# Wind resource assessment and yield prediction

## Post construction analysis

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## Hoevensche Beemden, Laakse Vaart, Zwartenbergseweg

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# Summary


Ecofys performed a post construction wind resource assessment and yield prediction for wind farms Laakse Vaart, Hoevensche Beemden and Zwartenbergseweg. The goal of this study is to replace the preconstruction WRA's created in 2010-2011, which could not be based on actual accurate onsite data, therefore considered as less reliable estimate of the real long term production.

The current assessment is based on wind climatology (KNMI and Cabauw) and includes, as supportive evidence, real production data from the wind farms Hoevensche Beemden and Zwartenbergseweg curtailed to actual wind farm operating conditions. The wind farm layouts of three lines of five wind turbines each at a 105 m hub height were provided by the client, along with the turbines PV and CT curves "as built". Wind data acquired for the period 2000-2009 of the KNMI met station Cabauw was used (100%) climate in WindPro calculations.

Surface roughness information of the surroundings was acquired from the Data for Wind source and adjusted by information taken from satellite data and corrected for recent developments. The impact due to newly constructed developments north of the wind farms site was evaluated and according modifications of roughness lengths have been performed.

The resulting wind climate was validated against production data from nearby wind farms Hoevensche Beemden and Zwartenbergseweg. The WAsP/Windpro model results for the selected wind climate showed a particular good match with the long-term corrected production data of wind farm.

The wind turbine energy yields were calculated, including losses and uncertainties, as shown in the table below.


**Table 1 - Key results**

| | Hoevensche Beemden | Laakse Vaart | Zwartenbergseweg |
|---|---|---|---|
| Wind farm rated power [MW] | 15 | 10 | 10 |
| Hub height [m] | 105 | 105 | 105 |
| Wind speed at hub height [m/s] | 7.1 ± 0.3 | 7.1 ± 0.3 | 7.1 ± 0.3 |
| Ideal energy yield (no losses) [MWh/y] | 37143 | 32,902 | 31399 |
| Wake losses [%] | 6% ± 2% | 11% ± 3% | 5% ± 1% |
| Total losses [%] | 12% ± 2% | 15% ± 3% | 10% ± 1% |
| **Net energy yield - P50 [MWh/y]** | **32,869** | **27,849** | **28,343** |
| Full load hours - P50 | 2191 | 2785 | 2834 |
| Uncertainty (long-term) [%] | 11.5% | 10.4% | 10.2% |
| **Net energy yield (P90 long-term) [MWh/y]** | **28,036** | **24,132** | **24,659** |
| Full load hours - P90 (long-term) | 1869 | 2413 | 2466 |
| **Net energy yield (P90 1 year) [MWh/y]** | **25,511** | **22,365** | **22,828** |
| Full load hours - P90 (1 year) | 1701 | 2236 | 2283 |

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# Table of contents

# 1 Introduction

In reflection of on-going methodology improvements and tool enhancements in the field of wind resource assessments since a first report on three wind farms near the municipality of Etten-Leur was issued by Ecofys in early 2011, Eneco decided to request a new wind and yield study. The investigated wind farms Hoevensche Beemden, Laakse Vaart and Zwartenbergseweg consist of rows of five turbines each, located north-west of the town of Breda.

The wind farms are located in open agricultural area with scattered trees and houses. A group of five wind farms is formed which consisting of Hoevensche Beemden, Laakse Vaart, Van Gogh, Etten-Leur and Zwartenbergseweg, seen from west to east. Laalkse Vaart is planned to be built in the near future while the rest have been already in operation.

Using available wind data and the EMD software WindPro version 2.9, Ecofys has modelled the local wind climate and calculated the energy yield for the wind farms Laakse Vaart, Hoevensche Beemden and Zwartenbergseweg with ”as built” layouts consisting of 5 Vestas model V90 of 2MW rated power wind turbines each at a hub height of 105m for Laakse Vaart and Zwartenbergseweg, and 5 Vestas model V90 of 3MW rated power wind turbines at a hub height of 105m for Hoevensche Beemden. The calculations take into account wake losses of neighbouring wind turbines which are already in operation or planned to be built (Laakse Vaart).

The proposed wind farms were analysed for energy production, losses and uncertainties. The final results are presented in terms of the $P_{50}$ and $P_{90}$ long-term annual energy yield.

# 2 Methodology

## 2.1 WindPro and WAsP

The software used to simulate the energy yield of the wind farm is WindPro 2.9 created by the Danish company EMD. This software bases all the analyses related to wind resource assessment on the WAsP wind flow model (version 11) developed by Risoe/DTU, Denmark. In 1987 the Wind Energy and Atmospheric Physics Department at Risø National Laboratory introduced WAsP – a powerful tool for wind data analysis, wind atlas generation, wind climate estimation and siting of wind turbines based on the European Wind Atlas, describing theory and data sets used in WAsP. Over the years, the program has become the industry standard for wind resource assessment and siting of wind turbines and wind farms and it has been employed in more than 90 countries around the world.

WAsP is a PC-program for the vertical and horizontal extrapolation of wind climate statistics. It contains several models to describe the wind flow over different terrains and close to sheltering obstacles.

WindPro, based on the main structure of WAsP, consists of five main calculation blocks:

*Analysis of raw data*. This option enables an analysis of any time-series of wind measurements to provide a statistical summary of the observed wind climate.

*Generation of wind atlas data*. Analysed wind data can be converted into a regional wind climate or wind atlas data set. In a wind atlas data set the wind observations have been 'cleaned' with respect to site-specific conditions. The wind atlas data sets are site-independent and the wind distributions have been reduced to some standard conditions. An illustration is given in Figure 1.

*Wind climate estimation*. Using a wind atlas data set calculated by WAsP or one obtained from another source the program can estimate the wind climate at any specific point by performing the inverse calculation as is used to generate a wind atlas. By introducing descriptions of the terrain around the predicted site, the models can predict the actual, expected wind climate at this site. There is also the possibility to set the stability of the atmosphere in this section.

*Estimation of wind power potential*. The total energy content of the mean wind is calculated by WAsP. Furthermore, an estimate of the actual, annual mean energy production of a wind turbine can be obtained by providing WAsP with the power curve of the wind turbine in question.

*Calculation of wind farm production*. Given the thrust coefficient curve of the wind turbine and the wind farm layout, WAsP can finally estimate the wake losses for each turbine in a farm and thereby the net annual energy production of each wind turbine and of the entire farm, i.e. the gross production minus the wake losses.

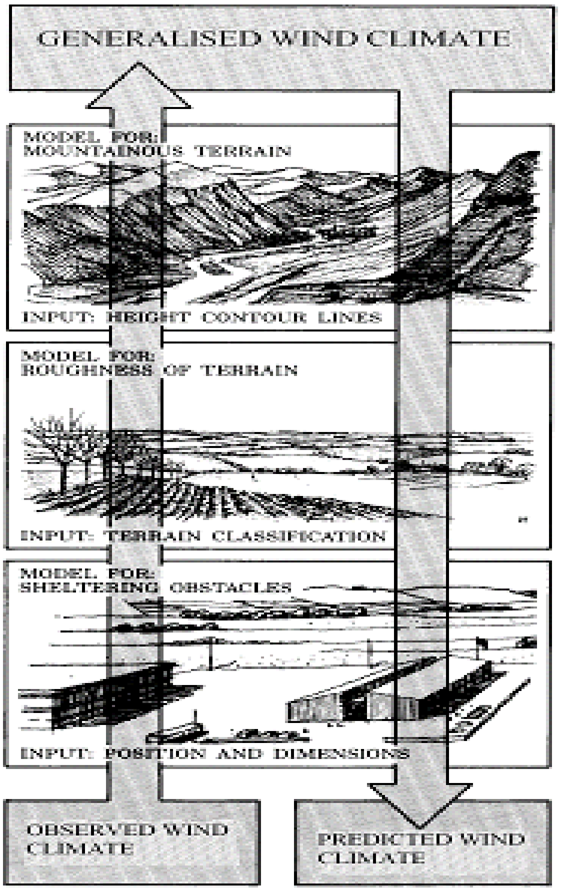


**Figure 1 – WAsP Wind Atlas.**

## 2.2 Modelling surface roughness and orography

WAsP models the roughness using the simple logarithmic wind profile reported in the equation below, where z0 is the reference roughness length, u is the wind speed and z the height (and $u_*$ is the friction velocity). The authors suggest some values for different terrain's characteristics, but any value in the range $0 < z_0 < 1$ m can be used according to professional experience.

$$u = \frac{u_*}{k} \ln\left(\frac{z}{z_0}\right)$$

The value used in WAsP for smooth surfaces like ice and water is 0.0002 m, anyway to let the program knowing that it is water instead of a smooth surface it must be set the parameter as 0. This only makes a difference in the stability considerations.

## 2.3 Modelling obstacles

WAsP has the possibility to model the effect on the wind flow due to obstacles. Obstacles are modelled as blocks with three dimensions (height, width and length) and an orientation. The only other parameter that is need is the porosity. The porosity is the percentage of the flow that can pass through an obstacle. For fully solid obstacles the porosity is defined as 0, a solidity of 1 means a fully transparent obstacle. In case of trees, for instance, the porosity is between 0 and 1 because the flow can pass through the leaves of the trees and the porosity augments when the vegetation density diminishes. Standard values for porosity are given in the European Wind Atlas.

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# 3 Site Details

## 3.1 Location

The wind farms looked at are located in the municipalities of Etten-Leur and Oudenbosch, to the north of the town of Etten-Leur. The geographical overview is given in Figure 2. Five wind farms are operating, from west to east: Hoevensche Beemden, Laakse Vaart, Van Gogh, Etten-Leur and Zwartenbergseweg. All wind farms are aligned perpendicular to the small river Dintel (see Figure 3Figure 2).

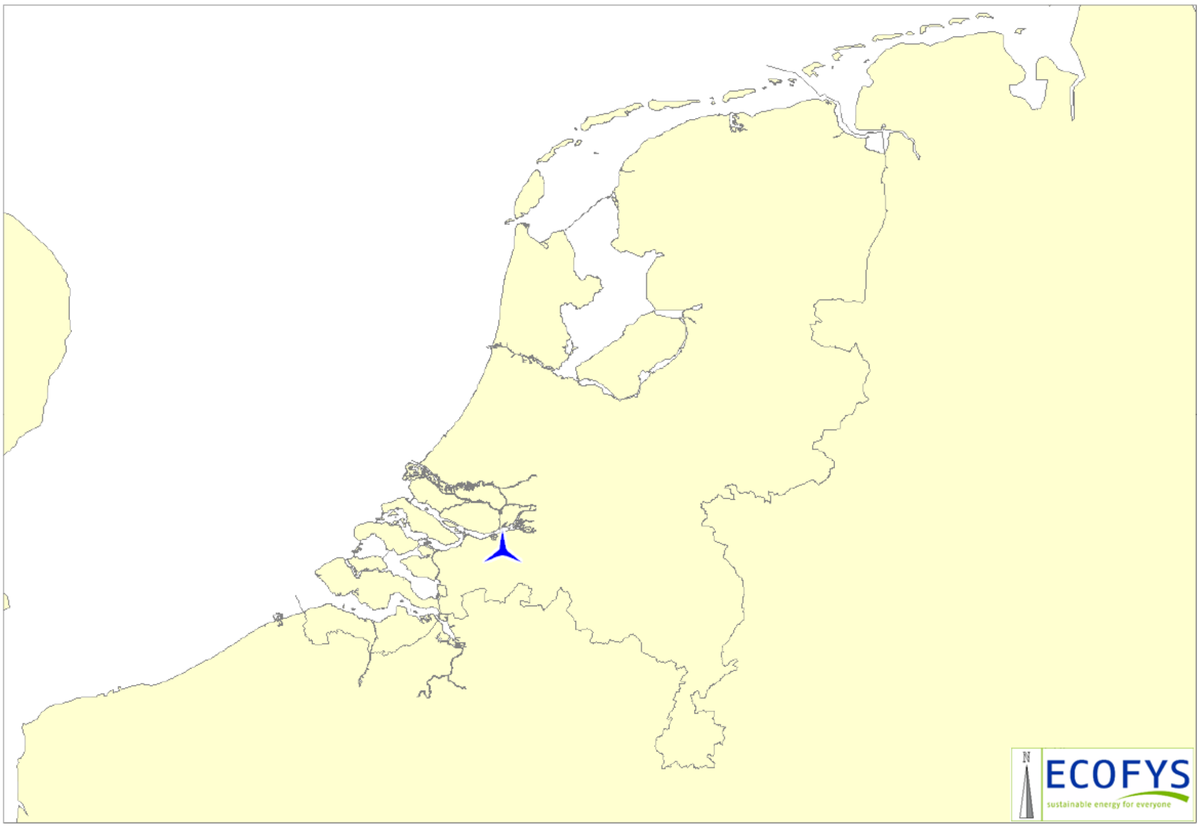


**Figure 2 – Location of the wind farm sites in the municipality of Etten-Leur.**

Their environment is an open landscape with agricultural fields, scattered trees and houses. The city of Breda lies to the south east, while to the south the villages of Etten-Leur, Hoeven and Oudenbosch can be found. The river Waal is located to the north of the site. Finally to the northeast, the towns of Moerdijk, Geertruidenberg and Oosterhout can be found.

## 3.2 Wind Farm Layouts

The layout of the group of wind farms were specified by the client and consists of five rows of wind turbines per wind farm. Table 2 gives the coordinates of the wind turbines in the RD coordinate system. Figure 3 presents a map of the investigated wind farms at the site, and depicts the layouts under study: Hoevensche Beemden, Laakse Vaart and Zwartenbergseweg, plus the 2 other wind farms within the same area.


**Figure 3 - Wind farms in the Etten–Leur & Oudenbosch Municipality.**

From the above 5 wind farms Laakse Vaart is under development, while the rest are already in operation.

The wind turbine positions and wind turbine types are shown below, as they were provided by the client.

**Table 2 – Wind turbine positions in RD coordinates**
**(figures in bold represent the wind farms studied; all coordinates provided by client).**

| Wind farm | Turbine Type | Turbine No. | East | North |
|---|---|---|---|---|
| **Hoevensche Beemden** (existing) | **Vestas V90 3MW, 105m(hh)** | 1 | 99879 | 403358 |
| | | 2 | 99879 | 402958 |
| | | 3 | 99879 | 402558 |
| | | 4 | 99880 | 402158 |
| | | 5 | 99880 | 401758 |
| **Laakse Vaart** (projected) | **Vestas V90 2MW, 105(hh)** | 1 | 100432 | 403937 |
| | | 2 | 100425 | 403557 |
| | | 3 | 100417 | 403178 |
| | | 4 | 100409 | 402798 |
| | | 5 | 100401 | 402418 |
| **Zwartenbergseweg** (existing) | **Vestas V90 2MW, 105(hh)** | 1 | 104229 | 404720 |
| | | 2 | 104286 | 404344 |
| | | 3 | 104343 | 403968 |
| | | 4 | 104400 | 403592 |
| | | 5 | 104457 | 403216 |
| Etten-Leur (Groene Dijk) (existing) | Bonus 1300 1.3MW, 62m(hh) | 1 | 102262 | 403728 |
| | | 2 | 102436 | 403556 |
| | | 3 | 102623 | 403393 |
| | | 4 | 102822 | 403289 |
| | | 5 | 102194 | 403965 |
| Van Gogh (Bollendonk) (existing) | Enercon E-82 2.3MW, 98.4m(hh) | 1 | 100866 | 403825 |
| | | 2 | 101010 | 403510 |
| | | 3 | 101163 | 403170 |
| | | 4 | 101313 | 402847 |
| | | 5 | 101457 | 402533 |

## 3.3 Roughness description

The roughness map of the terrain was taken from the European roughness contour dataset. These data are based on an extract from www.dataforwind.com. This roughness data was based on a combination of Geo data and satellite-imaging programme and the information has a spatial resolution of around 3 arc sec (~200 m). For the inner area of the wind farm and its surroundings of up to 2km a refinement of this roughness map has been carried out by comparison against most recent satellite and aerial images.

The data is separated into summer and winter values; the summer value is commonly used for the wind resource assessment analysis. The use of only the summer value is due to the fact that the winter values have been seen to largely underestimate the roughness length and also it is difficult to separate the time series relating exactly the right roughness length. Thus the more conservative approach of using only the summer values is highly recommended and taken for this study.

Comparison with aerial photographs indicated a relatively good correspondence to the roughness lengths and surface type. However a manual update was performed to the dataset, to account for minor deviations in the vicinity of the wind farm region. The most significant being a small dwelling/industrial zone c.a. 2 km north-west of the Zwartenbergseweg wind farm as shown in Figure 4. Moreover, the roughness of the small forest areas within radius 1km from the wind farms as well as nearby town was properly adjusted.

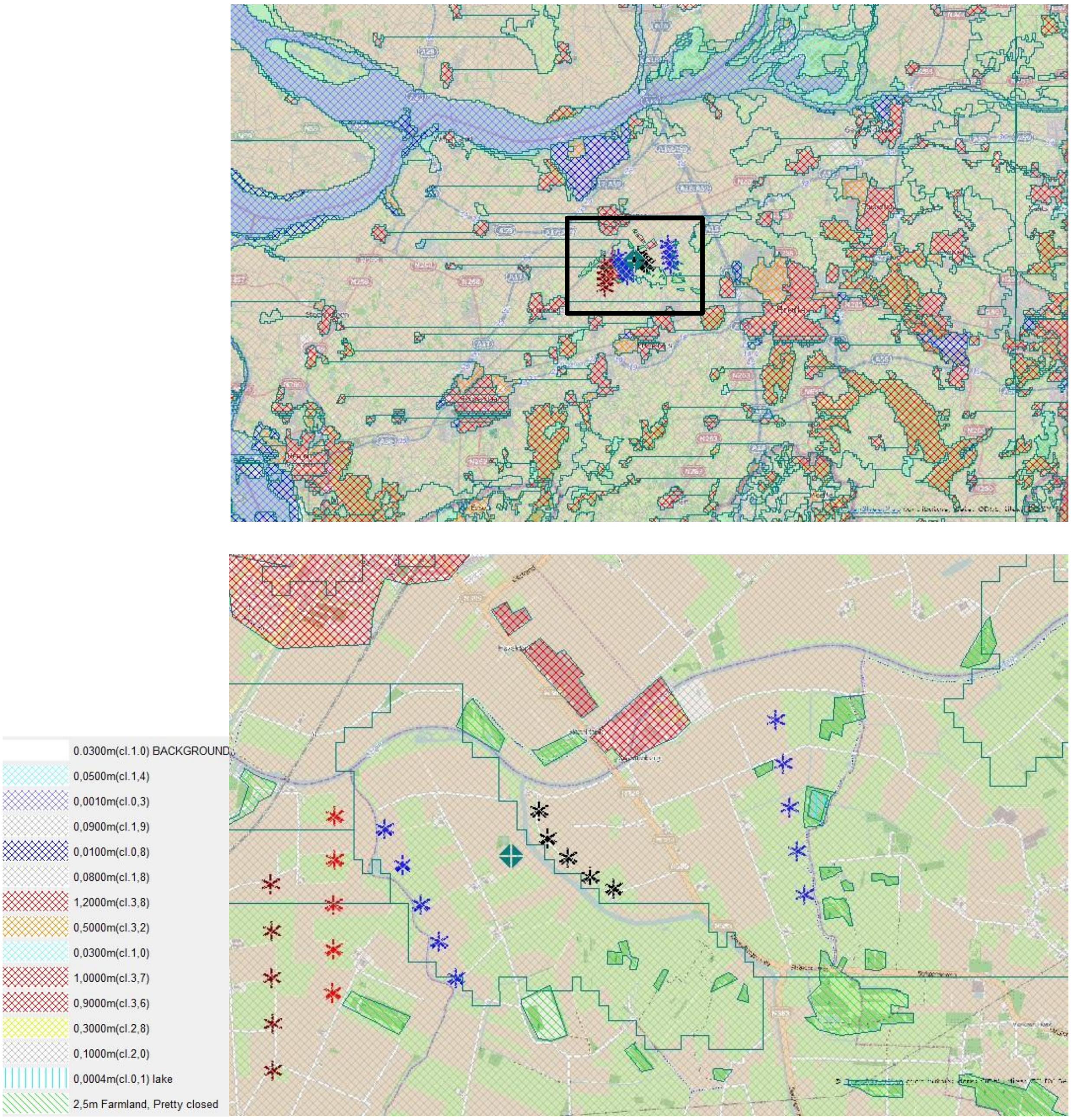


**Figure 4 – Overview of roughnesses assigned to the region (top) and detailed (zooms in) map for the vicinity of the site (bottom)**

Adjustments to the local roughness map were done to account for these constructions. As a validation, yield calculations with and without these modifications were performed to assess the effect of the added roughness lengths. The impact found is insignificant in terms of AEP and are covered within the uncertainty margins (0.5% difference).

## 3.4 Orography

The topography of the site was assumed perfectly flat at sea level height. The difference with more advanced satellite based data is minor and leads to difference in calculated yield well below 0.05%. Due to the flatness of the area, orography was not taken into account in this study.

## 3.5 Obstacles

Based on Algemene Hoogtekaart Nederland, and satellite images from Google Earth, it was verified that there was no influence of tall buildings or considerable obstacles on the local wind climate.

## 3.6 Wind climate

The local wind climate was based on the wind statistics from the nearby KNMI meteorological stations of Cabauw, at c.a. 45 kilometres from the site centre, respectively. The stations were chosen merely due to the flat terrain characteristics to the wind farms' site, added to the proximity and similarities in the local conditions. The Cabauw station was applied with a 100% weighting.

The data set used in this calculation consists of 10 years over the period 2000-2009 for the KNMI station Cabauw. KNMI is responsible for the quality and consistency of the data and provides documentation on the website ([www.knmi.nl](http://www.knmi.nl)).

The wind climate was verified using actual production data corrected for unavailability and curtailment (see Chapter 4).

## 3.7 Air Density

Air density information is necessary for a good estimation of the power yield. In the current calculation, air density was based on statistical temperature and pressure data from the KNMI station at Gilze-Rijen, taken at an elevation of 11m which is located 21km of distance.

The air density calculation is based on an annual mean temperature of 9.3°C. The resulting average air density at a hub height used in the calculations is 1.237 kg/m$^3$.

## 3.8 Wind turbine information

The wind turbine types, hub heights and positions for the three wind farms were provided by the client. Table 3 lists the important characteristics of the wind turbines. Power curve information of these wind turbines is given in Appendix B. The power curve were provided by the client. Those power curves matched power curves already present in the EMD WindPro database.

**Table 3 – Wind turbine types.**

| Wind farm | Turbine Type |
|---|---|
| Hoevensche Beemden | Vestas V90<br>3MW, 105m(hh) |
| Laakse Vaart | Vestas V90<br>2MW, 105(hh) |
| Zwartenbergseweg | Vestas V90<br>2MW, 105(hh) |

# 4 Verification of Wind Climate

The wind climate data used for verification was recorded at the KNMI meteo station Cabauw during the period of 2000-2009. The Cabauw mast is located c.a. 45 Kilometres to the north east, in rural terrain which compares well to the site conditions near Etten-Leur, as semi-open.

The data set was subsequently treated by the WAsP program, applying a model for the terrain roughness throughout the distance from the Cabauw and stations to the location of the wind farms. After running the roughness model in the Windpro environment, the time series was transformed into a Windpro "local wind climate" for further analysis. In this case orographic models were discarded as the terrain from the stations and the wind farms themselves can be considered flat.

The local wind climate was verified against the realised AEP data of the operational wind farms Zwartenbergseweg and Hoevensche Beemden. Realised AEP data of the wind farm Laakse Vaart was not used since the wind farm is not in operation yet.

The observed production data was corrected based on technical availability over the recording period in order to be representative of the long-term wind climate of the area. Additional correction was applied for the wake losses that both wind farms have been undergone, due to the presence of significant number of wind turbines in their vicinity. Additionally for Hoevensche Beemden wind farm, further correction was applied to account for curtailment losses, which have been calculated by the Client.

In order to be representative of the long-term wind climate of the area, the treated production data was subsequently corrected based on the Windunie Windex for the Netherlands, to represent a long-term average over the period 1995-2009.

For the Hoevensche Beemden wind farm, the data provided by the client covered the period from April 2013 to March 2014 in single monthly figures, with additional information on curtailment losses and wind park availability. Due to delayed availability of the Windex (available only until end of December 2013 at time of writing), only data till the end of 2013 has been used.
For the Zwartenbergseweg wind farm, data from January till December 2013 was made available. The correlation between the Windex corrected values and calculated AEP of both wind farm was very good for the chosen wind climate; 99% for the Hoevensche Beemden wind farm and 98% for the Zwartenbergseweg wind farm.

The results for both wind farms compared to the wind climate fall well within the expected uncertainty range and therefore are considered to have been verified adequately with respect to P50/P90.

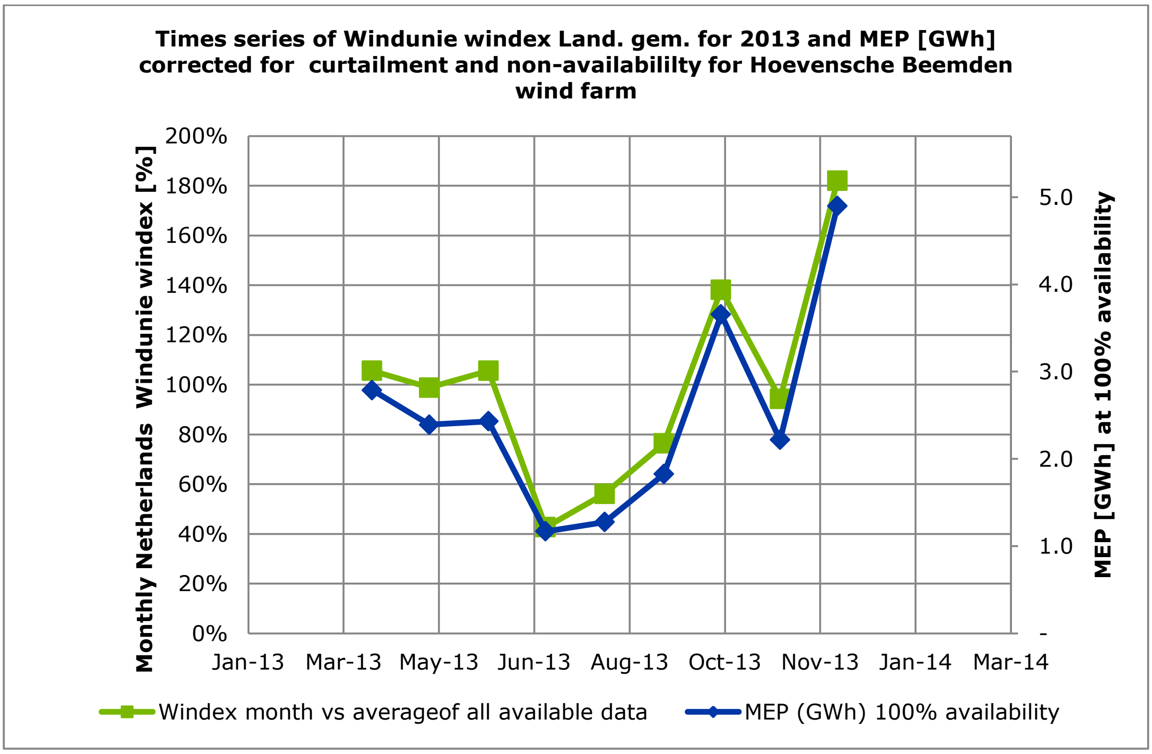


**Figure 5 - Relative match between production data of Hoevensche Beemden wind farm and Windunie Windex Nederland**

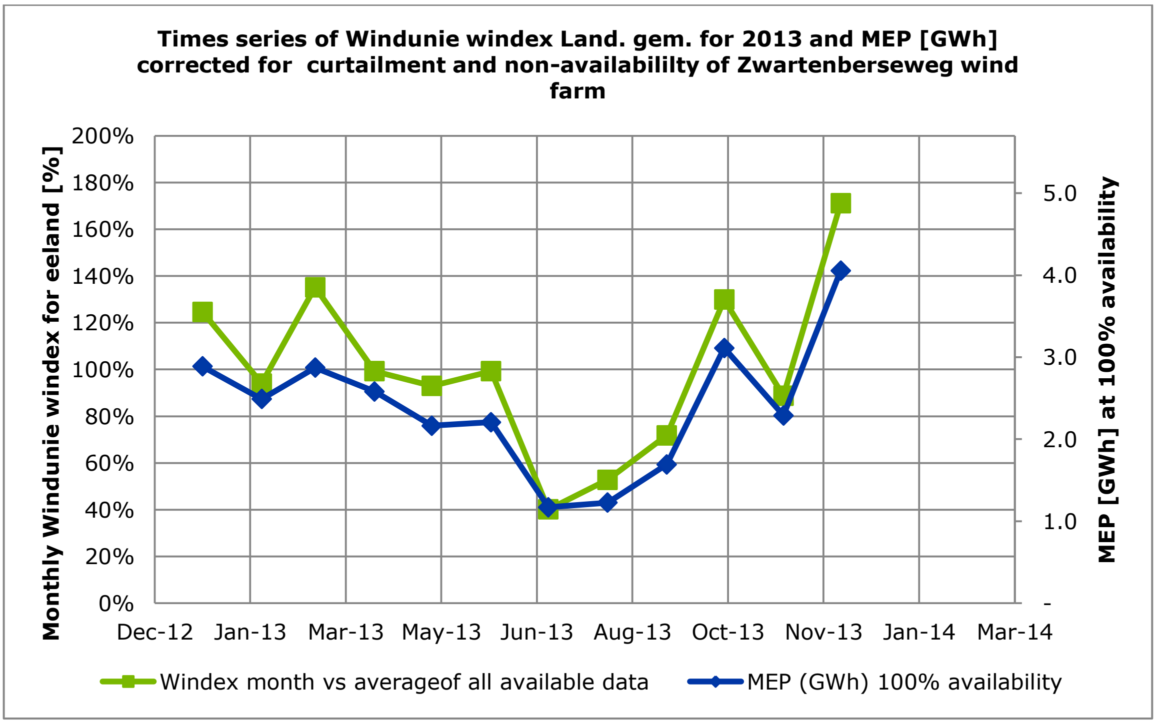


**Figure 6 - Relative match between production data of Zwartenbergseweg wind farm and Windunie Windex Nederland**

The resulting values are well in line with the WAsP/Windpro results if the following weighting factor is applied to the calculation: Cabauw 100%.

Ecofys therefore chose to apply this wind climate based on the weighting factor of both KNMI stations, to the AEP calculation of the three wind farms Hoevensche Beemden , Laakse Vaart, and Zwartenbergseweg.

# 5 Results

## 5.1 Local wind climate

Based on the WAsP flow modelling, the calculated mean wind speed at a height of 105 meters is 7.1 m/s. The change in wind speed with height, for the centre position between the wind farms, is shown in Table 4.

**Table 4 – Wind speed variation with height**

| Height [m] | Mean wind speed [m/s] |
|---|---|
| 45 | 5.84 |
| 55 | 6.10 |
| 65 | 6.35 |
| 75 | 6.56 |
| 85 | 6.75 |
| 95 | 6.92 |
| 105 | 7.09 |
| 115 | 7.27 |
| 125 | 7.45 |
| 135 | 7.60 |
| 145 | 7.75 |

The prevailing wind direction at the site is **SSW-WSW**, whereas the strongest mean wind speed is found in the **WSW** direction. Lower mean wind speeds are found in the **Northern and Eastern** sectors. The Weibull distribution and wind roses for the wind climate in Etten-Leur are given in Figure 7. Using this climate, the gross energy yield was calculated and corrected for losses and uncertainties.

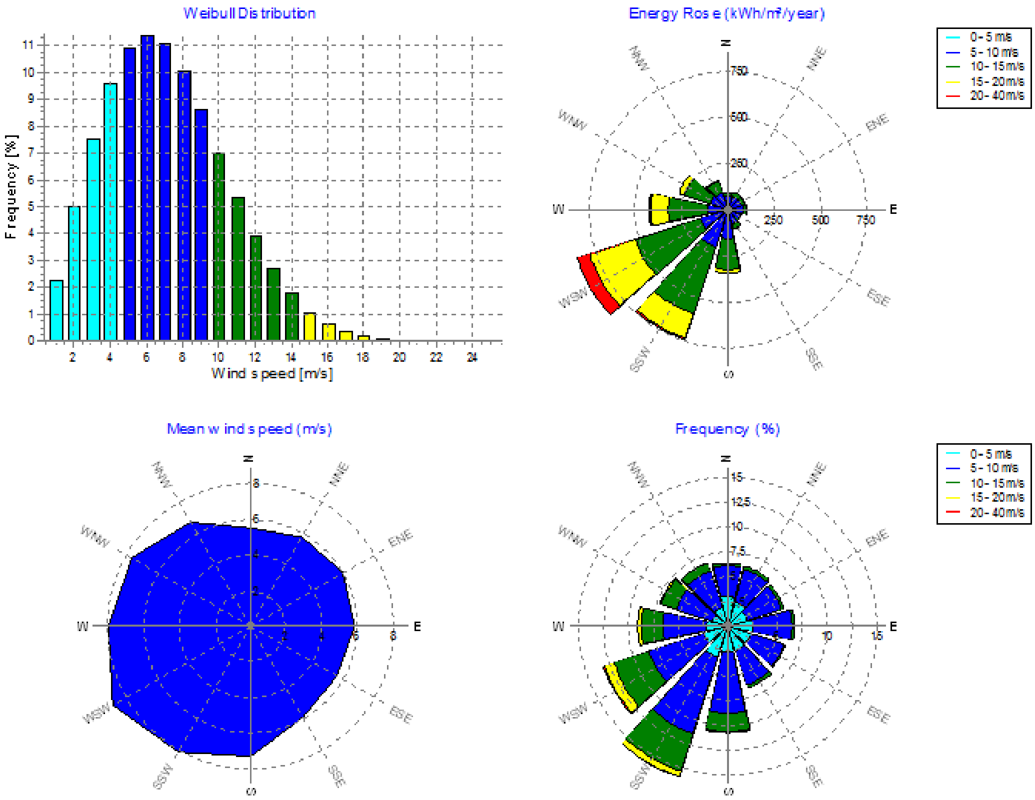


**Figure 7 –Wind climate at 105 m**

## 5.2 Losses

The possible loss factors have been divided into seven categories: wake effects, non-availability, electrical, environmental, wind turbine performance, curtailment and other.

A summary of all losses is given in Table 5. Each loss is assumed to act independently on the gross energy production. Not all loss factors may apply to a given wind farm, but the full list is provided for the sake of completeness and transparency. A generic description of each loss is given in Appendix C.

Internal wake effects were calculated using the industry-standard N.O. Jensen model with a wake decay constant of 0.075 (farmland).

Ecofys at this point clarifies that based on input from the client several standard losses have been pre-specified, including non-availability, Electrical losses, Turbine performance, environmental and others.

**Table 5 - Summary of loss factors used**

| Loss description | Hoevensche Beemden | Laakse Vaart | Zwartenbergseweg |
|---|---|---|---|
| Wake effects | | | |
| - Internal (including also external) | 6.5% | 10.5% | 4.6% |
| - External | | | |
| - Future | | | |
| Non-availability | | | |
| - Turbine | 3.0% | 3.0% | 3.0% |
| - Balance of plant | | | |
| - Grid | | | |
| - Other | | | |
| Electrical | | | |
| - Operational electrical efficiency | 1.0% | 1.0% | 1.0% |
| - Wind farm consumption | | | |
| Environmental | | | |
| - Blade contamination & degradation (build-up) | 0.5% | 0.5% | 0.5% |
| - Blade contamination & degradation (icing) | | | |
| - Shutdown due to adverse weather | | | |
| - Shutdown due to temperature | | | |
| - Site access | | | |
| - Forestry | | | |
| Wind turbine performance | | | |
| - High wind hysteresis | 0.5% | 0.5% | 0.5% |
| - Power curve adjustment (site-specific) | | | |
| - Power curve adjustment (generic) | | | |
| - Other | | | |
| Curtailment | | | |
| - Noise, visual and environmental | | | |
| - Wind sector management | | | |
| - Grid | | | |
| - Power purchase agreement | | | |
| Other | | | |
| - Other | 0.5% | 0.5% | 0.5% |
| | | | |
| **Total** | **11.5%** | **15.4%** | **9.7%** |

For the yield calculations of the wind farms Hoevensche Beemden, Laakse Vaart and Zwartenbergseweg, also wind farms Van Gogh and Etten Leur were considered as "existing". Thus, for each of the investigated wind farms, the internal wake losses plus the external wake losses from four neighbouring wind farms have been included.

## 5.3 Uncertainties

Uncertainties have been separated into two categories: those related to wind speed and those related to energy yield. The uncertainties in the wind speed prediction have been evaluated and set to the values presented in Table 6.

Uncertainty in wind statistics represents the uncertainty for quality the production data as well as the processing that these datasets underwent.
Uncertainty in vertical extrapolation to hub height was set only to 1%, as the production data against which the wind climate was verified was taken from 105 meters hub height as per wind farms.

**Table 6 - Uncertainties related to wind speed**

| Uncertainty description | Hoevensche Beemden | Laakse Vaart | Zwartenbergseweg |
|---|---|---|---|
| - Wind statistics | 4.0% | 4.0% | 4.0% |
| - Vertical extrapolation to hub height | 1.0% | 1.0% | 1.0% |
| - Horizontal extrapolation to WTG site | 1.0% | 1.0% | 1.0% |
| - Long term representation | 1.9% | 1.9% | 1.9% |
| - Other | | | |
| | | | |
| **Total** | **4.6%** | **4.6%** | **4.6%** |

Using the sensitivity in energy yield to a change in wind speed, it is possible to express the wind speed uncertainty in terms of an energy yield uncertainty. This factor, together with additional energy yield uncertainties, is listed in Table 7.

For Hoevensche Beemden additional uncertainty equal to 0.2 was assigned to the curtailment losses.

**Table 7 - Uncertainties related to energy yield**

| Uncertainty description | Hoevensche Beemden | Laakse Vaart | Zwartenbergseweg |
|---|---|---|---|
| Sensitivity (% increase in energy yield / % increase in wind speed) | 2.20 | 1.89 | 1.89 |
| Uncertainty in wind speed, in terms of energy yield | 10.2% | 8.8% | 8.8% |
| | | | |
| Energy calculation | | | |
| - Power curve | 5.0% | 5.0% | 5.0% |
| - Metering | | | |
| - Long term correction | | | |
| - Other | | | |
| Losses | | | |
| - Wake effects | 1.6% | 2.6% | 1.1% |
| - Non-availability | | | |
| - Electrical | | | |
| - Environmental | | | |
| - Turbine Performance | | | |
| - Curtailment | 0.2% | | |
| - Other | | | |
| | | | |
| **Total** | **11.5%** | **10.4%** | **10.2%** |

## 5.4 Net energy yield

Finally, the net annual energy yield is calculated as the gross energy yield, minus all losses. This is often expressed as the $P_{50}$ value (the value that will be exceeded with a probability of 50%). For symmetrical distributions, the $P_{50}$ is equal to the mean. For financial purposes, it is also common to use the $P_{90}$ value (the value that will be exceeded with a probability of 90%). Assuming a Gaussian distribution of the results, the $P_{90}$ value is $P_{50} - 1.28 \times \sigma$ (where σ is the uncertainty). The results of both the $P_{50}$ and $P_{90}$ net energy yield are given in Table 8.

**Table 8 - Overall results**

| | Hoevensche Beemden | Laakse Vaart | Zwartenbergseweg |
|---|---|---|---|
| Wind farm rated power [MW] | 15 | 10 | 10 |
| Hub height [m] | 105 | 105 | 105 |
| Wind speed at hub height [m/s] | 7.1 ± 0.3 | 7.1 ± 0.3 | 7.1 ± 0.3 |
| Ideal energy yield (no losses) [MWh/y] | 37143 | 32,902 | 31399 |
| Wake losses [%] | 6% ± 2% | 11% ± 3% | 5% ± 1% |
| Total losses [%] | 12% ± 2% | 15% ± 3% | 10% ± 1% |
| **Net energy yield - P50 [MWh/y]** | **32,869** | **27,849** | **28,343** |
| Full load hours - P50 | 2191 | 2785 | 2834 |
| Uncertainty (long-term) [%] | 11.5% | 10.4% | 10.2% |
| **Net energy yield (P90 long-term) [MWh/y]** | **28,036** | **24,132** | **24,659** |
| Full load hours - P90 (long-term) | 1869 | 2413 | 2466 |
| **Net energy yield (P90 1 year) [MWh/y]** | **25,511** | **22,365** | **22,828** |
| Full load hours - P90 (1 year) | 1701 | 2236 | 2283 |

It should be noted that for the yield calculations of the Hoevensche Beemden and Zwartenbergseweg, the wake effects of the future wind farm Laakse Vaart have been considered.

# 6 Conclusions

Ecofys performed a post construction wind resource and yield prediction for wind farms Hoevensche Beemden, Laakse Vaart and Zwartenbergseweg, in the municipality of Etten-Leur, the Netherlands. The layout of the total group of wind farms in which these are situated were provided by the client and consist of 5 rows of five turbines, out of which Laakse Vaart is not yet in operation.

Wind data acquired for the period 2000-2009 of the KNMI meteo station Cabauw (100%) was used as input climate in the WindPro calculations. Roughness lengths were modified according to actual conditions acquired from satellite data and corrected for recent developments.

The resulting wind climate was validated against realised production data from wind farms Hoevensche Beemden and Zwartenbergseweg. The WAsP/Windpro model results for the selected wind climate of Cabauw showed a very good match with the long-term corrected production data of both wind farms. The selected wind climate, was applied for the yield calculations of the wind farms Hoevensche Beemden, Laakse Vaart and Zwartenbergseweg.

The wind turbine energy yields were calculated, including losses and uncertainties, as presented in the preceding chapter.

# Appendix A WindPro results

## Hoevensche Beemden wind farm

WindPRO version 2.9.269 Nov 2013

Project:
**Zwartenbergsweg post construction WRA - For WRA in three wind farms_v2.0_SoB**

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Calculated:
28-4-2014 11:56/2.9.269

### PARK - Main Result

**Calculation:** AEP Hoevensche Beemden 5 x V90 3MW at 105m

**Wake Model** N.O. Jensen (RISØ/EMD)

**Calculation settings**

| | |
|---|---|
| Air density calculation mode | Individual per WTG |
| Result for WTG at hub altitude | 1,234 kg/m³ to 1,239 kg/m³ |
| Air density relative to standard | 100,7 % to 101,1 % |
| Hub altitude above sea level (asl) | 66,0 m to 105,0 m |
| Annual mean temperature at hub alt. | 9,3 °C to 9,5 °C |
| Pressure at WTGs | 1.000,5 hPa to 1.005,2 hPa |

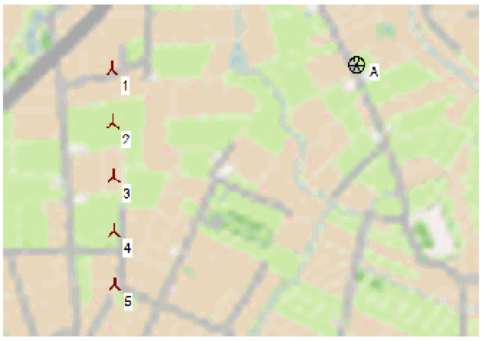
**Wake Model Parameters**
Wake Decay Constant 0,075 Open farmland

**Wake calculation settings**

| Angle [°] start | end | step | Wind speed [m/s] start | end | step |
|---|---|---|---|---|---|
| 0,5 | 360,0 | 1,0 | 0,5 | 30,5 | 1,0 |

**Wind statistics** NL Cabauw 2000-2009 (10m) - Cabauw 2000-2009 10.00 m.lib

**WAsP version** WAsP 11 Version 11.00.0214




Scale 1:40.000
New WTG
Site Data

### Key results for height 105,0 m above ground level

**Terrain Dutch Stereo-RD/NAP 2008**

| | East | North | Name of wind distribution | Type | Wind energy [kWh/m²] | Mean wind speed [m/s] | Equivalent roughness |
|---|---|---|---|---|---|---|---|
| A | 101.688,74 | 403.365,14 | 100% Cabauw_final | WAsP (WAsP 11 Version 11.00.0214) | 3.381 | 7,1 | 2,0 |

### Calculated Annual Energy for Wind Farm

| WTG combination | Result PARK [MWh/y] | Result-10,0% [MWh] | GROSS (no loss) Free WTGs [MWh/y] | Park efficiency [%] | Specific results¤) Capacity factor [%] | Mean WTG result [MWh/y] | Full load hours [Hours/year] | Mean wind speed @hub height [m/s] |
|---|---|---|---|---|---|---|---|---|
| Wind farm | 34.746,6 | 31.271,9 | 37.143,3 | 93,5 | 23,8 | 6.254,4 | 2.085 | 7,1 |

¤) Based on Result-10,0%

### Calculated Annual Energy for each of 5 new WTGs with total 15,0 MW rated power

| Links | WTG type Valid | Manufact. | Type-generator | Power, rated [kW] | Rotor diameter [m] | Hub height [m] | Power curve Creator | Name | Annual Energy Result [MWh] | Result-10,0% [MWh] | Park Efficiency [%] | Mean wind speed [m/s] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 A | Yes | VESTAS | V90-3.000 | 3.000 | 90,0 | 105,0 | EMD | Level 0 - Estimated - 107.0 dB(A) - 06-2009 | 6.924,3 | 6.232 | 92,67 | 7,09 |
| 2 A | Yes | VESTAS | V90-3.000 | 3.000 | 90,0 | 105,0 | EMD | Level 0 - Estimated - 107.0 dB(A) - 06-2009 | 6.843,2 | 6.159 | 91,74 | 7,09 |
| 3 A | Yes | VESTAS | V90-3.000 | 3.000 | 90,0 | 105,0 | EMD | Level 0 - Estimated - 107.0 dB(A) - 06-2009 | 6.858,4 | 6.173 | 92,21 | 7,08 |
| 4 A | Yes | VESTAS | V90-3.000 | 3.000 | 90,0 | 105,0 | EMD | Level 0 - Estimated - 107.0 dB(A) - 06-2009 | 6.941,2 | 6.247 | 93,78 | 7,06 |
| 5 A | Yes | VESTAS | V90-3.000 | 3.000 | 90,0 | 105,0 | EMD | Level 0 - Estimated - 107.0 dB(A) - 06-2009 | 7.179,4 | 6.461 | 97,39 | 7,05 |

### WTG siting

**Dutch Stereo-RD/NAP 2008**

| | | East | North | Z [m] | Row data/Description |
|---|---|---|---|---|---|
| 1 | New | 99.879,01 | 403.357,99 | 0,0 | VESTAS V90 3000 90.0 !O! hub: 105,0 m (TOT: 150,0 m) (56) |
| 2 | New | 99.879,01 | 402.957,99 | 0,0 | VESTAS V90 3000 90.0 !O! hub: 105,0 m (TOT: 150,0 m) (57) |
| 3 | New | 99.879,01 | 402.557,99 | 0,0 | VESTAS V90 3000 90.0 !O! hub: 105,0 m (TOT: 150,0 m) (58) |
| 4 | New | 99.880,01 | 402.157,99 | 0,0 | VESTAS V90 3000 90.0 !O! hub: 105,0 m (TOT: 150,0 m) (59) |
| 5 | New | 99.880,01 | 401.757,99 | 0,0 | VESTAS V90 3000 90.0 !O! hub: 105,0 m (TOT: 150,0 m) (60) |

For WAsP 11 and newer, "WAsP classic profile modeling" parameters shown here WILL NOT BE USED!
Instead the parameters stored in the Wind Statistic file(s) are used to ensure consistency, please have a look at Wind statistics info report.
*) Included in array losses is influence from 20 WTG(s) in the neighborhood, which has status as "Reference WTGs", see separate report to identify these

# Laakse Vaart wind farm

WindPRO version 2.9.269 Nov 2013

Project:
**Zwartenbergsweg post construction WRA - For WRA in three wind farms_v2.0_SoB**

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25-4-2014 10:20/2.9.269

## PARK - Main Result

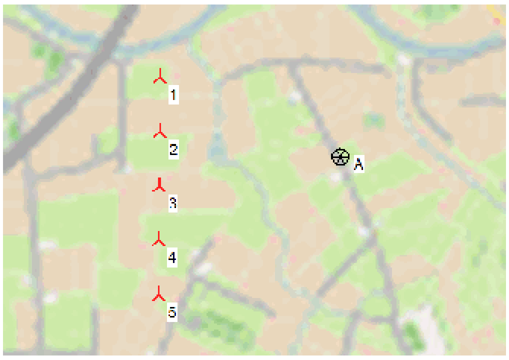
Calculation:AEP Laakse Vaart 5 x V90 2MW at 105m

| | |
|---|---|
| **Wake Model** | N.O. Jensen (RISØ/EMD) |
| **Calculation Settings** | |
| Air density calculation mode | Individual per WTG |
| Result for WTG at hub altitude | 1,234 kg/m³ to 1,239 kg/m³ |
| Air density relative to standard | 100,7 % to 101,1 % |
| Hub altitude above sea level (asl) | 66,0 m to 105,0 m |
| Annual mean temperature at hub alt. | 9,3 °C to 9,5 °C |
| Pressure at WTGs | 1.000,5 hPa to 1.005,2 hPa |
| **Wake Model Parameters** | |
| Wake Decay Constant | 0,075 Open farmland |

**Wake calculation settings**

| Angle [°] start | end | step | Wind speed [m/s] start | end | step |
|---|---|---|---|---|---|
| 0,5 | 360,0 | 1,0 | 0,5 | 30,5 | 1,0 |

| | |
|---|---|
| **Wind statistics** | NL Cabauw 2000-2009 (10m) - Cabauw 2000-2009 10.00 m.lib |
| **WAsP version** | WAsP 11 Version 11.00.0214 |




Scale 1:40.000
New WTG  Site Data

### Key results for height 105,0 m above ground level

**Terrain Dutch Stereo-RD/NAP 2008**

| | East | North | Name of wind distribution | Type | Wind energy [kWh/m²] | Mean wind speed [m/s] | Equivalent roughness |
|---|---|---|---|---|---|---|---|
| A | 101.688,74 | 403.365,14 | 100% Cabauw_final | WAsP (WAsP 11 Version 11.00.0214) | 3.381 | 7,1 | 2,0 |

### Calculated Annual Energy for Wind Farm

| WTG combination | Result PARK [MWh/y] | Result-10,0% [MWh] | GROSS (no loss) Free WTGs [MWh/y] | Park efficiency [%] | Specific results¤) Capacity factor [%] | Mean WTG result [MWh/y] | Full load hours [Hours/year] | Mean wind speed @hub height [m/s] |
|---|---|---|---|---|---|---|---|---|
| Wind farm | 29.439,6 | 26.495,7 | 32.902,1 | 89,5 | 30,2 | 5.299,1 | 2.650 | 7,1 |

*¤) Based on Result-10,0%*

### Calculated Annual Energy for each of 5 new WTGs with total 10,0 MW rated power

| Links | WTG type Valid | Manufact. | Type-generator | Power, rated [kW] | Rotor diameter [m] | Hub height [m] | Power curve Creator | Name | Annual Energy Result [MWh] | Result-10,0% [MWh] | Park Efficiency [%] | Mean wind speed [m/s] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 A | Yes | VESTAS | V90-2.000 | 2.000 | 90,0 | 105,0 | USER | 15-04-2014 V90 2MW 1.225 25.00 0.00 | 6.034,2 | 5.431 | 91,49 | 7,10 |
| 2 A | Yes | VESTAS | V90-2.000 | 2.000 | 90,0 | 105,0 | USER | 15-04-2014 V90 2MW 1.225 25.00 0.00 | 5.839,5 | 5.256 | 88,53 | 7,10 |
| 3 A | Yes | VESTAS | V90-2.000 | 2.000 | 90,0 | 105,0 | USER | 15-04-2014 V90 2MW 1.225 25.00 0.00 | 5.773,6 | 5.196 | 87,67 | 7,09 |
| 4 A | Yes | VESTAS | V90-2.000 | 2.000 | 90,0 | 105,0 | USER | 15-04-2014 V90 2MW 1.225 25.00 0.00 | 5.790,8 | 5.212 | 88,18 | 7,08 |
| 5 A | Yes | VESTAS | V90-2.000 | 2.000 | 90,0 | 105,0 | USER | 15-04-2014 V90 2MW 1.225 25.00 0.00 | 6.001,5 | 5.401 | 91,52 | 7,07 |

### WTG siting

**Dutch Stereo-RD/NAP 2008**

| | East | North | Z [m] | Row data/Description |
|---|---|---|---|---|
| 1 New | 100.432,01 | 403.936,99 | 0,0 | VESTAS V90 2000 90.0 !O! hub: 105,0 m (TOT: 150,0 m) (51) |
| 2 New | 100.425,01 | 403.556,99 | 0,0 | VESTAS V90 2000 90.0 !O! hub: 105,0 m (TOT: 150,0 m) (52) |
| 3 New | 100.417,01 | 403.177,99 | 0,0 | VESTAS V90 2000 90.0 !O! hub: 105,0 m (TOT: 150,0 m) (53) |
| 4 New | 100.409,01 | 402.797,99 | 0,0 | VESTAS V90 2000 90.0 !O! hub: 105,0 m (TOT: 150,0 m) (54) |
| 5 New | 100.401,01 | 402.417,99 | 0,0 | VESTAS V90 2000 90.0 !O! hub: 105,0 m (TOT: 150,0 m) (55) |

For WAsP 11 and newer, "WAsP classic profile modeling" parameters shown here WILL NOT BE USED!
Instead the parameters stored in the Wind Statistic file(s) are used to ensure consistency, please have a look at Wind statistics info report.
*) Included in array losses is influence from 20 WTG(s) in the neighborhood, which has status as "Reference WTGs", see separate report to identify these

## Zwartenbergseweg wind farm

*WindPRO version 2.9.269 Nov 2013*

Project:
**Zwartenbergsweg post construction WRA - For WRA in three wind farms_v2.0_SoB**

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Calculated:
28-4-2014 12:00/2.9.269

# PARK - Main Result

**Calculation:**AEP Zwartenbergseweg 5 x V90 2MW at 105m

**Wake Model** N.O. Jensen (RISØ/EMD)

**Calculation Settings**

| | |
|---|---|
| Air density calculation mode | Individual per WTG |
| Result for WTG at hub altitude | 1,234 kg/m³ to 1,239 kg/m³ |
| Air density relative to standard | 100,7 % to 101,1 % |
| Hub altitude above sea level (asl) | 66,0 m to 105,0 m |
| Annual mean temperature at hub alt. | 9,3 °C to 9,5 °C |
| Pressure at WTGs | 1.000,5 hPa to 1.005,2 hPa |

**Wake Model Parameters**
Wake Decay Constant 0,075 Open farmland

**Wake calculation settings**

| Angle [°] | | | Wind speed [m/s] | | |
|---|---|---|---|---|---|
| start | end | step | start | end | step |
| 0,5 | 360,0 | 1,0 | 0,5 | 30,5 | 1,0 |

**Wind statistics** NL Cabauw 2000-2009 (10m) - Cabauw 2000-2009 10.00 m.lib

**WAsP version** WAsP 11 Version 11.00.0214


Scale 1:40.000
New WTG Site Data

## Key results for height 105,0 m above ground level

**Terrain Dutch Stereo-RD/NAP 2008**

| | East | North | Name of wind distribution | Type | Wind energy [kWh/m²] | Mean wind speed [m/s] | Equivalent roughness |
|---|---|---|---|---|---|---|---|
| A | 101.688,74 | 403.365,14 | 100% Cabauw_final | WAsP (WAsP 11 Version 11.00.0214) | 3.381 | 7,1 | 2,0 |

## Calculated Annual Energy for Wind Farm

| WTG combination | Result PARK [MWh/y] | Result-10,0% [MWh] | GROSS (no loss) Free WTGs [MWh/y] | Park efficiency [%] | Specific results¤) Capacity factor [%] | Mean WTG result [MWh/y] | Full load hours [Hours/year] | Mean wind speed @hub height [m/s] |
|---|---|---|---|---|---|---|---|---|
| Wind farm | 31.399,0 | 28.259,1 | 32.905,5 | 95,4 | 32,2 | 5.651,8 | 2.826 | 7,1 |

¤) *Based on Result-10,0%*

## Calculated Annual Energy for each of 5 new WTGs with total 10,0 MW rated power

| Links | WTG type Valid | Manufact. | Type-generator | Power, rated [kW] | Rotor diameter [m] | Hub height [m] | Power curve Creator | Name | Annual Energy Result [MWh] | Result-10,0% [MWh] | Park Efficiency [%] | Mean wind speed [m/s] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 A | Yes | VESTAS | V90-2.000 | 2.000 | 90,0 | 105,0 | USER | 15-04-2014 V90 2MW 1.225 25.00 0.00 | 6.377,3 | 5.740 | 97,41 | 7,08 |
| 2 A | Yes | VESTAS | V90-2.000 | 2.000 | 90,0 | 105,0 | USER | 15-04-2014 V90 2MW 1.225 25.00 0.00 | 6.251,5 | 5.626 | 95,14 | 7,09 |
| 3 A | Yes | VESTAS | V90-2.000 | 2.000 | 90,0 | 105,0 | USER | 15-04-2014 V90 2MW 1.225 25.00 0.00 | 6.225,7 | 5.603 | 94,54 | 7,10 |
| 4 A | Yes | VESTAS | V90-2.000 | 2.000 | 90,0 | 105,0 | USER | 15-04-2014 V90 2MW 1.225 25.00 0.00 | 6.231,7 | 5.608 | 94,49 | 7,10 |
| 5 A | Yes | VESTAS | V90-2.000 | 2.000 | 90,0 | 105,0 | USER | 15-04-2014 V90 2MW 1.225 25.00 0.00 | 6.312,9 | 5.682 | 95,54 | 7,11 |

## WTG siting

**Dutch Stereo-RD/NAP 2008**

| | | East | North | Z [m] | Row data/Description |
|---|---|---|---|---|---|
| 1 | New | 104.457,01 | 403.215,99 | 0,0 | VESTAS V90 2000 90.0 !O! hub: 105,0 m (TOT: 150,0 m) (31) |
| 2 | New | 104.400,01 | 403.591,99 | 0,0 | VESTAS V90 2000 90.0 !O! hub: 105,0 m (TOT: 150,0 m) (32) |
| 3 | New | 104.343,01 | 403.967,99 | 0,0 | VESTAS V90 2000 90.0 !O! hub: 105,0 m (TOT: 150,0 m) (33) |
| 4 | New | 104.286,01 | 404.343,99 | 0,0 | VESTAS V90 2000 90.0 !O! hub: 105,0 m (TOT: 150,0 m) (34) |
| 5 | New | 104.229,01 | 404.719,99 | 0,0 | VESTAS V90 2000 90.0 !O! hub: 105,0 m (TOT: 150,0 m) (35) |

For WAsP 11 and newer, "WAsP classic profile modeling" parameters shown here WILL NOT BE USED!
Instead the parameters stored in the Wind Statistic file(s) are used to ensure consistency, please have a look at Wind statistics info report.
*) Included in array losses is influence from 20 WTG(s) in the neighborhood, which has status as "Reference WTGs", see separate report to identify these

# Appendix B Wind turbine power curves

Power curves of Laakse Vaart, Hoevensche Beemden and Zwartenbergseweg wind farms were provided by Eneco (Vestas V90, 105m hub height, 2MW and 3MW). Van Gogh and Etten-Leur power curves were obtained from WindPro database by Ecofys.

## Vestas V90 – 2MW (Laakse Vaart and Zwartenbergseweg wind farms)

| Wind Speed [m/s] | Power [kW] |
|---|---|
| 4 | 89 |
| 5 | 204 |
| 6 | 368 |
| 7 | 594 |
| 8 | 896 |
| 9 | 1247 |
| 10 | 1599 |
| 11 | 1881 |
| 12 | 1981 |
| 13 | 1998 |
| 14 | 2000 |
| 15 | 2000 |
| 16 | 2000 |
| 17 | 2000 |
| 18 | 2000 |
| 19 | 2000 |
| 20 | 2000 |
| 21 | 2000 |
| 22 | 2000 |
| 23 | 2000 |
| 24 | 2000 |
| 25 | 2000 |

From Doc. Number: 0005-6279 V13: Provided by Eneco for Laakse Vaart wind park

## Vestas V90 – 3MW (Hoevensche Beemden wind farm)

| Wind Speed [m/s] | Power [kW] |
|---|---|
| 4 | 77 |
| 5 | 190 |
| 6 | 353 |
| 7 | 581 |
| 8 | 886 |
| 9 | 1273 |
| 10 | 1710 |
| 11 | 2145 |
| 12 | 2544 |
| 13 | 2837 |
| 14 | 2965 |
| 15 | 2995 |
| 16 | 3000 |
| 17 | 3000 |
| 18 | 3000 |
| 19 | 3000 |
| 20 | 3000 |
| 21 | 3000 |
| 22 | 3000 |
| 23 | 3000 |
| 24 | 3000 |
| 25 | 3000 |

From Doc. Number: 0000-5450 V07: Provided by Eneco

# Appendix C Losses and Uncertainties

The possible loss factors have been divided into seven categories: wake effects, non-availability, electrical, environmental, wind turbine performance, curtailment and other. Not all loss factors may apply to a given wind farm, but the full list is provided for the sake of completeness and transparency.
Uncertainties have been separated into three categories: wind speed, energy yield and losses.

## Losses – Wake effects

### Internal

Within a wind farm, turbines working downstream of another (in its wake) will experience reduced wind speeds. The magnitude of these 'wake effects' can be calculated using wake models incorporated in the wind resource software. Several studies have shown that the N.O. Jensen model estimates these losses with good accuracy (using a wake decay constant of 0.075 for onshore wind farms, and 0.040 offshore).

### External

Wind turbines can also experience wake effects from neighbouring wind turbines that are not part of the wind farm being investigated. These losses are calculated in the same way as internal wake effects.

### Future

These losses account for wake effects from nearby wind turbines which are expected to be constructed after the commissioning of the wind farm being investigated. These losses may be calculated, or estimated if the project details are unknown. This loss factor should be averaged over the wind farm lifetime.

## Losses – Non-Availability

### Wind turbine

The non-availability loss factor reflects the loss of energy yield due to wind turbine downtime. The level of likely non-availability can be estimated based on the manufacturer's guaranteed turbine availability. However, this guaranteed availability is typically in terms of the amount of time that the wind turbines will be available to produce electricity, which does not equate directly to energy yield. The loss of energy yield, as a percentage, may be higher than the percentage of downtime, as non-availability is more likely during times of high speed (and thus, high energy yield). As well, depending on the site, the guaranteed turbine availability could be regarded as conservative, and a more realistic value should be used. A final consideration is that availability is likely to change with time, so this loss factor should represent the average over the wind farm lifetime.
Typical values for non-availability are 2-3% for onshore wind turbines and 8-10% offshore.

### Balance of plant

This non-availability factor includes the downtime of all components between the wind turbine and the grid connection point. An estimate of 0.3% (approximately one day per year) may be used if no site-specific information is given.

### Grid

This non-availability factor covers grid downtime. Depending on the local grid strength, a value of 0.3-0.6% (one to two days per year) may be estimated.

### Other

This loss factor can cover non-availability of any components that are not included elsewhere.

## Losses – Electrical

### Operational electrical efficiency

This loss factor includes electrical losses in all parts of the electrical infrastructure of the wind farm (cabling, transformers, substation, etc) until the metering point. This value is dependent most strongly on the distance to substation and usually ranges from 1% to 3%.

### Wind turbine energy consumption

The wind turbine's internal systems (pitch, yaw, hydraulics, computer systems, etc) consume energy, which is not accounted for in the *production* power curve. Analysis of wind farm maintenance figures indicates that consumption levels of 0.5-2% are reasonable. However, in most cases, this loss factor is not included as it is instead considered as a wind farm operational cost.

## Losses – Environmental

### Blade contamination and degradation (build-up)

As wind turbine blades inevitably become dirty and slightly pitted, there is a reduction in their aerodynamic performance resulting in reduced energy yield. This loss can be estimated as 0.5% assuming mitigation with repairs, blade cleaning and regular precipitation.

### Blade contamination and degradation (icing)

Similarly, the aerodynamic performance of blades can be reduced by temporary ice accumulation. This loss factor can be estimated based on local weather conditions or on recorded icing periods during an on-site measurement campaign.

### Shutdown due to adverse weather

The wind turbine may be shutdown during adverse weather, such as lightning, hail, or sandstorms. This loss factor can be estimated based on local weather conditions, with typical values of 0.5-1% in moderate climates.

### Shutdown due to temperature

Temperatures outside the wind turbine's operating envelope can also cause standstill. Again, this loss factor can be estimated based on local weather conditions, with typical values of 0.25-1% in moderate climates.

### Site access

Adverse weather can also restrict access to the wind farm site, reducing availability. This loss can be included within the availability loss factors, or separately here.

### Forestry

Wind farms located within or near to forests will be affected by the growth or felling of trees. This loss factor should reflect the expected impact of these forestry changes on the energy yield, averaged over the wind farm lifetime. This loss can be negative (a gain) in the case of felled trees.

## Losses – Wind turbine performance

### High wind hysteresis

When the wind speed exceeds the cut-out wind speed, the wind turbines will automatically shut down. However, the wind turbine will not restart immediately once the wind speed drops below the cut-out threshold, as this would lead to repeated start/stop stresses. Instead, the control system waits until the wind speed has dropped to a lower cut-in wind speed.
The precise sensitivity of a wind turbine to this effect is dependent on the control system settings and the wind regime. In general, hysteresis losses are larger at high wind sites. Typically, loss factors range from 0.3 to 4%.

### Power curve adjustment (site-specific)

Wind farm sites may experience different wind conditions (turbulence, inclined flow, high shear, etc) than the simple terrain where the wind turbine power curve was certified. This factor can account for any losses due to this difference.

### Power curve adjustment (generic)

This loss factor should be applied if there is reason to expect that the supplied power curve does not accurately represent the power curve that would be achieved during an IEC power curve certification.

### Other

This loss factor can cover any reductions in wind turbine performance that are not included elsewhere.

## Losses – Curtailment

### Noise, visual and environmental

It may be necessary to curtail a wind farm to mitigate for noise, shadow flicker or environmental impacts. These impacts can be calculated or estimated based on local conditions.
This loss factor does not include the use of wind turbine modes with reduced output, as the appropriate power curves are applied in the gross energy yield calculations.

### Wind sector management

Wind turbines that are closely spaced, near obstacles or other wind turbines might experience too high turbulence and may have to be curtailed to reduce loading due to wakes.

### Grid

The grid connection agreement may require curtailments under certain circumstances.

### Power purchase agreement

The power purchase agreement may require curtailments under certain circumstances.

## Losses – Other

### Other

This loss factor can cover any losses that are not included elsewhere.

## Uncertainties – Wind speed

### Wind statistics

Measurement errors can be affected by the quality of the instruments, the calibration process, the meteorological mast design, data coverage and data processing.
Traceability of the wind data is an important factor in assessing the quality of the wind statistics. Highly traceable data allows for a precise analysis of uncertainties, while more uncertainty must be attributed to poorly traceable data.

### Long term representation

The annual variability of wind speed leads to an uncertainty in the long-term representation of short-term measurements. The standard error for a single year of measurements has been statistically determined to be 5.5% (based on a large number of Dutch meteorological stations) and 6% (based on stations throughout Europe). Therefore, the standard error in measurements with a longer duration can be approximated as $\sigma = 6\% / \# years$.

If MCP methods were used to extend a short-term time series, an additional uncertainty should be added to account for errors in this process. The quality of correlation gives a good indication of the uncertainty to be added.

Additionally, future land-use changes in the area may add uncertainty in the long-term wind climate. For instance, a change in agricultural activities or a build-up of urban areas may lead to change in the surface roughness or in thermal characteristics. Climate change could also be expected to affect the long-term wind speed.

#### Horizontal extrapolation

The accuracy in the horizontal extrapolation of wind speeds depends primarily on the complexity of the terrain and the distance between the measurement site and the wind turbines. The industry standard flow modelling software (WAsP) has been used in this analysis. This flow model is well suited to simple terrain, but does not account for flow separation in hilly terrain. The ruggedness index (RIX) calculation is a good indication of the complexity of the terrain and informs the uncertainty estimation. Also, uncertainties in the flow modelling are increased if the measurement mast is not on-site or if the wind farm covers a large area.
As well, the quality of the terrain description (height contours and roughness maps) affects the accuracy of the flow modelling.

#### Vertical extrapolation

In order to minimise errors in vertical extrapolation, the measurement height should be close to the proposed hub height. Using a met mast with multiple instrument heights, it is possible to verify the vertical profile and estimate the uncertainties.
Larger uncertainties are inherent using measurements at the WMO standard height of 10 m (for instance, masts at airports or meteorological stations). The vertical profile is highly dependent on the surface roughness description, as well as the accuracy of the measurement height.

#### Other

This uncertainty can cover any additional errors related to wind speed.

### Uncertainties – Relationship between wind speed and energy yield

The overall uncertainties are accounted for in terms of energy yield. Therefore, uncertainties related to wind speed must be converted to uncertainties in energy yield, based on the relationship between the two. This relationship can be calculated as the ratio of the relative increase in energy yield based on a relative increase in wind speed. Typically, these ratios are between 1 and 3. The ratio is lower at high wind sites, due to the form of the wind turbine’s power curve.

### Uncertainties – Energy Yield

#### Power curve

The power curve is a sensitive element in the calculations. The power curve guarantee varies from one manufacturer to the other, typically ranging from 95-100%.

#### Metering

It may be necessary to consider uncertainties in metering at the grid connection point, depending on the terms of the power purchase agreement.

#### Long term correction

This uncertainty applies to corrections that are applied to the predicted energy yield based on information regarding long-term trends. This should not include corrections that are applied to the wind speed, such as MCP calculations.

**Other**

This uncertainty can cover any additional errors related to energy yield.

## Uncertainties – Losses

Uncertainties are assessed for all included losses, divided into the seven categories:

- wake effects
- non-availability
- electrical
- environmental
- wind turbine performance
- curtailment
- other

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