable, if machines produce 2-3 times the production in this project). However the production data shows no significant down times or under production of the machines in individual months. It seems that the low production is related only to the very low wind potential at the site.

**Table 26: Production data of selected NEG Micon 750 kW machines**

| Site | Production | Production (kWh) |           |         |           |           |         |           | 6 yr rel. to group avg. |
|------|------------|------------------|-----------|---------|-----------|-----------|---------|-----------|-------------------------|
|      |            | 2002             | 2003      | 2004    | 2005      | 2006      | 2007    | 6 yr avg. |                         |
| 1    | high       | 1.172.018        | 1.088.646 | 982.359 | 1.045.198 | 1.023.989 | 959.491 | 1.045.284 | 126%                    |
| 2    | high       | 1.112.282        | 1.050.739 | 997.364 | 1.037.506 | 1.004.415 | 890.050 | 1.015.393 | 122%                    |
| 4    | average    | 921.984          | 889.032   | 863.270 | 813.812   | 848.504   | 759.840 | 849.407   | 102%                    |
| 17   | average    | 940.154          | 855.071   | 819.254 | 818.975   | 810.157   | 709.998 | 825.602   | 99%                     |
| 3    | low        | 801.128          | 744.128   | 728.914 | 690.172   | 688.660   | 603.110 | 709.352   | 85%                     |
| 16   | low        | 761.713          | 675.034   | 668.182 | 658.939   | 650.195   | 571.402 | 664.244   | 80%                     |

**Figure 17: 6 year production of selected individual machines**

In Figure 18 the monthly production of the same machines as in Figure 17 is shown. When regarding the relation between each 2 of the machines, they are nearly constant for all the months and show no significant deviations (Some small differences in the individual ratios are caused most probably by different wind directions in the months). This is a hint towards that no technical problems of individual machines have influenced the production.

**Figure 18: Monthly Production of Selected Machines**

It is assumed that the availability of all of the machines has been very high all the time. Probably it has been even higher than the 97% considered for the machines without major errors in the 2 other wind farms. As a conservative approach it is assumed with 97% and nearly constant over the last 6 years.

#### 4.2.3 Summary and overview on the availability and production of all machines

After analyzing and discussing the development of production and availability of the individual machines in the previous chapter, now some main findings shall be presented in an overview.

**Table 27: Overview on the availability of all machines**

| Year             | 2003 | 2004 | 2005 | 2006 | 2007 | Average    |
|------------------|------|------|------|------|------|------------|
| NEG Micon 750 kW | 97%  | 97%  | 97%  | 97%  | 97%  | <b>97%</b> |

Table 27 shows the availability figures. As in this wind farm all machines are of the same type, the availability of the total wind farm has not to be calculated as an weighted average of different machine types. For the wind farm the availability is very satisfying and has been stable at 97% over the last 5 years.

**Table 28: Production overview for the wind farm**

| Type           | 2003       | 2004       | 2005       | 2006       | 2007       | Average           |
|----------------|------------|------------|------------|------------|------------|-------------------|
| <b>NEG 750</b> | 23.816.221 | 22.320.891 | 21.608.238 | 23.013.253 | 20.422.836 | <b>22.236.288</b> |

**Table 29: Estimated Losses for the wind farm**

| Type           | 2003    | 2004    | 2005    | 2006   | 2007   | Average        |
|----------------|---------|---------|---------|--------|--------|----------------|
| <b>NEG 750</b> | 110.300 | 125.660 | 113.874 | 71.315 | 85.250 | <b>101.280</b> |

In Table 28 an overview on the production of the complete wind farm and Table 29 shows estimated losses. This loss estimation is done in a quite simple way and is intended as a first step towards an understanding of the potential for optimization in the wind farm. The background for the loss estimation are the real production and the estimated availabilities for the individual machines. Then an estimation of the theoretical potential production is calculated by assuming that all machines would have reached an availability of 97%. Finally the estimated loss is calculated as difference between this estimated theoretical and the registered real production.

As a result of the presented availability and loss figures it shall be pointed out that only very little potential for an improvement of the technical availability of the machines is existing.

Concerning a strategy, it should be tried to maintain the excellent technical state of the machines.

#### **4.2.4 Comparison of production data with calculations based on measurements**

In the first phase of the Performance Improvement Project two measurement masts have been installed at the end of 2005 with the intention to verify the production in the wind farm in relation to the wind speeds and to check exemplarily the power curve of individual turbines. The detailed evaluations of a power curve would need a substantial extended effort regarding operational data storage (20 minute time series of the production of the machines and these synchronized to the met mast data) and the analyses and have not been explicitly required in the current project.

The met masts were erected in the vicinity of machines #3 and #13 and in the following they are named with these positions. In Table 30 the periods covered with available data are shown. Months covered at least to 90% with data are marked green. This threshold has been selected under consideration of the requirements for reliable data evaluation.



**Table 30: Availability of data of the individual met masts in Dandong**

| Period         | Dandong03 | Dandong13 |
|----------------|-----------|-----------|
| May 2006       | 99%       | 99%       |
| June 2006      | 100%      | 100%      |
| July 2006      | 100%      | 100%      |
| August 2006    | 100%      | 100%      |
| September 2006 | 100%      | 100%      |
| October 2006   | 100%      | 100%      |
| November 2006  | 100%      | 100%      |
| December 2006  | 100%      | 100%      |
| January 2007   | 100%      | 100%      |
| February 2007  | 100%      | 100%      |
| March 2007     | 100%      | 100%      |
| April 2007     | 100%      | 100%      |
| May 2007       | 79%       | 79%       |
| June 2007      | 0%        | 0%        |
| July 2007      | 0%        | 0%        |
| August 2007    | 0%        | 0%        |
| September 2007 | 39%       | 55%       |
| October 2007   | 100%      | 100%      |
| November 2007  | 100%      | 100%      |
| December 2007  | 100%      | 73%       |
| January 2008   | 100%      | 100%      |
| February 2008  | 78%       | 78%       |
| March 2008     | 0%        | 0%        |
| April 2008     | 0%        | 0%        |
| May 2008       | 0%        | 0%        |
| June 2008      | 0%        | 0%        |
| July 2008      | 0%        | 0%        |
| August 2008    | 0%        | 0%        |
| September 2008 | 0%        | 0%        |
| October 2008   | 0%        | 0%        |

It can be seen that data is available for a period of little more than 12 consecutive months (May 2006 to May 2007, quite the same period as in the Dabancheng wind farm) and additionally for some time periods throughout 6 more months. As the production of a complete year is considered the most interesting, only the 12 consecutive months from May 2006 to April 2007 have been analyzed.

A check of the provided data showed some noticeable problems for individual time periods, particularly the following ones:

- At met mast #3 all anemometers had some short standstills. Bearing problems can not be excluded. The wind directions measured at 10 m and 45 m are inconsistent for most of the time. The difference between the both measurements is changing, which is probably caused by moving mounting booms due to the force of high wind speeds. At least the boom of the 45 m measurement is moving, for the second boom it is not absolutely excluded.

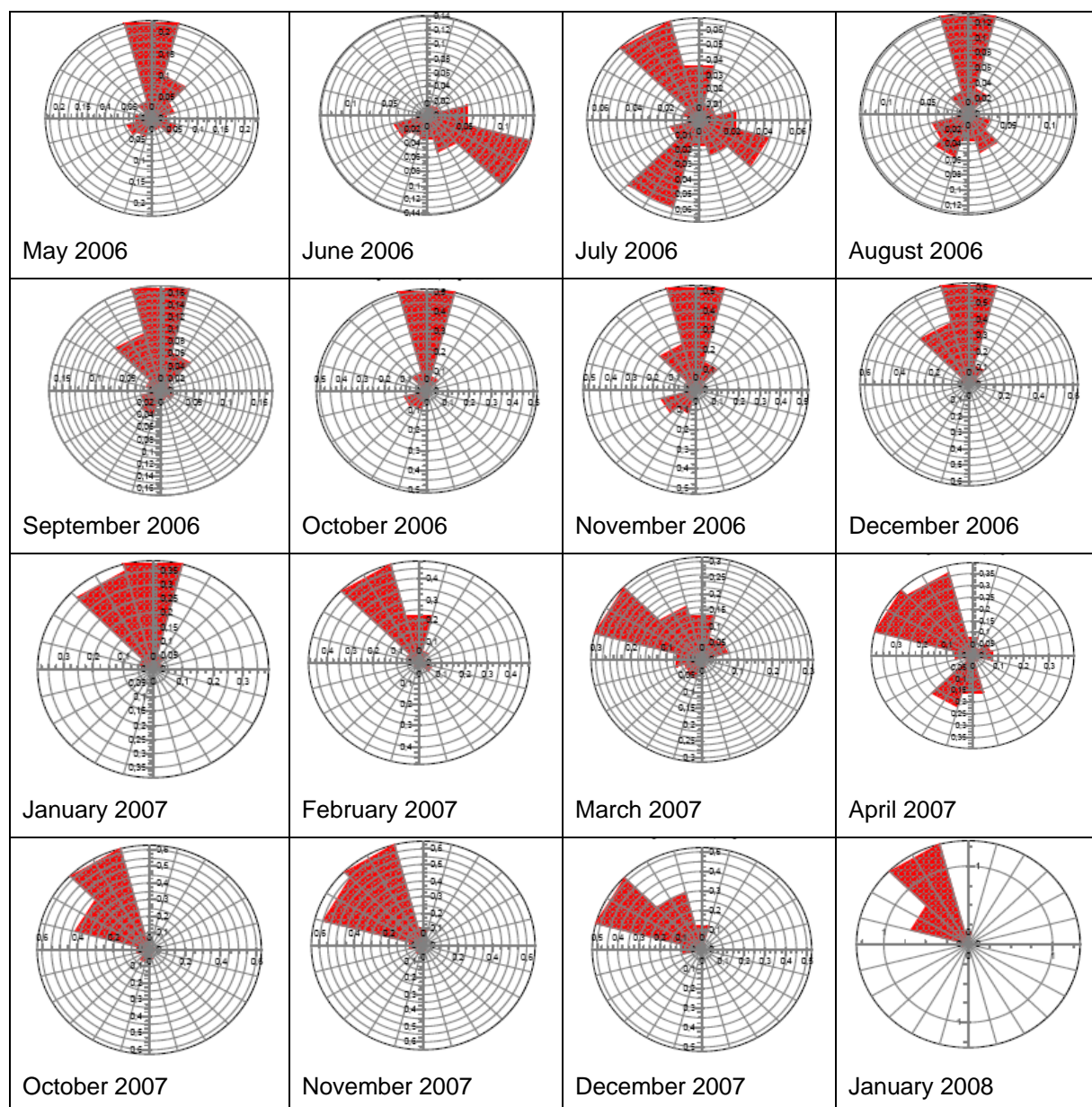
- At met mast #13 anemometers had some shorts standstills. One of the lower mounted anemometers has obviously a bearing problem. The both wind direction measurements are consistent, but from one wind vane it can be seen that the mounting boom is horizontal moved. The recordings of air temperature, relative humidity and air pressure can not be used, because they are all complete out of a reasonable range.
- Some deviations have been found between the wind directions recorded at the both met masts in same time periods. And deviations measured during the site visit have been found, too. The booms are turned by heavy wind forces.

No documentation of the met masts is available. An exact allocation of the single sensors to the recorded data channels is not possible. It can not be stated if the anemometers have been calibrated and if the calibrations have been applied to the data recording. The used anemometer type NRG Max40 has a big uncertainty in complex terrain and tends to have an inappropriate long-term behavior.

No maintenance works are performed at the met masts. Data from the masts were collected.

No data checks to ensure liability of sensor function and recorded data could be undertaken.

To give a better impression of the inaccuracies in the wind direction measurement, in Table 31 the resulting wind energy roses calculated with the industry standard software package WAsP are shown for the first 12 consecutive months of measurements and additionally for 4 later months. With the exception of the summer months June and July 2006 which are not representative due to the low wind speeds, up to the end of the year 2006 there is the main energy coming from northern winds. Starting from January 2007 this is changing and the main energy is coming from winds approx. 30-60 degree rotated to the west. This cannot be explained with a change of the wind flow in the area (this could affect individual months with unusual winds, but not a long row of consecutive months), and it is most probably caused by a moved or moving boom of the wind vane. So the wind direction at latest starting in January 2007 is no longer reliable. But it is not absolutely sure, when the boom started to move and whether it is then stopped in a new stable position or is still moving from time to time. So also for further months up to December 2006 the wind data is not very reliable.

**Table 31: Energy roses for the Dandong wind farm for 16 months**

In summary the data of the met masts cannot be trusted for the whole time. For the wind directions in principle, it would be possible to apply much effort to sort out which of the deviating values are the more logic ones for all time periods, but this would be very time consuming.

Furthermore the uncertainty of the measurements (amongst others due to not known calibrated sensor characteristics) is of an order which does not allow absolute evaluations and comparisons. It is possible to use the wind speed data in some degree for relative comparisons. Hence from the available wind speed data a theoretical monthly energy production was calculated and compared with the real observed production of the nearest machine.

The monthly theoretical energy yields have been calculated from the time series of wind speeds under use of (measured) power curve of a NEG Micon 750 kW turbine. For that purpose wind speed has been averaged from anemometers which were adjacent to the hub height of the turbine. Because of seasonal air density changes at the site (mainly caused by the temperature differences) long-term data from a proximate meteorological station were used to calculate the air density and applied for the energy yield calculations. The theoretical yields are presented in Table 32. The average total of the 2 masts for a period of 12 months is roughly 624,000 kWh.

Same wind speeds in different months may result in different theoretical yields and the theoretical yield is regarded as a better parameter for understanding the wind potential. Nevertheless, as an indication for one of the masts the corresponding wind speed is show in Table 33 (the wind speeds at the other mast are not so much different and are thus not shown).

The found average wind speed for the 12 month period is far below the value from the feasibility study of the project of 6.1 m/s. This means the real wind potential is much lower than the expected potential and this is the main reason for the extreme low production of this wind farm.

**Table 32: Theoretical Yields for a NEG Micon 750 at the 2 met mast positions in Dandong**

| Month          | Yield at Mast near #03 (kWh) | Yield at Mast near #13 (kWh) |
|----------------|------------------------------|------------------------------|
| May 2006       | 42,990                       | 49,055                       |
| June 2006      | 32,372                       | 33,224                       |
| July 2006      | 17,247                       | 17,741                       |
| August 2006    | 27,697                       | 28,266                       |
| September 2006 | 28,881                       | 30,014                       |
| October 2006   | 53,539                       | 69,429                       |
| November 2006  | 82,455                       | 92,846                       |
| December 2006  | 76,291                       | 82,402                       |
| January 2007   | 46,508                       | 53,880                       |
| February 2007  | 50,049                       | 50,802                       |
| March 2007     | 55,855                       | 60,467                       |
| April 2007     | 80,216                       | 85,342                       |
| <b>Total</b>   | <b>594,099</b>               | <b>653,476</b>               |

**Table 33: Wind speed at Mast near #13 (45 m height) in the Dandong wind farm**

| <b>Month</b>          | <b>Speed of Mast near #13 (m/s)</b> |
|-----------------------|-------------------------------------|
| <b>May 2006</b>       | 4.5                                 |
| <b>June 2006</b>      | 3.8                                 |
| <b>July 2006</b>      | 3.2                                 |
| <b>August 2006</b>    | 3.6                                 |
| <b>September 2006</b> | 4.0                                 |
| <b>October 2006</b>   | 4.9                                 |
| <b>November 2006</b>  | 5.5                                 |
| <b>December 2006</b>  | 5.1                                 |
| <b>January 2007</b>   | 4.5                                 |
| <b>February 2007</b>  | 4.5                                 |
| <b>March 2007</b>     | 4.6                                 |
| <b>April 2007</b>     | 5.4                                 |
| <b>Average</b>        | <b>4.5</b>                          |

It has to be considered that wake effects in the wind farm have a strong influence on the wind measurements, which is not absolutely comparable to the influence on a turbine which would be positioned at the position of the met mast. For the following it is, nevertheless, assumed that it is the same.

Furthermore the theoretical energy yields do not include production losses according to the availability of the machines. To consider this effect, a deduction of 5% from the theoretical energy yield of a single machine is applied. This means that according to the wind data the machines should have reached an average production of 593,000 kWh (95% of the above mentioned 624,000 kWh average of the 2 masts).

The real average production of all the machines in the relevant period has been 723,000 kWh, i.e. more than the average of the 2 theoretical yields. But the yield of the machines differs very much, with the worst / best being at 570,000 / 924,000 kWh. These differences are related to the complex terrain and the irregular layout of the wind farm. A better way to judge the yield is the direct comparison of the theoretical yield with the data of the machines near-by (i.e. #03 and #13). The correlation is very well for both masts with the corresponding machines and the machine #03 yielded nearly the same electricity as calculated with the met mast data. For machine #13 the real yield was significantly higher than the theoretical value. This is most probably related also to the complex terrain and the difference in height of the location of the mast and the machine.

The comparison of the production data of the 2 machines with the data of other machines in the wind farm shows no significant under production for the 2 machines in the period and it is assumed that they operated at around 97-99% availability.

**Table 34: Theoretical and Real Yields for 2 met mast positions in Dandong**

| Month          | Mast 03 (kWh)  | Machine #03 (kWh) | Mast 13 (kWh)  | Machine #13 (kWh) |
|----------------|----------------|-------------------|----------------|-------------------|
| May 2006       | 42,990         | 42,806            | 49,055         | 52,056            |
| June 2006      | 32,372         | 28,213            | 33,224         | 44,299            |
| July 2006      | 17,247         | 18,858            | 17,741         | 22,352            |
| August 2006    | 27,697         | 32,506            | 28,266         | 37,514            |
| September 2006 | 28,881         | 28,210            | 30,014         | 39,468            |
| October 2006   | 53,539         | 65,941            | 69,429         | 79,101            |
| November 2006  | 82,455         | 87,001            | 92,846         | 103,289           |
| December 2006  | 76,291         | 78,149            | 82,402         | 90,775            |
| January 2007   | 46,508         | 48,915            | 53,880         | 61,947            |
| February 2007  | 50,049         | 46,913            | 50,802         | 55,588            |
| March 2007     | 55,855         | 49,010            | 60,467         | 61,225            |
| April 2007     | 80,216         | 75,300            | 85,342         | 91,736            |
| <b>Total</b>   | <b>594,099</b> | <b>601,822</b>    | <b>653,476</b> | <b>739,350</b>    |

Despite the limitations in the accuracy of the wind data some calculations were carried out with the software packages WindPRO and WAsP. These results are not very exact, but may give some more comfort in accepting the conclusions as presented above. In the annex a detailed table showing the differences between the calculations and the real yields for individual months over the first 8 months of the measurement period with the most reliable direction data are shown. In Table 35 some main features of the comparison are presented. In all the months the real yields have been higher than the calculated values for the whole wind farm. But two striking aspects have to be mentioned. First it can be seen that for the last 5 months the difference between the calculations and the reality are significantly higher (on average 117%) than for the first 3 months (on average only 105%). And the differences between the individual machines are getting much more important. Whereas from May to July the biggest deviations for individual machines are in the range of 71% to 151%, in the later months the range is much wider, from 72% to 223%.

**Table 35: Dandong: Comparison between real yields and WAsP calculations**

|   | May 2006 | June 2006 | July 2006 | August 2006 | September 2006 | October 2006 | November 2006 | December 2006 |
|---|----------|-----------|-----------|-------------|----------------|--------------|---------------|---------------|
| Calculated monthly yields for the wind farm (MWh) | 1,370    | 942       | 614       | 866         | 885            | 1,834        | 2,536         | 2,083         |
| Real yield  | 1,437    | 1,017     | 623       | 985         | 1,043          | 2,146        | 2,850         | 2,605         |
| Real : Calc                                       | 105%     | 108%      | 102%      | 114%        | 118%           | 117%         | 112%          | 125%          |
| Minimum Deviation of Real : Calc                  | 77%      | 73%       | 71%       | 78%         | 72%            | 74%          | 75%           | 82%           |
| Maximum Deviation of Real : Calc                  | 151%     | 135%      | 126%      | 155%        | 192%           | 176%         | 169%          | 223%          |

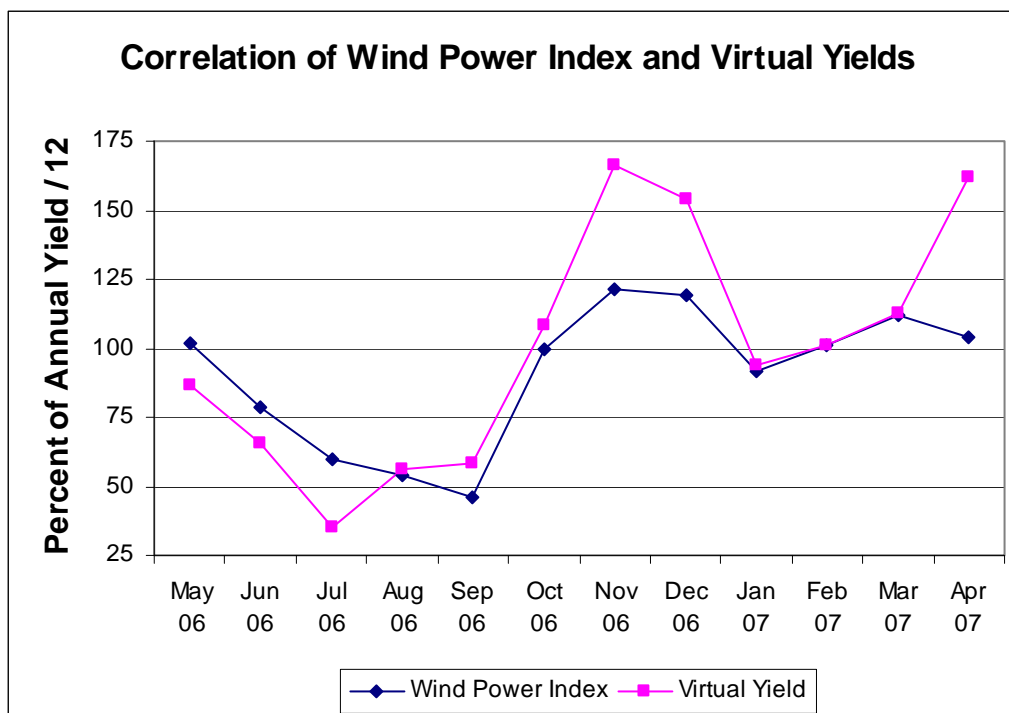
Both above mentioned effects mean the same, i.e. that the calculation result of the WAsP simulation is getting worse in the course of the time. The accuracy of the WAsP results is not real acceptable from August 2006 on. For the calculation results getting significantly lower than the real production, there could be 2 explanations. At first, it is sure that the wrong wind directions (as mentioned earlier) cause a wrong wake effect. At second, it cannot be absolutely excluded that the anemometers are already having bearing problems resulting in too low wind speeds. But this is not very probable, as the anemometers are not known for getting problems so quick. An additional the comparison in Table 34 which was done in a simpler way and without regard of the wind directions show no such big differences. Thus very probable already starting in August 2007 the wind direction measurements are negatively influenced and lead to bad WAsP calculation results. But although the complex terrain is a reason why the WAsP model is not very suitable for a calculation of detailed expected productions for each individual machine.

All in all the comparison of the met mast and real production data leads to the conclusion that the real production is acceptable and that the machines exploited the available wind resources. This is a positive result, although the very low wind potential can not satisfy.

In the next step again, it is tried to find additional long-term data that could be used to evaluate also the production data of the past in relation to the wind potential. One source for such long-term wind data is the World Wind Atlas (cf. chapter 4.1.5). As can be seen in Figure 19 there is no high correlation between the Index (based on the World Wind Atlas) and the Virtual Yields (calculated with the measured wind speeds). This means that the long-term data show a certain similar pattern as the measured wind speeds in the wind farm but nevertheless they are not representative for the local wind regime. The main deviations are that the month with the lowest production is not correctly represented

(July versus September) and that the relation between individual months is very different (the Index is in April lower than in March whereas the virtual yields are the other way around and differ significantly; also for July and August). Thus, this data cannot be used to evaluate the long-term development of wind speeds and energy yield in the wind farm. It was researched what other long-term data of proximate meteorological stations is available. Unfortunately with all found sources a sufficient correlation is not given.

**Figure 19: Correlation of Wind Power Index and Virtual Yields for Dandong**



This means that with the available and accessible data it is not possible to evaluate how the wind potential and theoretical energy yield have developed in the past.



### **4.3 Evaluation of data from the Inner Mongolia Huitengxile Wind Farm**

#### **4.3.1 Global production data of the wind farm**

For the Inner Mongolia Huitengxile Wind Farm the coverage of past data is rather weak. For all the 6 types of Wind Energy Converters operated in the project, data is available only for the last year. Additional data is available for 2 more years for 5 types of Wind Energy Converters, but thereof 1 type was commissioned only in early 2005 so that for this type not for the complete year data is available. Furthermore it is an disadvantage that for the type that represents approx. 50% of the number of machines in the wind farm, no data for these 2 years 2005 and 2006 is available.

For this reason the analysis of the global production of the complete wind farm is not possible.

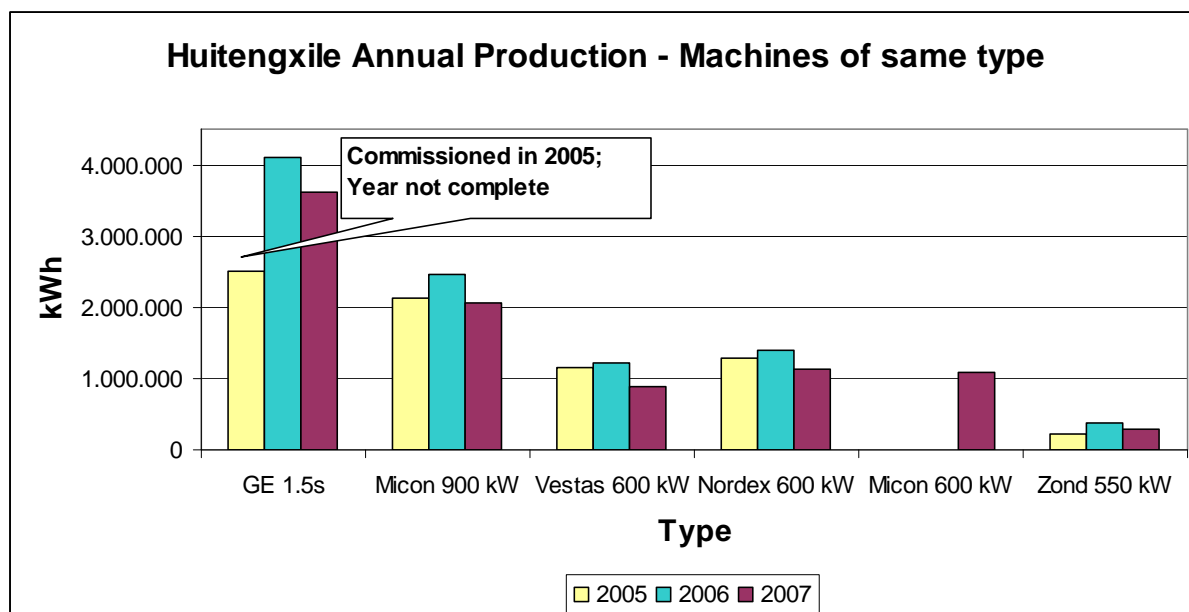
#### **4.3.2 Production data of the different machine types over the past 3 years**

In Figure 20 the average production for all machines of the same type in the Huitengxile wind farm up to 3 years in the past is shown.

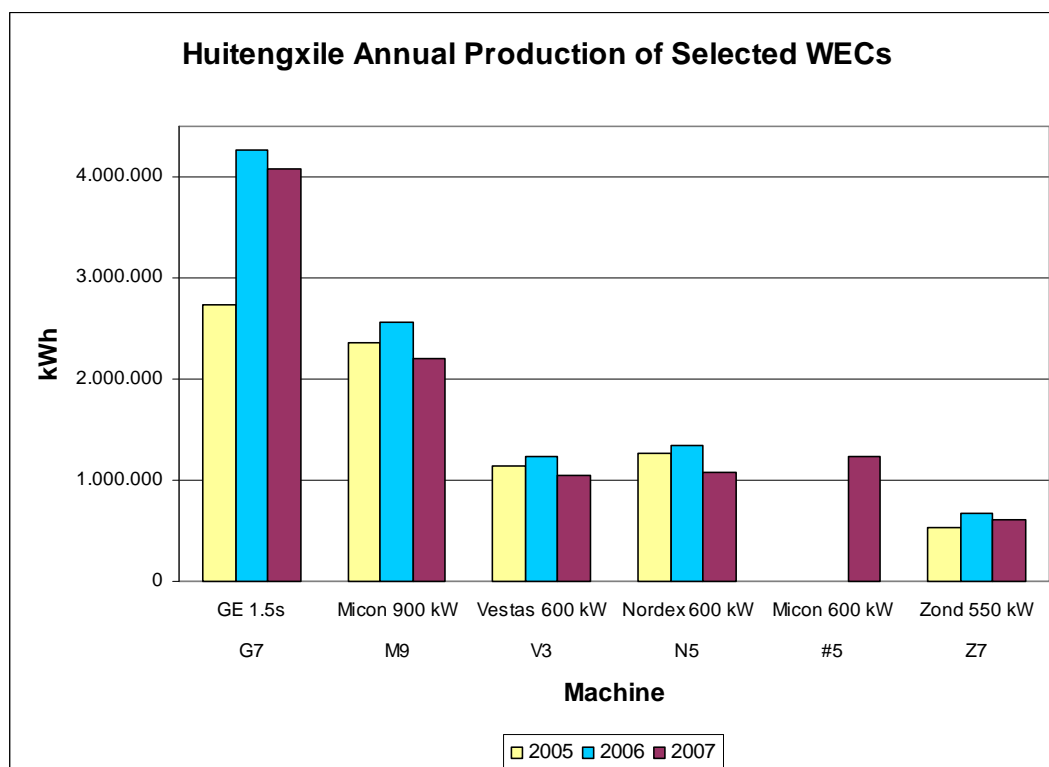
For the Zond 550 kW machine the data is not representative, because of very unstable operation of this type of machine. For the GE 1.5s machines the production of the year 2005 cannot be compared with the data of the other types, as the machines have been commissioned in April and data is only available for 9 months.

For the other 3 types of machine (Micon 900 kW, Vestas 600 kW, Nordex 600 kW), the development over the 3 years shows a similar pattern; the production in 2006 was highest and in 2007 the production was quite similar to that of 2005. For the Vestas 600 kW type, it strikes out that the production in 2007 is quite low. The difference between 2005 and 2007 is more significant for this machine type as for the other 2 types.

The pattern for the 3 years is quite similar to the pattern for the 3 years observed in the Xinjiang Dabancheng wind farm. Although there is a big distance of several 100 kms between the two wind farms, this is a hint, that the pattern could be related closely to the general wind potential.

**Figure 20: Development of Production over time for machine types in Huitengxile**

In Figure 21 the production of selected individual machines over the 3 years period is shown. In this case for the Vestas machine the difference between 2005 and 2007 is much less distinguished than for the average of all machines of this type. This is a hint that on average the Vestas machines had quite a lot of losses in 2007.

**Figure 21: Production of Selected individual WECs in the Huitengxile Wind Farm**

### 4.3.3 Production data of individual machines

#### 4.3.3.1 GE 1.5 MW

The GE 1.5s machines are the newest and technologically most advanced type in the wind farm. There are 10 machines of this type.

Out of the 10 machines there are only 3 which showed a satisfying to good performance over the past 3 years; 1 performed very bad and the remaining 6 showed a just acceptable performance.

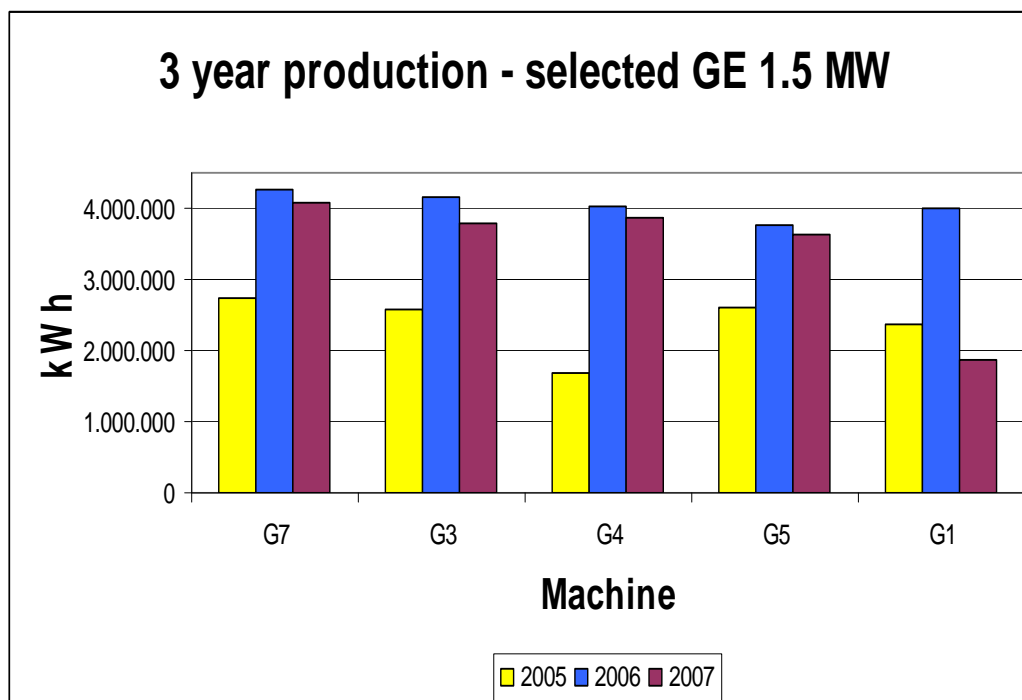
The average annual production of single machines ranged from 3,690,000 to 3,845,000 kWh for the good performing machines, from 3,190,000 to 3,510,000 kWh (approx. 83% to 92% of the production of the good performing machines) and was as low as 2,720,000 kWh (72%) for the worst performing machine. But for this worst performing machine, the years 2005 and 2007 had been even worse; only in 2006 the performance reached that of the other machines.

The production data of selected machines is shown in Table 36 and Figure 22.

**Table 36: Production data of selected GE 1.5 MW machines**

| Site | No. | Performance | Production (kWh) |           |           |           |                         |
|------|-----|-------------|------------------|-----------|-----------|-----------|-------------------------|
|      |     |             | 2005             | 2006      | 2007      | 3 yr avg. | 3 yr rel. to group avg. |
| G7   |     | good        | 2.736.915        | 4.263.786 | 4.078.013 | 3.692.905 | 109%                    |
| G3   |     | acceptable  | 2.580.266        | 4.160.650 | 3.795.716 | 3.512.211 | 103%                    |
| G4   |     | acceptable  | 1.690.113        | 4.025.526 | 3.863.694 | 3.193.111 | 94%                     |
| G5   |     | acceptable  | 2.604.110        | 3.766.669 | 3.633.918 | 3.334.899 | 98%                     |
| G1   |     | bad         | 2.366.461        | 4.011.132 | 1.870.738 | 2.749.444 | 81%                     |

It can be clearly seen that the good performing machine has the highest result in each year. For the other machines, there are big differences between the years. In 2006 even the bad performing machine G1 had a quite acceptable production, not far behind of the 2 acceptable performing machines G3 and G4. Also in 2005 the production of this machine was higher than that of G4 and nearly acceptable.

**Figure 22: 3 year production of selected individual GE 1.5 MW machines**

The estimated rough availability of the worst and 2 acceptable performing GE machines together with the average of all identical machines is shown in Table 37. The average of all machines of this type is only a bad 92%. This value is distressing because the 3 years represent the warranty period and still the manufacturer was responsible for the maintenance. Especially alarming is the fact that the value for the last year was even the worst of the period, indicating a certain down trend.

**Table 37: Average availability (rough estimate) of selected GE 1.5 MW machines**

| Year                                 | 2005 | 2006 | 2007 | Average |
|--------------------------------------|------|------|------|---------|
| Average Availability of all machines | 91%  | 95%  | 89%  | 92%     |
| G4                                   | 64%  | 97%  | 97%  | 86%     |
| G5                                   | 92%  | 91%  | 91%  | 91%     |
| G1                                   | 89%  | 94%  | 48%  | 77%     |

In the following, it is analyzed how the production losses are seen in the behaviour of the machine over the last year.

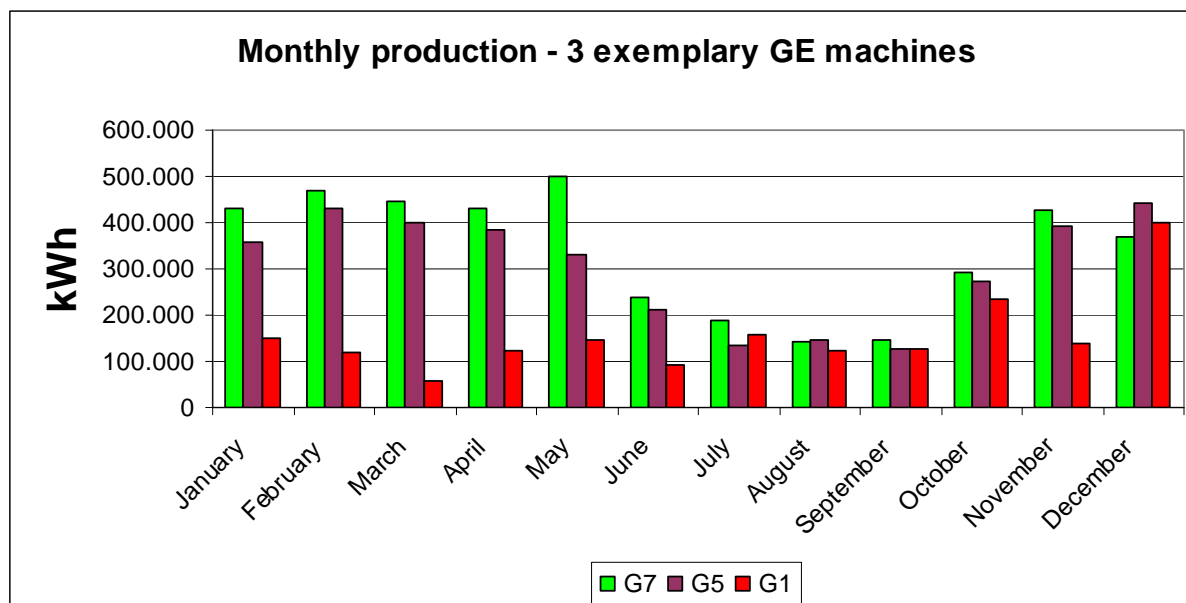
**Table 38: Monthly production data 2007 of selected GE 1.5 MW machines**

| Site        | G7        | G5         | G1        |
|-------------|-----------|------------|-----------|
| Performance | good      | acceptable | bad       |
| January     | 428.864   | 358.889    | 150.334   |
| February    | 467.523   | 432.205    | 117.442   |
| March       | 446.834   | 401.362    | 58.302    |
| April       | 429.037   | 385.425    | 124.673   |
| May         | 500.583   | 330.443    | 144.892   |
| June        | 238.270   | 211.610    | 90.570    |
| July        | 188.367   | 135.710    | 159.561   |
| August      | 142.874   | 145.403    | 124.842   |
| September   | 144.731   | 128.624    | 128.232   |
| October     | 293.566   | 271.280    | 233.994   |
| November    | 426.221   | 390.514    | 137.693   |
| December    | 371.143   | 442.453    | 400.203   |
| Total Year  | 4.078.013 | 3.633.918  | 1.870.738 |

For the GE machines the loss of production occurs nearly always as an under production in a month, but nearly never with a long complete outage (not shown here, only found for one machine over 3 months in 2005).

Another striking effect is that the worst performing machine was working quite well for 3 months (July to September), but afterwards showed again problems.

Additionally, it can be seen that even a good performing machine may have a problem in a single month (G7 in December).

**Figure 23: Diagram of monthly production data, GE 1.5 MW**

#### 4.3.3.2 Micon 900 kW

Of the Micon 900 kW machines a total of 12 machines is operated in this wind farm.

Out of these, 3 have performed well over the last 3 years with an annual production between 2,330,000 and 2,450,000 kWh.

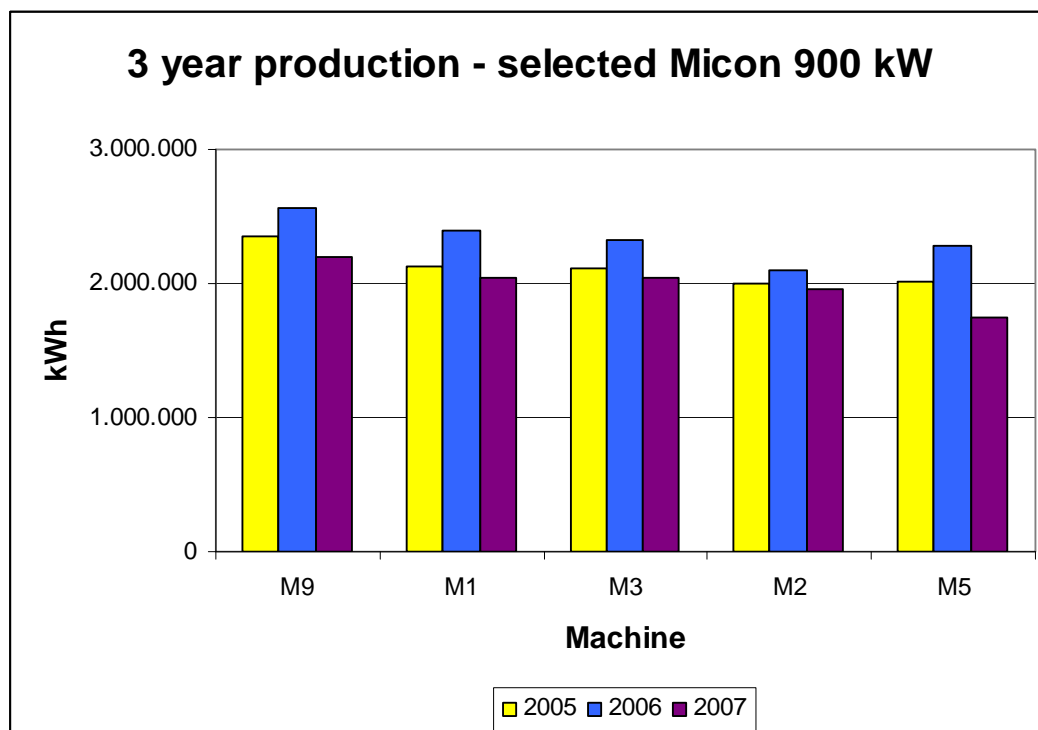
2 of the machines have performed quite bad with an annual production of approx. 2,015,000 kWh each (85% of the yield of the good performing machines), the remaining 7 machines had a production of 2,085,000 to 2,310,000 kWh (88% to 97% of the yield of the best machines).

Table 39 and Figure 24 show detailed annual data of selected machines.

**Table 39: Production data of selected Micon 900 kW machines**

| Site | No. | Performance | Production (kWh) |           |           |           |                                 |
|------|-----|-------------|------------------|-----------|-----------|-----------|---------------------------------|
|      |     |             | 2005             | 2006      | 2007      | 3 yr avg. |                                 |
| M9   |     | good        | 2.358.613        | 2.563.191 | 2.197.644 | 2.373.149 | 3 yr rel. to group avg.<br>107% |
| M1   |     | normal      | 2.122.499        | 2.399.479 | 2.035.314 | 2.185.764 | 98%                             |
| M3   |     | normal      | 2.113.114        | 2.321.971 | 2.037.149 | 2.157.411 | 97%                             |
| M2   |     | bad         | 1.997.140        | 2.097.077 | 1.959.677 | 2.017.965 | 91%                             |
| M5   |     | bad         | 2.018.742        | 2.276.207 | 1.743.466 | 2.012.805 | 91%                             |

The production losses for the bad machines are not extreme, but remarkable. The most important difference is that one machine (M2) has a significant loss in 2006, while the other one has a significant loss in 2007.

**Figure 24: 3 year production of selected individual Micon 900 kW machines**

The estimated average availability for all of the machines and the 2 worst performing ones is shown in Table 40. Over the analyzed period the average availability of all machines of this type was at a satisfying level of 96%, and even for the 2 worst machines the average availability of 93% and 94% is remarkable high.

**Table 40: Average availability (rough estimate) of selected Micon 900 kW machines**

| Year                                 | 2005 | 2006 | 2007 | Average |
|--------------------------------------|------|------|------|---------|
| Average Availability of all machines | 94%  | 96%  | 96%  | 96%     |
| M2                                   | 97%  | 89%  | 97%  | 94%     |
| M5                                   | 97%  | 97%  | 86%  | 93%     |

Regarding the high availability level, a further analysis of the characteristics of the losses is not suitable.

#### 4.3.3.3 Vestas 600 kW

Of the Vestas 600 kW type in the Huitengxile wind farm 9 machines are operated.

Out of the 9 machines only 1 showed a good performance over the past 3 years, but nevertheless not the highest average yield.; 3 machines performed bad and the remaining 5 showed a just acceptable performance.

The average annual production of the constant good performing machine amounted to 1,140,000 kWh, the worst performing one reached only 820,000 kWh (72%) and the others produced between 1,019,000 kWh (89%) and 1,219,000 kWh (107%). For the worst performing machine, especially the most recent year 2007 was extremely low and also for 3 other machines the performance in 2007 was much worse than in the years before.

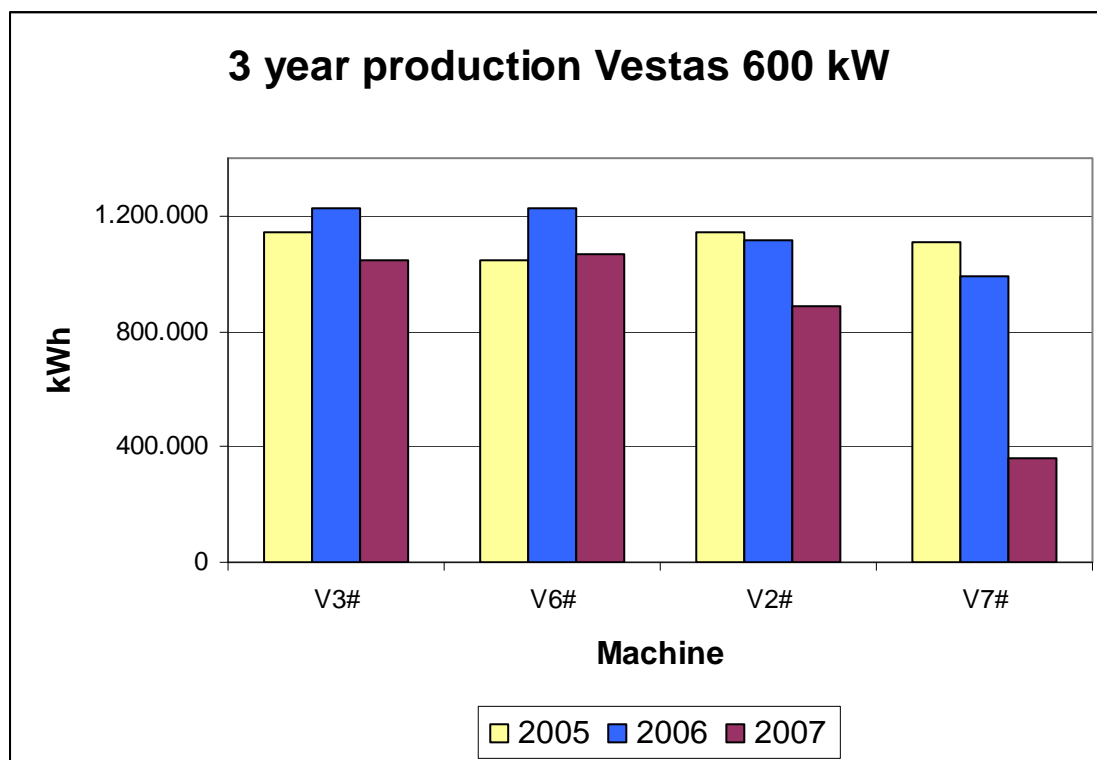
The production data of selected machines is shown in Table 41 and Figure 25.

**Table 41: Production data of selected Vestas 600 kW machines**

| Site | No. | Performance | Production (kWh) |           |           |           |                         |
|------|-----|-------------|------------------|-----------|-----------|-----------|-------------------------|
|      |     |             | 2005             | 2006      | 2007      | 3 yr avg. | 3 yr rel. to group avg. |
| V3   |     | good        | 1.146.687        | 1.227.136 | 1.046.230 | 1.140.018 | 105%                    |
| V6   |     | acceptable  | 1.043.615        | 1.229.398 | 1.063.956 | 1.112.323 | 103%                    |
| V2   |     | acceptable  | 1.144.569        | 1.113.453 | 889.512   | 1.049.178 | 97%                     |
| V7   |     | bad         | 1.105.585        | 992.892   | 362.549   | 820.342   | 76%                     |

The table and the diagram show clearly the extreme bad performance in 2007 for the worst performing machine. Furthermore it can be seen that the production of the constantly good performing machine is not the highest and it can be derived that one of the acceptable performing machines (V6) could have been better than the good performing one.



**Figure 25: 3 year production of selected individual Vestas 600 kW machines**

The estimated rough availability of the worst and 2 acceptable performing Vestas machines together with the average of all identical machines is shown in Table 42. The average of all machines of this type is only a bad 89%. Alarming is the fact that the value for the last year was the worst of the period.

**Table 42: Average availability (rough estimate) of selected Vestas 600 kW machines**

| Year                                 | 2005 | 2006 | 2007 | Average |
|--------------------------------------|------|------|------|---------|
| Average Availability of all machines | 92%  | 93%  | 81%  | 89%     |
| V6#                                  | 83%  | 97%  | 97%  | 92%     |
| V2#                                  | 97%  | 88%  | 81%  | 89%     |
| V7#                                  | 88%  | 78%  | 33%  | 66%     |

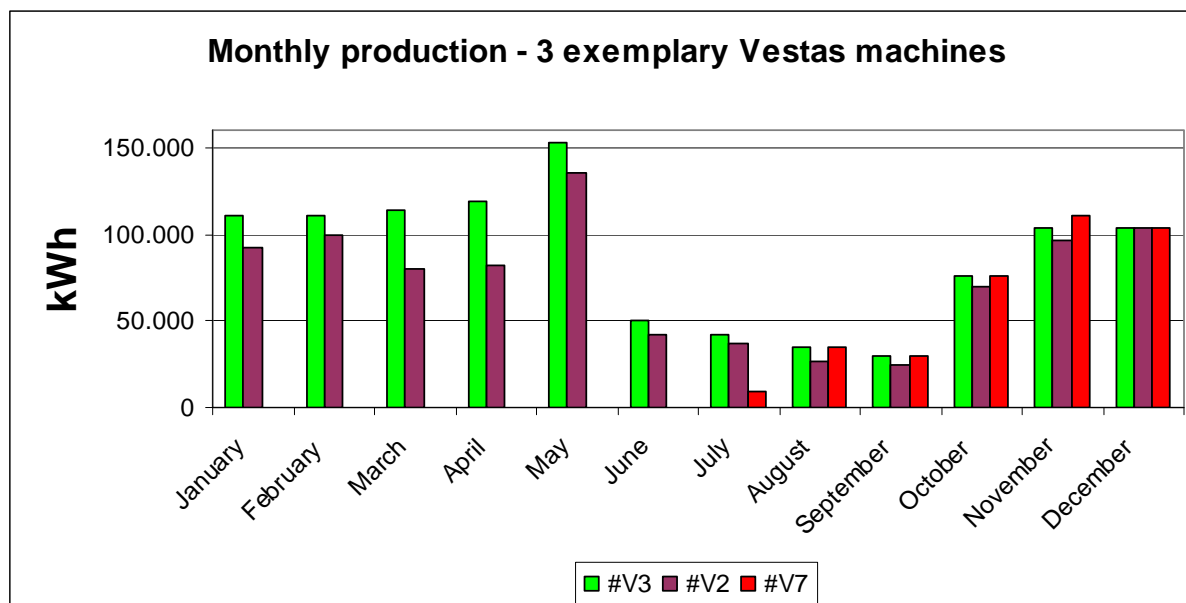
In the following, it is analyzed how the production losses are seen in the behaviour of the machine over the last year.

**Table 43: Monthly production data 2007 of selected Vestas 600 kW machines**

| Site        | #V3       | #V2        | #V7     |
|-------------|-----------|------------|---------|
| Performance | good      | acceptable | bad     |
| January     | 110.771   | 92.533     | 0       |
| February    | 110.305   | 99.142     | 0       |
| March       | 113.971   | 80.415     | 0       |
| April       | 119.424   | 81.618     | 0       |
| May         | 152.900   | 135.235    | 0       |
| June        | 49.824    | 42.317     | 0       |
| July        | 41.705    | 36.625     | 8.737   |
| August      | 34.672    | 26.434     | 34.429  |
| September   | 30.034    | 24.928     | 29.468  |
| October     | 75.942    | 69.428     | 75.506  |
| November    | 103.080   | 96.887     | 110.309 |
| December    | 103.602   | 103.950    | 104.100 |
| Total Year  | 1.046.230 | 889.512    | 362.549 |

The nature of losses for the Vestas machines are as well longer down times as also significant under production in individual months.

Additionally, it can be seen that the worst performing machine can reach the production of the good performing one, if no technical problems exist in the concerned month (as at the end of the year).

**Figure 26: Diagram of monthly production data, Vestas 600 kW**

#### 4.3.3.4 Nordex 600 kW

Of the Nordex 600 kW type in the Huitengxile wind farm also 9 machines are operated.

3 of the 9 machines showed a good performance over the past 3 years, 3 machines had remarkable problems in 2 years and the remaining 3 problems in one year.

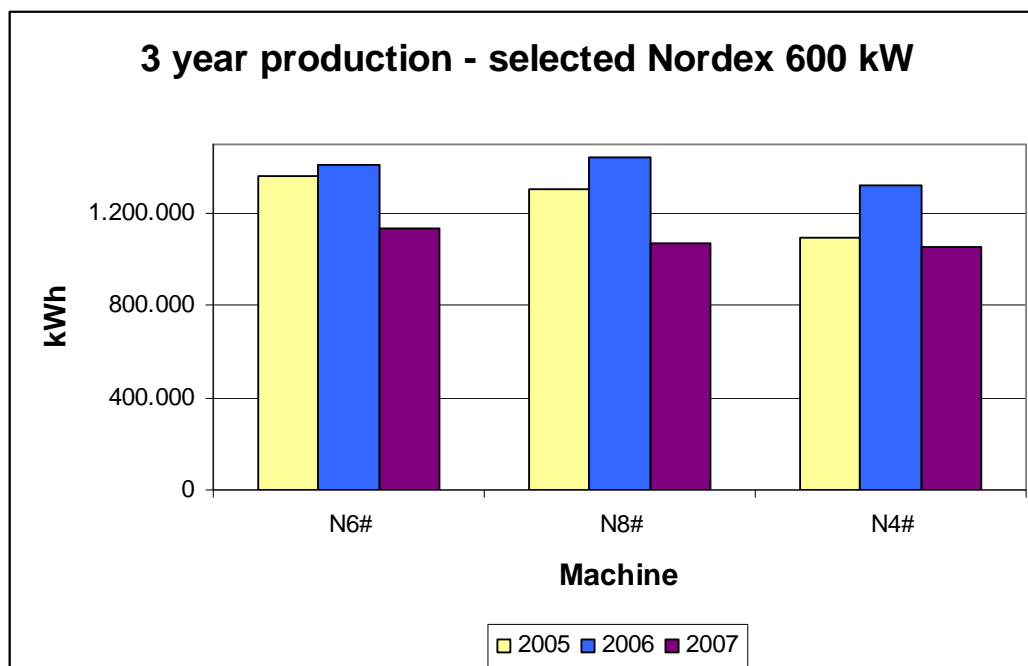
The average annual production of the constant good performing machines amounted to 1,230,000 kWh to 1,348,000 kWh, the 3 worst performing ones reached 1,156,000 kWh (89%) to 1,273,000 kWh (98%) and the others produced between 1,257,000 kWh (96%) and 1,380,000 kWh (106%). All in all the production of all machines is within a quite narrow range, meaning that even the bad performing machines reach quite acceptable levels.

The production data of selected machines is shown in Table 44 and Figure 27.

**Table 44: Production data of selected Nordex 600 kW machines**

| Site | No. | Performance | Production (kWh) |           |           |           | 3 yr rel. to group avg. |
|------|-----|-------------|------------------|-----------|-----------|-----------|-------------------------|
|      |     |             | 2005             | 2006      | 2007      | 3 yr avg. |                         |
| N6   |     | good        | 1.363.454        | 1.411.177 | 1.139.152 | 1.304.594 | 98%                     |
| N8   |     | acceptable  | 1.305.629        | 1.444.873 | 1.068.742 | 1.273.081 | 97%                     |
| N4   |     | bad         | 1.091.482        | 1.317.877 | 1.057.880 | 1.155.746 | 90%                     |

The table and the diagram show that the differences in production of the individual machines are not very significant.

**Figure 27: 3 year production of selected individual Nordex 600 kW machines**

The estimated rough availability of the 2 worst performing Nordex machines together with the average of all identical machines is shown in Table 45. The average of all machines of this type is a satisfying 95%. Additionally, the availability is quite constant over the years.

**Table 45: Average availability (rough estimate) of selected Nordex 600 kW machines**

| Year                                 | 2005 | 2006 | 2007 | Average |
|--------------------------------------|------|------|------|---------|
| Average Availability of all machines | 94%  | 96%  | 95%  | 95%     |
| N4                                   | 83%  | 97%  | 95%  | 92%     |
| N8                                   | 91%  | 97%  | 86%  | 91%     |

The production losses of the individual machines are rather limited and show no characteristic patterns. Thus it is not analyzed further.

#### 4.3.3.5 Micon 600 kW

The Micon 600 kW machine is the type with the biggest installation number (42 machines) in this wind farm. Unfortunately, only production data of the last year was made available and thus the analysis is more limited than for the other machine types.

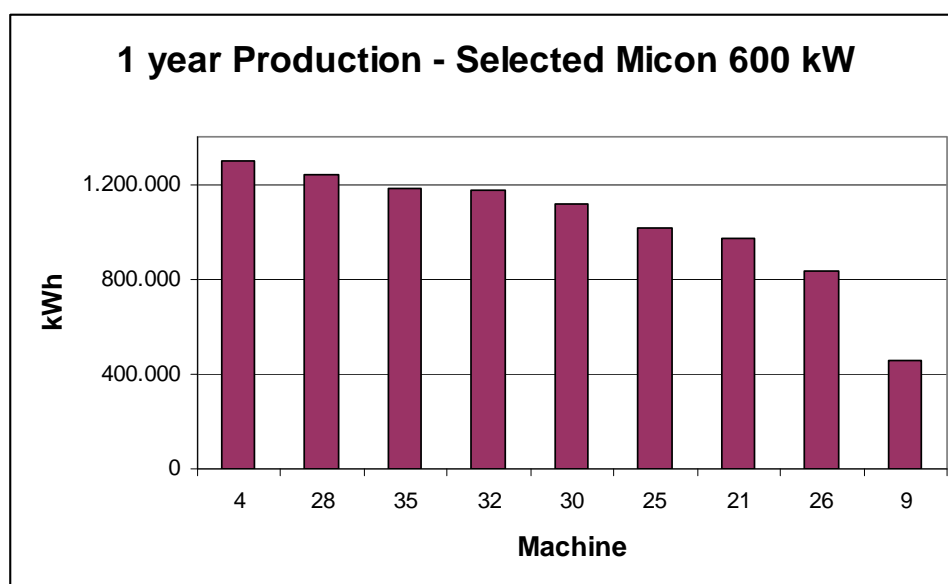
14 of the machines (i.e. 33%) showed a good performance in 2007 and reached a production of 1,183,000 kW to 1,298,000 kWh. 10 machines performed bad and produced only 456,000 kWh to 972,000 kWh (37 to 79 % of the level of the good performing machines).

The production data of selected machines is shown in Table 41 and Figure 28.

**Table 46: Production data of selected Micon 600 kW machines**

| Site | No. | Performance | Production (kWh) |      |           |           | relative to group avg. |
|------|-----|-------------|------------------|------|-----------|-----------|------------------------|
|      |     |             | 2005             | 2006 | 2007      | 3 yr avg. |                        |
| 4    |     | good        |                  |      | 1,297,681 |           | 120%                   |
| 28   |     | good        |                  |      | 1,243,862 |           | 115%                   |
| 35   |     | good        |                  |      | 1,182,892 |           | 110%                   |
| 32   |     | average     |                  |      | 1,175,135 |           | 109%                   |
| 30   |     | average     |                  |      | 1,118,934 |           | 104%                   |
| 25   |     | average     |                  |      | 1,015,402 |           | 94%                    |
| 21   |     | bad         |                  |      | 972,207   |           | 90%                    |
| 26   |     | bad         |                  |      | 835,752   |           | 77%                    |
| 9    |     | bad         |                  |      | 455,803   |           | 42%                    |

**Figure 28: 1 year production of selected individual Micon 600 kW machines**



The estimated rough availability of the 3 worst and 3 acceptable performing Vestas machines together with the average of all identical machines is shown in Table 47. The average of all machines of this type is only a bad 89%.

**Table 47: Average availability (rough estimate) of selected Micon 600 kW machines**

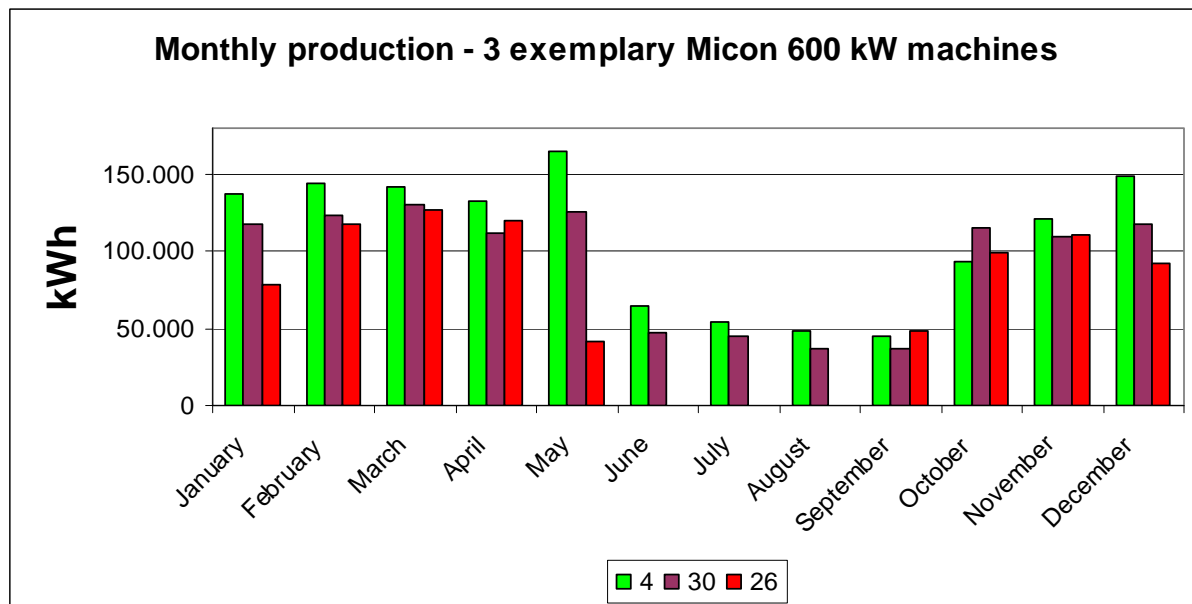
| Year                                 | 2005 | 2006 | 2007 | Average |
|--------------------------------------|------|------|------|---------|
| Average Availability of all machines |      |      | 89%  |         |
| 21                                   |      |      | 80%  |         |
| 26                                   |      |      | 80%  |         |
| 9                                    |      |      | 39%  |         |

In the following, it is analyzed how the production losses are seen in the behaviour of the machine over the last year.

**Table 48: Monthly production data 2007 of selected Micon 600 kW machines**

| Site        | 4         | 30        | 26      |
|-------------|-----------|-----------|---------|
| Performance | good      | average   | bad     |
| January     | 137.282   | 118.248   | 78.535  |
| February    | 144.465   | 123.344   | 118.230 |
| March       | 142.234   | 129.828   | 126.927 |
| April       | 132.421   | 112.228   | 120.045 |
| May         | 165.370   | 126.293   | 41.538  |
| June        | 64.860    | 47.530    | 0       |
| July        | 54.584    | 44.653    | 0       |
| August      | 48.049    | 37.024    | 0       |
| September   | 44.974    | 37.024    | 48.181  |
| October     | 93.605    | 115.374   | 99.087  |
| November    | 121.255   | 110.092   | 111.131 |
| December    | 148.582   | 117.296   | 92.078  |
| Total Year  | 1.297.681 | 1.118.934 | 835.752 |

It can be seen clearly that the losses are caused by both, long downtimes and underproduction during only 1 month.

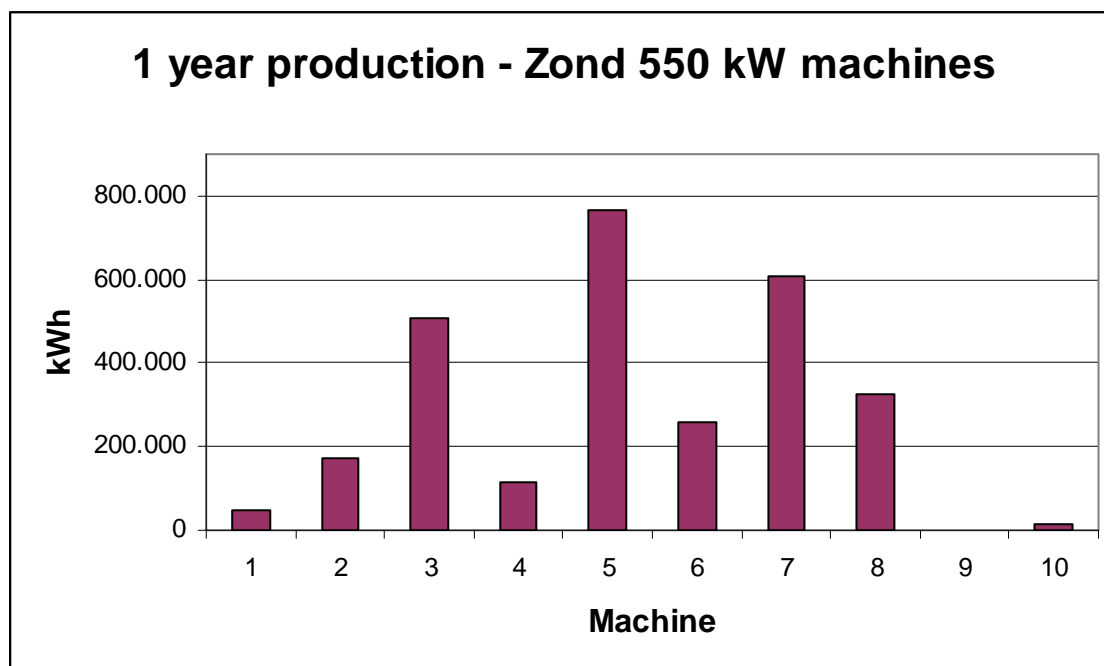
**Figure 29: Diagram of monthly production data, Micon 600 kW**

#### 4.3.3.6 Zond 550 kW

Of the Zond 550 kW type 10 machines are operated in the wind farm.

1 of those is out of order since more than 3 years and only 5 have produced a noticeable electricity amount in 2007, however even their production reached only approx. 25 to 80 % of the potential possible production. As the manufacturer of these machines has disappeared several years ago, it is estimated to be very difficult to further maintain or even improve the operation of these machines in the wind farm. It makes not much sense to analyze their data in more detail. An overview on the production of all the machines is given in Figure 30.

In 2007 there were only five machine with considerable production. For the remaining 4 machines (#2, #4 and especially #1 and #10) it seems to make no sense to keep them operating. It could be better to dismantle them, use their components as spare parts and use the sites partly with new to be installed modern machines.

**Figure 30: 1 year production of Zond 550 kW machines**

#### 4.3.4 Summary and overview on the availability and production of all machines

After analyzing and discussing the development of production and availability of the individual machines of the different types in the previous chapter, now some main findings for this wind farm shall be presented in an overview.

**Table 49: Overview on the availability of the machine types**

| Year                    | 2005       | 2006       | 2007       | Average      |
|-------------------------|------------|------------|------------|--------------|
| GE 1.5 MW               | 91%        | 95%        | 89%        | <b>92%</b>   |
| Micon 900 kW            | 94%        | 96%        | 96%        | <b>96%</b>   |
| Vestas 600 kW           | 92%        | 93%        | 81%        | <b>89%</b>   |
| Nordex 600 kW           | 94%        | 96%        | 95%        | <b>95%</b>   |
| Micon 600 kW            |            |            | 89%        | <b>89%</b>   |
| <b>Weighted Average</b> | <b>93%</b> | <b>95%</b> | <b>90%</b> | <b>92.6%</b> |

Table 49 shows the availability figures that had been presented for the different machine types in the chapters before. In order to get an impression on the availability of the total wind farm, the availability of the different types has been weighted with the number of machines of the same type in the wind farm. Only the Zond type has not been included as this type is considered a special case. For the



complete wind farm the availability is rather low with on average 92.6% over the last 3 years and especially the extreme low availability in 2007 is alarming.

**Table 50: Production overview for the Huitengxile wind farm**

| Type              | 2005              | 2006              | 2007               | Average           |
|-------------------|-------------------|-------------------|--------------------|-------------------|
| <b>GE 1.5s</b>    | 25,149,000        | 40,926,000        | 36,033,000         | <b>34,036,000</b> |
| <b>Micon 900</b>  | 25,658,000        | 29,631,000        | 24,728,000         | <b>26,672,000</b> |
| <b>Vestas 600</b> | 10,385,000        | 10,982,000        | 7,928,000          | <b>9,765,000</b>  |
| <b>Nordex 600</b> | 11,602,000        | 12,476,000        | 10,172,000         | <b>11,417,000</b> |
| <b>Micon 600</b>  |                   |                   | 45,352,000         | <b>45,352,000</b> |
| <b>Total</b>      | <b>72,794,000</b> | <b>94,015,000</b> | <b>124,212,000</b> |                   |

**Table 51: Estimated Losses for the Huitengxile wind farm**

| Type              | 2005             | 2006             | 2007             | Average          |
|-------------------|------------------|------------------|------------------|------------------|
| <b>GE 1.5s</b>    | 1,658,000        | 862,000          | 3,239,000        | <b>1,920,000</b> |
| <b>Micon 900</b>  | 707,000          | 184,000          | 258,000          | <b>383,000</b>   |
| <b>Vestas 600</b> | 564,000          | 472,000          | 1,566,000        | <b>868,000</b>   |
| <b>Nordex 600</b> | 370,000          | 130,000          | 214,000          | <b>238,000</b>   |
| <b>Micon 600</b>  |                  |                  | 4,077,000        | <b>4,077,000</b> |
| <b>Total</b>      | <b>3,300,000</b> | <b>1,648,000</b> | <b>9,353,000</b> |                  |

In Table 50 an overview on the production of the complete wind farm and for all machines of the different types is given and Table 51 shows the estimated losses. This loss estimation is done in a quite simple way and is intended as a first step towards an understanding of the potential for optimization in the wind farm. The background for the loss estimation are the real production and the estimated availabilities for all types of machines. Then an estimation of the theoretical potential production is calculated by assuming that all machines would have reached an availability of 97%. Finally the estimated loss is calculated as difference between this estimated theoretical and the registered real production.

As a result of the presented availability and loss figures it shall be pointed out that the GE 1.5 MW and Micon 600 kW machines have a nearly equal part in the losses in 2007.

Although the GE machines are installed in a quite small number, their 2.5 times higher rated capacity in conjunction with a similar low availability as the Micon 600 kW machines leads to this result. Additionally, the Vestas machines had a very high sum loss in 2007.

Concerning a strategy, it arises from the calculations that it would be worth to concentrate with improvement measures at highest priority on the GE machines – a low number of machines of a new type and with still quite good access to the manufacturer may be easier worked on as a high number

of older machines. Nevertheless, also improvement of the operation of the Micon 600 kW machines should be worked on. For the Nordex 600 and Micon 900 machines on the other hand, it should be tried to maintain the actual very good level of availability.

#### **4.3.5 Comparison of production data with calculations based on measurements**

In the first phase of the Performance Improvement Project measurement masts have been installed some years ago with the intention to verify the production in the wind farm in relation to the wind speeds and to check exemplary the power curve of individual turbines. The detailed evaluations of a power curve would need a substantial extended effort regarding collection and storage of production data (10 minute time series and synchronized to the met mast data) and analysis and have not been explicitly required in the current project.

Currently three met masts of different heights, with different measurement heights and for different measured parameters are installed in the wind farm. The masts are located near to machines of the NEG Micon 900 kW, Nordex 600 kW and GE 1.5 MW type. The names of the met masts have been chosen corresponding to their different top anemometer mounting height. Table 52 shows the data coverage for the past months. Where the data coverage is at least 90%, the fields are marked green. This threshold has been chosen in consideration of the requirements for reliable data.

The only period covered by data extends for little more than 11 months for 2 masts and nearly 5 months for the third one. The first and last (incomplete) months of the interval for the 2 masts have been excluded as no parallel production data for exact the same time periods is available. The resulting 10 months period for the evaluation is quite in parallel with the longest covered periods in the other 2 wind farms.

A detailed check of the provided data showed some noticeable problems for individual time periods. Details are given in the following.

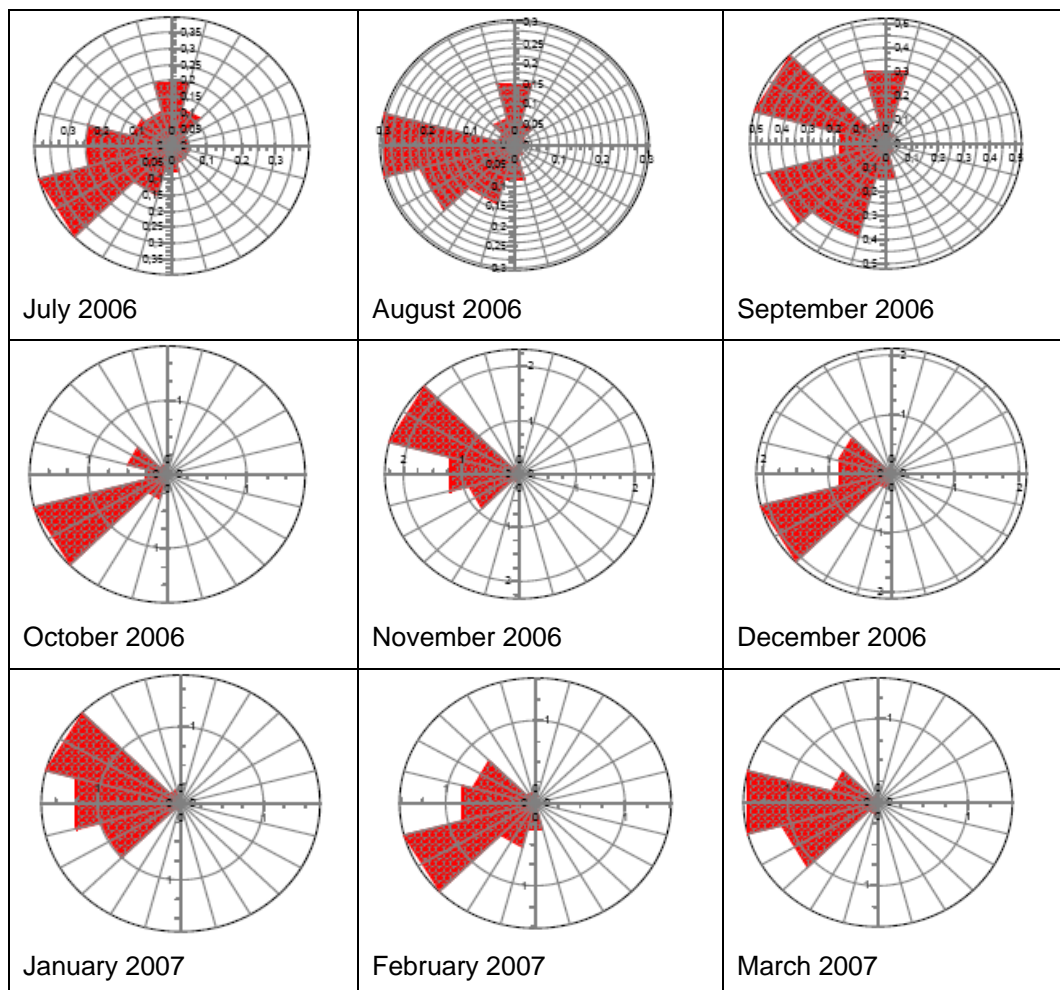
- At the 50 m met mast some short standstills occurred in the winter months. They are probably caused by icing.
- At the met mast of 55 m measurement height also some short standstills occurred during winter. They are probably caused by icing. The recordings of relative humidity and air pressure can not be used, because they are all complete out of a reasonable range.
- The wind speed measurement of one of the anemometers at 70 m height broke down in July of 2006. The other one seems to have problems to start-up, which might be a bearing problem. An indication has been found that the mounting boom of the wind vane has been slightly horizontal turned.
- The offset of the wind directions for all the met masts could not be verified, because it was not possible to get data of the day when the site visit took place. No documentation of the met masts is available. An exact allocation of the single sensors to the recorded data channels is not possible. It can not be stated if the anemometers have been calibrated and if the calibrations have been applied to the data recording.

The used anemometer type NRG Max40 has a big uncertainty in complex terrain and tends to have an inappropriate long-term behavior. No maintenance works are performed at the met masts.

**Table 52: Availability of data of the individual met masts in Huitengxile**

| Period         | Huitengxile50 | Huitengxile55 | Huitengxile70 |
|----------------|---------------|---------------|---------------|
| May 2006       | 0%            | 0%            | 0%            |
| June 2006      | 68%           | 68%           | 75%           |
| July 2006      | 100%          | 100%          | 100%          |
| August 2006    | 100%          | 100%          | 100%          |
| September 2006 | 100%          | 100%          | 100%          |
| October 2006   | 100%          | 100%          | 100%          |
| November 2006  | 100%          | 100%          | 16%           |
| December 2006  | 100%          | 100%          | 0%            |
| January 2007   | 100%          | 100%          | 0%            |
| February 2007  | 100%          | 100%          | 0%            |
| March 2007     | 100%          | 100%          | 0%            |
| April 2007     | 100%          | 100%          | 0%            |
| May 2007       | 72%           | 72%           | 0%            |
| June 2007      | 0%            | 0%            | 0%            |
| July 2007      | 0%            | 0%            | 0%            |
| August 2007    | 0%            | 0%            | 0%            |
| September 2007 | 0%            | 0%            | 0%            |
| October 2007   | 0%            | 0%            | 0%            |
| November 2007  | 0%            | 0%            | 0%            |
| December 2007  | 0%            | 0%            | 0%            |
| January 2008   | 0%            | 0%            | 0%            |
| February 2008  | 0%            | 0%            | 0%            |
| March 2008     | 0%            | 0%            | 0%            |
| April 2008     | 0%            | 0%            | 0%            |
| May 2008       | 0%            | 0%            | 0%            |
| June 2008      | 0%            | 0%            | 0%            |
| July 2008      | 0%            | 0%            | 0%            |
| August 2008    | 0%            | 0%            | 0%            |
| September 2008 | 0%            | 0%            | 0%            |
| October 2008   | 0%            | 0%            | 0%            |

In the following the wind energy roses derived from the 55m mast are analyzed (Table 53). They show two predominant directions, either from north-east or south-east and changing from one month to the next. It is assumed that this could be correct, at least no clear sign has been found that the wind directions would be wrong due to moving sensor booms.

**Table 53: Wind energy roses in the Huitengxile wind farm**

In summary the data of the met masts cannot be trusted for the whole time. For the wind directions of the 70m mast in principle, it would be possible to apply much effort to sort out which of the deviating values are the more logic ones for all time periods, but this would be very time consuming.

Furthermore the uncertainty of the measurements (amongst others due to not known calibrated sensor characteristics) is of an order which does not allow absolute and exact evaluations and comparisons. But still it is possible to use the wind speed data in some degree for relative comparisons. Hence from the available wind speed data a theoretical monthly energy production was calculated and compared with the real observed production.

The monthly theoretical energy yields have been calculated from the time series of wind speeds under use of turbine type dependent (measured) power curves for the 3 aforementioned machine types. For that purpose wind speed has been averaged and inter- or extrapolated from anemometers which were adjacent to the hub height of the related turbine type. Because of extreme monthly variety of air density at the site and in order to take into account its influence, long-term data from proximate

meteorological stations were used to calculate the air density and applied for the energy yield calculations. The theoretical yields are presented in Table 54.

Same wind speeds in different months may result in different theoretical yields and the theoretical yield is regarded as a better parameter for understanding the wind potential. Nevertheless, as an indication for one of the masts the corresponding wind speed is shown in Table 55 (the wind speeds at the other masts are not so much different and are thus not shown).

**Table 54: Theoretical Yields for machines at the 3 met mast positions in Huitengxile**

| Month          | Huitengxile 50 / N43 (kWh) | Huitengxile 55 / NM 52/900 (kWh) | Huitengxile 70 / GE 1.5s (kWh) |
|----------------|----------------------------|----------------------------------|--------------------------------|
| July 2006      | 66,478                     | 121,574                          | 249,412                        |
| August 2006    | 51,090                     | 92,983                           | 193,594                        |
| September 2006 | 83,413                     | 144,998                          | 289,125                        |
| October 2006   | 124,861                    | 212,656                          | 410,914                        |
| November 2006  | 153,411                    | 254,729                          |                                |
| December 2006  | 159,331                    | 280,486                          |                                |
| January 2007   | 132,797                    | 230,923                          |                                |
| February 2007  | 135,801                    | 243,824                          |                                |
| March 2007     | 121,997                    | 205,477                          |                                |
| April 2007     | 135,291                    | 204,172                          |                                |
| <b>Total</b>   | <b>1,164,470</b>           | <b>1,991,821</b>                 | <b>1,143,044</b>               |

**Table 55: Wind speed at Mast 1 (50 m height) in the Huitengxile wind farm**

| Month          | Speed Huitengxile 55 (m/s) |
|----------------|----------------------------|
| July 2006      | 6.0                        |
| August 2006    | 5.5                        |
| September 2006 | 6.5                        |
| October 2006   | 7.7                        |
| November 2006  | 8.4                        |
| December 2006  | 8.4                        |
| January 2007   | 7.8                        |
| February 2007  | 8.3                        |
| March 2007     | 7.1                        |
| April 2007     | 8.1                        |
| <b>Average</b> | <b>7.4</b>                 |

It has to be considered that wake effects in the wind farm have an influence on the wind measurements, which is not absolutely comparable to the influence they would have on a turbine which is positioned at the position of the met mast. For the following it is assumed that it is the same.

Further the theoretical energy yields do not include production losses according the availability of the machines. To consider this effect, a deduction of 5% from the theoretical energy yield of a single machine is applied. This means that according to the wind data the machines of the same type should have reached an average production of 1,106,000 kWh (95% of the above mentioned yield for the N43 machine) and 1,892,000 kWh (95% of the above mentioned yield for the NEG 900 kW machine).

The real average production of all the machines of Nordex N43 type in the relevant period has been 1,021,000 kWh, i.e. nearly exact the average theoretical yield calculated with the measured wind data. For the NEG Micon 900 kW machines the real production averaged to 1,899,000 kWh, i.e. more than the theoretical values. The differences in production for the Nordex machines are not significant (-6% to +7%), but for the NEG Micon machines the worst / best machines are -12% / +13% away from the average.

In Table 56 the real production data of the closest machines to the masts Huitengxile 50 and Huitengxile 55 are shown in parallel to the theoretical production. There is a certain correlation, but it is not very well. Nevertheless the accumulated production over the period matches very well the theoretical figures. The 2 Nordex machines reached 84.0% and 86.6% of the theoretical yield (without deduction of 5% for technical unavailability) and the Micon 900 kW machines show even 95.6% and 100.3%. The additional comparison of the production data of these 4 machines with the data of other neighboring machines shows no significant under production for the 4 machines in the period and it is assumed that they operated at around 97-99% availability and that the deviations from the met mast data in individual months is of no relevance.

**Table 56: Theoretical and Real Yields for 2 met mast positions in Huitengxile**

| Month                 | Huitengxile 50 /<br>Nordex 600 (kWh) | N5 (kWh)       | N6 (kWh)         | Huitengxile 55 /<br>Micon 900 (kWh) | M6 (kWh)         | M7 (kWh)         |
|-----------------------|--------------------------------------|----------------|------------------|-------------------------------------|------------------|------------------|
| <b>July 2006</b>      | 66,478                               | 55,362         | 61,605           | 121,574                             | 110,916          | 111,425          |
| <b>August 2006</b>    | 51,090                               | 40,599         | 46,260           | 92,983                              | 78,801           | 81,415           |
| <b>September 2006</b> | 83,413                               | 76,771         | 76,017           | 144,998                             | 144,398          | 145,041          |
| <b>October 2006</b>   | 124,861                              | 106,380        | 112,944          | 212,656                             | 213,807          | 211,520          |
| <b>November 2006</b>  | 153,411                              | 123,021        | 127,298          | 254,729                             | 237,071          | 228,028          |
| <b>December 2006</b>  | 159,331                              | 129,934        | 120,272          | 280,486                             | 287,179          | 262,477          |
| <b>January 2007</b>   | 132,797                              | 99,795         | 109,303          | 230,923                             | 223,062          | 194,531          |
| <b>February 2007</b>  | 135,801                              | 122,716        | 122,836          | 243,824                             | 244,775          | 242,626          |
| <b>March 2007</b>     | 121,997                              | 107,193        | 114,730          | 205,477                             | 228,705          | 214,323          |
| <b>April 2007</b>     | 135,291                              | 116,812        | 117,531          | 204,172                             | 228,363          | 224,229          |
| <b>Total</b>          | <b>1,164,470</b>                     | <b>978,583</b> | <b>1,008,796</b> | <b>1,991,821</b>                    | <b>1,997,077</b> | <b>1,915,615</b> |

Although the correlation of the theoretical and real values is not the highest, the comparison of the met mast and real production data leads to the conclusion that the real production is acceptable and that the machines exploited the available wind resources in a good manner. This is a positive result.

Despite the measured wind data having the mentioned problems, calculations based on this data have been carried out using the WAsP software package for a number of months. For this wind farm the representativeness of these calculations is reduced, as

- (1) for the most employed machine in the wind farm no production data for the relevant time period were available,
- (2) no exact map of the locations of the individual machines was made available, and
- (3) no sufficient topographic maps of the wind farm for the terrain modeling were available.

The detailed results of the calculations are included in the annex; due to the aforementioned problems the results of the calculation are not very representative and may be even less correct than in the case of the other two wind farms. Thus the results are not discussed here in more detail. However, as can be seen in the annex, the real yields seem to be quite consistent with the calculated data (except for the GE machines) and show the main deviations for the individual machines and months where based on only the production data underperformance had already been identified.

In the next, also for this wind farm, additional long-term data is searched in order to evaluate also the production data of the past in relation to the wind potential. One source for such long-term wind data is the World Wind Atlas. As can be seen in Figure 31 there is a certain correlation between the Index (based on the World Wind Atlas) and the Virtual Yields (calculated with the measured wind speeds). This means that the long-term data (and the Index calculated from it) can give a hint at the wind potential in the wind farm in past years. Now the Index derived from the long-term data is shown in parallel with real production data with one of the machines in the wind farm. For this purpose one of the Micon 900 kW machines was selected (#11), which has shown stable production throughout the 3 years where data are available. The diagram is shown in Figure 32.

Figure 31: Correlation of Wind Power Index and Virtual Yields for Huitengxile

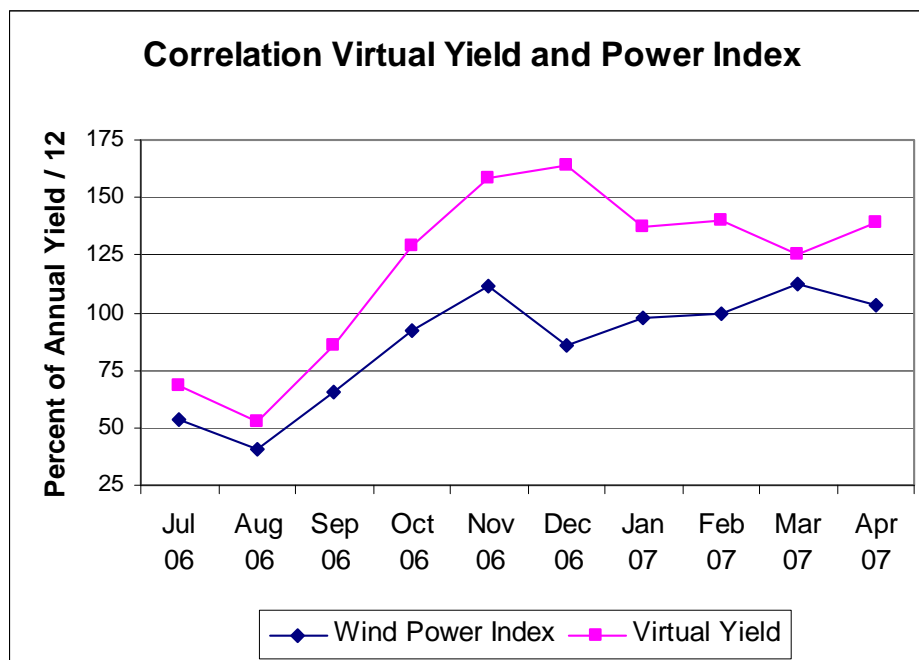
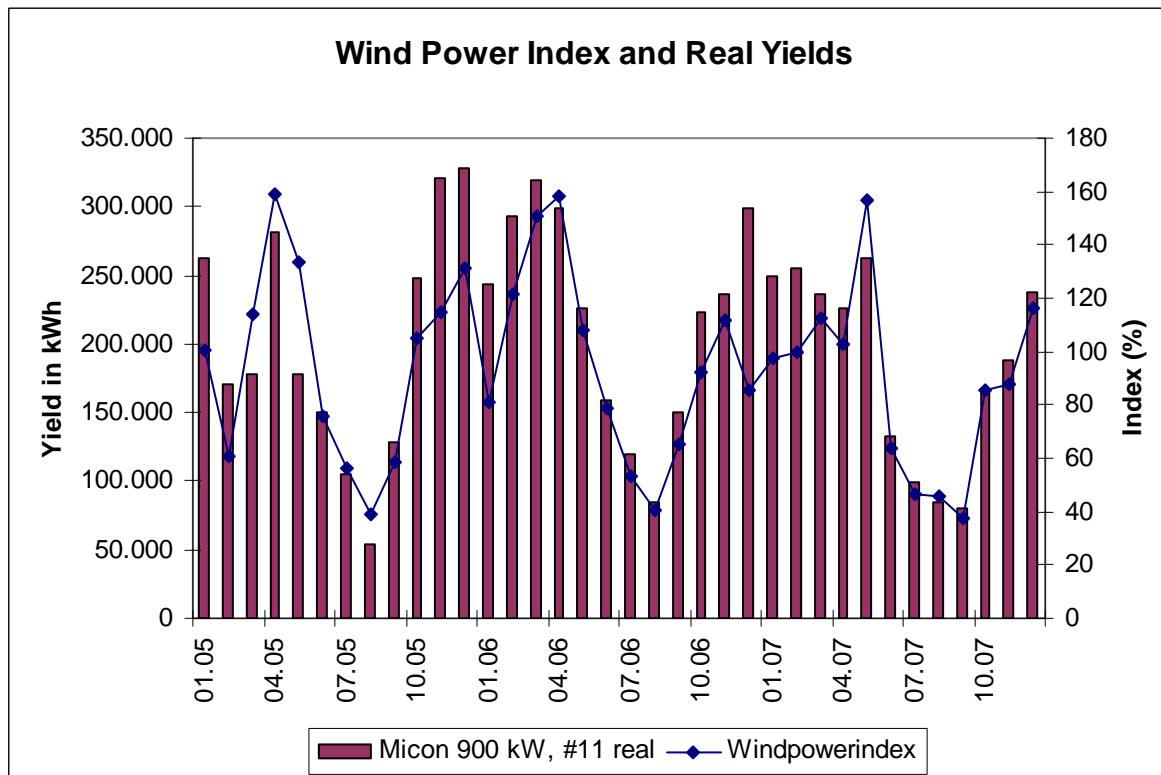


Figure 32: Wind Power Index and Real Yield for a selected machine in Huitengxile



It can be seen that the real production followed quite well the development of the Wind Index in 2005 and 2007; for 2006 the real production was significantly higher than it would have been expected



according to the Wind Index. As conclusion this means that the appearing differences in production between individual months for this wind farm are caused significantly by the corresponding wind potential in the month. And it also confirms that for the 3 years the machine shown in the graph exploited the existing wind potential in a rather satisfying manner. Only for a few months technical problems might have slightly reduced the electricity generation.

It was also researched what other long-term data of proximate meteorological stations is available and if this would correlate also or even better with the observed real production. But with all data of six further near-by stations (Ba-Dao-Gou, Hohhot, Bogus Chinese, You-Yu, Jining, Chu Le Pu) a sufficient correlation is not given.

#### **4.3.6 Base for Benchmarking the Future Performance**

In the same manner as for the Dabancheng wind farm also for the Huitengxile wind farm the distribution of machines in 4 performance classes is used as tool for benchmarking the development of the performance.

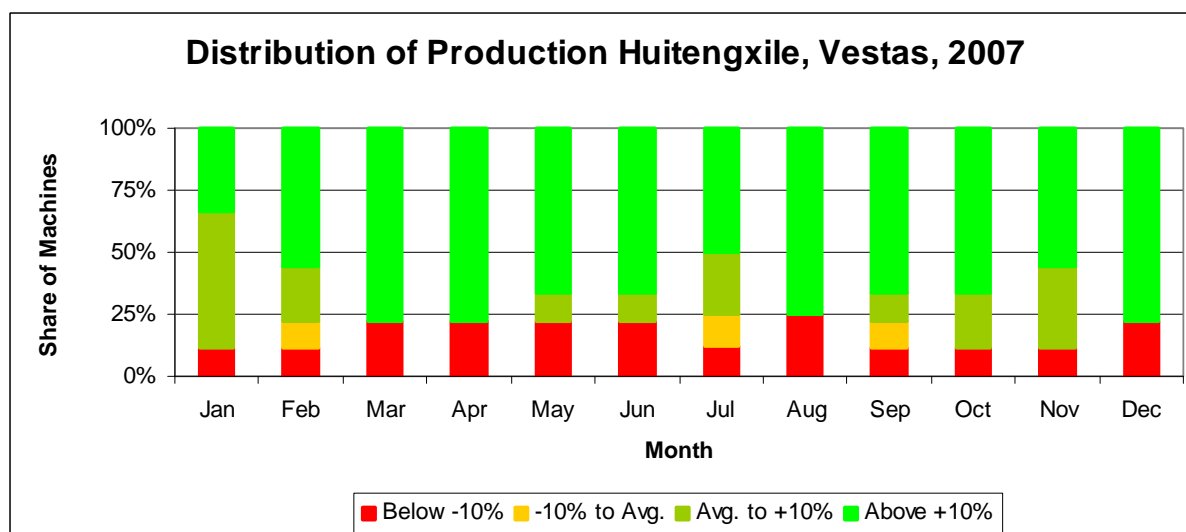
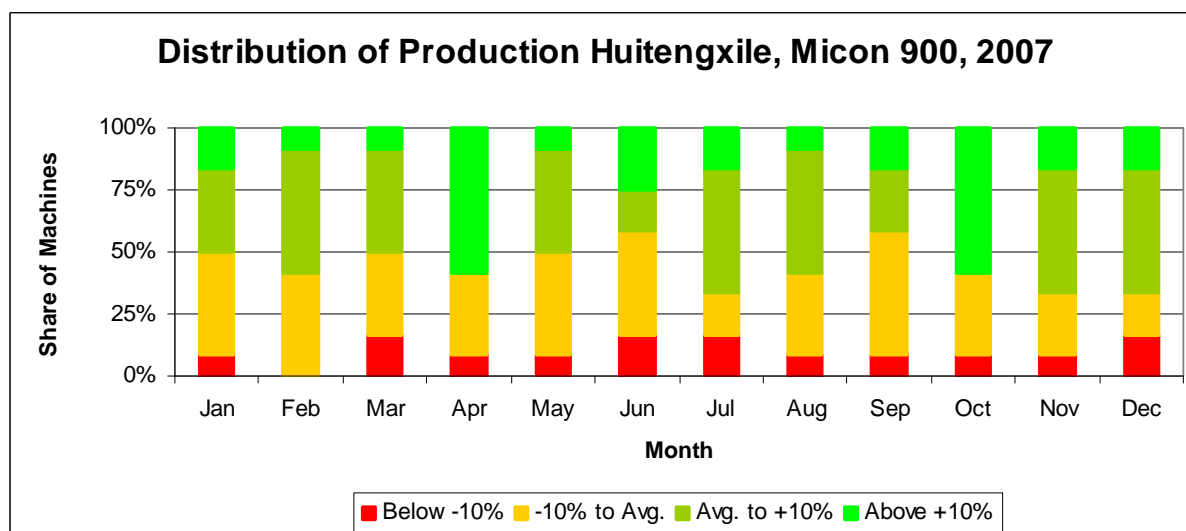
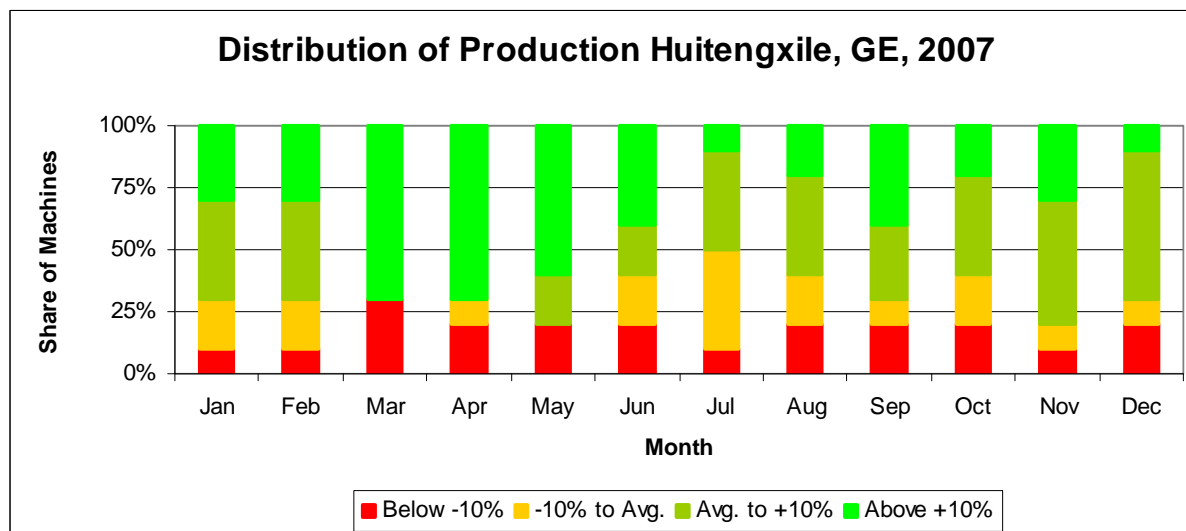
The 4 classes are again the following:

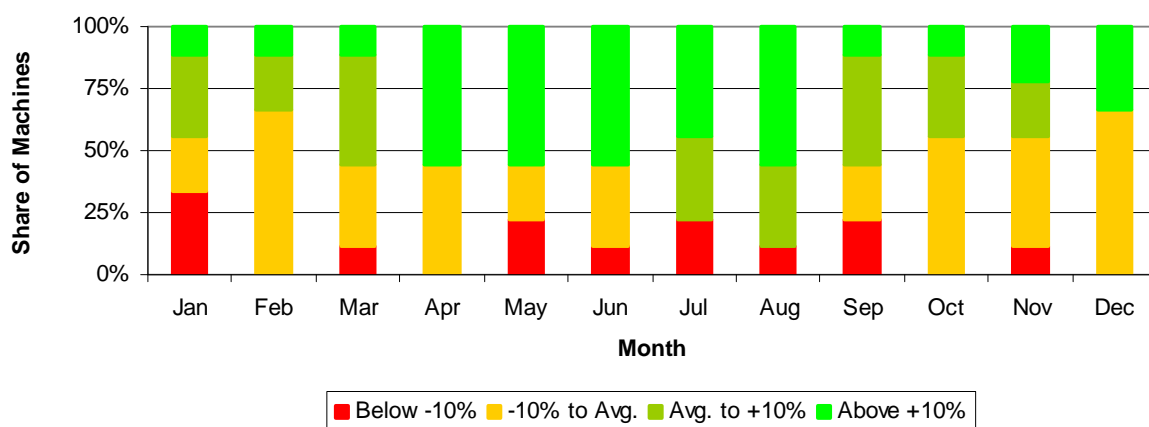
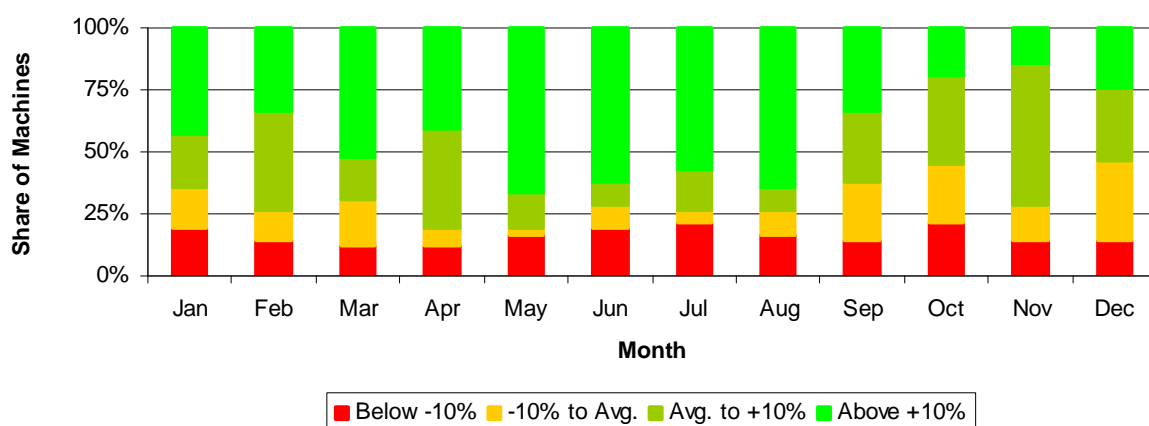
- 5) Worst performing machines, with a production below 10% of the average of all machines of the same type
- 6) Low performing machines, with a production between -10% and the average of all machines of the same type
- 7) High performing machines, with a production between the average of all machines of the same type and +10%
- 8) Best performing machines, with a production above +10% of the average of all machines of the same type

This classification allows a quick evaluation of the actual performance, of the improvement since begin of the project and of focus for the work.

In the best case all machines should perform around the average (classes 2 and 3) and only a small number should fall in the best and worst categories. An improvement of the performance is characterized by an increasing number in the higher classes in comparison to the month before.

In the following diagrams the share of the machines in the different classes is shown for the year 2007.



**Distribution of Production Huitengxile, Nordex, 2007****Distribution of Production Huitengxile, Micon 600, 2007**

#### **4.4 Conclusions from the evaluation of past production data**

In all 3 wind farms there are a certain number of machines that are performing very well over a 3-6 year period and in the 2 bigger wind farms Xinjiang Dabancheng and Inner Mongolia Huitengxile there are also a remarkable number of machines with very bad performance; only in the Liaoning Dandong wind farm the machines seem to have no or at least no major technical problems.

The average availability over 3-5 years of the machines in the 2 big wind farms is similarly low with only less than 93%. An increase of the level to 95-97% should be possible. A such high availability is already reached as average for some of the machine types; i.e. in 2007 for the Nordtank 300 and Bonus 450 machines in Dabancheng and for the Micon 900 and Nordex 600 machines in Huitengxile. Reaching these higher levels of availability of the machines would mean an additional production of the Dabancheng wind farm of annually 4-6 million kWh and in the case of the Huitengxile wind farm even annually 7-10 million kWh.

## **5. Recommended Improvement Measures**

### **5.1 Xinjiang Dabancheng and Inner Mongolia Huitengxile Wind Farm**

As the analysis of the past production data and of the wind measurement data for a limited period have shown, individual machines in the wind farms often have significant down times and, on the hand, the good performing machines seem to exploit well the available wind potential.

This means that in order to improve the operation and production of the wind farm the focus must be to achieve for all machines the same reliability as for the best performing machines. In the following some measures are proposed.

#### **1. Improve the regular maintenance**

The regular maintenance is intended to keep the machines always in a good technical state and to identify worn parts. If much worn parts are exchanged early, this can avoid downtimes due to their failure. According to general experiences in wind farms world wide, it is estimated that an improved regular maintenance starting from the actual situation in the two bigger wind farms of Dabancheng and Huitengxile can avoid on average at least one unexpected stop of each machine during a year. As the analysis of the production data and fault events in these wind farms have shown that on average after a failure a machine is down for approx. half a day (12 hours), such improvement of the maintenance could roughly lead to 0.5 day of additional production. This translates according to the part of the time of a year of this half day roughly to an increase in production of 1 – 1.5 percent. This may look unimportant at first, but would be equivalent to approx. 15 percent of the losses in the wind farms.

#### **2. Improve the diagnostics of failures**

The fault lists for the period of March to July 2008 have been analyzed in the course of the project. They often showed repeated problems at the same machines within a few days. This is an indication that the real causes of the failures have not been found at the first intervention. If the staff would be well trained and work very diligently they should be able to identify the real problem quicker and thus further stops of the machine with related downtimes and losses of production could be avoided. In addition to the training of the staff, also detailed check lists and procedures for the failure diagnostics could be developed in the wind farms. The check lists should then be regularly adapted to include the most recent problems at the machines. This would assure that not only the common and often repeated problems are recognized quickly, but also others that have been encountered in the past (and where the real cause may have been identified only after a lengthy procedure with several repair attempts).

This improvement measure would not affect all down-times and problems in the wind farms – it has for example no influence on times waiting for spare parts and does not affect the problems, where the repair is done correctly at the first attempt. However, it is estimated that it could increase the production in the wind farms, by approx. 0.25 to 0.5 percent (equivalent to approx. 3-7 percent of the actual production losses in the wind farms).

3. Improve the performance monitoring and reporting

During the data collection within the actual consulting project, it was found that the reports on problems at the machines were quite limited. In general it was stated in the failure lists an error message from the controller of the machine that was not necessarily self-explaining (“for example “pitch angle low”) and presented rather a symptom of than a cause for a problem.

It is not clear whether this manner of failure registration represents the knowledge of the staff correctly (did they know more about the reason for the problem or not?). However, it should be tried to register not only the symptom but also a known or supposed reason for the problem. Taking the above example “pitch angle low”, this might be “problem with hydraulic hose”, “sensor fault” or even “known problem with certain wind condition”.

To enhance the reporting in this way, would help everyone involved in the operation of the wind farm to understand the nature of the problem, to decide the correct reaction on the problem and to check afterwards whether the problem is been tackled appropriate.

Then there should be a detailed reporting of failure statistics, including nature of problem, number of occurrence within the actual period (month or year), the average down time related to this problem and the comparison of this time to the average of the down time caused by the same problem in the past. Such statistical monitoring would help to see the improvement achieved in handling the problem, the improvement in avoiding the occurrence of the problem – or, in the worst case, to find out that it would be necessary to work more intensively on reducing the losses caused by this type of failure.

For this measure it is hard to quantify the impact on the reduction of the losses in the wind farms, but it is expected that it would be in the same order as the proposed improvement in failure diagnostics.

4. Shorten the repair times

The most important reduction in production losses can be achieved by reducing the times needed for repair measures. This can be achieved amongst others by the next 2 proposed measures. The impact on the production would be a reduction of losses by approx. 30-40%.

5. Improve the spare parts availability

A key factor in reducing the down times and repair times is also the availability of needed spare parts. The more spare parts are available, the quicker a repair measure can be done. However, the spare parts stock also causes costs and it should be avoided to have too many

spare parts that are not needed. It is necessary to find a good volume for the individual spare parts and also a good mixture of the different parts that are kept at stock.

It should be analysed what parts and how many of the different parts have been needed annually for the repair during the past years. And then it should be tried to have always the necessary spare parts for the next 3 to 6 months at stock. This means also to order new spare parts in time before all the available stock has gone.

It is recommended to keep at stock also 1 piece of each of the major components (gearbox, generator, set of rotor blades) at least for the most important machine type in the wind farm, i.e. for the Vestas machines in the Xinjiang wind farm and the Micon 600 and GE machines in the Huitengxile wind farm (although there is only a small number of GE machines, they are important, because their rated power is at far the highest in the wind farm).

#### 6. Shorten decision times

It was understood during the discussions with the local staff, that in the past from time to time repair or retrofit measures had been delayed, because the decision on the necessity of the implementation was taken only with a long delay.

It is probable that the necessary time for the decision is related also to the costs (the higher the costs, the longer is thought about the decision) and this is plausible. However the decision should not be based only on the costs for the measure, but also on the effect that it would have. I.e. if the measure has high costs (for example repairing a gear box), but impacts heavily the production (the machine is stopped until the gear box is repaired) than the costs of the production loss of each day may outbalance the costs of the repair measure.

#### 7. Concentrate on the worst machines

It was found that the performance of the individual machines of the same type is stretching over a wide range. To work on the worst performing machine with priority may bring much higher additional production than working on one that is performing quite well. I.e. if machine A is producing in a month only 20% of the reference production of machine C and machine B is reaching 75% of the production of machine C, than the potential for improving the production when working on machine A is much higher (80% of the reference production) than in the case of working on machine B (only 25% of the reference production, i.e. roughly  $\frac{1}{4}$  of the potential related to machine A).

The impact of this measure on the reduction of losses is hard to quantify and no individual figure is given here.

#### 8. Improve the knowledge of the staff

The knowledge of the staff in the wind farm can be improved in different ways. It is important that the "total" knowledge and experience of all staff members is taken into account. If the staff consists of 5% specialists and 95% unexperienced workers, it would normally be better to

improve the knowledge of the high number of unexperienced workers than giving more training to the specialists.

The “total” knowledge of the staff depends also on the seniority of the staff and their experience in the wind farm. It would normally be more effective to try to keep a worker, technician or engineer, etc. in the wind farm for the future than trying to get a new staff member from the outside.

As a measure to increase the knowledge of the individual staff members dedicated training courses should be designed. These training courses should be as well internal as external. The internal courses would be held in the wind farm for all relevant workers and there might be external teachers or teachers could be selected from the senior staff of the wind farm. These internal courses would normally cover a broader spectrum and help to improve the basic skills of the workers. The external training courses would cover more specialized aspects (for example introduction of new work procedures, advanced failure diagnostic techniques or implementation of condition monitoring systems) and could be selected probably from general training course offers of national or international institutions. Such external training courses could be offered also by manufacturers of main components (gear boxes, generators, rotor blades) or could be developed in cooperation with them so that they cover the particular needs of the staff and are appropriate for the machine types or characteristic problems found in a selected wind farm.

## **5.2 Liaoning Dandong Wind Farm**

For the Liaoning Dandong Wind Farm the analysis of the past operational and wind data revealed no important technical problems (apart from some grid problems and small deficits in the power curve of individual machines) at the machines and no major deficits in the know-how and capability of the staff. The only – but nevertheless very important – problem of this wind farm is the low wind potential in the area.

It should be worked on maintaining the high availability and the technical conditions of the machines and the know-how of the local operating staff. As areas for further investigations the above mentioned grid problems and power curve analyses by means of the wind farm SCADA system can be mentioned.



## 6. Expected Future Performance of the 3 Projects

It is expected that the operation of the 2 bigger wind farms (Xinjiang Dabancheng and Inner Mongolia Huitengxile) can be substantially improved. There is a big potential for reducing the down times of the machines in both wind farms. The technical availability of the machines in these 2 wind farms of around 93% is lower than international standard (around 95%), however still above 90% and not extremely low.

It should be possible to increase the production by the proposed measures by at least 3-5%. This increase would mean to reach an availability of an international standard level. But then there would still be a theoretical potential for improvements by bringing the availability even beyond international standard.

For the third wind farm in Dandong there is only a minimal potential for optimisation. The very big problem of this wind farm is the much lower than anticipated wind potential at the site. The evaluation of the actual wind measurements in the wind farm showed that the machines exploit well the given potential. Problems like the unsatisfying production of this wind farm could only be avoided in future projects by a much more cautious preparation of projects and elaboration of high quality wind studies before the decision for implementing a wind farm at a given site is taken.

## 7. Main experiences from the project

In the following some main experiences from the work on the 3 wind farms shall be highlighted. It is commented also whether or how these experiences may apply to other wind farms in the country.

### 1. The importance of data collection

As mentioned in this report, it was not possible to perform very sophisticated operations in the analysis of the meteorological and production data (i.e. calculation of power curves and/or calculation of wind potential maps for the wind farms). As mentioned and shown also, measured data was not available for all months where the met masts are operated.

This demonstrates the importance of thorough data collection, a good planning of the needed parameters (should have included production data synchronized with the meteorological data) and assuring the maintenance of the measurement equipment. It is not sufficient to install measurement equipment in the wind farms, but also the collection of the data has to be assured by appropriate working procedures. Otherwise the high quality measurement equipment can not be used to its potential.

This aspect would have to be considered also for other wind farms in China, when verification and improvement of the performance is aimed at.

### 2. The nature of production lower than expected electricity production

It was found that in the Dabancheng and Huitengxile wind farms the production losses are attributed to a quite limited number of bad performing machines, while identical neighbouring machines showed good performance. The losses are on the other hand attributed to quite long times of outage or significant underproduction. Several problems occur repeated times and for several problems the staff basically knows the solution, but the implementation does not occur – often due to missing spare parts or due to missing decisions by the executive staff, headquarter, etc.

In the Dandong wind farm, in contrast, the production below the expectations is not related to technical problems of the machines and real losses, but is mainly caused by the expectations being too high due to an inappropriate wind study in the planning procedure of the wind farm. For the one year where measurement data from the project's met masts was available, an average wind speed of only 4.5 m/s was found, whereas the feasibility study in 1999 had concluded the long-term wind speed to be 6.1 m/s. It could not be verified in this project whether the mentioned 4.5 m/s are representative for the long term as no nearby meteorological long-term station could be found that correlated sufficiently with the on-site measurements. It might be and is quite probable that the period had a wind potential below the long-term average, but nevertheless, the difference to the value of the feasibility study is thus big, that it is clear that the long-term potential is below the expectations.

Another problem in the planning phase was, that the machine type has been changed to bigger machines (featuring bigger rotor diameters) without adapting the layout wherever necessary so that several of the machines are sited quite close to each other and have high wake losses.

The two different aspects for production below the expectations, that have been found in this project are likely to be found also in other wind farms in China. It is well probable that there are also wind farms where both aspects apply, meaning that there would be optimisation potential for bad performing wind farms at sites with a lower than expected wind potential.

### 3. The differences in performance of identical machines in a wind farm

It is very remarkable that in the 2 bigger wind farms for the different machine types as well good as very bad performing machines have been found. This has the positive aspect, that there is potential for improving the performance by bringing the bad machines to the performance level of the better or best machines.

On the other hand, this effect means that to a very important extent the necessary improvement measures are related to structural and organisational arrangements in the wind farms. As there are human beings involved these kind of measures have to be achieved in a very different way from just implementing technical improvements on the machines.

It is very probable that similar problems in the structure and organisation of the management of the wind farms are existing also in other wind farms. Also, it is probable that in other wind farms additionally, serial technical problems at machines exist that can be blamed for an important portion of the losses.

