

**LESOTHO POWER GENERATION MASTER PLAN**

**PROJECT # LEC/GEN/1-2009**

**FINAL MILESTONES REPORT**

**VOLUME 1**

**PART 1.2**

**WIND POWER GENERATION  
OPTION**

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## ABBREVIATIONS

ADP	Automated Data Processing
agl	Above ground level
asl	Above sea level
IEC	International Electro-technical Commission
NCAR	National Center for Atmospheric Research
NCEP	National Centre for Environmental Prediction
NE	North/East
NNE	North/North-East
NWP	Numerical Weather Prediction
Lat	Latitude
Long	Longitude
RPD	Region of Potential Development
RSME	Root Mean Square Error
SW	South West
SSW	South/South West
SRTM	Shuttle Radar Topography Mission
UTM	Universal Transverse Mercator
WASP	Computer program for power system development planning
WGS	World Geodetic System
WRF	Weather Research and Forecast
WTG	Wind Turbine Generator

## LIST OF MEASUREMENT UNITS

GwH	Gigawatt Hour
Km	Kilometre
m	meter
m/s	meter/second
MW	Mega Watt
MWh/y	megawatt-hour/year
W/m <sup>2</sup>	watt/square meter

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## 1. INTRODUCTION

Consultants were engaged to supply a mesoscale Wind Resource Map of Lesotho and to identify locations within the Kingdom that may be suitable for utility scale wind power development.

The purpose of this final report is to provide overview results from the Wind Resource Map, detail the Consultant's findings in respect of the potential for wind development in the Kingdom, indicate the identified locations and their generation potential, as well as to explain the methodology behind their selection and the wider study.

The generation potential from wind energy is extremely sensitive to local site conditions – small difference in topography can affect wind speed and thus production. A detailed review of potential sites in a geographical area as extensive as the Kingdom can be a time consuming activity which will still not produce concrete results as, before installing a wind energy facility, on-site measurements still need to be taken.

For reasons of thoroughness and efficiency, rather than either opportunistically identifying sites or reviewing the entire Kingdom at a micro-level, the study took a top-down approach - the Kingdom's wind power potential was analysed at varying levels of detail in order to systematically identify sites with high potential as well as to act as a guide for future investigations.

- Firstly, a Wind Resource Map was produced for the entire Kingdom – this map was simulated from satellite data by a world leading specialist in “mesoscale” technology;
- Then, the simulated data was analysed and based on limited criteria such as wind speed, altitude and topography, seven “Regions of Potential Development” (RPD) were identified with the three most promising selected for further analysis;
- Next, high resolution simulations of wind flow were performed over the three previously selected RPD which were examined in greater detail. Fifteen potential wind farm sites were identified, based on the derived data and the consultants experience - preliminary wind power capacity and efficiency was established for these sites; and
- Finally, studies were then focused on the five potentially most attractive sites where preliminary micro-siting and a basic wind resource assessment was made.

It should be noted that the RPDs were selected at a country level in order to “filter” regions and select areas of focus for further more detailed investigation. Furthermore, the initial analysis of the potential sites within the RPDs was firstly at a high level with more detailed analysis only on a number of these. This top down approach together with some inherent uncertainties in the modelling methodology make it possible that sites suitable for wind development may exist within the areas discarded as part of this screening

process - a microscale consideration and further factors could result in successful wind developments in areas outside of the RPDs or at different sites within them.

The analysis is based on wind and topographic data derived from satellite information. Wind measurement campaigns on site and detailed topographic information are needed to confirm estimated wind resource and suitability for wind farm development of the selected sites.

It should be noted that the potential wind farm sites were identified taking only into account estimated wind resource and topography. In addition to the need to monitor wind on site, other significant factors including road access, proximity of electricity network, social and environmental restrictions, engineering feasibility will have to be considered to confirm the feasibility of the proposed wind farms.

The next stage in the development process would be to consider these factors and install physical wind monitoring equipment on the chosen sites. When shown, coordinates are in WGS84 Datum and -35 Time Zone.

## **2. MESOSCALE WIND MAP**

### **2.1 Overview of technology**

Historically, producing a country-level Wind Resource Map involved the installation of geographically disbursed wind monitoring masts for at least a year and access to other local data sources. However, recent advances in satellite data based computer modelling - so called “mesoscale modelling” - mean that simulations can be run and estimations made of wind resource in shorter time and lower cost.

The mesoscale wind map and data for the Lesotho Wind Resource Analysis is provided by Normawind in partnership with world leading specialist in the technology, 3Tier.

3Tier employs a physics-based Numerical Weather Prediction modelling system based on the WRF (Weather Research and Forecasting model) model. Developed in a collaborative partnership between US federal agencies and universities, WRF represents the next generation in weather forecast models and is suitable for a broad spectrum of applications across scales ranging from meters to thousands of kilometres. In addition, WRF provides a flexible and computationally efficient framework that allows advancements in physics, numerics, and data assimilation to be continually contributed by the research community at academic, government, and private institutions worldwide. The models can be run at any location worldwide, with or without on-site measurements, from 10 to 40 years into the past, at custom heights, and at resolutions from hundreds of kilometres down to a few meters.

3Tier’s proprietary techniques to employ the WRF model use complex computer based simulations to model the interaction between the entire atmosphere and the earth’s surface, creating complete, 4-dimensional

datasets of weather information. The techniques can create realistic wind fields anywhere on earth by modelling the physical processes responsible for wind, from jet level dynamics to surface level processes.

## **2.2 Validation of model**

To assess the quality of the information provided by 3Tier's global wind dataset, wind speeds were compared with publicly available wind speed observations from the independent data source, National Centres for Environmental Prediction (NCEP) Automated Data Processing (ADP) surface observations dataset.

- Verification study includes 4000 NCEP-ADP network stations worldwide;
- Overall bias is +0.05 m/s relative to NCEP-ADP observations;
- Overall RMSE (Root Mean Squared Error) is 0.93 m/s; and
- The difference between annual mean wind speed data from the 3Tier dataset and actual on-site measurements is less than 0.5 m/s at 50% of observational stations and less than 1 m/s at 78% of stations.

## **2.3 Configuration of simulation for Lesotho**

In order to produce a Wind Resource Map for the purposes of this stage of the Lesotho Generation Master Plan project, it was considered that the data derived from a model run at 5 km resolution would be suitable.

The spatial analysis of wind resources in the region of Lesotho presented in this report is based on a period of one year (from 1 January 2001 to 31 December) simulated data using a non-hydrostatic model of regional primitive-equation of the atmosphere. A whole year of data was generated by an individual simulation of each calendar day in which the year was chosen at random from a record corresponding to the period 2000-2009.

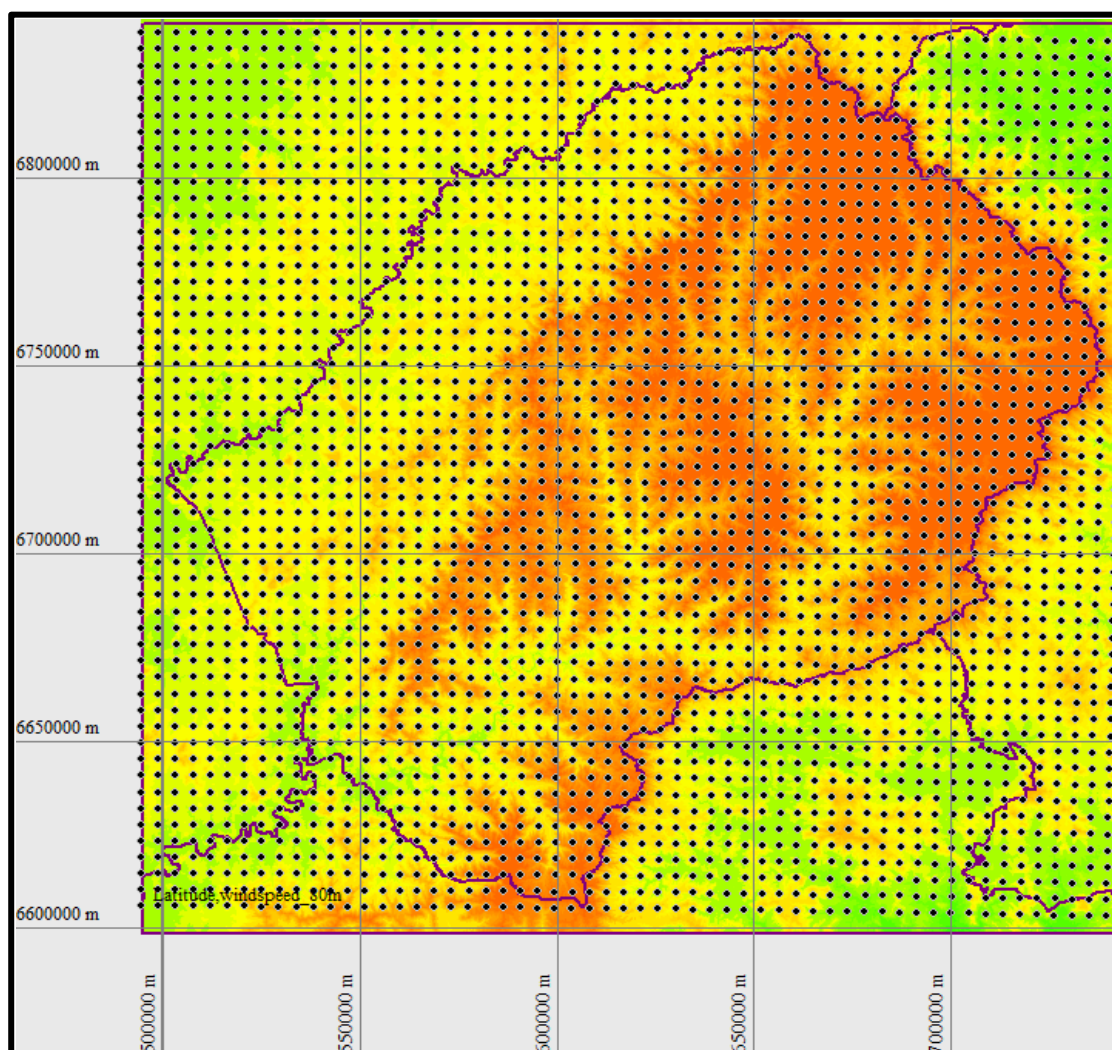
The numerical model uses a nested grid layout. The size of the coarser grid was defined to consider the effects of synoptic weather events on the wind resource in the region of interest, as well as to allow develop the model circulations caused by thermal factors.

An increasingly fine grid of 45.0 km, 15.0 km and 5.0 km are used to simulate the effect of local terrain and local atmospheric circulations. Table 1 shows some details of the final configuration of the NWP model.

Figure 1 shows a map of the location of the project in the region of Lesotho. The study area is defined by the red box, and the black dots represent the model grid points actually used in this analysis.

Parameter	Value
Mesoscale NWP Model	WRF
Horizontal resolution of the study area	5.0km
Number of vertical levels	31
Topography database	3 seconds SRTM
Vegetation database	10 sec ESA GlobCover
Surface parameterization	Monin-Obukhov Similarity Model
Boundary layer parameterization	YSU Model (MRF model with entrainment)
Land surface model	5-layer thermal diffusion model

**Table 1: Configuration of NWP Model**

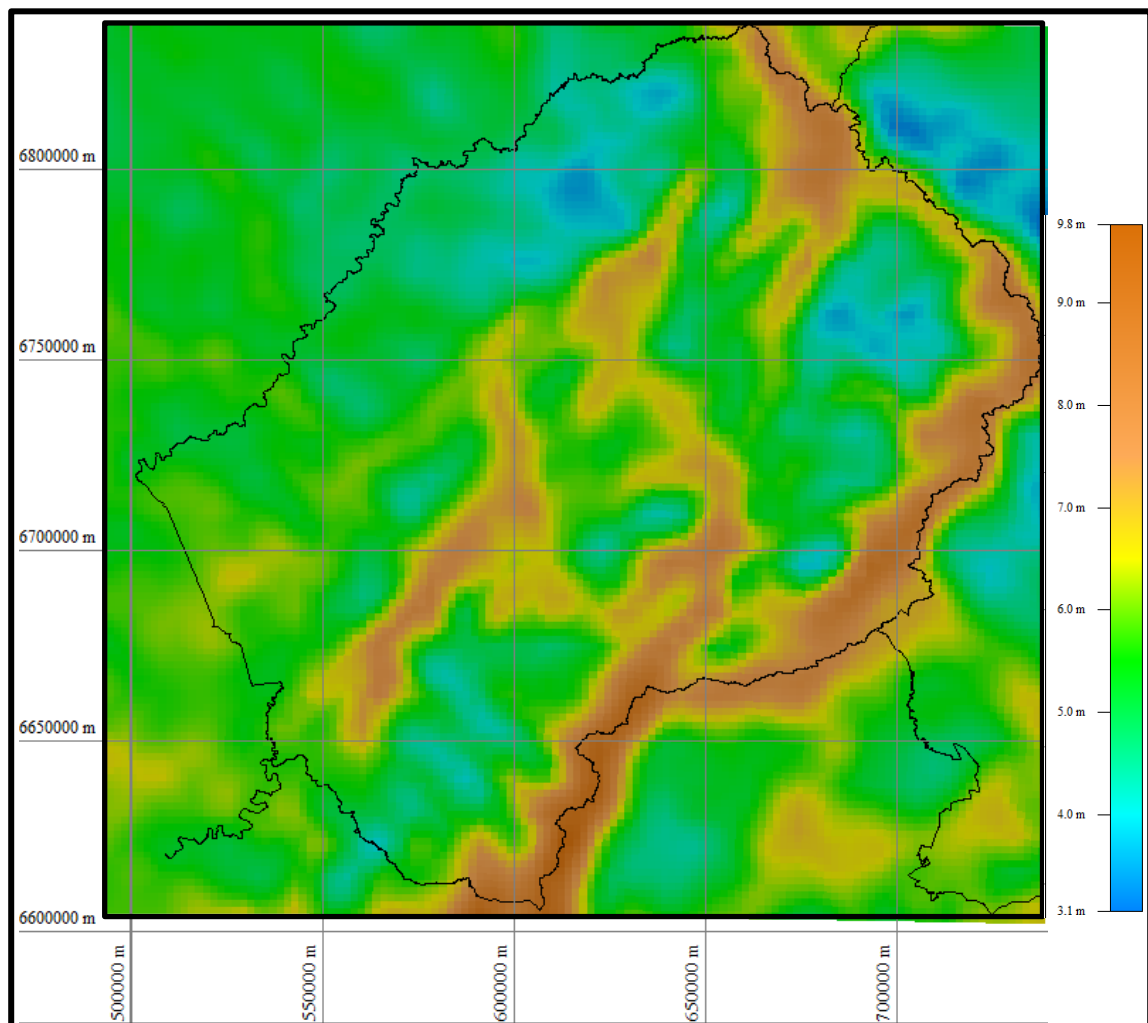


**Figure 1: Map of the topography of the region studied. The black dots denote the individual points of the grid numerical model with a resolution of 5km (Data Set).**

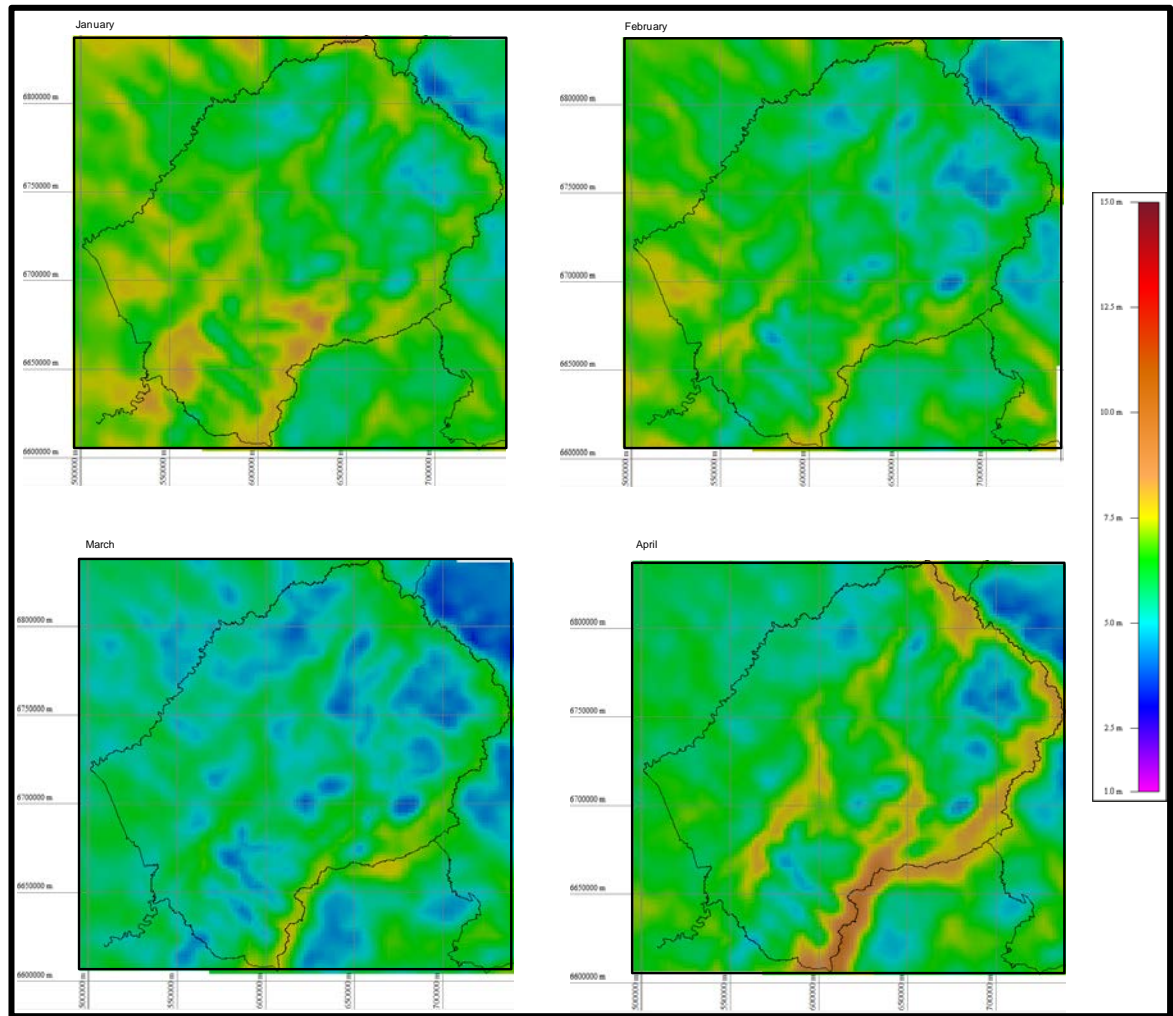
#### Maps

This section presents the spatial maps of the simulated wind resource in the region of Lesotho with a 5km resolution. All maps in this section represent the results generated by the NWP model without any adjustment.

## Annual Average Wind Speed Map



**Figure 2 shows the map of annual average wind speed simulated with a resolution of 5 km at a height of 80m.**

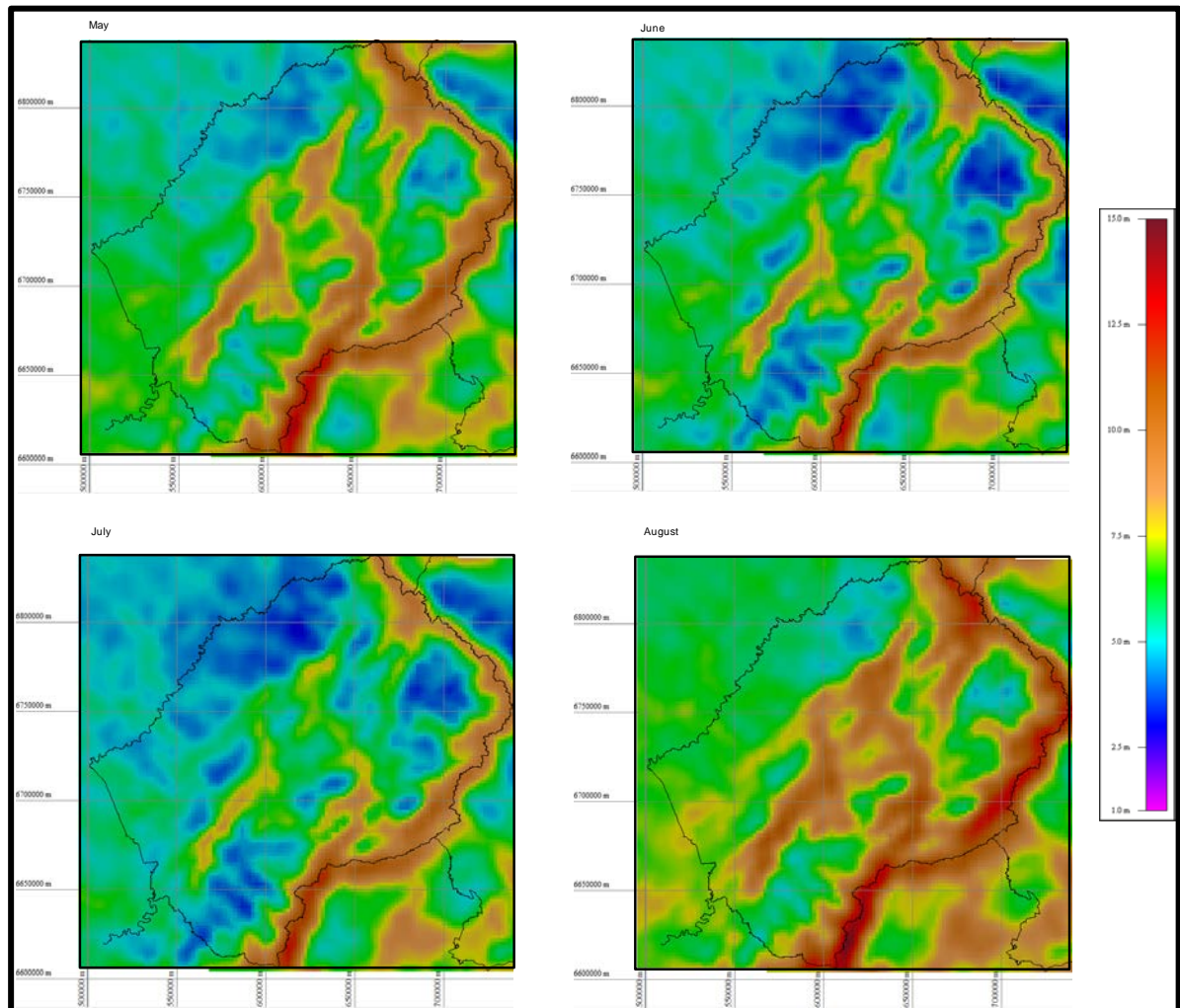


**Figure 2: Average annual wind speed of 5 km for Lesotho at a height of 80m from January to December**

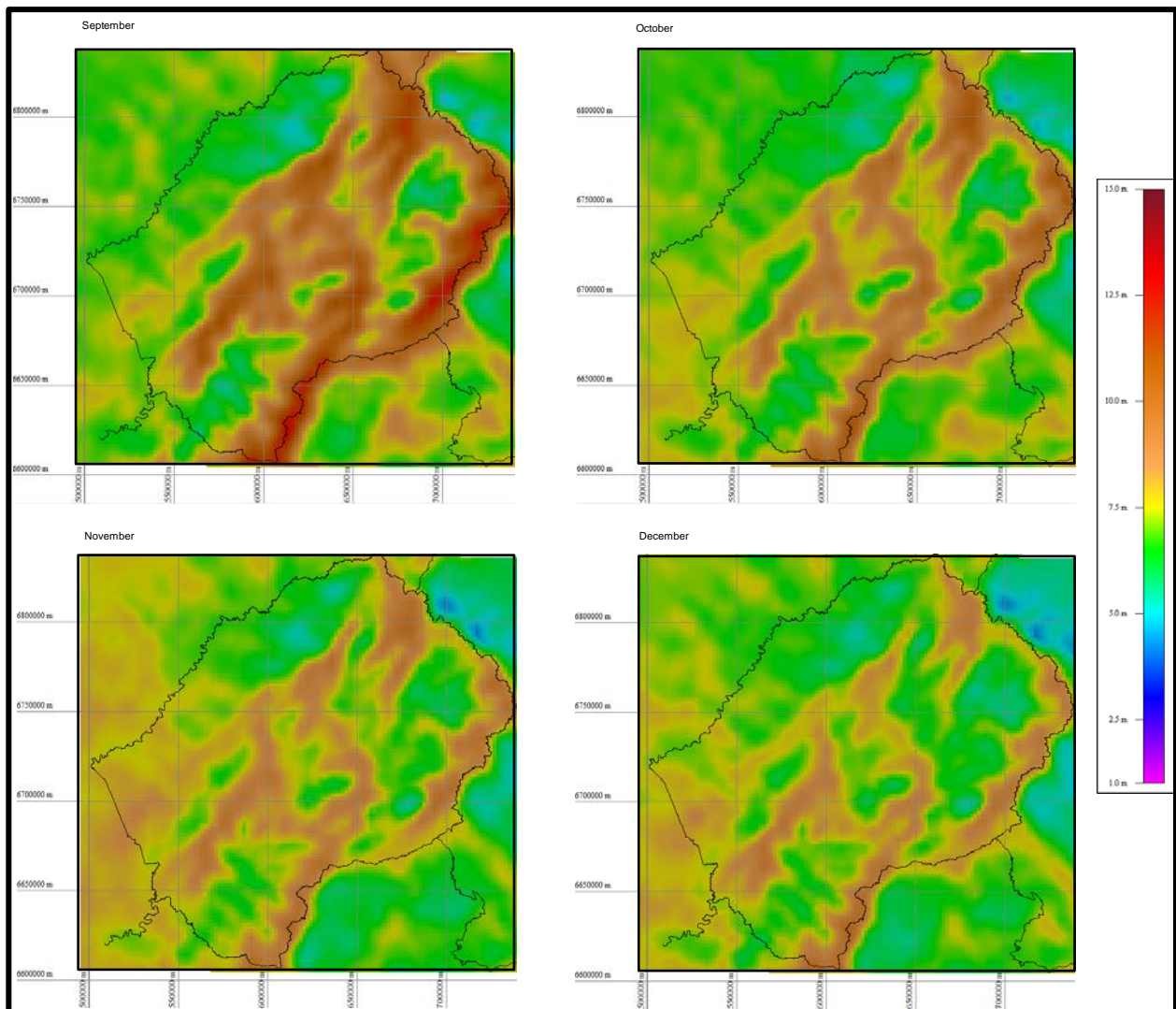
#### Map of Average Monthly Wind Speeds

Figures 3-5 show maps of average wind speed simulated with a 5km resolution of each month at a height of 80m

**Figure 3: Monthly average wind speed of 5 km for Lesotho at a height of 80m: January to April**



**Figure 4: Monthly average wind speed of 5 km for Lesotho at a height of 80m: May to August**



**Figure 5: Monthly average wind speed of 5 km for Lesotho at a height of 80m: September to December**

## 2.4 Dataset

3Tier produced its global wind dataset by operating the WRF model using high-quality inputs from a long-term, observation based dataset called, NCAR/NCEP. The model was then run for a period of 10 years, producing a dataset with a spatial resolution of 5 km for the world's entire land mass. To strike a balance between the need to resolve small-scale terrain features and the need to reduce the computational demand, the dataset combines a number of different model simulations.

For the modelling performed for Lesotho as part of the current project, a scan was made of the 5x5km grid squares generating 87,600 simulated registry entries for speed, direction, pressure and temperature.

These data can be used at a microscale level to simulate production and design of specific wind sites.

### 3. SELECTION OF REGIONS OF POTENTIAL DEVELOPMENT

#### 3.1 Methodology

The total surface area of Lesotho was considered for potential development with the aim of ascertaining regions with the highest theoretical wind resource. For these purposes factors that would limit the economic and technical feasibility were not considered, with only mesoscale wind data and topography being used in this initial analysis.

Simulated wind data obtained for the purposes of mesoscale wind map were used; this data was studied (taking into account the need to correct for air-density variations with height) and analysed in combination with the topography with specific reference to estimated wind speed and direction.

All parts of Lesotho were considered as potential areas for siting of wind farms with the following exceptions that were introduced to reflect technical and wind speed limitations:

- Wind speed over 6.5m/s;
- height above sea level: >2700m; and
- slopes > 25%.

##### 3.1.1 Wind speed

A modern wind turbine starts producing energy at a low level of wind speed (~4 m/s), however full nominal power production is not reached until around 12-14 m/s therefore, within limits, the higher the wind speed the more efficient/economic a wind site will be.

Accurate production estimates are based on estimates of wind data at 10 min intervals together with other data such as wind direction; however, for screening purposes yearly averages provide a good indication of higher production.

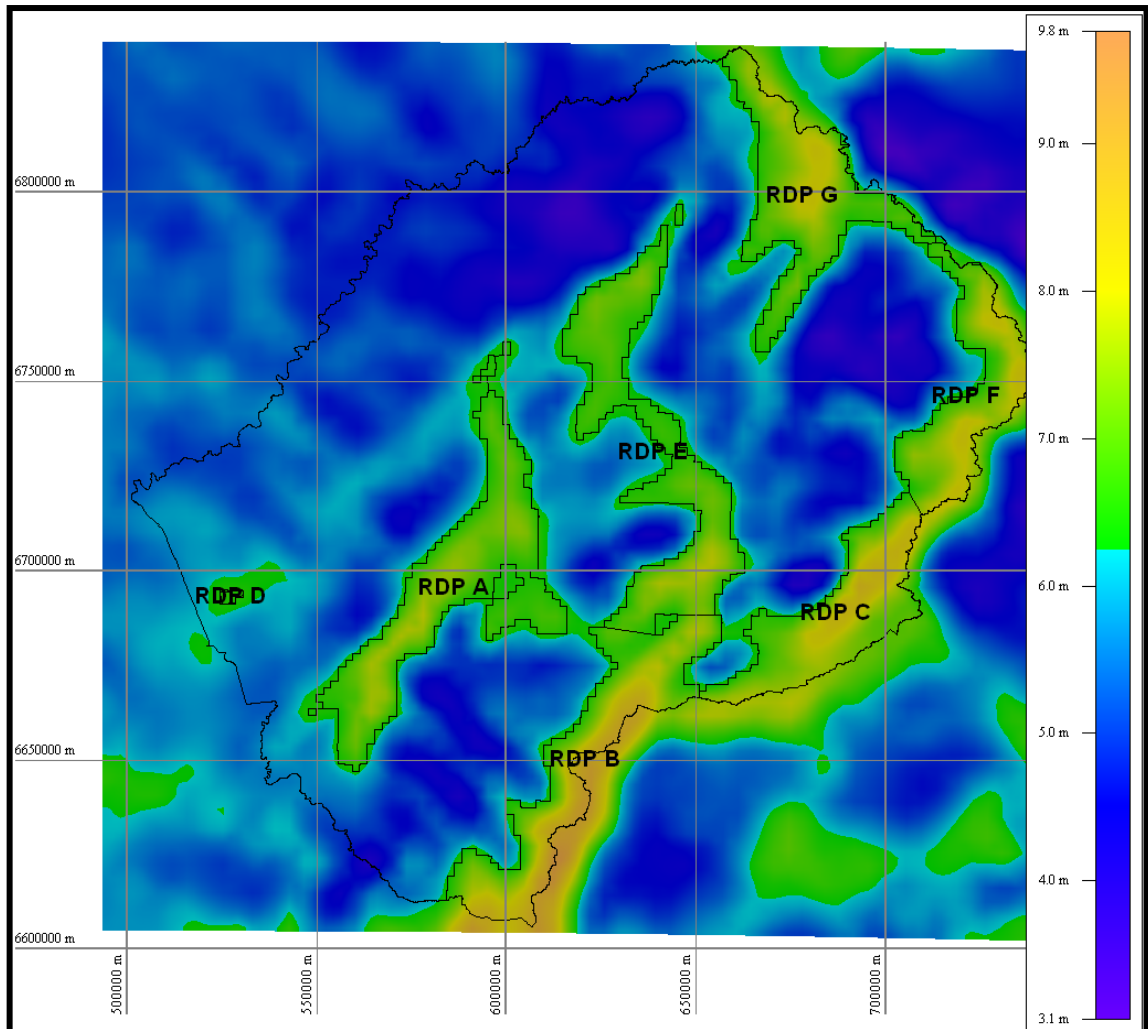
When analysing the theoretical wind resource of Lesotho, it was decided to focus on areas with estimated average wind speeds of greater than 6.5 m/s (at 80m. above ground level), whilst in effect, this is an economic filter it was considered that this was necessary in order to narrow the focus. These areas can be seen in Figure 6.

The figure of 6.5 m/s was chosen based on:

- experience from Europe as to what will ultimately be feasible;
- the fact that the high altitudes of Lesotho would depress production at this speed further due to lower air density (see discussion below); and
- the extent of the Kingdom with estimated average wind speeds above 6.5m/s; for this reason this figure was not considered overly restrictive.

A further caveat should be noted related to the scale of the wind map used; the estimated data is based on 5x5km grid which necessarily involves

estimates of topographical effects in addition to the inherent uncertainties of the modelling methodology; this was considered adequate for these screening purposes however, when reviewing specific sites at a micro level higher wind speeds than 6.5m/s may be found in the "discarded" areas.

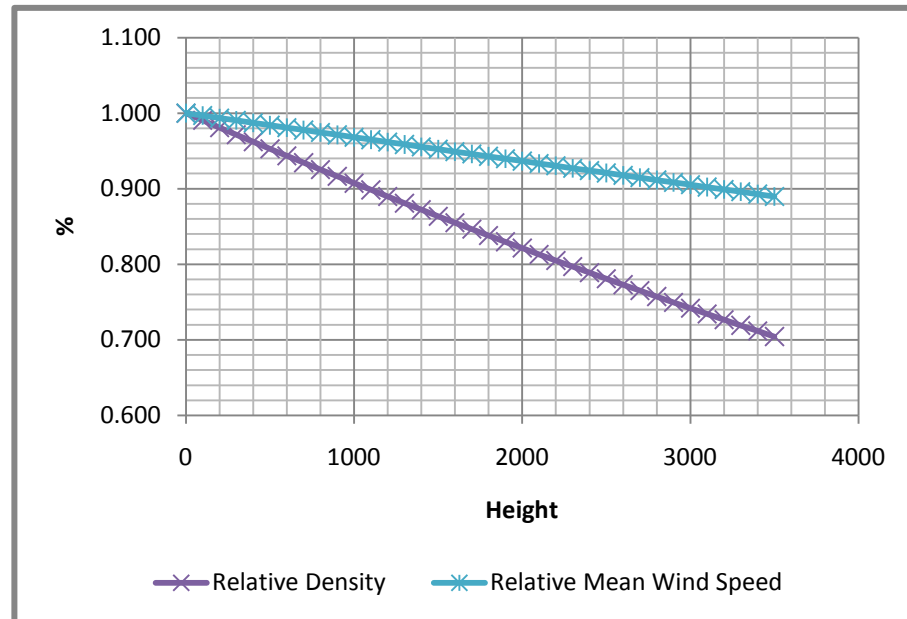


**Figure 6: Areas with estimated wind speed >6.5m/s (at 80m above ground level)**

### 3.1.2 *Height above sea level*

When considering potential locations for siting of wind farms, a very important consideration is the height above sea level. The altitude has implications not only for the operating conditions (especially the temperature of the turbine) but also affects substantially the density of the air and therefore the potential production that can be obtained from the wind flow.

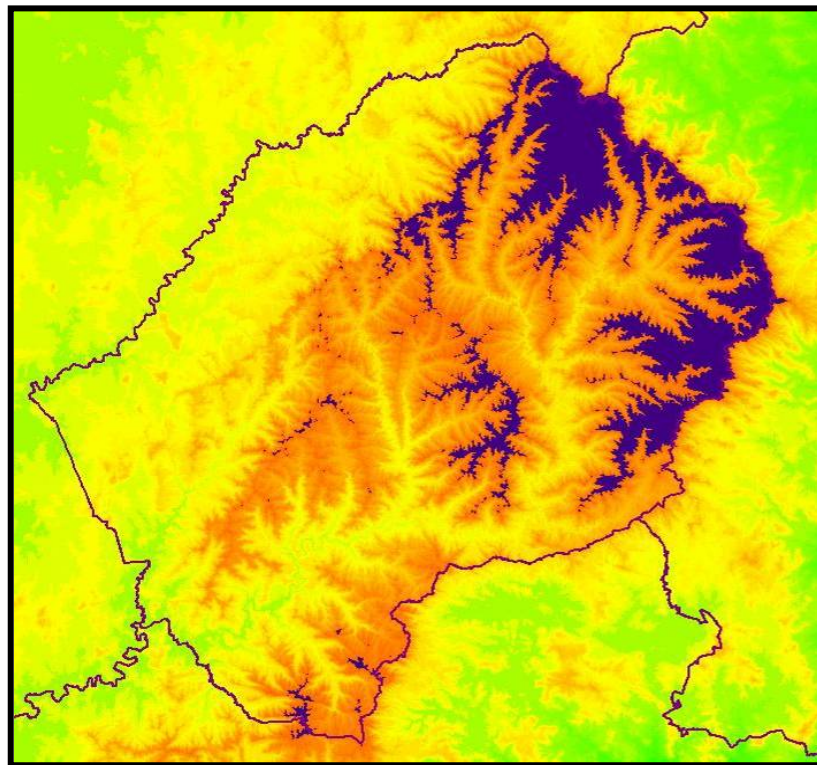
Figure 7 shows how increases in altitude result in a fall in air density relative to that which would exist at sea level (based on a standard atmosphere). Also shown is an indication of the effect on wind speed that an increase in height would have.



**Figure 7: Variations of air density and relative wind speed with height above sea level**

Conventional wind turbines were historically designed to operate at ranges up to 1500m above sea level. As result of the opening of new markets for wind turbines, such as the Americas, this operating altitude has been increased substantially by the manufacturers allowing the analysis of sites at much higher altitudes. This allows a country like Lesotho to study the implementation of wind energy projects although this altitude limitation must be borne in mind when considering the wind potential and specific siting possibilities.

For the purposes of this analysis it has been considered that all areas with altitudes above 2700 m should be discarded due to potential manufacturer limitations and decreased wind production (these areas can be seen in

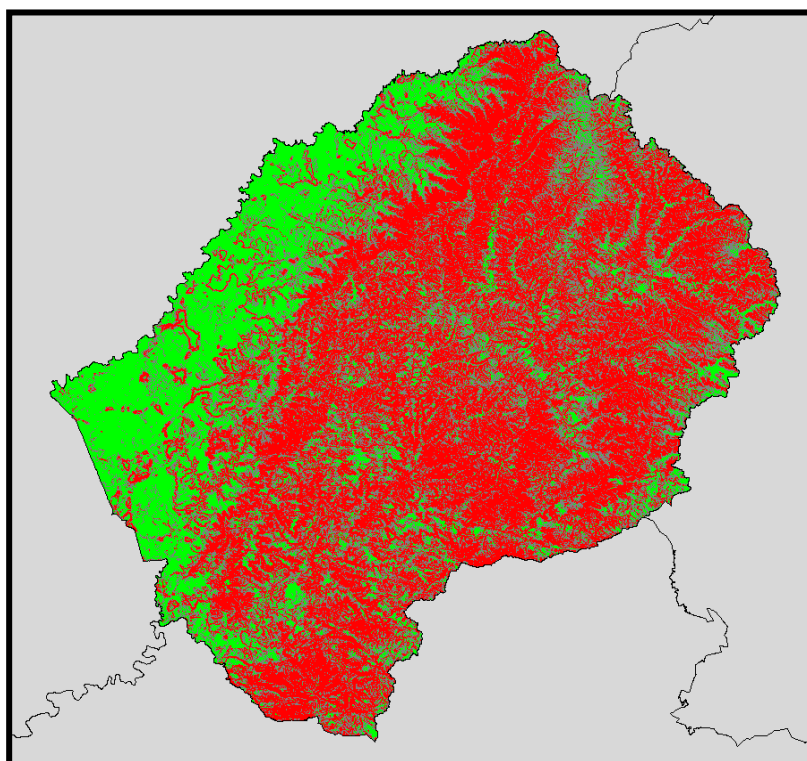


**Figure 8: Topography excluding areas more than 2700m above sea level (marked in blue)**

### **3.1.3 Slopes**

Another important factor to consider when analysing potential sites for the location of wind farms is the slope of terrain. Changes in terrain patterns will enable positive phenomena such as the acceleration of the wind flow however if overly steep can hinder the civil works and installation of turbines as well as produce negative phenomena such as recirculation and turbulences which will reduce the life of the turbine and the overall viability of a site.

For the purposes of this analysis it was considered appropriate to select areas of smooth topography and plateaus with a maximum of 25% slope.



**Figure 9: Indicates the level of slope of the topography; it can be seen that the Kingdom has a strong relief**

Figure 9: Topography showing relative slope (red areas show slope over 25%).

### **3.2 Initial selection of regions based on wind speed**

#### **3.2.1 Country level wind resource**

When analyzing the country-level implementation of wind energy consideration has to be given to the prevailing wind.

After analyzing the different data sets, it can be seen that the Kingdom of Lesotho is characterized by a strong westerly wind and that the winters (Southern hemisphere - August-May) are windier than summers (Southern hemisphere: February-March).

As an example of these seasonal differences, Figure 10 shows the results of a simulation from the closest mesoscale derived data point to Letseng:

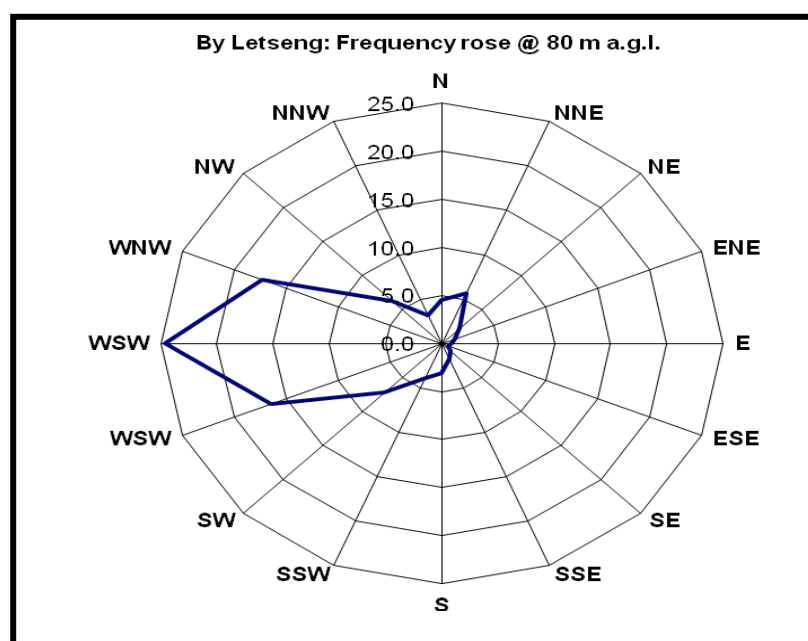
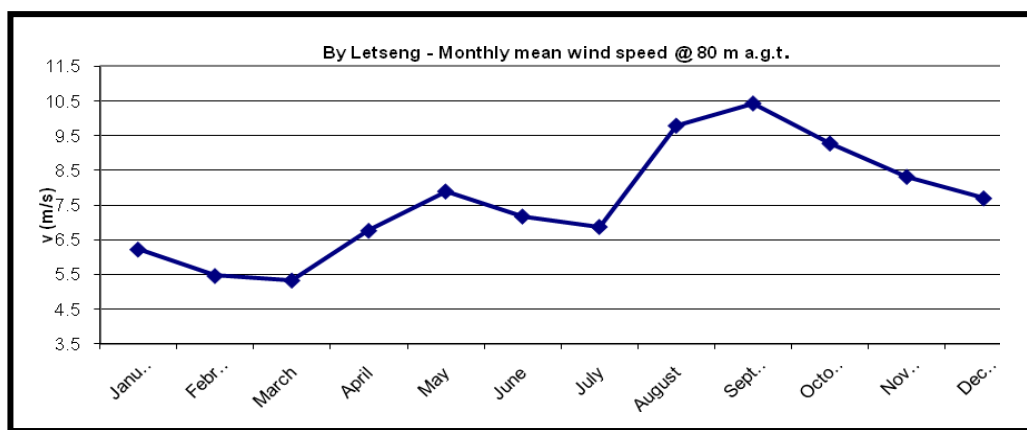
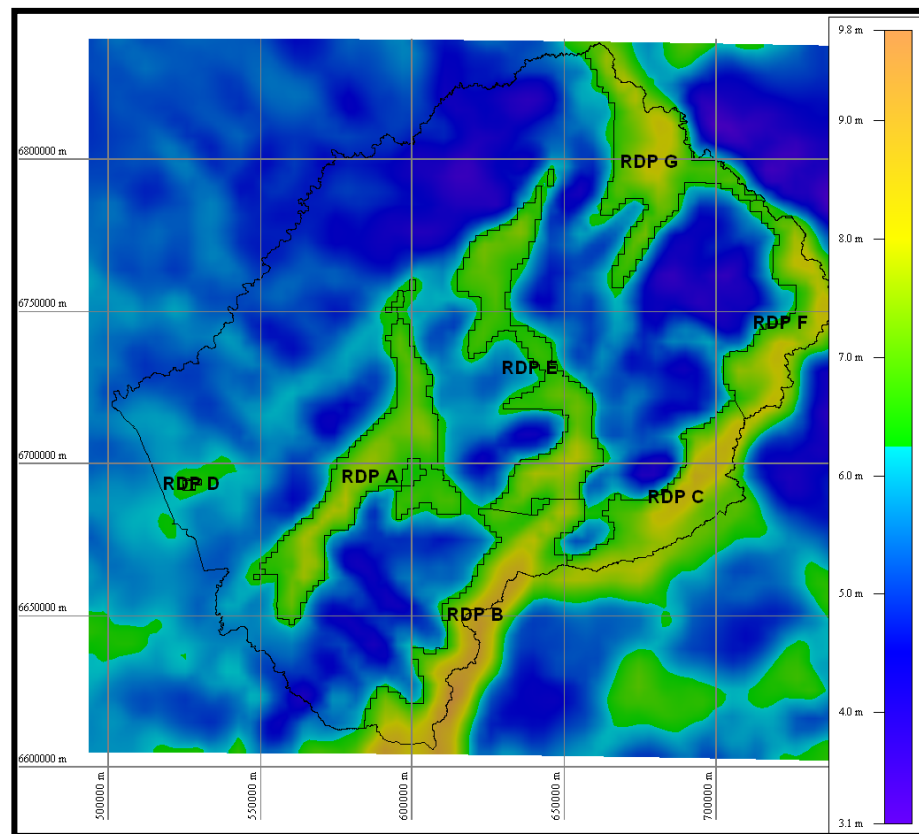


Figure 10: Simulation results for point close to Letseng



**Figure 11: Map showing areas of country with estimated average wind speeds over 6.5m/s (at 80m a.g.l) grouped into regions of further analysis**

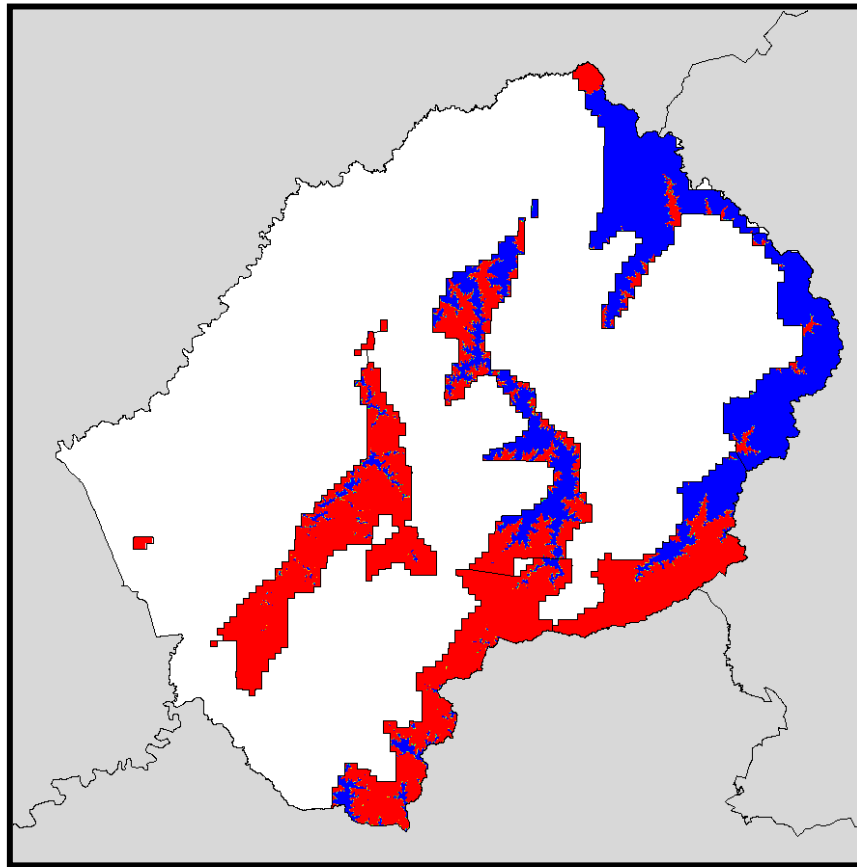
### **3.2.2 Areas of higher wind speed**

As noted above, the first filter to be applied was wind speed. Following the exclusion of areas with estimated annual wind speeds less than 6.5 m/s, the remaining areas were grouped into regions for the purpose of further analysis; these are shown below in figure 11 and analyse further in Section 3.3.

## **3.3 Further Analysis of all Regions**

### **3.3.1 Country Level Filter for Altitude**

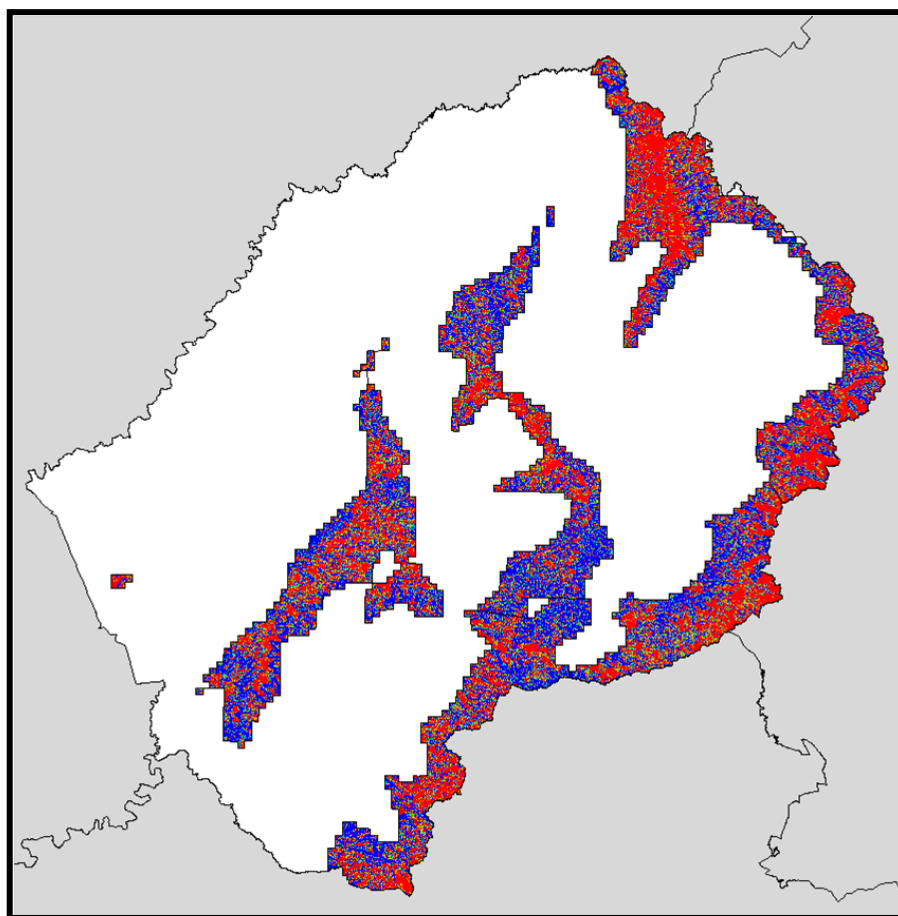
As noted above in section 3.1 after the selection of areas with higher wind speeds, it was also considered necessary to take into account altitude – it was decided to focus on areas less than 2700metres a.s.l.. The combination of this factor and wind speed can be seen below in Figure 12.



**Figure 12: Areas that have a combination of wind speeds higher than 6.5m/s and altitude less than 2700m absl**

### **3.3.2 Country Level Filter for Topography**

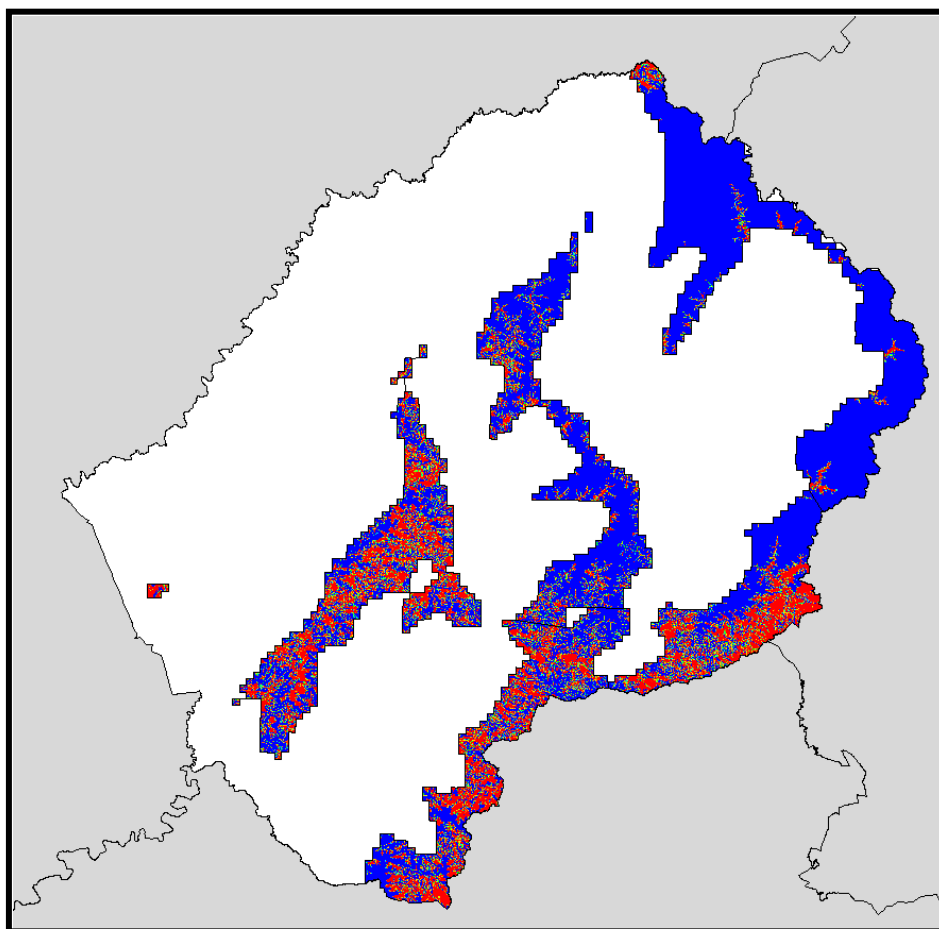
As noted above in section 3.1 after the selection of areas with higher wind speeds, it was also considered necessary to take into account topography – it was decided to focus on areas with slope >25%. The combination of this factor and wind speed can be seen below in Figure 13.



**Figure 13: Areas that have a combination of wind speeds higher than 6.5m/s and slope less than 25%**

### **3.3.3 Country level filter for altitude and topography**

As the effect of combining the factors discussed in sections X and Y (altitude and topography) together with the higher wind speed areas can be seen below in Figure 14.



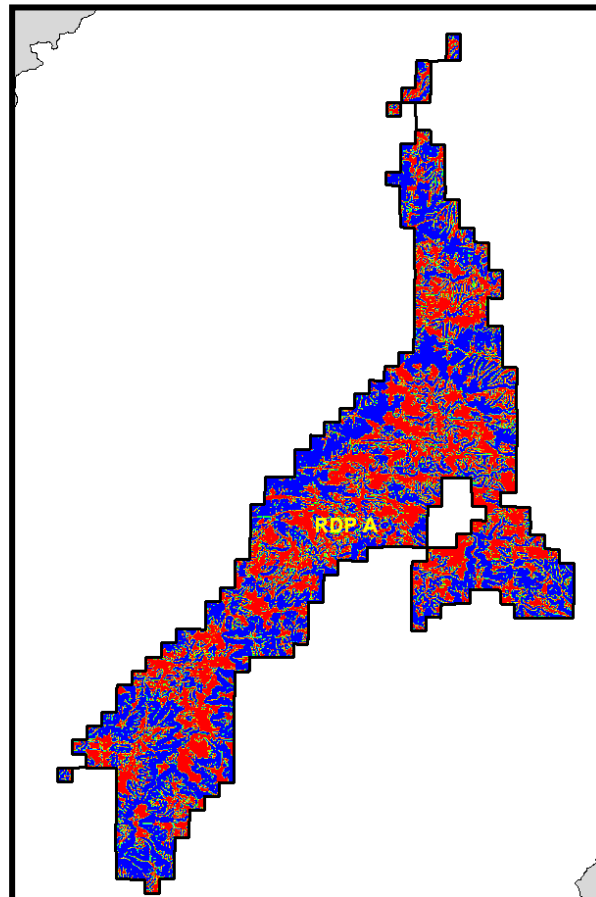
**Figure 14: Areas that have a combination of wind speeds higher than 6.5m/s, altitude less than 2700m abs, and slope less than 25%**

It should be noted that the above exercise has been performed at a country level in order to “filter” regions and select areas of focus for further more detailed investigation; sites suitable for wind development may exist within the areas discarded as part of this screening process due to altitude or topography or even outside the Regions themselves. Before selecting specific sites for wind farm development, consideration should be given to the accessibility (i.e. electrical grid and transport for turbines) of this theoretical resource and any social, cultural or environmental restrictions.

### 3.4 Description and Ranking of all Regions

#### 3.4.1 Region A

Figure 15 showing areas that have a combination of wind speeds higher than 6.5m/s, altitude less than 2700m absl, and slope less than 25%. Discarded areas are marked in blue.



**Figure 15: Region A**

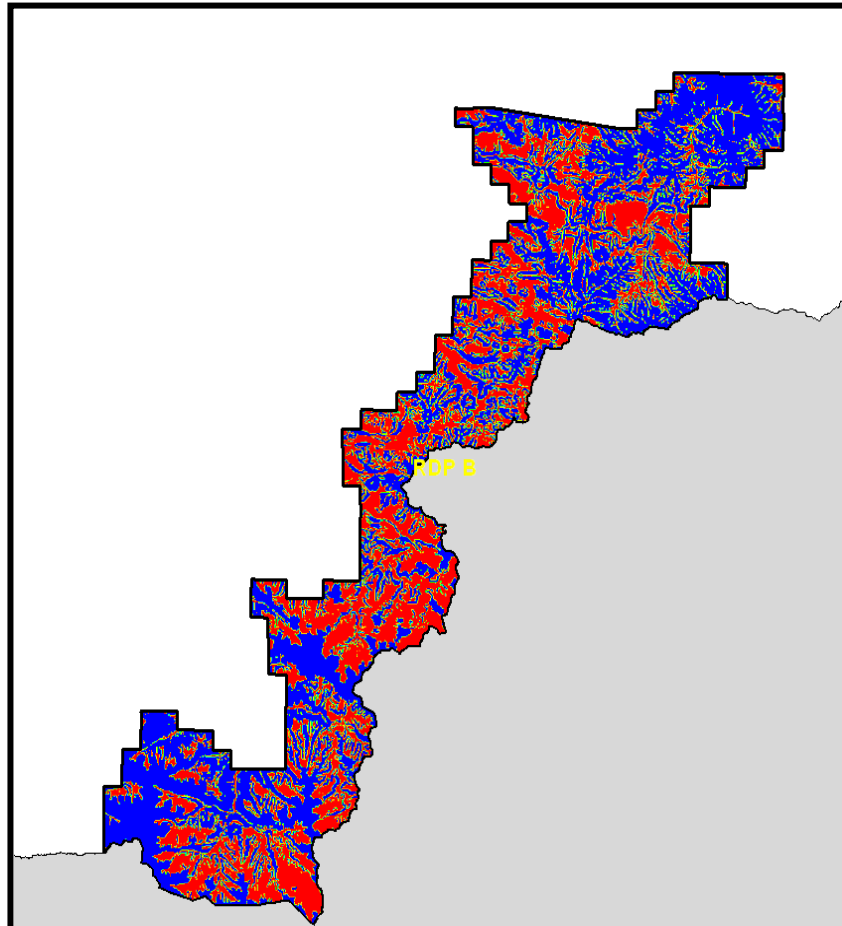
Located in the Central-South Western region of the Kingdom, Region A consists of a mountainous range running NE-SW. The length of the area covered is approximately 100km in length, it extends to 1,700km<sup>2</sup> and the altitude of the mountains is largely in the range 2300m-2700m.

The area is likely to have average wind speeds of around 7 m/s at 80m (above ground level ("a.g.l.")). The prevailing westerly wind will have a clear flow from South Africa meaning that the region will be less likely to experience turbulences

Considering the physical characteristics of this region it can be seen that 94% of the land area is under 2700m a.b.s.l and that 44% has a slope of less than 25%.

### 3.4.2 *Region B*

Figure 16 showing areas that have a combination of wind speeds higher than 6.5m/s, altitude less than 2700m absl, and slope less than 25%. Discarded areas are marked in blue.



**Figure 16: Region B**

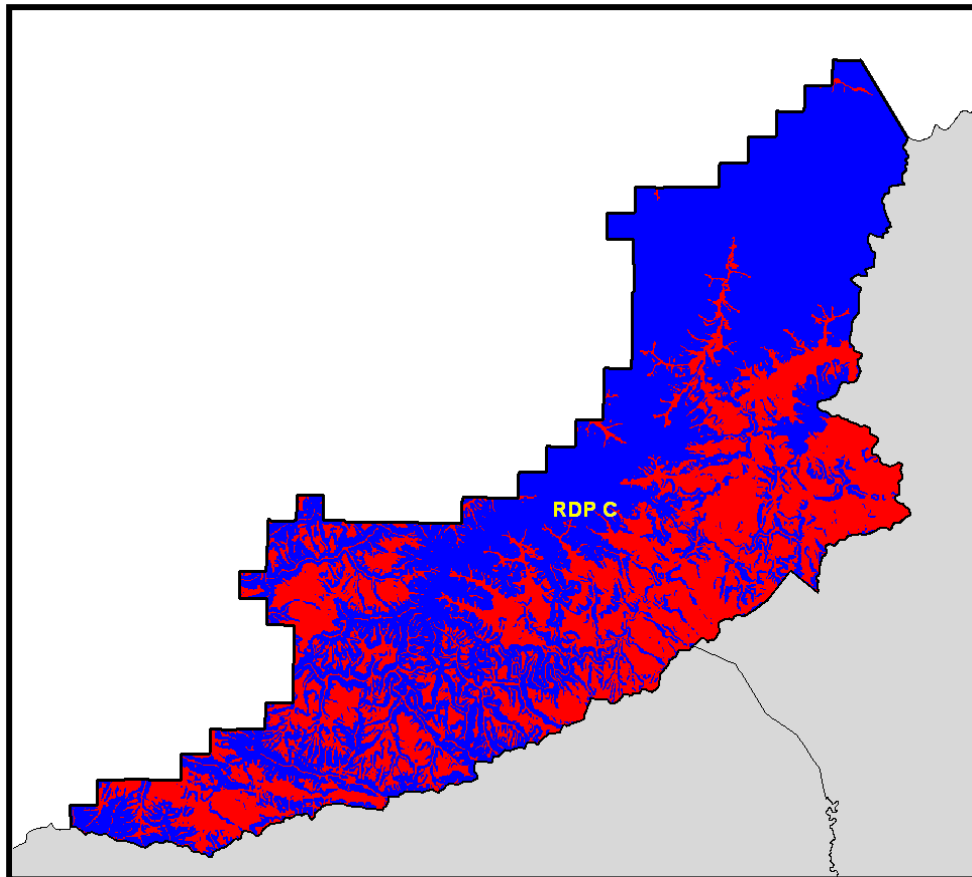
Region B is the South Eastern region of the Kingdom and forms the natural border with the Republic South Africa. The area is approximately 100 km in length, 1,400km<sup>2</sup> with the mountains ranging up to around 2700m.

The region's orientation relative to prevailing wind appears to be optimal, as evidenced by its high wind resource, of around 9 m/s at 80m (a.g.l.)

Considering the physical characteristics of this region it can be seen that 89% of the land area is under 2700m a.b.s.l and that 43% has a slope of less than 25%.

### 3.4.3 Region C

Figure 17 showing areas that have a combination of wind speeds higher than 6.5m/s, altitude less than 2700m absl, and slope less than 25%. Discarded areas are marked in blue.



**Figure 17: Region C**

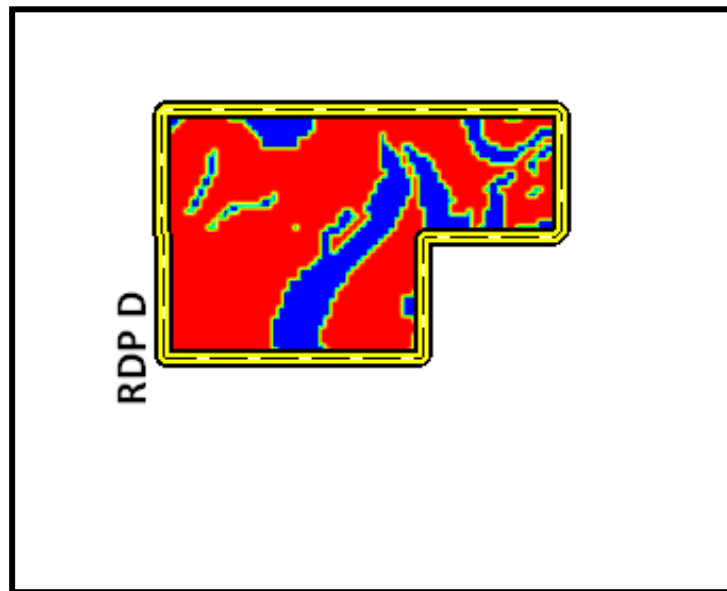
Region C is in the South of the Kingdom and forms the natural border with the Republic of South Africa. The region has a total length of around 70 km, it extends to 1,200km<sup>2</sup> with mountains of around 2100m ranging up to 3000m in the North.

The potential average wind speed is around 7.5 m / s to at 80m (a.g.l.) in the Westerly areas, Eastern areas could show speeds around 8m/s. Although it has higher wind speeds, the Northern area should largely be excluded for these purposes due to the excessive heights

Considering the physical characteristics of this region it can be seen that 71% of the land area is under 2700m a.b.s.l and that 49% has a slope of less than 25%.

### 3.4.4 Region D

Figure 18 showing areas that have a combination of wind speeds higher than 6.5m/s, altitude less than 2700m absI, and slope less than 25%. Discarded areas are marked in blue.



**Figure 18: Region D**

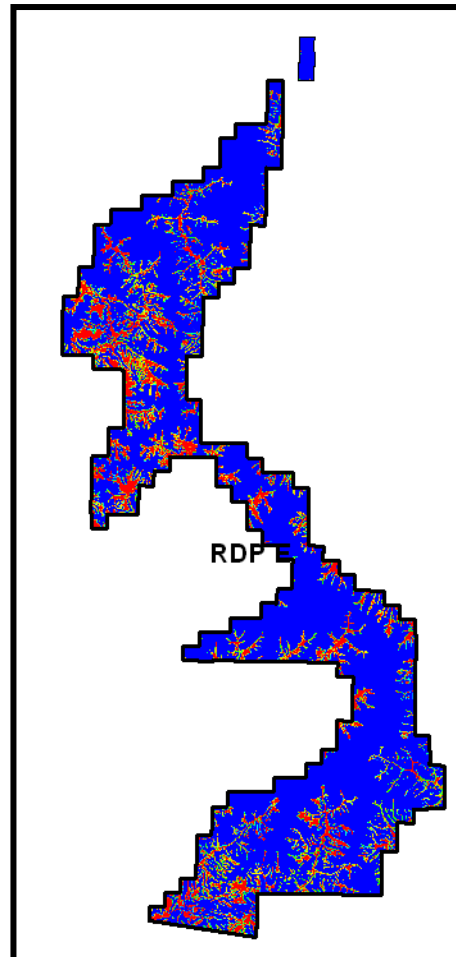
Region D is in the West of the Kingdom and forms a small raised area of higher ground of approximately 17km<sup>2</sup> in the midst of the lowlands; maximum altitude is around 2000m absI.

The region's orientation relative to prevailing wind appears excellent as the prevailing wind will arrive unhindered from South Africa at around 6.8m/s.

Considering the physical characteristics of this region it can be seen that 100% of the land area is under 2700m a.b.s.l and that 76% has a slope of less than 25%.

### 3.4.5 *Region E*

Figure 19 showing areas that have a combination of wind speeds higher than 6.5m/s, altitude less than 2700m absl, and slope less than 25%. Discarded areas are marked in blue.



**Figure 19: Region E**

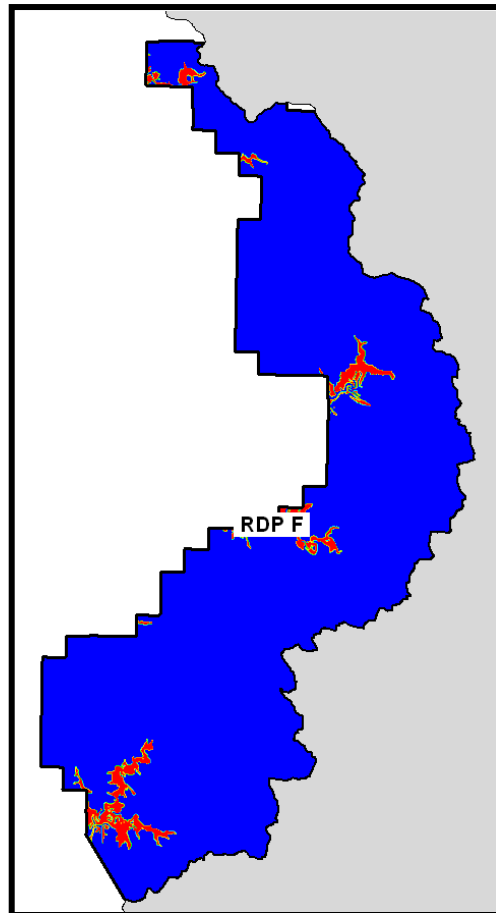
Region E is in the centre of the country formed by an range of mountains of around 2200-2500m running North/South. The region is approximately 100 km in length and extends to 1,600km<sup>2</sup>

The region's orientation relative to prevailing wind appears sub-optimal as the wind flow to the greater part of this region is likely to be affected by the mountains that form part of Region B; an area in the North does show promise and could warrant further investigation. Average wind speeds are likely to be medium at around 7 m/s.

Considering the physical characteristics of this region it can be seen that 50% of the land area is under 2700m a.b.s.l and that 39% has a slope of less than 25%.

### 3.4.6 *Region F*

Figure 20 showing areas that have a combination of wind speeds higher than 6.5m/s, altitude less than 2700m absl, and slope less than 25%. Discarded areas are marked in blue.



**Figure 20: Region E**

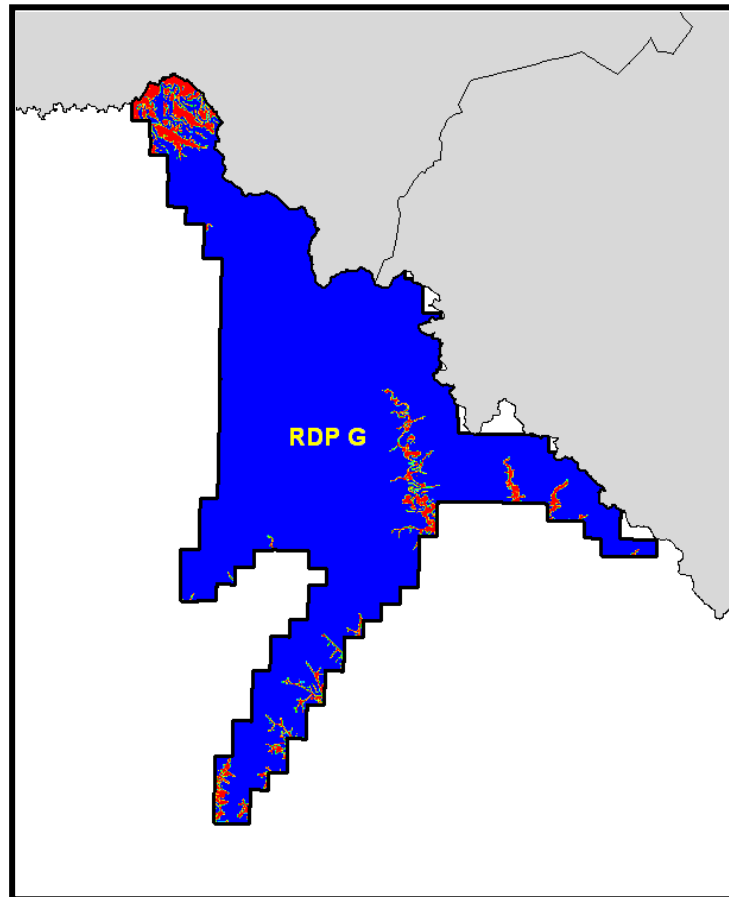
Region F forms the Eastern border with South Africa consisting of a 90km mountain range with high altitudes of upto 3000m absl, it extends to 100km<sup>2</sup>.

The region's orientation relative to prevailing wind appears sub-optimal due to being located in the extreme East of the country. Wind speeds are high - 8m/s could be seen but are likely to be mostly in accessible due to altitude and turbulences.

Considering the physical characteristics of this region it can be seen that 4.6% of the land area is under 2700m a.b.s.l and that 55% has a slope of less than 25%.

### 3.4.7 Region G

Figure 21 showing areas that have a combination of wind speeds higher than 6.5m/s, altitude less than 2700m absl, and slope less than 25%. Discarded areas are marked in blue.



**Figure 21: Region E**

Region G consists of the high mountain ranges in the North East of the Kingdom bordering South Africa and extending upto 50km into the country; it extends to 1,300km<sup>2</sup>

The region's orientation relative to prevailing wind appears sub-optimal due to being located in the extreme East of the country. The region has some of the highest wind speeds in the country but at significant altitude - over 2700m. Furthermore, the topographical features mean that turbulences are likely.

An area in the North, whilst has lower wind speeds, is at a lower altitude and better positioned - could be worth further investigation.

Considering the physical characteristics of this region it can be seen that 11% of the land area is under 2700m a.b.s.l and that 60% has a slope of less than 25%.

### 3.4.8 **Ranking**

Comparing the potential for wind development between the Regions, the following variables were considered:

- Wind characteristics (speed, prevailing wind);
- Altitude; and
- Slope/ orography.

The Regions were then ranked into two tiers:

#### Tier 1 - For Further Analysis

Region	Rank	Comment
B	1	High wind speeds, large percentage under 2,700m and a lower proportion of slope with optimal positioning for the prevailing winds.
A	2	Well positioned for the prevailing winds; smoother topography resulting in less slope and lower heights
C	3	Less than optimal location for prevailing winds - easterly parts excessively high but west has lower altitudes and could present attractive sites

**Table 2: Tier 1 Regions**

#### Tier 2- No Further Analysis

Region	Rank	Comment
D	4	Well positioned but with lower wind speeds and small size
E	5	Largely overshadowed by area B and with average wind speeds, although some areas in the North could show promise
G	6	High wind speeds but with nearly 90% over 2700m; topography means turbulences likely. Area in North could show promise
F	7	Extremely mountainous with sub-optimal positioning

**Table 3: Tier 2 Regions**

It should be again noted that this ranking was performed in order to focus resources in the search for utility scale wind farms as part of a filtering exercise that looks at the most likely concentration of "good" sites – it is quite possible that attractive sites can be found in discarded/unconsidered Regions or even areas outside of these.

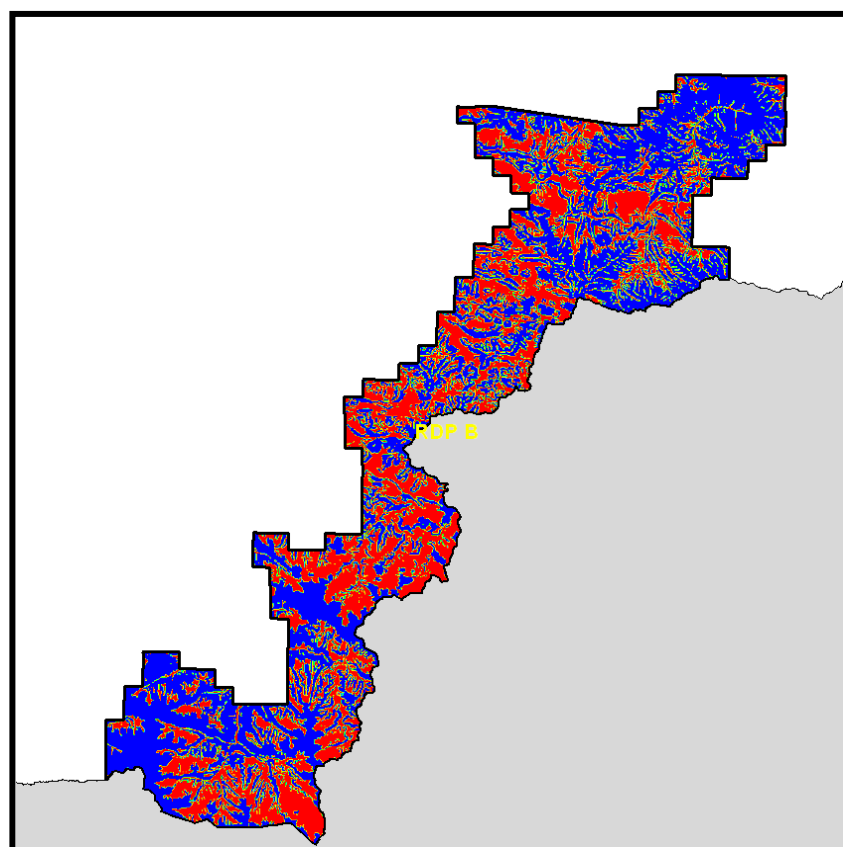
### 3.5 Selection and Further Analysis Regions of Potential Development

#### 3.5.1 Introduction

The regions of potential development A, B and C were considered in more detail in order to confirm the previous analysis and ranking as well as to examine the wind characteristics in more detail.

Within each region a three representative points were chosen in order to confirm the previous analysis and consider the potential of a hypothetical wind farm in this region.

#### 3.5.2 Region B



**Figure 22: Region B. Discarded areas are marked in blue**

Region B is the South Eastern region of the Kingdom and forms the natural border with the Republic South Africa. The area is approximately 100 km in length, 1,400km<sup>2</sup> with the mountains ranging up to around 2700m.

The region's orientation relative to prevailing wind appears to be optimal, as evidenced by its high wind resource, of around 9 m/s at 80m (a.g.l.)

Considering the physical characteristics of this region it can be seen that 89% of the land area is under 2700m a.b.s.l and that 43% has a slope of less than 25%.

A high level analysis at this stage indicates that up to 600-700 megawatts could be installed in the region; this figure is based on a consideration of the wind resource and typical topographical features within the region – it does not take into account the possibility of grid connection nor access ability (via roads) for installation. Furthermore, when considering specific sites consideration will need to be taken of environmental, social and cultural factors as well as microscale wind characteristics such as turbulences.

### Example Point

As noted above, a representative point within the Region was chosen in order to confirm the previous analysis and consider the potential of a hypothetical windfarm; the [Southern] point is shown below.



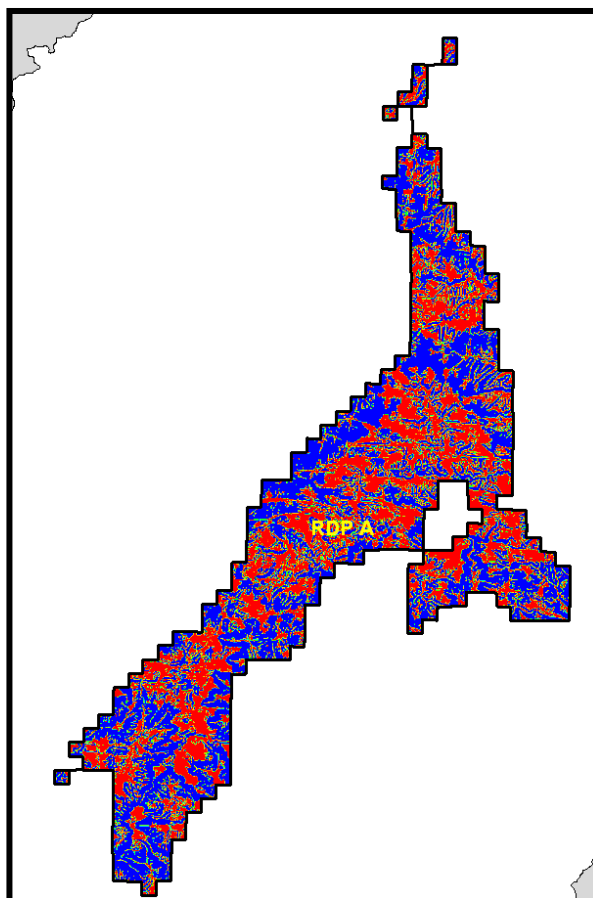
**Figure 23: Region B, example point South**

An area totaling 36 km<sup>2</sup> was selected as an example in order to review the possibilities for siting a wind farm. Within this area the ridges running NNE-SSW were considered for a potential windfarm site as they faced the prevailing wind.

Based on a conservative high level criteria for spacing of wind turbines (10 rotor diameters apart), it was considered that at least 60 MW could be potentially installed. This high level of estimation was considered appropriate for these purposes - in order to confirm this, a more detailed micro siting analysis would be necessary.

A very basic analysis of wind resource shows that if 60 MW was installed the output could range between 150 and 180 GWh; this high level of estimation was considered appropriate for these purposes - a more detailed micro siting analysis would be necessary before more accurate estimations can be made.

### 3.5.3 Region A



**Figure 24: Region A. Discarded areas are marked in blue**

Located in the Central-South Western region of the Kingdom, Region A consists of a mountainous range running NE-SW. The length of the area covered is approximately 100km in length, it extends to 1,700km<sup>2</sup> and the altitude of the mountains is largely in the range 2300m-2700m.

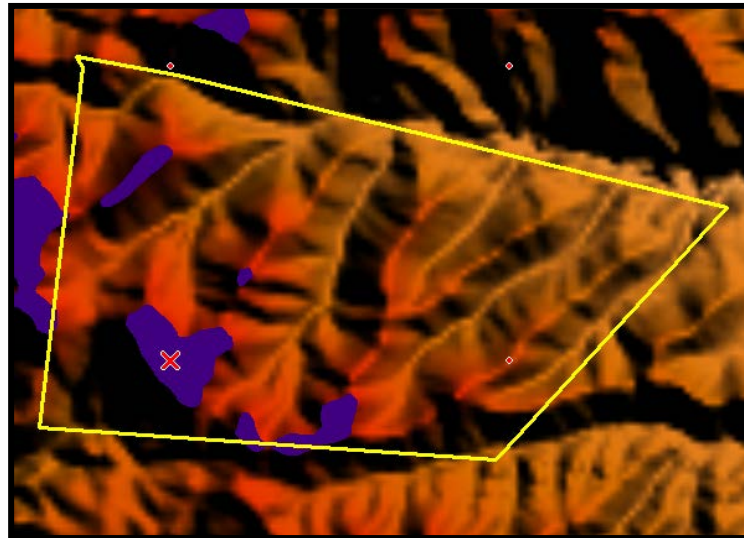
The area is likely to have average wind speeds of around 7 m/s at 80m (above ground level ("a.g.l.")). The prevailing westerly wind will have a clear flow from South Africa meaning that the region will be less likely to experience turbulences

Considering the physical characteristics of this region it can be seen that 94% of the land area is under 2700m a.b.s.l and that 44% has a slope of less than 25%.

A high level analysis at this stage indicates that up to 600-700 megawatts could be installed in the region; this figure is based on a consideration of the wind resource and typical topographical features within the region – it does not take into account the possibility of grid connection nor access ability (via roads) for installation. Furthermore, when considering specific sites consideration will need to be taken of environmental, social and cultural factors as well as microscale wind characteristics such as turbulences.

### Example Point

As noted above, a representative point within the Region was chosen in order to confirm the previous analysis and consider the potential of a hypothetical windfarm; the [Northern] point is shown below.



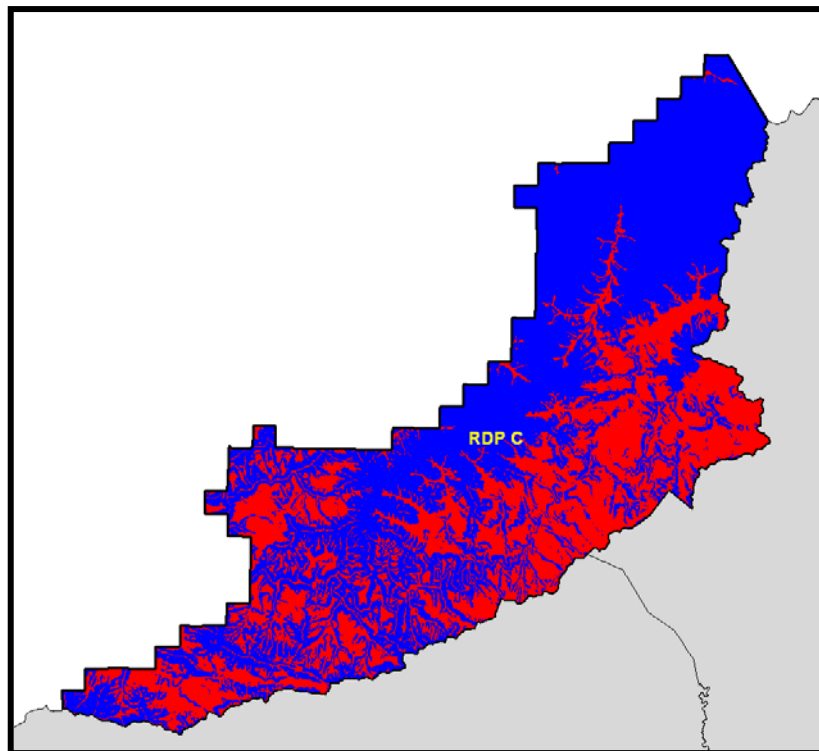
**Figure 25: Region A, example Point North**

An area totalling 36 km<sup>2</sup> was selected as an example in order to review the possibilities for siting a wind farm. Within this area the ridges running NNE-SSW were considered for a potential windfarm site as they faced the prevailing wind.

Based on a conservative high level criteria for spacing of wind turbines (10 rotor diameters apart), it was considered that at least 60 MW could be potentially installed. This high level of estimation was considered appropriate for these purposes - in order to confirm this, a more detailed micro siting analysis would be necessary.

A very basic analysis of wind resource shows that if 60 MW was installed the output could range between 140 and 170 GWh; this high level of estimation was considered appropriate for these purposes - a more detailed micro siting analysis would be necessary before more accurate estimations can be made.

### 3.5.4 Region C



**Figure 26: Region C. Discarded areas are marked in blue**

Region C is in the South of the Kingdom and forms the natural border with the Republic of South Africa. The region has a total length of around 70 km, it extends to 1,200km<sup>2</sup> with mountains of around 2100m ranging up to 3000m in the East.

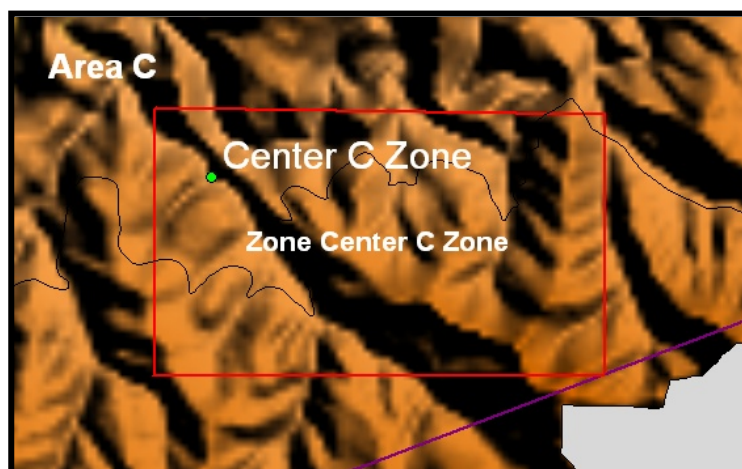
The potential average wind speed is around 7.5 m / s to at 80m (a.g.l.) in the Westerly areas, Eastern areas could show speeds around 8m/s. Although it has higher wind speeds, the eastern area should largely be excluded for these purposes due to the excessive heights

Considering the physical characteristics of this region it can be seen that 71% of the land area is under 2700m a.b.s.l and that 49% has a slope of less than 25%.

A high level analysis at this stage indicates that up to 600-700 megawatts could be installed in the region; this figure is based on a consideration of the wind resource and typical topographical features within the region – it does not take into account the possibility of grid connection nor access ability (via roads) for installation. Furthermore, when considering specific sites consideration will need to be taken of environmental, social and cultural factors as well as microscale wind characteristics such as turbulences.

#### Example Point

As noted above, a representative point within the Region was chosen in order to confirm the previous analysis and consider the potential of a hypothetical windfarm; the [Central] point is shown below:



**Figure 27: Region C, example point Centre**

An area totaling 36 km<sup>2</sup> was selected as an example in order to review the possibilities for siting a wind farm. Within this area the ridges running NNE-SSW were considered for a potential windfarm site as they faced the prevailing wind.

Based on a conservative high level criteria for spacing of wind turbines (10 rotor diameters apart), it was considered that at least 60 MW could be potentially installed. This high level of estimation was considered appropriate for these purposes - in order to confirm this, a more detailed micro siting analysis would be necessary.

A very basic analysis of wind resource shows that if 30 MW was installed the output could range between 70 and 90 GWh; this high level of estimation was considered appropriate for these purposes - a more detailed micro siting analysis would be necessary before more accurate estimations can be made.

#### **4. SELECTION OF POTENTIAL WIND FARM SITES**

Selection of the RPD was done considering large regions with wind speed mainly above the 6,5m/s, with heights mainly below the 2700m, and where areas with relatively low terrain complexity could be found. As noted earlier, three regions were identified.

The methodology followed in the Phase I work consists in narrowing down the process, in order to identify suitable wind farms sites within the three regions - sites where it is suggested to focus future studies.

The methodology focused on the selections of potential sites within the three previously selected RPDs. It should be noted that other suitable sites may be found outside the selected RPD's.

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Followed methodology and results are detailed below.

## **4.1 Methodology**

### **4.1.1 *Criteria for selection of possible sites***

As per the selection of the RPD, the following selection criteria were considered:

- The areas have to be within the 6,5m/s wind speed limit;
- Considering that wind farms are likely to be less efficient if operating above the 2700m asl, areas with heights above the 2700 are ruled out; and
- Taking into account that wind turbines can not be installed in terrain with slopes greater than 25%, such areas are ruled out.

### **4.1.2 *High resolution wind flow simulation***

High level simulation of the wind flow allows converting the country scale wind information produced by 3Tier, to a local scale. Wind resource grid with resolution between 100m and 200m has been generated.

Colored wind resource maps were produced achieved, which helps with the identification of high wind resource areas within the sites considered suitable in terms of height and slopes.

Fifteen potential sites have been identified. All the sites are presented in Paragraph 3.2.

### **4.1.3 *Model used and input data***

To calculate the wind flow over each sub-zone, the WindPRO 2.7 software is used. WindPRO has been developed by EMD International, a Danish software and consultancy company.

The inputs to the models are a digitized map of the topography, surface roughness of the site and its surrounding areas, and the wind data.

#### **4.1.3.1 *WindPRO – WAsP calculation***

The WAsP calculation model is commonly used to calculate the transformation of wind data from the point of metering to the each individual turbine. The model is described in detail by (Troen and Petersen, 1989). First step is to generate from the metering data and the terrain around the virtual mast a description of the regional wind climate (a wind statistic), secondly to apply this wind statistic on each individual turbine at hub height, reintroducing the local terrain description.

21 wind statistics for the regional wind climate has been calculated based on mesoscale wind data at 80m and topographic data.

The wind flow calculations were performed with WindPRO using the WAsP calculation engine with wind statistics and the terrain description as input.

#### 4.1.3.2 *Wind data*

The input wind data is derived from meso-scale data sets provided by 3Tier in the previous work phase.

3Tier has delivered a 5km\*5km resource grid, covering the whole country, with registry entries for speed, direction, pressure and temperature at 50m and 80m above ground.

21 wind data sets, from 21 different grid points distributed over the RPD's, were chosen to simulate the wind flow. The chosen grid points were selected taking into account height, surroundings, etc. When possible, the chosen points are localized in areas clear of topographic obstacles, in order to be representative of the wind conditions (speed and prevailing wind) of a large area.

Location of chosen grid points is detailed in Table 1.

#### 4.1.3.3 *Orography and roughness*

A 3D digital model of the terrain has been obtained through interpolation of satellite data. 3D model of each sub-zone has been considered, covering areas from 12\*12km up to 35km\*35km with contour lines every 10m or 20m.

The general roughness length of the sites (predominance of open areas and farm land) is set to 0,03m.

#### 4.1.4 ***Delimitation of potential sites***

The topography of the sites is highly complex, and it is generally difficult to find areas large enough to group 5 or more wind turbines. Potential sites have therefore been delimited taking into account the wind resource and the restrictions for slopes and height, but also avoiding too long distances between one group of turbines and the next. Different delimitations of the sites may be considered in the future, but it has to be borne in mind that the distance between turbines is likely to increase and this may reduce the feasibility of the project.

As defined in the scope of work, potential sites with a small capacity (lower than 14MW) were ruled out.

Other suitable sites may be found within the RPD's, but are likely to have a small capacity.

For the purpose of this study, no further criteria were taken into account. Other factors including - road access, proximity of electricity network, environmental restrictions and cost of the civil work will have to be considered to confirm the feasibility of the proposed sites.

#### **4.1.5 Estimation of the capacity**

Estimation of the capacity of each site has been based on a 2MW wind turbine, considering a 90m rotor diameter. Minimum separation between turbines is equivalent to 7 rotor diameter in the prevailing wind direction and 3 rotor diameter in the direction perpendicular to the prevailing wind. Further studies including micrositeing are needed to confirm the estimated capacity and delimitation of the proposed sites.

The highly complex topography of the considered RPD prevent from very large scale wind farm developing. Capacity of selected sites varies from 20MW to 134MW. Potential sites with a capacity lower than 14MW has been ruled out.

Estimated capacity for each RPD is shown in Table 5: .

#### **4.1.6 Estimation of the wind resource**

The estimation of the production of a single wind turbine within the selected sites has been performed, in order to narrow down focus, and estimate the suitability of the potential sites without performing in depth studies at each site.

The estimation of the production based on a single wind turbine is an efficient way to get an indicative of the production of a whole wind farm. As defined in the scope of work, more detailed micrositeing studies were performed only for the considered five most attractive sites (see Paragraph 4).

It has to be noted that the production of the whole wind farm is likely to be 20% lower than production based on a single wind turbine. Considering the complexity of the sites, the location of a single wind turbine may not be representative of the whole area, and variation in production from turbine to turbine is likely to occur. Production of a whole wind farm is also lower due to the loss of energy resulting from interaction between turbines (wake energy losses).

Estimation has been based on the production of a single wind turbine sited in a location considered as representative as possible of the whole site. Coordinates of the considered representative location for each site is detailed in Table 6.

Gross production has been reduced by 10% to account for energy losses. The following sources of energy losses were considered:

- 4% to account for wind turbine availability;
- 3% to account for electrical transmission losses; and
- 3% to account for losses due to high wind hysteresis and blade fouling.

#### 4.1.7 **Wind turbine**

Calculations are performed based on the Vestas 2MW wind turbines. A 2MW nominal power allows maximizing the production while minimizing the environmental impact.

The IEC class of the wind turbine has been chosen according to the wind speed predicted at hub height at the wind turbine site.

Site where predicted speed was found to be greater than 7,5m/s were calculated using the Vestas V80 with an 80m rotor diameter, hub height of 80m and 2MW nominal power. The Vestas V80 wind turbine suits well class IEC I sites as it provides a good productivity with both high and moderate winds.

Site where predicted speed was found to be lower than 7,5m/s were calculated using Vestas V90 with an 90m rotor diameter, hub height of 80m and 2MW nominal power. The Vestas V90 wind turbine suits well class IEC III sites.

It has to be noted that IEC requires other parameters to be checked prior to the selection of the class of the turbine (such as ambient turbulence level). Further studies are needed to establish the suitability of the chosen turbine.

#### 4.1.8 **Correction for air density**

Air density has been calculated from air pressure and air temperature predicted by 3Tier in 11 reference points.

The predicted energy yield of the representative WTG of each potential site has then been individually corrected taking into account air density variation from the reference point site to the WTG site.

Since the considered areas are often located above 2000m (asl), the air density drops considerably, with drops down to 73,6% of air density standard.

#### 4.1.9 **Terrain complexity index**

Due to the high complexity of the terrain, potential sites were rated according to a qualitative index of complexity.

Three levels were defined:

+	The terrain is highly complex, mainly formed by steep mountainous lines. Wind turbines can not be gathered in a same area. The wind flow is likely to be turbulent and life span of the turbine may be reduced.
++	The site is complex, formed alternatively by steep slopes and relatively flat areas.

	The site is relatively flat, allowing gathering several wind turbines in a same area. Turbine can be located far from steep slopes, avoiding zone of recirculation and turbulent flow.
--	--

#### **4.1.10 Associated uncertainties**

A typical figure of 2% associated uncertainty to the estimated production is generally considered to take account of accuracy in the wake and topographic modeling over flat terrain. Here, the terrain is very complex and the uncertainty associated to the accuracy of the wind flow simulation is significantly increased. Further studies are needed, including wind measurement campaign on site, to confirm the estimated resource.

Regarding performance of the wind turbine, a typical figure of 5% associated uncertainty is generally considered to take account of power curves deviations. Considering the altitude of the selected sites and drops in air density, the uncertainty associated to the performance of the wind turbine is likely to be significantly increased, and will have to be defined by the manufacturer.

When resource estimation is based on measured wind data, a typical figure of 2,5% uncertainty is generally considered to take account for accuracy in the measure. Here, the estimation is based on 3Tier mesoscale wind data and the uncertainty is significantly increased. According to 3Tier assessment of the quality of their predicted wind data, the difference between annual mean wind speed data from the 3Tier dataset and actual on-site measurements is less than 0,5m/s at 50% of observational station (i.e. 6,7% for a 7,5m/s predicted wind speed site) and less than 1m/s at 78% of stations (i.e. 13,3% for a 7,5m/s predicted wind speed site).

## **4.2 Description of Potential sites**

### **4.2.1 General considerations**

Complex topography is an obstacle to wind development in the country. Areas may be found to have a good wind resource but are not considered suitable due to their position on too steep mountainous lines. When topography is not an obstacle, the wind resource is often found to be too low.

Following the methodology described in 3.1, fifteen sites for potential wind farm developing were identified, with an estimated total capacity of 758MW.

Results presented here are based on satellite derived wind data and therefore have to be considered as preliminary. As explained earlier, estimated capacity and estimated production may vary when selected sites are studied in greater depth.

It should be noted that studies were focused on Area A, B and C (Region of Potential Development); sites suitable for wind development may exist in other parts of the country.

Road access, proximity of electricity network, environmental restrictions and cost of the civil work will have to be considered to confirm the feasibility of the proposed sites.

Potential sites are named according to their position within the RPD. For example the “A North 1” site is localized in the northern part of the RPD A.

#### **4.2.2 Description of each site**

The main characteristics of the identified potential sites are detailed in Table 7:

.

Position of each site can be found in Figure 33 to Figure 47 and in .kmz files format (attached to this report).

Figure 33 to Figure 47 shows delimitation of the selected sites over the wind resource (in  $W/m^2$ ) and topography maps.

Calculations were based on topography with contour lines every 10m to 20m. For clarity of the figures, all the contours lines are not shown. Height contours above 2700m are colored in red.

Areas with slopes greater than 25% within the selected sites are indicated with a cross hatching filling.

#### **4.2.3 Summary per RPD**

Total estimated capacity is 758MW. Table 5: summarizes results achieved for each RPD.

UTM X	UTM Y	Lat	Long
547,249.00	6,666,867.00	-30.1285	27.4905
596,018.00	6,710,409.00	-29.7328	27.9929
595,942.00	6,701,624.00	-29.8121	27.9929
564,871.00	6,671,155.00	-30.0891	27.6732
564,845.00	6,666,777.00	-30.1286	27.6732
578,197.00	6,688,597.00	-29.9308	27.8102
604,186.00	6,640,241.00	-30.3653	28.0842
612,919.00	6,635,788.00	-30.4047	28.1755
613,054.00	6,648,890.00	-30.2864	28.1755
603,977.00	6,618,429.00	-30.5621	28.0842
612,873.00	6,631,424.00	-30.444	28.1755
630,884.00	6,670,568.00	-30.0891	28.3582
626,332.00	6,657,490.00	-30.2075	28.3125
595,179.00	6,614,152.00	-30.6014	27.9929
661,629.00	6,665,780.00	-30.1286	28.6779
661,693.00	6,670,159.00	-30.089	28.6779
670,632.00	6,678,788.00	-30.01	28.7692
688,327.00	6,682,886.00	-29.9704	28.9519
692,734.00	6,682,810.00	-29.9704	28.9975
688,252.00	6,678,502.00	-30.0111	28.9518
674,968.00	6,674,338.00	-30.0495	28.8148

\* Blue marked entry indicate mesoscale data used for micrositing of selected wind farms (Phase II)

**Table 4: Characteristics of identified sites - Summary per RPD**

Area	Estimated carrying capacity (MW)	Mean speed of potential sites (m/s)	Mean Air Density (% to standard)	Full Load Hours (Mean value)	Mean hub altitude above sea level (m)
A	244	8.4	74.8	2808	2663
B	304	8.0	74.8	2694	2677
C	210	7.6	78.7	2511	2150

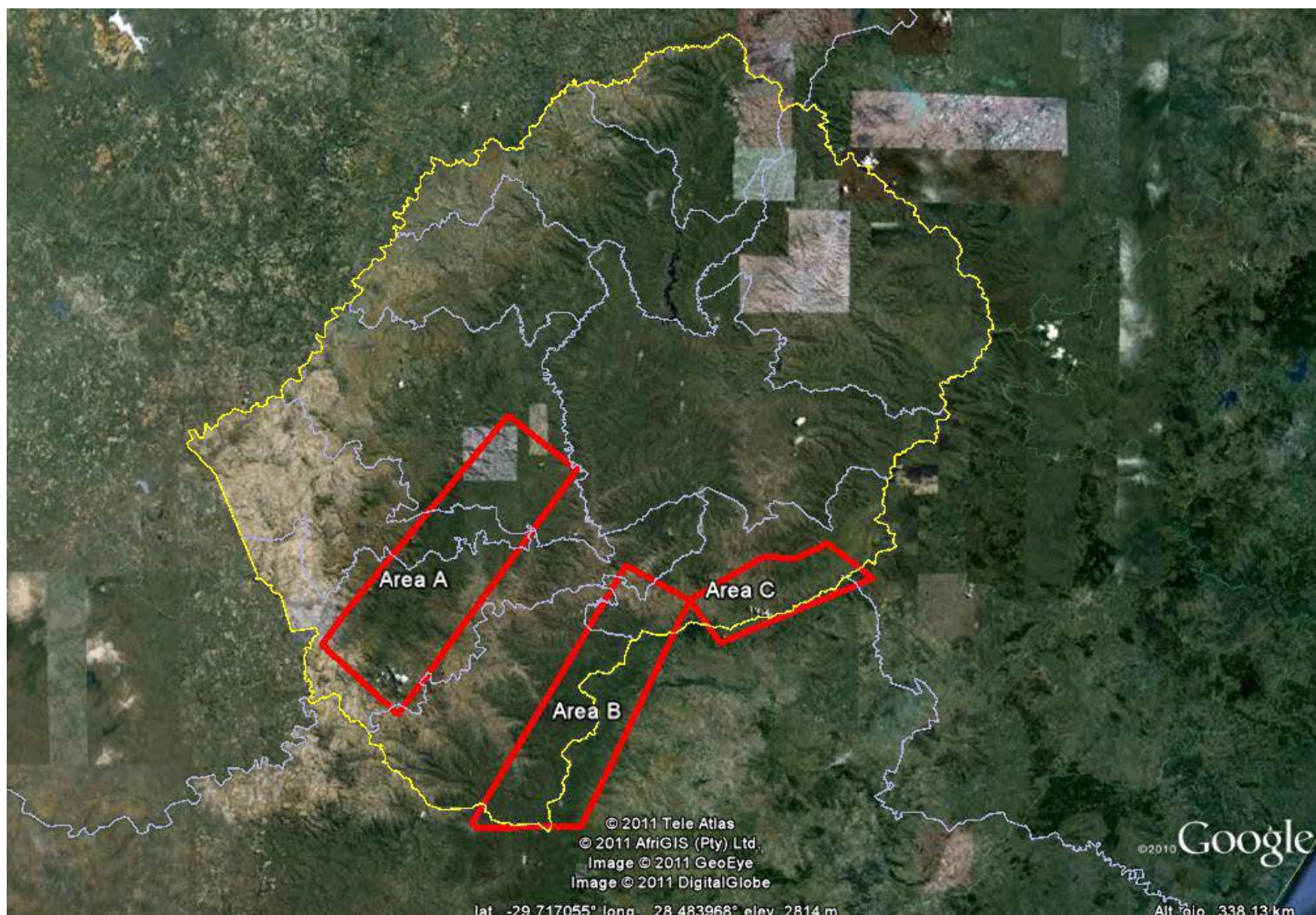
**Table 5: Location of representative wind turbine within potential sites**

Site name	UTM X	UTM Y
A North 1	594,206	6,711,038
A North 2	594,328	6,699,217
A North 3	596,069	6,721,239
A Center 1	579,022	6,690,377
A South 1	566,000	6,662,164
A South 2	564,416	6,672,234
B North 1	631,071	6,664,888
B Center 1	606,398	6,636,959
B Center 2	619,236	6,635,191
B South 1	607,536	6,618,448
B South 2	601,602	6,611,113
B South 3	593,430	6,612,483
C West 1	660087	6,667,209
C Center 1	673074	6,675,133
C East 1	693030	6,679,750

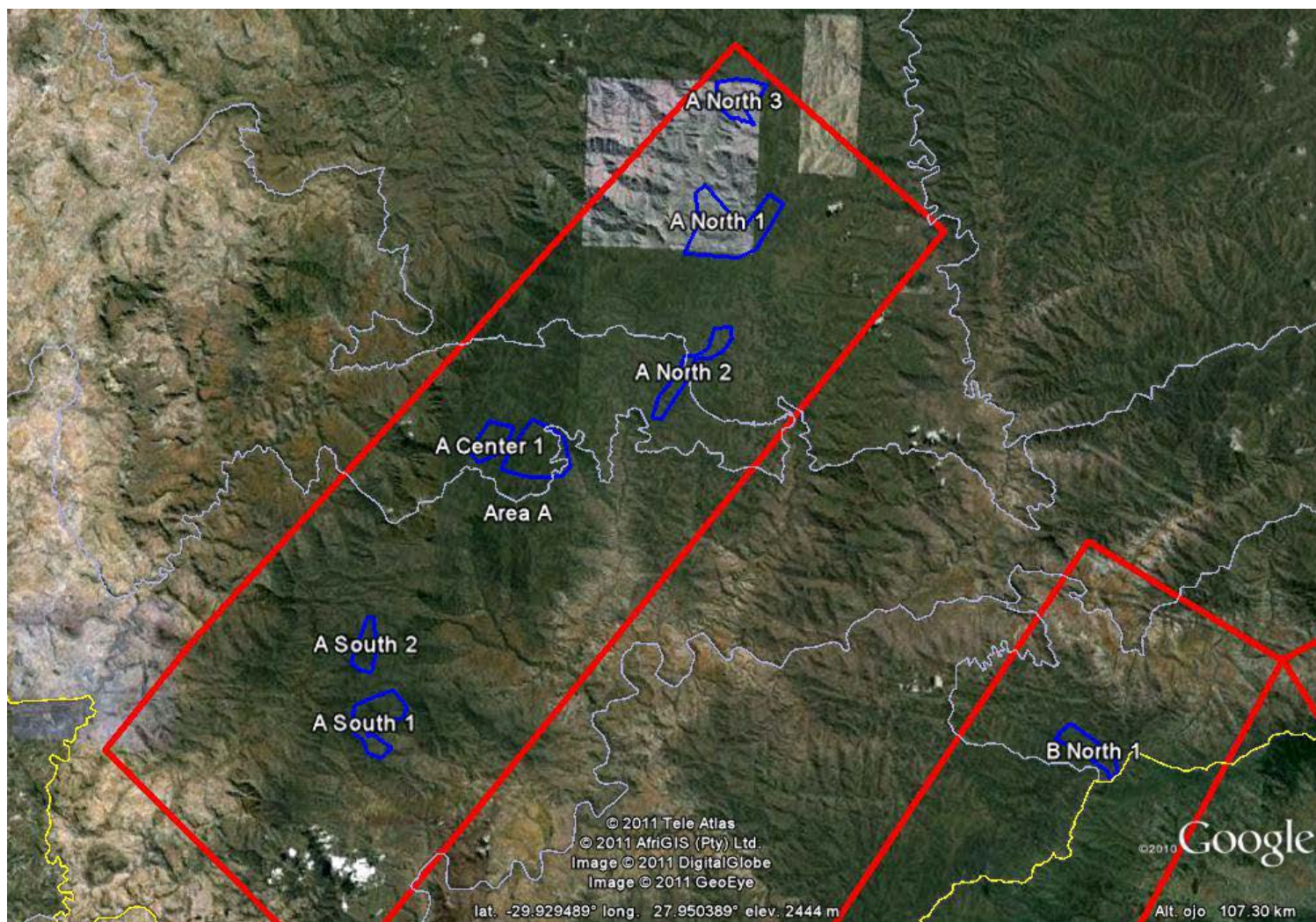
**Table 6: Location of mesoscale wind data (grid points)**

Name	Capacity (MW)	WTG	Single WTG production (MWh/y)	Single WTG production (load hours)	Single WTG hub wind speed (m/s)	Single WTG hub altitude (m asl)	Index terrain complexity	Air Density (% of standard)	Perimeter (km)
A North 1	62	Vestas V80	153822	2481	7.8	2748	++	74.2	29.2
A North 2	38	Vestas V80	110656	2912	8.7	2820	+	73.6	28.9
A North 3	24	Vestas V80	69672	2903	8.6	2795	+	73.8	17.5
A Center 1	56	Vestas V80	149184	2664	7.9	2520	+	75.9	30.2
A South 1	44	Vestas V80	148808	3382	9.4	2547	+++	75.8	21.1
A South 2	20	Vestas V80	50140	2507	7.8	2550	++	75.7	12.2
B North 1	26	Vestas V90	61464	2364	6.9	2620	++	75.1	16.1
B Center 1	110	Vestas V80	295240	2684	8.1	2651	++	75	54.5
B Center 2	36	Vestas V80	108684	3019	8.9	2720	+++	74.5	16.9
B South 1	52	Vestas V80	158548	3049	8.9	2770	+	74.1	31
B South 2	52	Vestas V80	128648	2474	7.7	2670	+++	74.9	25.1
B South 3	28	Vestas V90	72128	2576	7.3	2629	+	75.2	19.9
C West 1	28	Vestas V90	66388	2371	6.7	1916	++	80.6	33.1
C Center 1	48	Vestas V80	118176	2462	7.8	2080	+	79	28.6
C East 1	134	Vestas V80	361666	2699	8.2	2454	+++	76.6	41.5

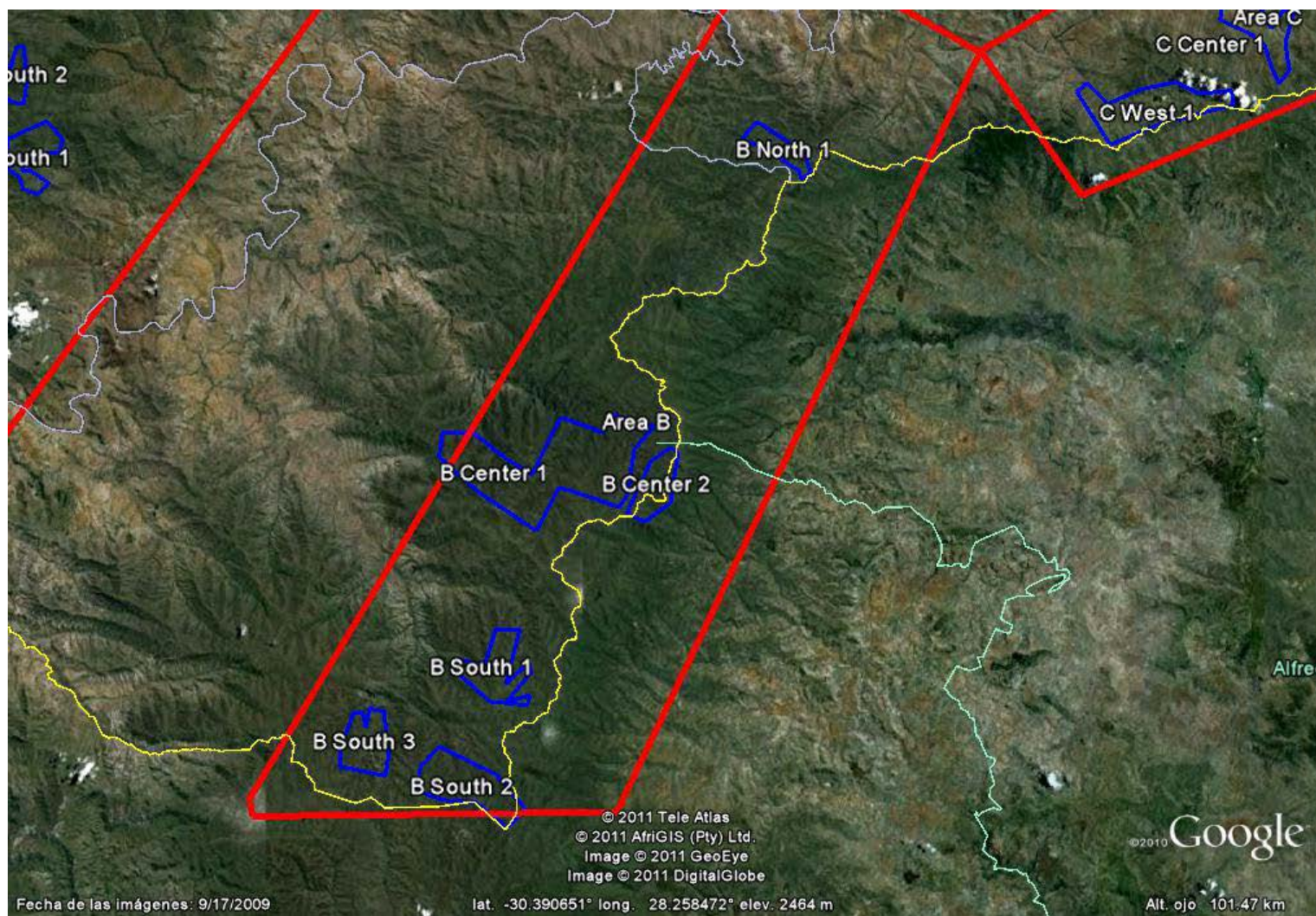
**Table 7: Characteristics of identified potential sites**



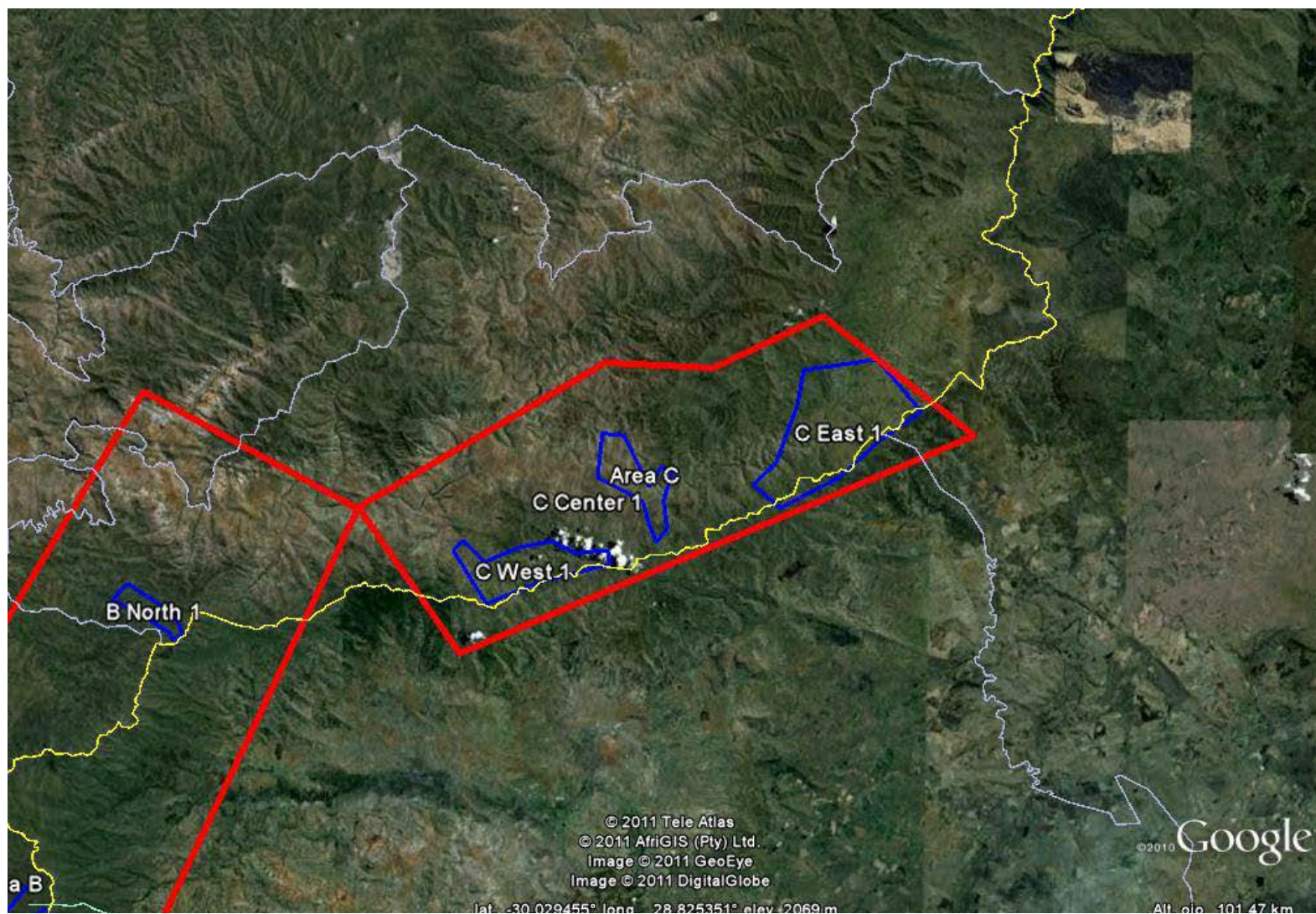
**Figure 28: Region of potential development**



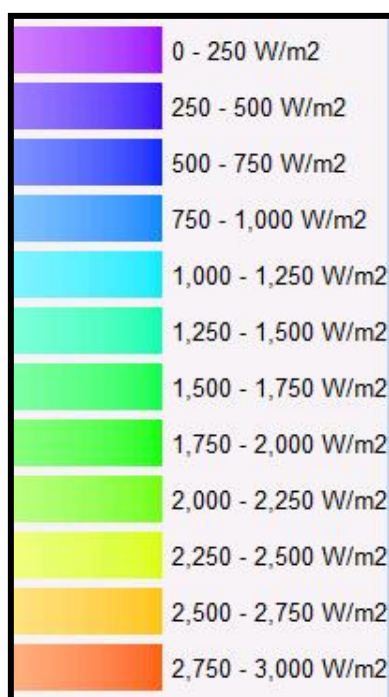
**Figure 29: Potential sites – RPD A**



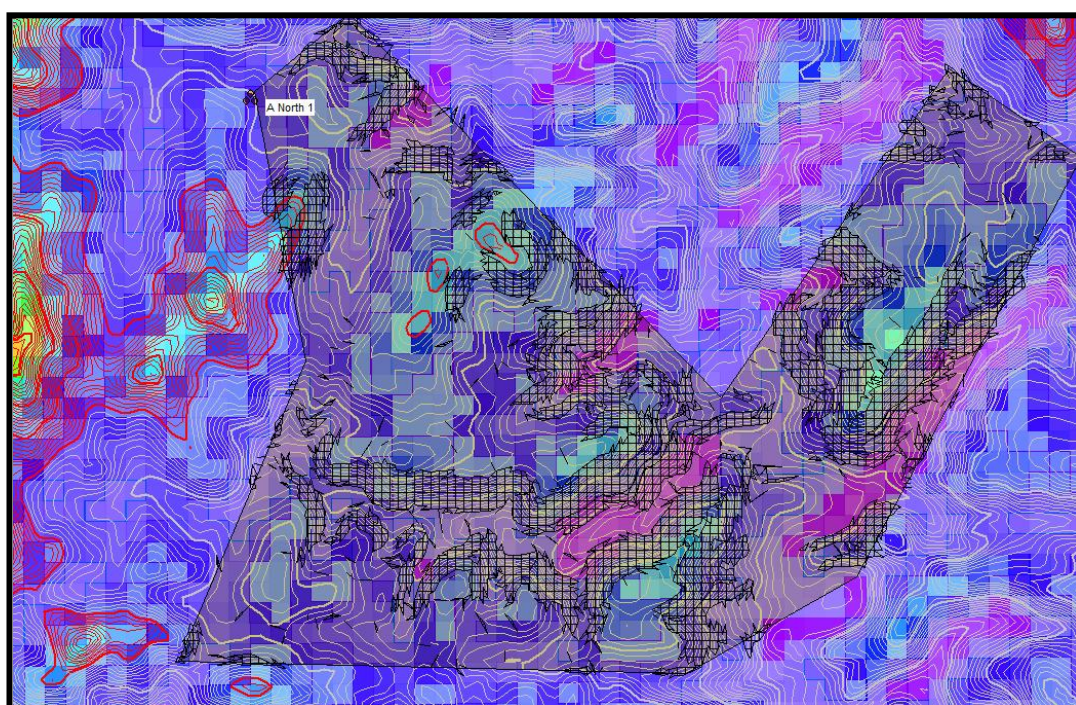
**Figure 30: Potential sites – RPD B**



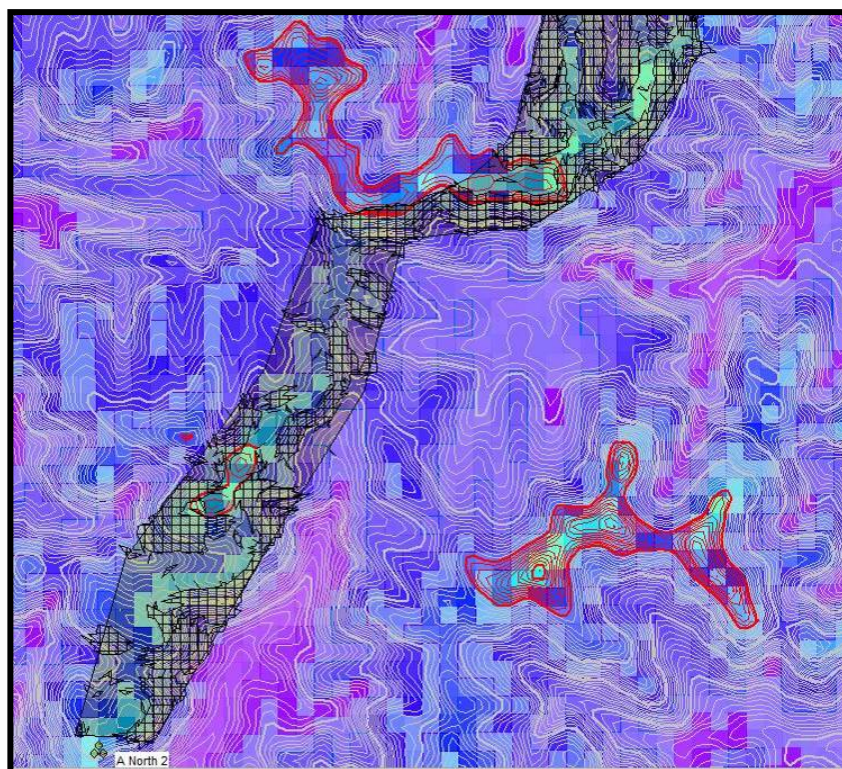
**Figure 31: Potential sites – RPD C**



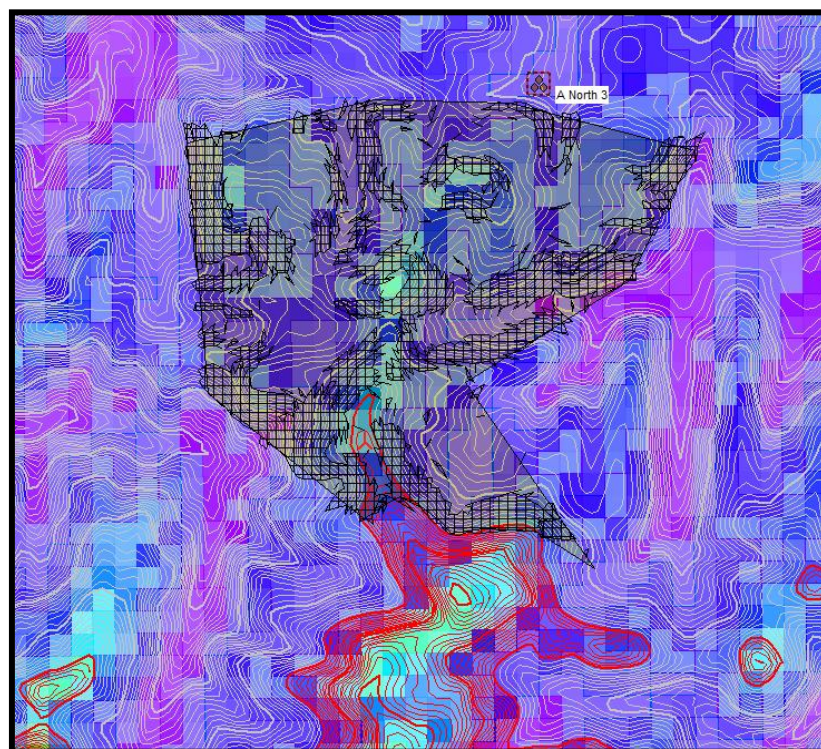
**Figure 32: Legend – Wind energy in W/m<sup>2</sup>**



**Figure 33: Wind energy (W/m<sup>2</sup>), exclusion zone (25% slopes) and height contours A North 1**



**Figure 34: Wind energy ( $\text{W/m}^2$ ), exclusion zone (25% slopes) and height contours A North 2**



**Figure 35: Wind energy ( $\text{W/m}^2$ ), exclusion zone (25% slopes) and height contours A North 3**

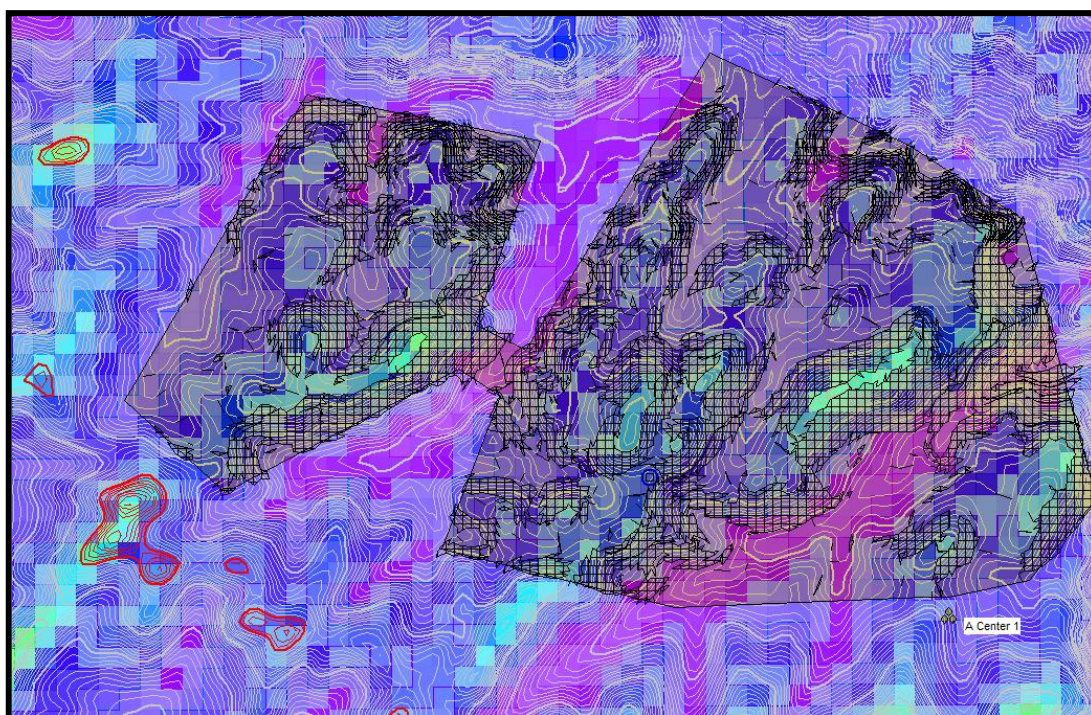


Figure 36: Wind energy ( $\text{W/m}^2$ ), exclusion zone (25% slopes) and height contours A Center 1

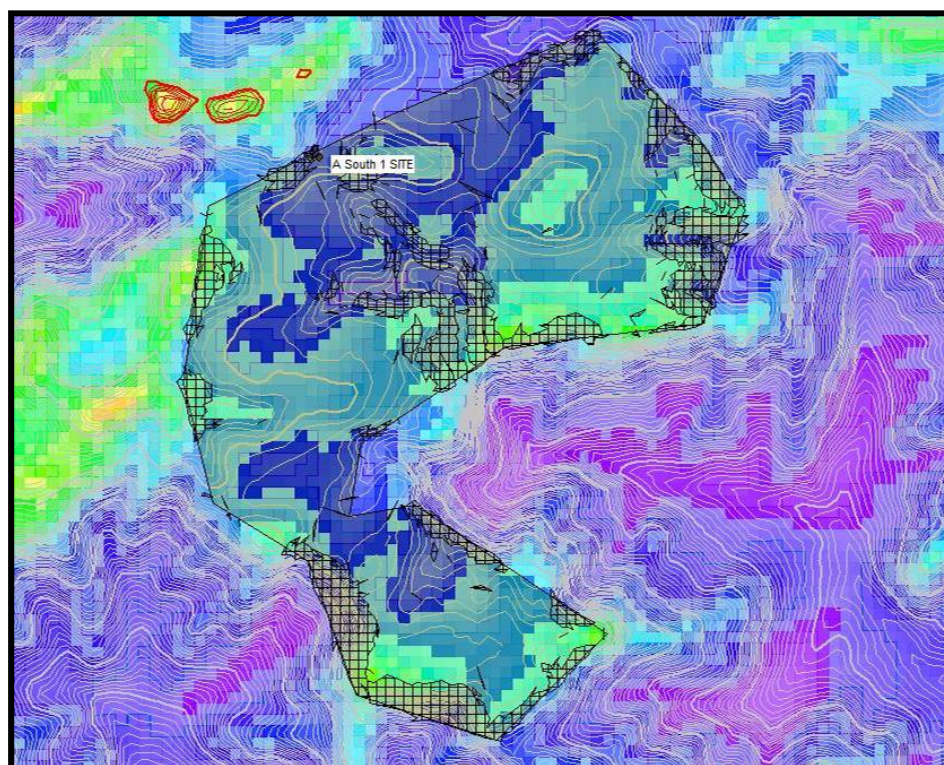
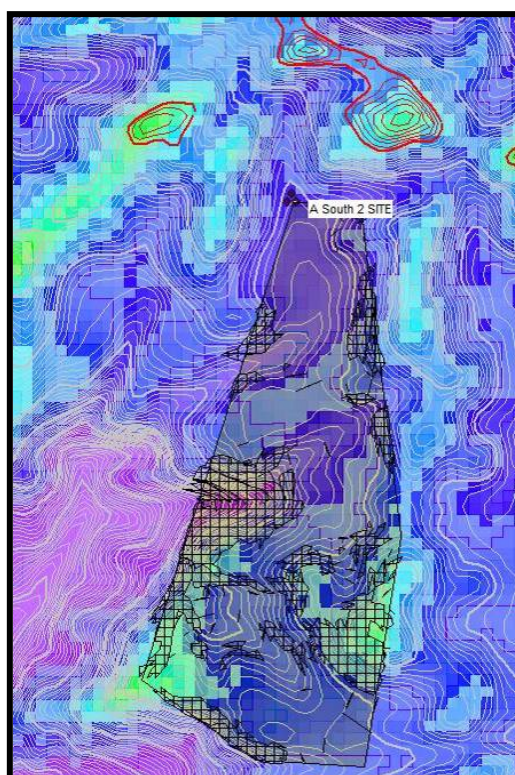
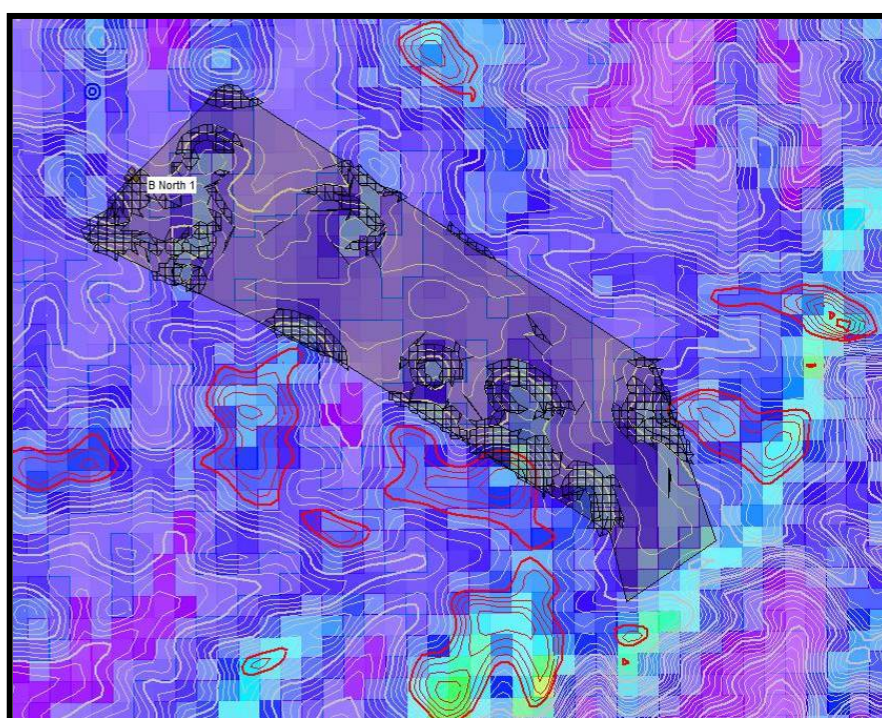


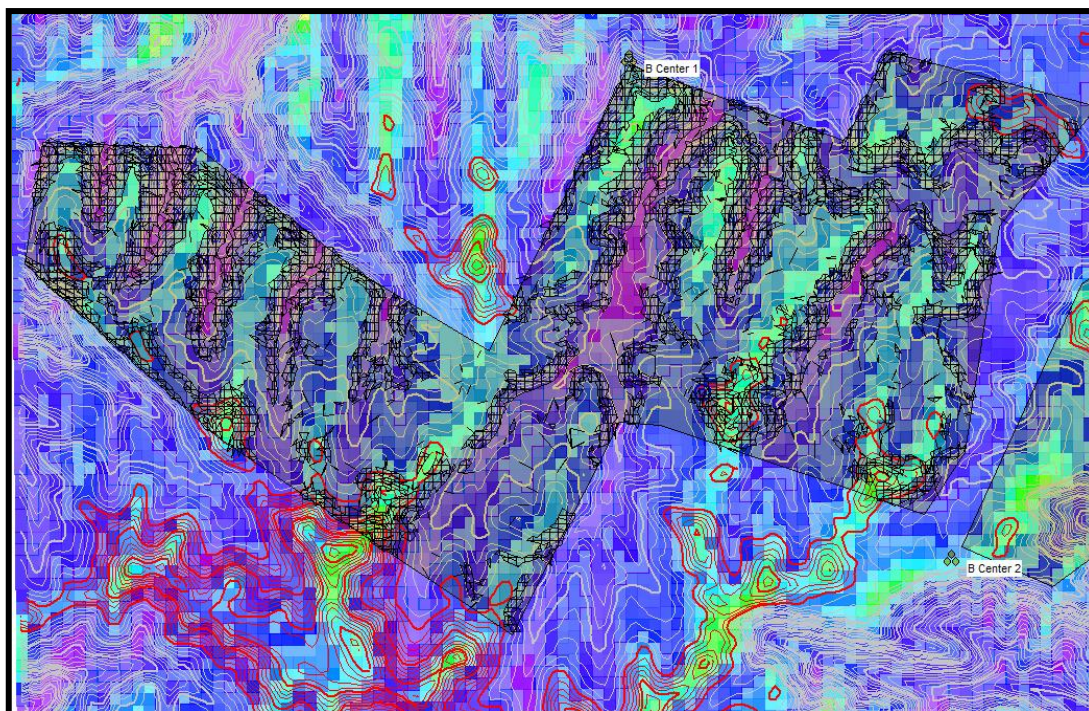
Figure 37: Wind energy ( $\text{W/m}^2$ ), exclusion zone (25% slopes) and height contours A South 1



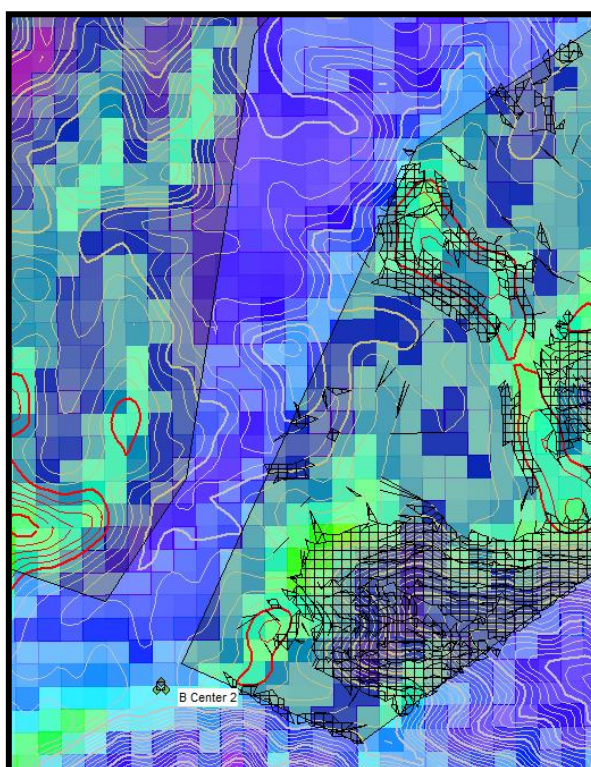
**Figure 38: Wind energy ( $W/m^2$ ), exclusion zone (25% slopes) and height contours A South 2**



**Figure 39: Wind energy ( $W/m^2$ ), exclusion zone (25% slopes) and height contours B North 1**



**Figure 40: Wind energy ( $\text{W/m}^2$ ), exclusion zone (25% slopes) and height contours B Center 1**



**Figure 41: Wind energy ( $\text{W/m}^2$ ), exclusion zone (25% slopes) and height contours B Center 2**

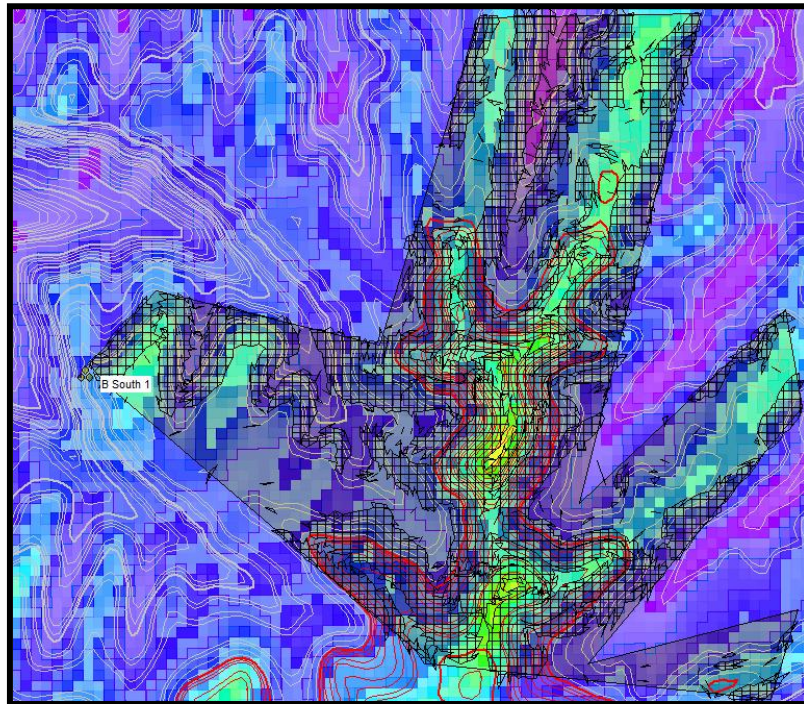


Figure 42: Wind energy ( $\text{W/m}^2$ ), exclusion zone (25% slopes) and height contours B South 1

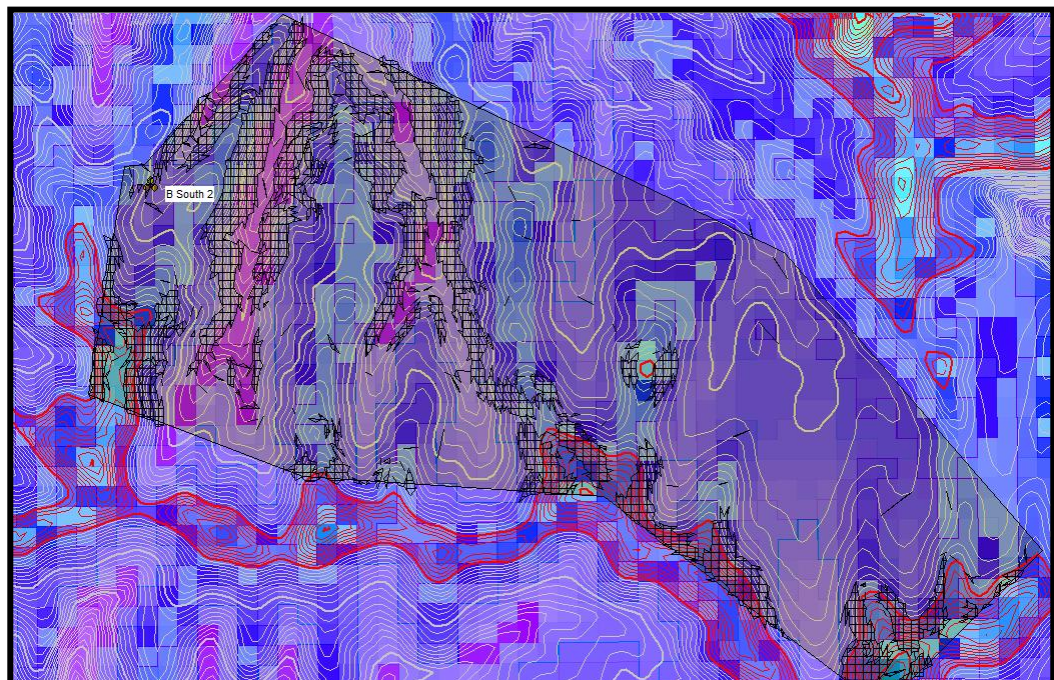
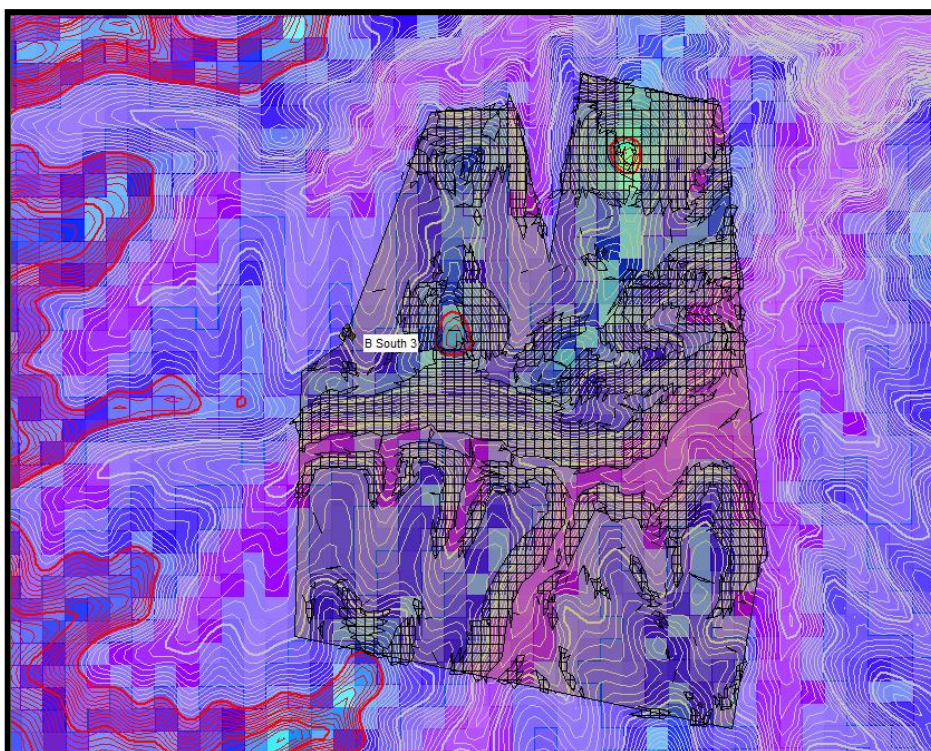
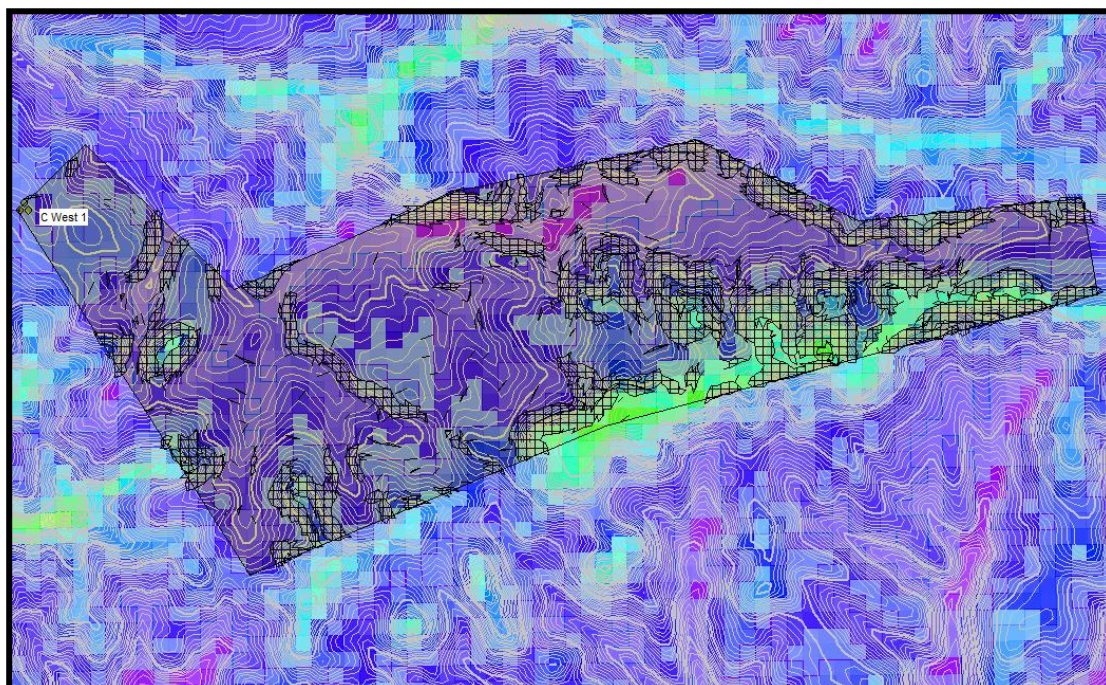


Figure 43: Wind energy ( $\text{W/m}^2$ ), exclusion zone (25% slopes) and height contours B South 2



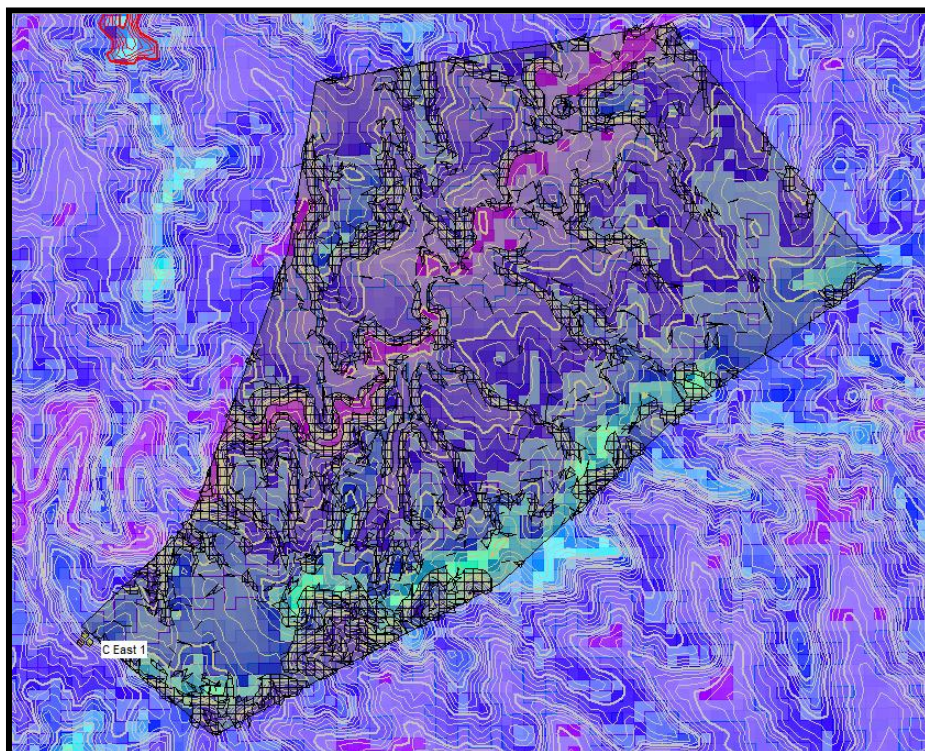
**Figure 44: Wind energy ( $\text{W/m}^2$ ), exclusion zone (25% slopes) and height contours B South 3**



**Figure 45: Wind energy ( $\text{W/m}^2$ ), exclusion zone (25% slopes) and height contours C West 1**



**Figure 46: Wind energy ( $W/m^2$ ), exclusion zone (25% slopes) and height contours C Center 1**



**Figure 47: Wind energy ( $W/m^2$ ), exclusion zone (25% slopes) and height contours C East 1**

## **5. PRELIMINARY STUDY OF THE 5 MOST ATTRACTIVE SITES**

Phase I's work focused on identifying potential wind farm sites within the three RPD's; 15 sites totaling a potential 758MW were identified.

In Phase II's work, studies are narrowed down to the considered five most attractive sites, where preliminary micro-siting is performed.

These 5 sites are considered, in terms of wind resource and topography, as the most suitable sites for wind development within the RPD's. It is therefore suggested to focus in priority the future studies on these sites, identifying in detail all the issues which may influence the feasibility, size and layout of the projects.

It should be noted that the 10 disregarded sites may present more obstacles in terms of topography or a lower wind resource, but may turn out to be more attractive if other criteria are taken into account (such as proximity to electricity grid, road access, etc...); this could also be the case for areas outside the studied area which were not considered under the current methodology.

It should also be noted that studies were based on satellite derived wind data. On site measurements and/or detailed topography may change the classification of the sites (i.e a site with a moderate resource may turn out to have a too low measured wind resource to be viable).

Criteria of selections are detailed below.

### **5.1 Criteria of Selection of the five most attractive sites**

The selection has been based on the following criteria:

- Index terrain complexity: Sites with relatively flat terrain were chosen in priority (site marked as “+++” in Table 7: ); and
- Single WTG production (load hours).

Four sites were rated as “+++” in term of terrain complexity. These four sites present a single WTG production above the 2300 full load hours and were therefore considered attractive. In order to select the fifth site, a classification of all the sites has been done from major to minor single WTG production (load hours). Sites with a “+” rate (site less suitable to wind farm developing) were ruled out.

“+++” and “++” sites ordered from major to minor full load hours are shown below.

Name	Capacity (MW)	Single WTG production (MWh/y)	Single WTG production (load hours)	Single WTG hub wind speed (m/s)	Single WTG hub altitude (m asl)	Index terrain complexity
A South 1	44	148808	3382	9.4	2546.6	+++
B Center 2	36	108684	3019	8.9	2720	+++
C East 1	134	361666	2699	8.2	2454	+++
B Center 1	110	295240	2684	8.1	2651	++
A South 2	20	50140	2507	7.8	2550	++
A North 1	62	153822	2481	7.8	2747.7	++
B South 2	52	128648	2474	7.7	2670	+++
C West 1	28	66388	2371	6.7	1916	++
B North 1	26	61464	2364	6.9	2620	++

\* Selected sites are marked in orange

**Table 8: Potential sites ordered by full load hours (from Phase I results)**

The B Center 1 site is found to have the best resource of the “++” rated site.

The chosen sites are therefore as follows:

- A South 1;
- B Center 2;
- C East 1;
- B South 2; and
- B Center 1.

## 5.2 Preliminary micrositing of the 5 selected sites - Methodology

A basic micrositing has been performed in order to propose a possible layout for each one of the 5 selected sites.

### 5.2.1 *Micrositing*

Micrositing were performed using WindPRO optimizer module. *WindPRO can optimize a wind farm layout for energy production given turbine spacing and setback distances to slopes.*

*Distance between turbines has been set to 3 rotor diameter in non prevailing winds direction and 7 rotor diameter in prevailing winds direction.*

---

*A 100m setback has been established to 25% slopes. For sites close to country border, a 90m setback has been established.*

The calculation is based on the pre-calculated wind resource map using the WAsP model. The available land for the wind farm is automatically defined including setbacks and exclusion zone, and within this area the optimization takes place. The optimizer gradually add turbines to the layout on the best location available keeping the already placed turbines optimal until the required number is reached or no more turbines can be placed.

*The micrositing achieved is preliminary and based only on the wind resource. Further studies are needed to take into account possible restrictions, such as environmental restrictions (birds, flora and fauna), civil work restriction (WTG foundation and access to crane for lifting), dwellings, etc...*

### **5.2.2 Wind turbine**

As explained earlier, the IEC class of the wind turbine has been chosen according to the wind speed predicted at hub height at the wind turbine site.

All the selected sites have predicted speed greater than 7,5m/s and were calculated using the Vestas V80 with an 80m rotor diameter, hub height of 80m and 2MW nominal power. The Vestas V80 wind turbine suits well class IEC I sites as it provides a good productivity with both high and moderate winds.

Further studies will have to be conducted to confirm the suitability of the chosen turbine.

### **5.2.3 Estimation of the energy yield and array losses**

The wind distribution at each WTG position is calculated from WAsP model calculations for each WTG location. The wind distribution is then adjusted for array losses using the PARK model (N.O. Jensen, RISØ). Finally the adjusted wind distribution is integrated with the power curve of the WTGs for the energy yield calculation.

For the five selected wind farms sites, array losses were kept lower than 4% of the gross production (see Table 9).

Gross production has been reduced by 10% to account for energy losses. The following sources of energy losses were considered:

- 4% to account for wind turbine availability;
- 3% to account for electrical transmission losses; and
- 3% to account for losses due to high wind hysteresis and blade fouling.

### **5.2.4 Correction for air density**

As explained earlier, air density has been calculated from air pressure and air temperature predicted by 3Tier in 11 reference points. The predicted energy

yield of each wind turbine has been individually corrected taking into account air density variation from the reference point site to the WTG site.

### **5.2.5 Associated uncertainties**

As explained earlier, uncertainties are introduced in the flow simulation due to the high complexity of the surroundings, and due to the use of mesoscale wind data. Measurement campaigns are needed to confirm quantity and quality of predicted wind.

Uncertainties associated to the efficiency of the wind turbine are also introduced due to the very low air density conditions of the sites.

## **5.3 Proposed layout and energy yield**

Three of the selected wind farms are located in the RPD B, one in RPD A and one in RPD C.

Summary of results achieved are presented in Table 9. Detailed reports, showing results achieved per wind turbine (production and efficiency) are given in pdf's format, and attached to this report. Position of each wind turbine within the selected wind farm are given in .kmz format and attached to this report.

Each site is described in detail below.

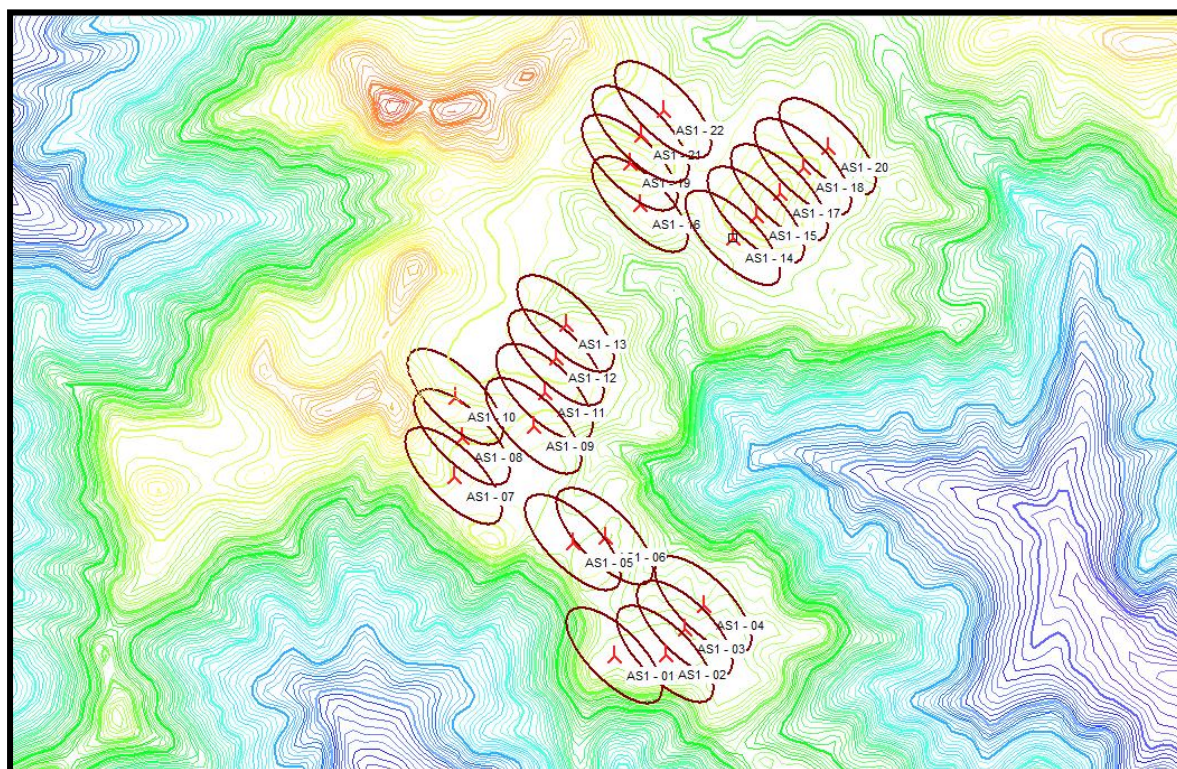
### **5.3.1 A South 1**

"A South 1" wind farm is located to the south of RPD A. This is an area relatively flat, with turbines located from 2447m to 2522m above sea level. The area is mainly formed by a plateau, well exposed to NorthWest prevailing winds and dominating the surroundings. Surroundings to the east, south and west presents heights below the 1800m. To the north, the site is sheltered by a 2750m mountainous range.

The estimated capacity is 44MW. The wind resource at the site is good, with a mean production of the 22 Vestas V80 wind turbines estimated to 2979 full load hours.

The site is flat, civil work is not likely to be an obstacle to the feasibility of the project. However, the site is located above the 2400m asl, far from any access route and far from the electricity network. These aspects have to be studied to confirm the feasibility of the project.

The proposed micrositeing is presented in the following figure. Wind turbines are centered in an ellipse with dimensions of 270m for minor semi-axis and 630m for the major semi axis.



**Figure 48: A South 1 – Proposed micro-siting and height contours line each 10m**

### 5.3.2 *B Center 1*

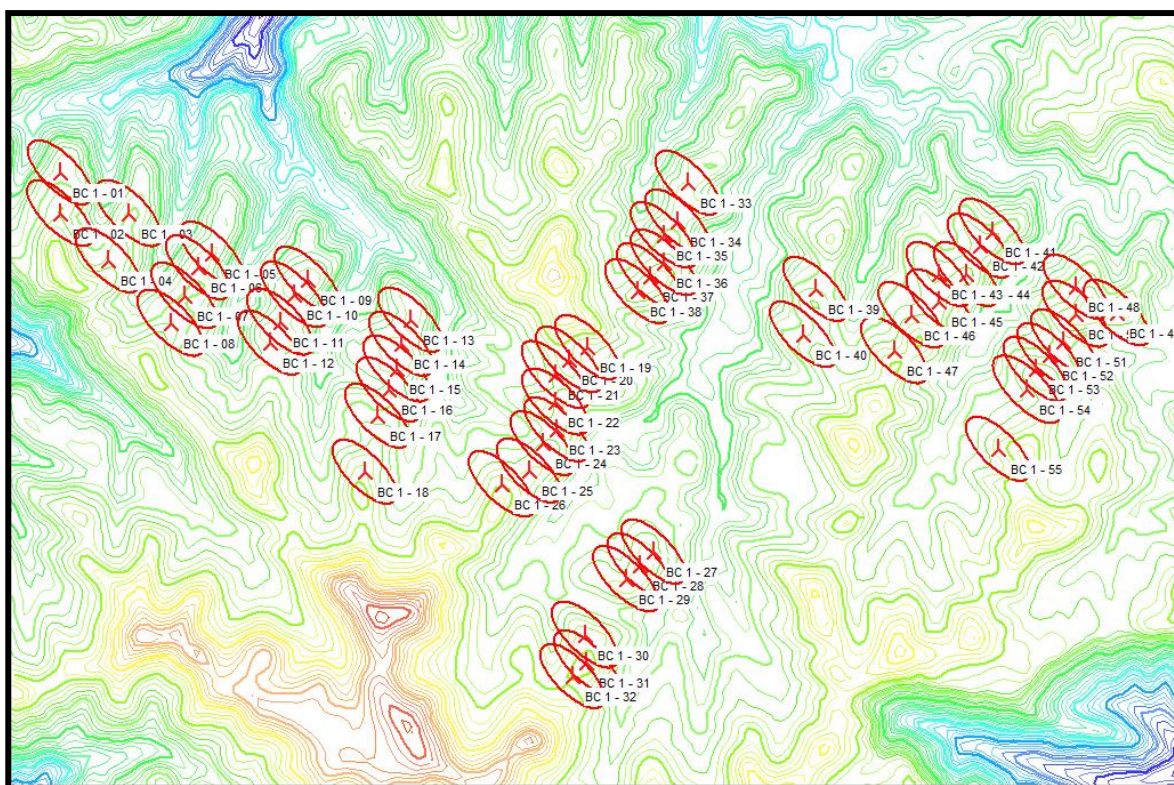
“B Center 1” proposed wind farm is located in the central part of RPD B.

“B Center 1” is mainly formed by mountainous lines oriented NNE – SSW. Within the site, heights vary from 2000m (dales) to 3000m (highest peaks). Wind turbines are located at heights between 2571m and 2700m.

The estimated capacity is 110MW. The wind resource at the site is moderate, with a mean production of the 55 Vestas V80 wind turbines estimated to 2374 full load hours.

The terrain site is complex, and distance between one group of turbine to the next goes up to 2700m. Cost of civil work (accesses between turbines, electricity connection, etc...) is likely to be an obstacle to the feasibility of the project. The site is located above the 2500m asl, far from any access route and far from the electricity network. These aspects also have to be studied to confirm the feasibility of the project.

The proposed micro-siting is presented in the following figure. Wind turbines are centered in an ellipse with dimensions of 270m for minor semi-axis and 630m for the major semi axis.



**Figure 49: B Center 1 – Proposed micro-siting and height contours line each 20m**

### 5.3.3 *B Center 2*

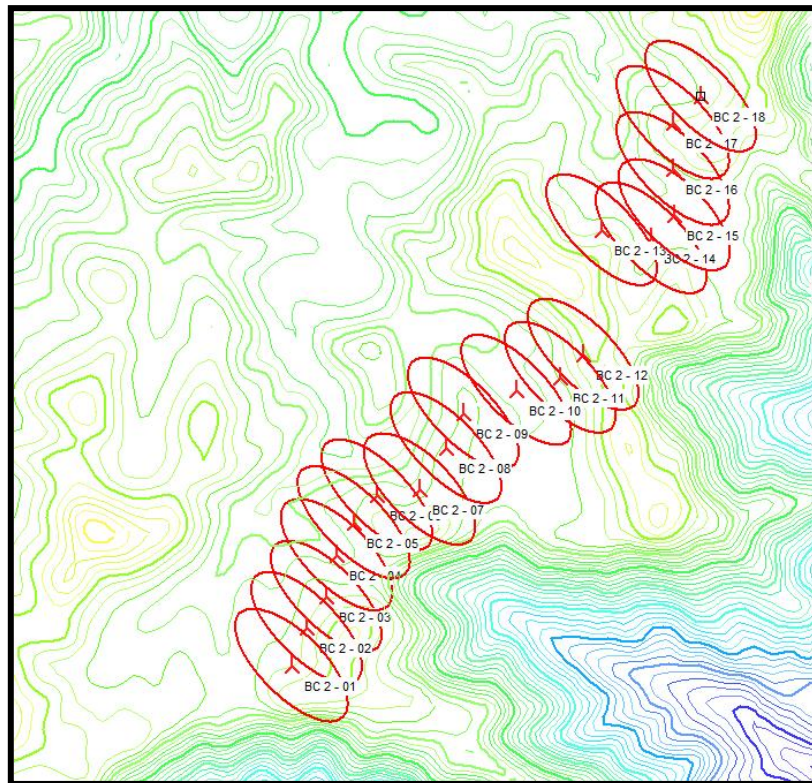
“B Center 2” proposed wind farm is located in the central part of RPD B.

“B Center 2” is a relatively flat site located close to the Republic of South Africa border. Wind turbines are located between 2620m and 2638m above sea level. Surroundings to the east and south present heights below 2000m. Surroundings to the north and west present heights above 2700m.

The estimated capacity is 36MW. The wind resource at the site is good, with a mean production of the 18 Vestas V80 wind turbines estimated to 2679 full load hours.

The site is flat, civil work is not likely to be an obstacle to the feasibility of the project. However, the site is located above the 2600m asl, far from any access route and far from the electricity network. These aspects have to be studied to confirm the feasibility of the project.

The proposed micro-siting is presented in the following figure. Wind turbines are centered in an ellipse with dimensions of 270m for minor semi-axis and 630m for the major semi axis.



**Figure 50: B Center 2 – Proposed micrositting and height contours line each 20m**

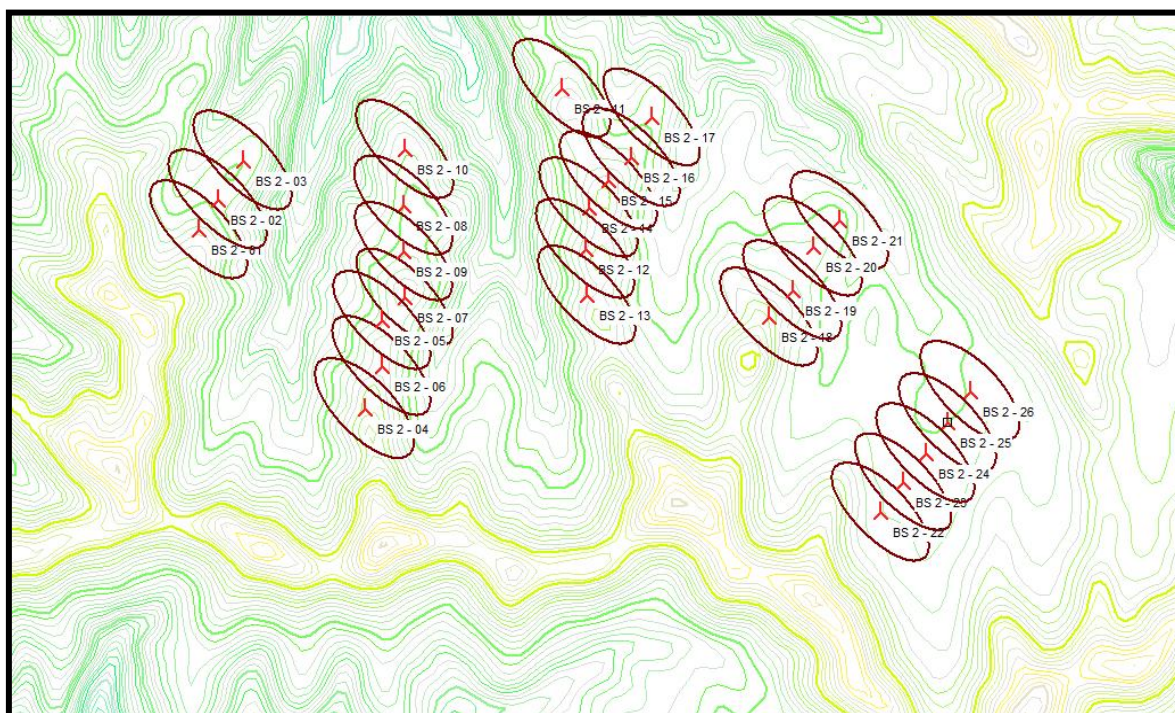
#### **4.1.1 B South 2**

“B South 2” is located to the south of RPD B. The site is close to South Africa border. To the east, the site is formed by a plateau dominating the east and south surroundings, and to the west by hills well exposed to prevailing winds. Wind turbines are located between 2595m and 2658m above sea level.

The estimated capacity is 52MW. The wind resource at the site is moderate, with a mean production of the 26 Vestas V80 wind turbines estimated to 2326 full load hours.

The site is flat, civil work is not likely to be an obstacle to the feasibility of the project. However, the site is located above the 2500m asl, far from any access route and far from the electricity network. These aspects have to be studied to confirm the feasibility of the project.

The proposed micrositing is presented in the following figure. Wind turbines are centered in an ellipse with dimensions of 270m for minor semi-axis and 630m for the major semi axis.



**Figure 51: B South 2 – Proposed micrositting and height contours line each 10m**

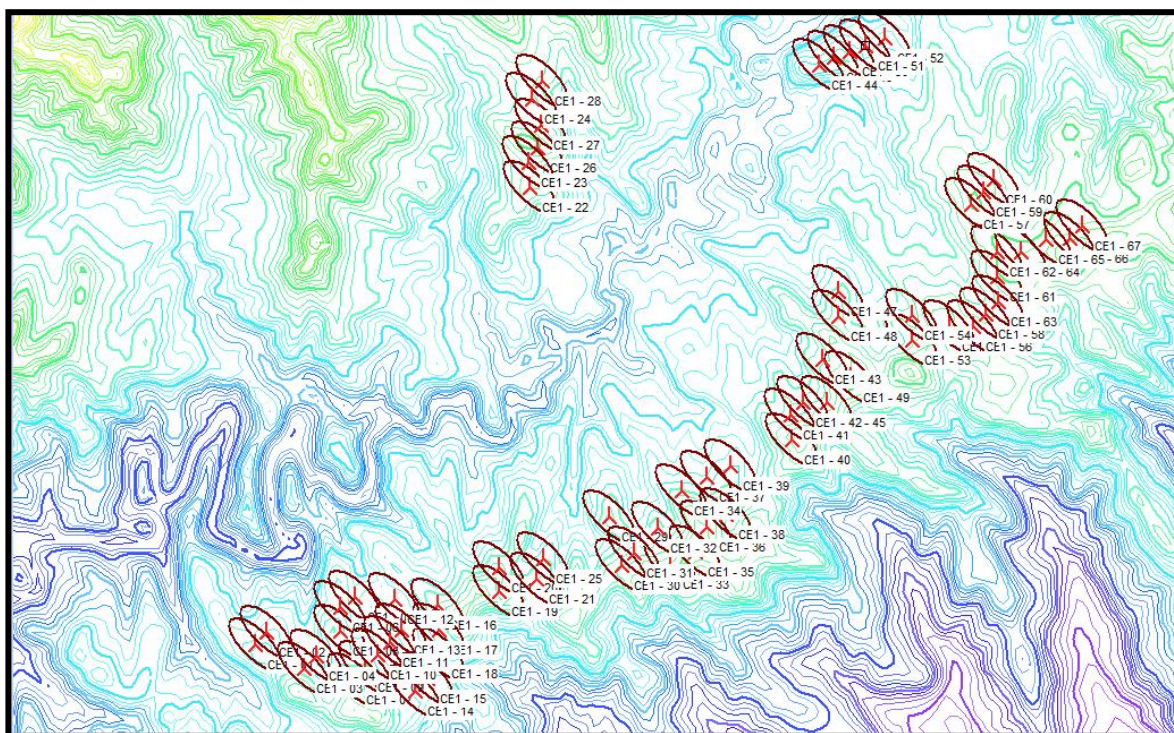
#### 5.3.4 C East 1

“C East 1” is located to the east of RPD C. The site is characterized by an extensive area, mainly formed by hills and flat areas, on both sides of a river. The site is sheltered to the north by a 3000m mountainous range, and dominates a 1700m valley to the south. Wind turbines are located between 2240m and 2453m above sea level.

The estimated capacity is 134MW. The wind resource at the site is moderate, with a mean production of the 67 Vestas V80 wind turbines estimated to 2495 full load hours.

The site is flat, civil work is not likely to be an obstacle to the feasibility of the project. The site is also crossed by a main access road, and it is located close to a small population center (Ramatseliso's Gate). These aspects will enhance the feasibility of the project. However, the site is located above the 2200m asl and as explained earlier this may affect the operation of the wind turbines, and reduce the production.

The proposed micrositing is presented in the following figure. Wind turbines are centered in an ellipse with dimensions of 270m for minor semi-axis and 630m for the major semi axis.



**Figure 52: C East 1 – Proposed micro-sitting and height contours line each 20m**

Name	Capacity (MW)	WT Type	Park efficiency (%)	Energy Yield (MWh/y)	Full load hours	Mean wind speed at hub height (m/s)
A South 1	44	Vestas V80	96.6	131,090.80	2979	8.8
B Center 2	36	Vestas V80	99.1	96,457.10	2679	8.2
C East 1	134	Vestas V80	96.9	334,377.40	2495	8.3
B Center 1	110	Vestas V80	97.4	261,156.70	2374	7.7
B South 2	52	Vestas V80	96.9	120,933.40	2326	7.6

**Table 9: Main characteristics of the selected sites**

## 6. CONCLUSIONS

Complex topography is an obstacle to wind development in the Kingdom. Areas may be found to have a good wind resource but are not considered suitable due to their position on too steep or to high mountainous lines. When topography is not an obstacle, the wind resource is often found to be too low.

Fifteen wind farms sites, from 20MW to 134MW, were identified within the three Regions of Potential Development. The total estimated capacity is 758MW. Calculations were based on the Vestas 2MW wind turbine.

Estimation of the energy yield based on a single wind turbine gives results varying between 2364 to 3382 full load hours.

Basic micrositing and preliminary resource assessment were then performed for the considered five most attractive sites. The wind farm sites were selected following criteria of terrain complexity and production in full load hours. Wind farm layouts were optimized, establishing a 100m setback to 25% slopes and 90m to country border. Estimation of the energy yield gives results varying between 2326 to 2979 full load hours, and park efficiency between 96,6% and 99,1%.

Results presented here are preliminary, based on satellite derived wind and topographic data. Physical wind measurement campaigns on site and detailed topographic information are needed to confirm estimated wind resource.

The fifteen wind farm sites presented here were considered suitable for wind farm development taking only into account wind resource and topography. Other factors including road access, proximity of electricity network, environmental restrictions and civil work will have to be considered to confirm the feasibility of the proposed wind farms.

## 7. APPENDIXES

Following files are attached to this report:

Selected RPD.kmz	Location of the Regions of Potential Development
Area A Potential Sites.kmz	Wind farm sites locations within the RPD A, B and C.
Area B Potential Sites.kmz	
Area C Potential Sites.kmz	
Wind Farm A South 1.kmz	Wind turbines locations within the selected wind farms
Wind Farm C East 1.kmz	
Wind Farm B Center 1.kmz	
Wind Farm B Center 2.kmz	
Wind Farm B South 2.kmz	
A South 1.pdf	Wind farms WindPRO reports
C East 1.pdf	
B Center 1.pdf	
B Center 2.pdf	
B South 2.pdf	

# **LESOTHO POWER GENERATION MASTER PLAN**

**PROJECT # LEC/GEN/1-2009**

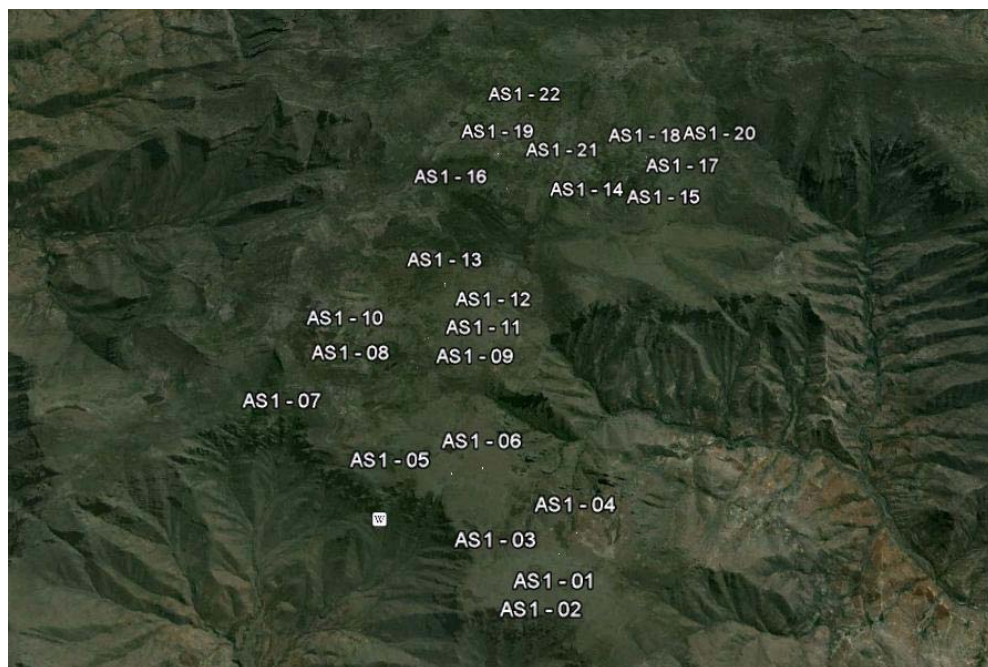
**FINAL MILESTONES REPORT**

**VOLUME 1 - PART 1.2**

**WIND POWER GENERATION OPTION**

## **APPENDIX 1.2.1**

### **A SOUTH 1 WIND FARM**



July 2011

# HYPERLINK

- a. Area A

Hyperlink: [b- Area A Potential Sites.KMZ](#)

- b. Area A - South 1 proposed Wind Farm

Hyperlink: [e- A South 1.kmz](#)

Project: SSI\_Fase2  
Description: Potential wind farm site SSI

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## PARK - Main Result

Calculation: A South 1 optimizado

Wake Model N.O. Jensen (RISØ/EMD)

### Calculation Settings

Air density calculation mode Individual per WTG  
Result for WTG at hub altitude 0.922 kg/m³ to 0.930 kg/m³  
Air density relative to standard 75.3 %  
Hub altitude above sea level (asl) 2,527.3 m to 2,617.4 m  
Annual mean temperature at hub alt. 8.1 °C to 8.6 °C  
Pressure at WTGs 744.0 hPa to 752.2 hPa

### Wake Model Parameters

From angle To angle Terrain type Wake Decay Constant  
[°] [°]  
-180.0 180.0 Zona agrícola abierta 0.075

### Wake calculation settings

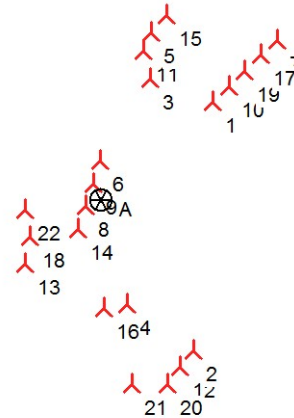
Angle [°] Wind speed [m/s]  
start end step start end step  
0.5 360.0 1.0 0.5 30.5 1.0

### Wind data

Wind statistics Distance Weight  
[km] [%]  
LS Zona A4 Mesoscale - 80.00 m.wws 7 26  
LS Zona A4 Mesoscale 2 - 80.00 m.wws 2 74

WASP version WASP 6-9 for Windows RVEA0011 1, 0, 0, 13

WASP parameters Detailed information at the end of "Main results"



## Key results for height 80.0 m above ground level

Terrain UTM WGS84 S Zone: 35

East	North	Name of wind distribution	Type	Wind energy [kWh/m²]	Mean wind speed [m/s]	Equivalent roughness
A 564,853	6,664,384	Zona A South 1 to WASP	WASP (WASP 6-9 for Windows RVEA0011 1, 0, 0, 13)	5,625	9.1	-0.3

## Calculated Annual Energy for Wind Farm

WTG combination	Result PARK	Result-10.0%	GROSS (no loss)	Park efficiency	Capacity factor	Mean WTG result	Full load hours	Mean wind speed @hub height
	[MWh/y]	[MWh]	Free WTGs [MWh/y]	[%]	[%]	[MWh/y]	[Hours/year]	[m/s]
Wind farm	145,654.4	131,088.9	150,710.6	96.6	34.0	5,958.6	2,979	8.8

\*) Basado en Result-10.0%

## Calculated Annual Energy for each of 22 new WTGs with total 44.0 MW rated power

Terrain	WTG type			Power, rated [kW]	Rotor diameter [m]	Hub height [m]	Power curve		Annual Energy		Park	
	Valid	Manufact.	Type-generator				Creator	Name	Result [MWh]	Result-10.0% [MWh]	Efficiency [%]	Mean wind speed [m/s]
1 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	6,491.5	5,842	94.5	8.85
2 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	6,677.9	6,010	95.3	8.83
3 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	6,040.8	5,437	97.0	8.29
4 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	6,476.1	5,829	93.8	8.73
5 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,818.6	5,237	97.8	8.07
6 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	6,600.0	5,940	98.9	8.64
7 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	6,825.2	6,143	98.3	8.90
8 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	6,784.9	6,106	97.9	8.87
9 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	6,671.4	6,004	98.6	8.73
10 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	6,911.0	6,220	94.9	9.24
11 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	6,357.2	5,721	98.1	8.52
12 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	6,805.8	6,125	93.9	9.03
13 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	6,360.2	5,724	97.4	8.50
14 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	6,444.5	5,800	96.4	8.64
15 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,667.6	5,101	98.7	7.91
16 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	6,163.8	5,547	95.9	8.39
17 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	6,962.6	6,266	96.9	9.15
18 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	6,260.6	5,634	96.2	8.53
19 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	7,314.3	6,583	96.0	9.57
20 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	7,091.6	6,382	94.5	9.26

To be continued on next page...

Project: SSI\_Fase2  
 Description: Potential wind farm site SSI

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## PARK - Main Result

Calculation: A South 1 optimizado

...continued from previous page

WTG type							Power curve		Annual Energy		Park	
Terrain	Valid	Manufact.	Type-generator	Power, rated [kW]	Rotor diameter [m]	Hub height [m]	Creator	Name	Result [MWh]	Result-10.0% [MWh]	Efficiency [%]	Mean wind speed [m/s]
21 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	8,161.6	7,345	97.7	10.05
22 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	6,767.2	6,091	98.6	8.88

## WTG siting

### UTM WGS84 S Zone: 35

	East	North	Z [m]	Row data/Description
UTM WGS84 S Zone: 35				
1 New	566,331	6,665,672	2,491.9	VESTAS V80-2.0MW 80.0 AS1 - 14
2 New	566,059	6,662,401	2,447.3	VESTAS V80-2.0MW 80.0 AS1 - 04
3 New	565,507	6,665,979	2,485.5	VESTAS V80-2.0MW 80.0 AS1 - 16
4 New	565,186	6,663,019	2,470.0	VESTAS V80-2.0MW 80.0 AS1 - 06
5 New	565,524	6,666,594	2,497.3	VESTAS V80-2.0MW 80.0 AS1 - 21
6 New	564,848	6,664,910	2,480.0	VESTAS V80-2.0MW 80.0 AS1 - 13
7 New	567,191	6,666,474	2,488.7	VESTAS V80-2.0MW 80.0 AS1 - 20
8 New	564,648	6,664,310	2,500.0	VESTAS V80-2.0MW 80.0 AS1 - 11
9 New	564,748	6,664,610	2,490.0	VESTAS V80-2.0MW 80.0 AS1 - 12
10 New	566,550	6,665,871	2,522.1	VESTAS V80-2.0MW 80.0 AS1 - 15
11 New	565,420	6,666,346	2,521.8	VESTAS V80-2.0MW 80.0 AS1 - 19
12 New	565,885	6,662,196	2,466.8	VESTAS V80-2.0MW 80.0 AS1 - 03
13 New	563,838	6,663,559	2,495.4	VESTAS V80-2.0MW 80.0 AS1 - 07
14 New	564,548	6,664,010	2,489.8	VESTAS V80-2.0MW 80.0 AS1 - 09
15 New	565,727	6,666,810	2,484.9	VESTAS V80-2.0MW 80.0 AS1 - 22
16 New	564,889	6,662,969	2,470.0	VESTAS V80-2.0MW 80.0 AS1 - 05
17 New	566,972	6,666,292	2,509.3	VESTAS V80-2.0MW 80.0 AS1 - 18
18 New	563,908	6,663,908	2,505.8	VESTAS V80-2.0MW 80.0 AS1 - 08
19 New	566,761	6,666,069	2,537.4	VESTAS V80-2.0MW 80.0 AS1 - 17
20 New	565,718	6,661,966	2,470.0	VESTAS V80-2.0MW 80.0 AS1 - 02
21 New	565,252	6,661,962	2,470.0	VESTAS V80-2.0MW 80.0 AS1 - 01
22 New	563,849	6,664,269	2,530.1	VESTAS V80-2.0MW 80.0 AS1 - 10

### Non-default WAsP parameters:

WAsP parameter	Minimum	Maximum	Default	Current value
Altura Estd. #4	5.0000	200.0000	100.0000	80.0000

Project:

SSI\_Fase2

Description:

Potential wind farm site SSI

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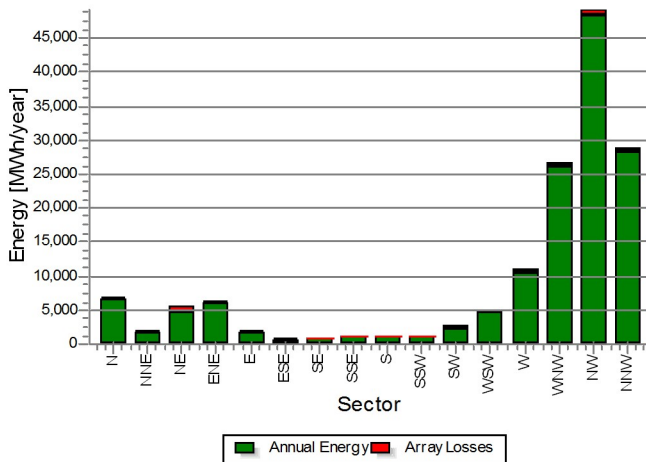
## PARK - Production Analysis

**Calculation:** A South 1 optimizado **WTG:** All new WTGs, Air density varies with WTG position 0.922 kg/m<sup>3</sup> - 0.930 kg/m<sup>3</sup>

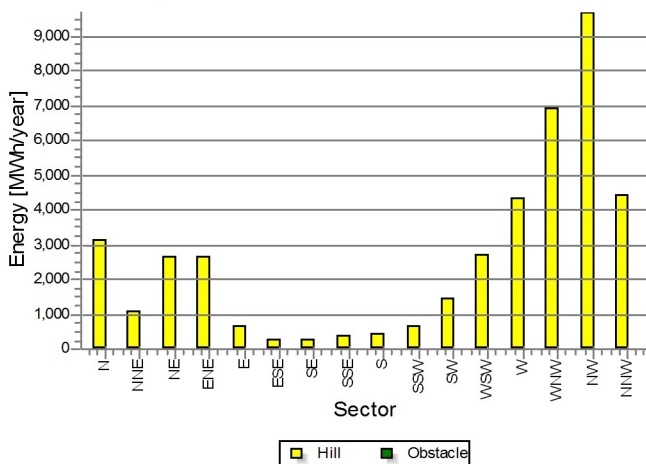
### Directional Analysis

Sector	0 N	1 NNE	2 NE	3 ENE	4 E	5 ESE	6 SE	7 SSE	8 S	9 SSW	10 SW	11 WSW	12 W	13 WNW	14 NW	15 NNW	Total
Roughness based energy [MWh]	3,742.2	800.6	2,720.8	3,676.7	1,168.0	426.9	677.3	797.5	632.2	598.9	1,168.8	2,269.0	6,679.4	19,750.5	39,510.9	24,419.7	109,039.6
+Increase due to hills [MWh]	3,143.1	1,079.8	2,643.4	2,651.0	664.0	272.1	255.9	369.5	415.6	636.3	1,479.0	2,709.1	4,311.1	6,901.5	9,688.7	4,450.8	41,671.0
-Decrease due to array losses [MWh]	416.0	209.6	826.4	292.5	76.0	21.8	22.8	46.3	69.1	156.2	428.7	289.1	427.4	548.2	766.3	459.9	5,056.2
<b>Resulting energy [MWh]</b>	<b>6,469.3</b>	<b>1,670.8</b>	<b>4,537.8</b>	<b>6,035.2</b>	<b>1,756.0</b>	<b>677.3</b>	<b>910.3</b>	<b>1,120.7</b>	<b>978.7</b>	<b>1,079.0</b>	<b>2,219.2</b>	<b>4,688.9</b>	<b>10,563.2</b>	<b>26,103.8</b>	<b>48,433.4</b>	<b>28,410.6</b>	<b>145,654.3</b>
Specific energy [kWh/m <sup>2</sup> ]																	1,317
Specific energy [kWh/kW]																	3,310
Increase due to hills [%]	84.0	134.9	97.2	72.1	56.9	63.7	37.8	46.3	65.7	106.2	126.5	119.4	64.5	34.9	24.5	18.2	38.22
Decrease due to array losses [%]	6.0	11.1	15.4	4.6	4.2	3.1	2.4	4.0	6.6	12.6	16.2	5.8	3.9	2.1	1.6	1.6	3.35
Utilization [%]	22.2	29.4	30.2	33.2	36.6	36.2	26.2	33.0	33.3	33.4	32.9	33.4	28.5	26.3	24.1	20.6	25.0
Operational [Hours/year]	326	181	372	395	164	120	131	146	135	174	308	496	748	1,353	1,946	991	7,986
Full Load Equivalent [Hours/year]	147	38	103	137	40	15	21	25	22	25	50	107	240	593	1,101	646	3,310

Energy vs. sector



Impact of hills and obstacles vs. sector



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Description: Potential wind farm site SSI

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## PARK - Power Curve Analysis

**Calculation:** A South 1 optimizado **WTG:** 1 - VESTAS V80-2.0MW 2000 80.0 !O! Mode 0, Hub height: 80.0 m

**Name:** Mode 0  
**Source:** Manufacturer

Source/Date	Created by	Created	Edited	Stop wind speed [m/s]	Power control	CT curve type
12/4/2009	EMD	12/07/2010	16/07/2010	25.0	Paso var. (Pitch)	Definido por usuario

Estimated power curve based on item n. 0004-7878 V03 04-12-2009.

**HP curve comparison** - Note: For standard air density and weibull k parameter = 2

Vmean	[m/s]	5	6	7	8	9	10
HP value	[MWh]	2,341	3,854	5,431	6,968	8,268	9,419
VESTAS V80-2.0MW 2000 80.0 !O! Mode 0	[MWh]	2,580	4,109	5,690	7,175	8,483	9,573
Check value	[%]	-9	-6	-5	-3	-3	-2

The table shows comparison between annual energy production calculated on basis of simplified "HP-curves" which assume that all WTGs performs quite similar - only specific power loading (kW/m<sup>2</sup>) and single/dual speed or stall/pitch decides the calculated values. Productions are without wake losses.

For further details, ask at the Danish Energy Agency for project report J.nr. 51171/00-0016 or see WindPRO manual chapter 3.5.2.

The method is refined in EMD report "20 Detailed Case Studies comparing Project Design Calculations and actual Energy Productions for Wind Energy Projects worldwide", jan 2003.

Use the table to evaluate if the given power curve is reasonable - if the check value are lower than -5%, the power curve probably is too optimistic due to uncertainty in power curve measurement.

### Power curve

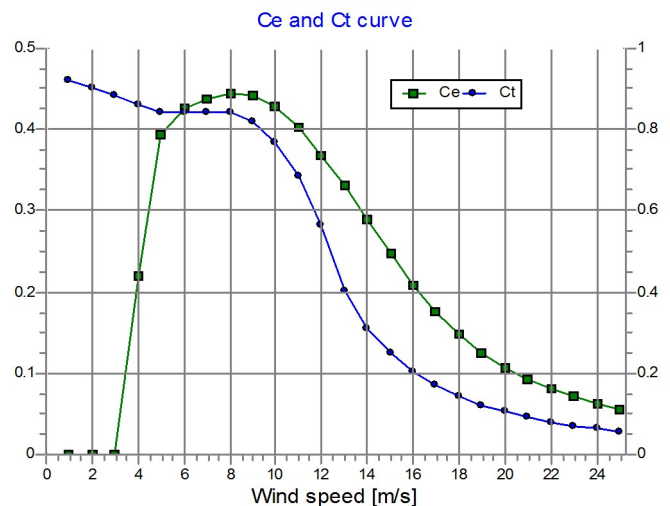
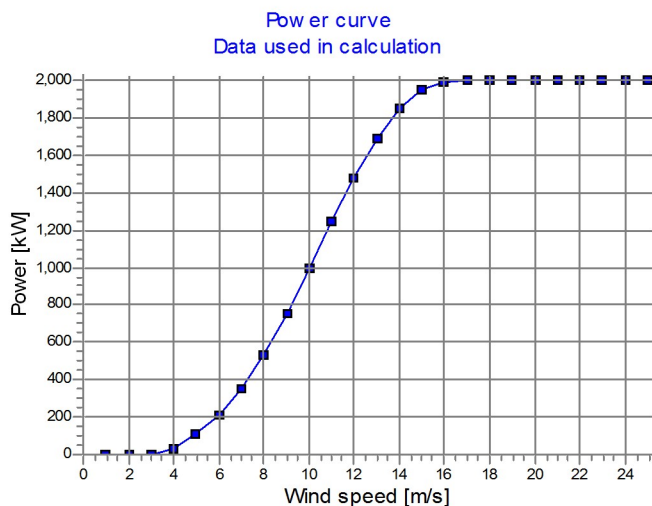
Original data from Windcat, Air density: 1.225 kg/m<sup>3</sup>

Wind speed [m/s]	Power [kW]	Ce	Wind speed [m/s]	Ct curve
4.0	66.0	0.33	4.0	0.86
5.0	156.0	0.41	5.0	0.84
6.0	285.0	0.43	6.0	0.84
7.0	467.0	0.44	7.0	0.84
8.0	706.0	0.45	8.0	0.84
9.0	1,001.0	0.45	9.0	0.82
10.0	1,329.0	0.43	10.0	0.77
11.0	1,652.0	0.40	11.0	0.68
12.0	1,892.0	0.36	12.0	0.56
13.0	1,982.0	0.29	13.0	0.40
14.0	2,000.0	0.24	14.0	0.31
15.0	2,000.0	0.19	15.0	0.25
16.0	2,000.0	0.16	16.0	0.20
17.0	2,000.0	0.13	17.0	0.17
18.0	2,000.0	0.11	18.0	0.14
19.0	2,000.0	0.09	19.0	0.12
20.0	2,000.0	0.08	20.0	0.10
21.0	2,000.0	0.07	21.0	0.09
22.0	2,000.0	0.06	22.0	0.08
23.0	2,000.0	0.05	23.0	0.07
24.0	2,000.0	0.05	24.0	0.06
25.0	2,000.0	0.04	25.0	0.06

### Power, Efficiency and energy vs. wind speed

Data used in calculation, Air density: 0.926 kg/m<sup>3</sup> Nuevo método WindPRO (método IEC ajustado, mejorado para que coincida con el control de la turbina) <RECOMENDADO>

Wind speed [m/s]	Power [kW]	Ce	Interval [m/s]	Energy [MWh]	Acc. Energy [MWh]	Relative [%]
1.0	0.0	0.00	0.50-1.50	0.0	0.0	0.0
2.0	0.0	0.00	1.50-2.50	0.0	0.0	0.0
3.0	0.0	0.00	2.50-3.50	0.0	0.0	0.0
4.0	32.9	0.22	3.50-4.50	23.8	23.8	0.4
5.0	114.6	0.39	4.50-5.50	79.1	102.9	1.6
6.0	213.8	0.43	5.50-6.50	154.8	257.7	4.0
7.0	349.8	0.44	6.50-7.50	253.1	510.8	7.9
8.0	529.5	0.44	7.50-8.50	364.6	875.4	13.5
9.0	750.6	0.44	8.50-9.50	472.8	1,348.2	20.8
10.0	998.5	0.43	9.50-10.50	559.7	1,907.9	29.4
11.0	1,247.9	0.40	10.50-11.50	614.7	2,522.6	38.9
12.0	1,479.0	0.37	11.50-12.50	634.8	3,157.4	48.6
13.0	1,688.2	0.33	12.50-13.50	619.7	3,777.1	58.2
14.0	1,851.8	0.29	13.50-14.50	575.2	4,352.3	67.0
15.0	1,946.7	0.25	14.50-15.50	507.2	4,859.4	74.9
16.0	1,989.8	0.21	15.50-16.50	423.4	5,282.8	81.4
17.0	2,000.0	0.17	16.50-17.50	338.7	5,621.5	86.6
18.0	2,000.0	0.15	17.50-18.50	262.9	5,884.4	90.6
19.0	2,000.0	0.13	18.50-19.50	198.2	6,082.6	93.7
20.0	2,000.0	0.11	19.50-20.50	145.1	6,227.8	95.9
21.0	2,000.0	0.09	20.50-21.50	103.1	6,330.8	97.5
22.0	2,000.0	0.08	21.50-22.50	71.0	6,401.8	98.6
23.0	2,000.0	0.07	22.50-23.50	47.3	6,449.1	99.3
24.0	2,000.0	0.06	23.50-24.50	30.5	6,479.7	99.8
25.0	2,000.0	0.06	24.50-25.50	11.8	6,491.5	100.0



Project:

**SSI\_Fase2**

Description:

Potential wind farm site SSI

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## PARK - Terrain

**Calculation:** A South 1 optimizado **Site Data:** A - Zona A South 1 to WAsP

### Obstacles:

0 Obstacles used

### Roughness:

Calculation uses following MAP files:

\\Server-dell\modeliza\Proyecto SSI\_2\03 WINDPRO\Data\WP Data (Step 2)\ROUGHNESSLIN Zona A4.wpo

Min X: 555,900, Max X: 575,603, Min Y: 6,657,609, Max Y: 6,681,409, Width: 19,703 m, Height: 23,800 m

### Orography:

Calculation uses following MAP files:

\\Server-dell\modeliza\Proyecto SSI\_2\03 WINDPRO\Data\WP Data (Step 2)\Curvas de nivel Zona A - IV.wpo

Min X: 558,012, Max X: 574,263, Min Y: 6,659,507, Max Y: 6,679,268, Width: 16,251 m, Height: 19,761 m

Project:

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Description:

Potential wind farm site SSI

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Calculated:

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**PARK - Wind Data Analysis****Calculation:** A South 1 optimizado **Wind data:** A - Zona A South 1 to WASP; Hub height: 80.0**Site Coordinates**

UTM WGS 84 South Zone: 35 East: 564,853 North: 6,664,384

**Wind data**

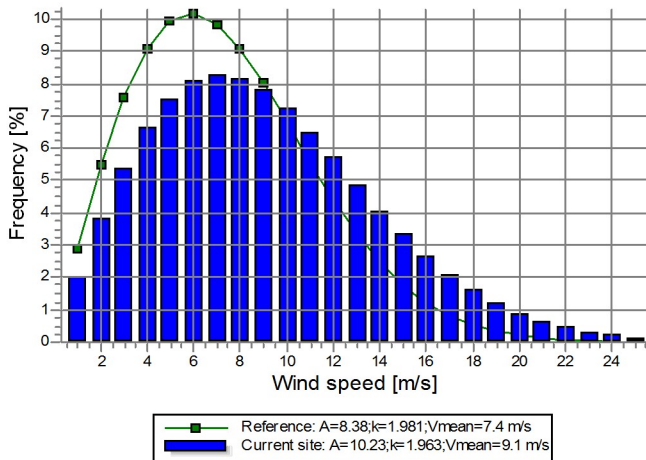
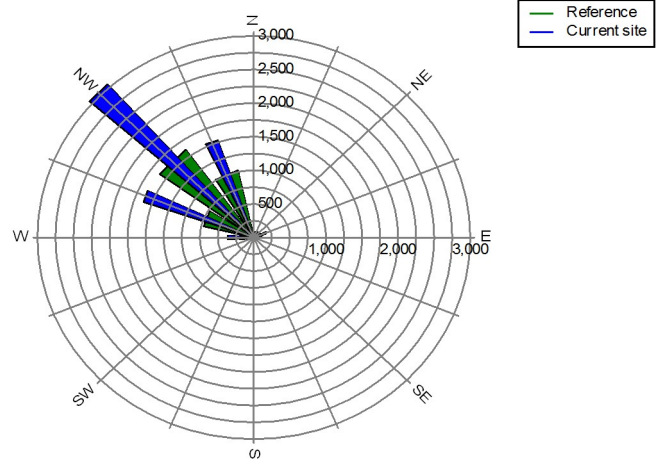
Wind statistics

	Distance [km]	Weight [%]
LS Zona A4 Mesoscale - 80.00 m.wws	7	26
LS Zona A4 Mesoscale 2 - 80.00 m.wws	2	74

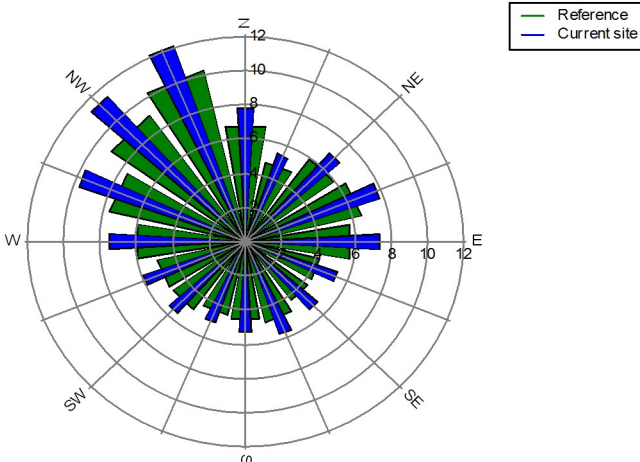
**Weibull Data**

Sector	Current site		Frequency [%]	Reference: Roughness class 1		
	A- parameter [m/s]	Wind speed [m/s]		A- parameter [m/s]	k- parameter	Frequency [%]
0 N	8.77	7.78	1.893	2.7	7.68	3.0
1 NNE	6.10	5.40	2.189	1.8	5.37	1.9
2 NE	7.74	6.89	2.744	4.0	6.71	4.3
3 ENE	8.70	7.74	2.729	5.0	7.29	5.1
4 E	8.30	7.37	2.607	2.5	6.54	2.1
5 ESE	6.02	5.36	1.748	1.7	4.72	1.6
6 SE	5.68	5.32	1.229	1.9	4.51	1.8
7 SSE	6.37	5.68	1.709	1.9	5.38	1.9
8 S	5.95	5.29	1.764	1.6	5.18	1.7
9 SSW	5.69	5.04	2.158	1.9	5.01	2.1
10 SW	6.26	5.56	2.615	3.2	5.41	3.5
11 WSW	6.67	5.91	2.412	5.3	5.55	5.5
12 W	8.37	7.43	1.904	8.8	6.81	8.5
13 WNW	10.94	9.69	2.150	19.6	8.59	17.7
14 NW	12.71	11.29	2.553	26.7	10.23	26.9
15 NNW	13.58	12.07	2.654	11.3	11.49	12.5
All	10.23	9.07	1.963	100.0	8.38	1.981

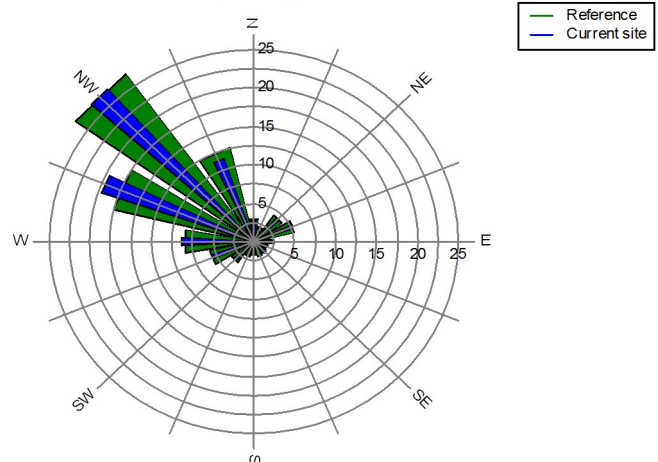
Weibull Distribution

Energy Rose (kWh/m<sup>2</sup>/year)

Mean wind speed (m/s)



Frequency (%)



Project: SSI\_Fase2  
Description: Potential wind farm site SSI

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## PARK - Wind Data Analysis

**Calculation:** A South 1 optimizado **Wind data:** A - Zona A South 1 to WASP; Hub height: 80.0

### Site Coordinates

UTM WGS 84 South Zone: 35 East: 566,331 North: 6,665,672  
VESTAS V80-2.0MW 80.0 AS1 - 14

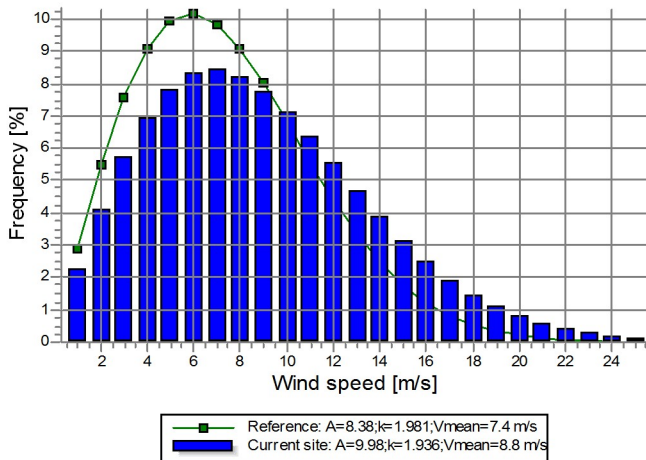
### Wind data

Wind statistics	Distance [km]	Weight [%]
LS Zona A4 Mesoscale - 80.00 m.wws	7	26
LS Zona A4 Mesoscale 2 - 80.00 m.wws	2	74

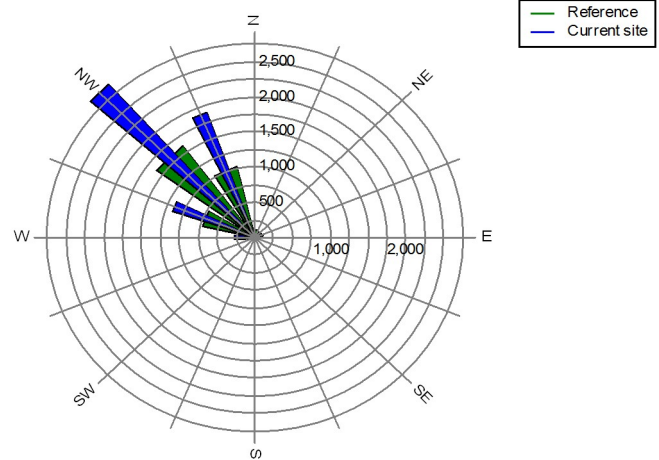
### Weibull Data

Sector	Current site		Frequency [%]	Reference: Roughness class 1		Frequency [%]
	A- parameter [m/s]	Wind speed [m/s]		A- parameter [m/s]	k- parameter	
0 N	9.05	8.04	1.881	7.68	1.900	3.0
1 NNE	6.47	5.73	2.240	5.37	2.187	1.9
2 NE	7.67	6.82	2.768	6.71	2.769	4.3
3 ENE	8.28	7.37	2.740	7.29	2.736	5.1
4 E	7.64	6.78	2.592	6.54	2.581	2.1
5 ESE	5.81	5.16	1.857	4.72	1.810	1.6
6 SE	5.48	5.15	1.205	4.51	1.194	1.8
7 SSE	6.53	5.82	1.701	5.38	1.713	1.9
8 S	6.18	5.50	1.775	5.18	1.751	1.7
9 SSW	5.89	5.21	2.201	5.01	2.160	2.1
10 SW	6.18	5.49	2.631	5.41	2.640	3.5
11 WSW	6.30	5.59	2.400	5.55	2.398	5.5
12 W	7.82	6.93	1.908	6.81	1.907	8.5
13 WNW	10.10	8.95	2.111	8.59	2.130	17.7
14 NW	12.31	10.93	2.521	10.23	2.553	26.9
15 NNW	13.90	12.35	2.674	11.49	2.701	12.5
All	9.98	8.85	1.936	8.38	1.981	100.0

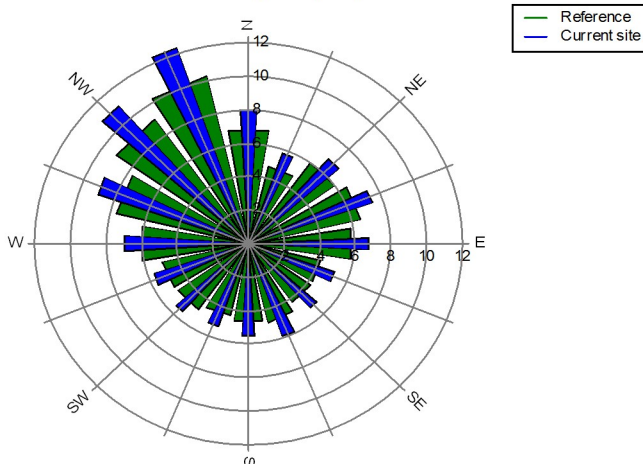
Weibull Distribution



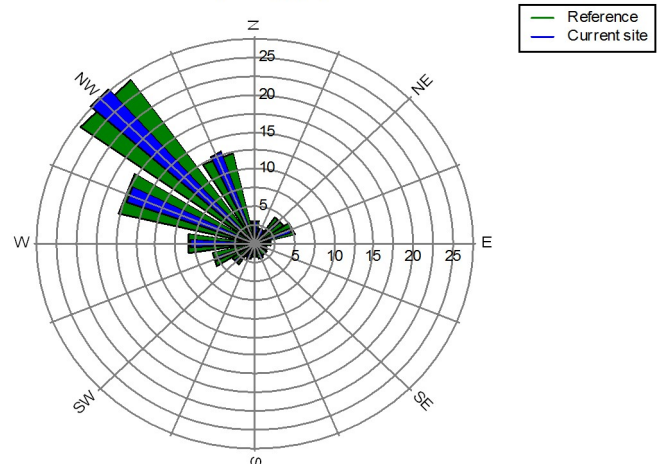
Energy Rose (kWh/m<sup>2</sup>/year)



Mean wind speed (m/s)



Frequency (%)



Project: SSI\_Fase2  
Description: Potential wind farm site SSI

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## PARK - Park power curve

Calculation: A South 1 optimizado

Wind speed	Free WTGs	Park WTGs	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
[m/s]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4.5	1,649	1,400	1,320	1,155	1,026	1,389	1,429	1,483	1,472	1,445	1,346	1,131	1,060	1,385	1,423	1,480	1,477	1,451
5.5	3,463	3,129	3,018	2,737	2,514	3,137	3,182	3,254	3,241	3,205	3,082	2,718	2,539	3,130	3,174	3,250	3,246	3,213
6.5	6,048	5,522	5,325	4,944	4,611	5,520	5,599	5,710	5,688	5,636	5,437	4,910	4,660	5,510	5,586	5,703	5,698	5,649
7.5	9,605	8,766	8,456	7,877	7,375	8,757	8,887	9,055	9,019	8,942	8,634	7,823	7,458	8,739	8,867	9,043	9,034	8,964
8.5	14,153	12,943	12,493	11,663	10,940	12,933	13,124	13,358	13,302	13,194	12,756	11,582	11,057	12,908	13,095	13,341	13,324	13,226
9.5	19,427	17,918	17,325	16,249	15,304	17,926	18,162	18,454	18,383	18,243	17,694	16,149	15,444	17,897	18,128	18,435	18,409	18,281
10.5	24,942	23,333	22,628	21,413	20,288	23,376	23,622	23,943	23,875	23,714	23,118	21,303	20,428	23,350	23,589	23,924	23,899	23,752
11.5	30,348	28,838	28,074	26,916	25,704	28,916	29,148	29,440	29,385	29,237	28,690	26,813	25,828	28,899	29,122	29,425	29,406	29,269
12.5	35,296	33,998	33,198	32,397	31,291	34,108	34,295	34,499	34,452	34,350	33,938	32,325	31,380	34,095	34,274	34,487	34,467	34,374
13.5	39,217	38,336	37,499	37,337	36,521	38,449	38,548	38,670	38,646	38,582	38,344	37,296	36,580	38,440	38,536	38,664	38,654	38,595
14.5	42,170	41,711	40,795	41,170	40,715	41,785	41,830	41,921	41,922	41,864	41,715	41,145	40,750	41,787	41,826	41,921	41,926	41,871
15.5	43,640	43,416	42,482	43,212	43,012	43,465	43,491	43,526	43,521	43,503	43,437	43,201	43,030	43,466	43,488	43,526	43,530	43,513
16.5	43,975	43,871	42,934	43,861	43,815	43,915	43,920	43,926	43,925	43,922	43,910	43,863	43,816	43,914	43,919	43,926	43,925	43,922
17.5	44,000	43,960	43,022	43,997	43,992	44,000	44,000	44,000	44,000	44,000	44,000	43,998	43,991	44,000	44,000	44,000	44,000	44,000
18.5	44,000	43,960	43,022	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000
19.5	44,000	43,960	43,022	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000
20.5	44,000	43,960	43,022	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000
21.5	44,000	43,960	43,022	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000
22.5	44,000	43,960	43,022	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000
23.5	44,000	43,960	43,022	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000
24.5	44,000	43,960	43,022	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000
25.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

### Description:

The park power curve is similar to a WTG power curve, meaning that when a given wind speed appears in front of the park with same speed in the entire wind farm area (before influence from the park), the output from the park can be found in the park power curve. Another way to say this: The park power curve includes array losses, but do NOT include terrain given variations in the wind speed over the park area.

Measuring a park power curve is not as simple as measuring a WTG power curve due to the fact that the park power curve depends on the wind direction and that the same wind speed normally will not appear for the entire park area at the same time (only in very flat non-complex terrain). The idea with this version of the park power curve is not to use it for validation based on measurements. This would require at least 2 measurement masts at two sides of the park, unless only a few direction sectors should be tested, AND non complex terrain (normally only useable off shore). Another park power curve version for complex terrain is available in WindPRO.

### The park power curve can be used for:

- Forecast systems, based on more rough (approximated) wind data, the park power curve would be an efficient way to make the connection from wind speed (and direction) to power.
- Construction of duration curves, telling how often a given power output will appear, the park power curve can be used together with the average wind distribution for the Wind farm area in hub height. The average wind distribution can eventually be obtained based on the Weibull parameters for each WTG position. These are found at print menu: >Result to file< in the >Park result< which can be saved to file or copied to clipboard and pasted in Excel.
- Calculation of wind energy index based on the PARK production (see below).
- Estimation of the expected PARK production for an existing wind farm based on wind measurements at minimum 2 measurement masts at two sides of wind farm. The masts must be used for obtaining the free wind speed. The free wind speed is used in the simulation of expected energy production with the PARK power curve. This procedure will only work suitable in non complex terrains. For complex terrain another park power curve calculation is available in WindPRO (PPV-model).

### Note:

From the >Result to file< the >Wind Speeds Inside Wind farm< is also available. These can (e.g. via Excel) be used for extracting the wake induced reductions in measured wind speed.

Project:

SSI\_Fase2

Description:

Potential wind farm site SSI

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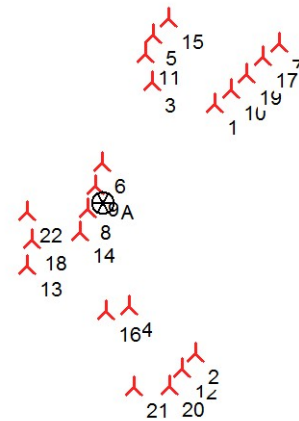
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**PARK - WTG distances****Calculation:** A South 1 optimizado**WTG distances**

Z	Nearest WTG	Z	Horizontal distance	Distance in
[m]		[m]	[m]	rotor diameters
1 2,491.9	10 2,522.1		296	3.7
2 2,447.3	12 2,466.8		269	3.4
3 2,485.5	11 2,521.8		377	4.7
4 2,470.0	16 2,470.0		301	3.8
5 2,497.3	11 2,521.8		269	3.4
6 2,480.0	9 2,490.0		316	4.0
7 2,488.7	17 2,509.3		285	3.6
8 2,500.0	9 2,490.0		316	4.0
9 2,490.0	8 2,500.0		316	4.0
10 2,522.1	19 2,537.4		289	3.6
11 2,521.8	5 2,497.3		269	3.4
12 2,466.8	2 2,447.3		269	3.4
13 2,495.4	18 2,505.8		356	4.4
14 2,489.8	8 2,500.0		316	4.0
15 2,484.9	5 2,497.3		296	3.7
16 2,470.0	4 2,470.0		301	3.8
17 2,509.3	7 2,488.7		285	3.6
18 2,505.8	13 2,495.4		356	4.4
19 2,537.4	10 2,522.1		289	3.6
20 2,470.0	12 2,466.8		284	3.6
21 2,470.0	20 2,470.0		466	5.8
22 2,530.1	18 2,505.8		366	4.6



New WTG

Scale 1:100,000  
Site Data

Project: **SSI\_Fase2**  
 Description: Potential wind farm site SSI

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## PARK - RIX calculation

Calculation: A South 1 optimizado

### Assumptions

Radius for calculation 3,500 m  
 Directional step 5 °  
 Steepness threshold 40.0 % / 22 °  
 Directional weight Equally distributed  
 Height contours used Curvas de nivel Zona A4

### Reference sites

Terrain	UTM WGS84 S Zone: 35	East	North	Z	Name of wind distribution	Type	Reference site RIX
				[m]			[%]
A	564,853	6,664,384	2500.0	Zona A South 1 to WAsP	WAsP (WAsP 6-9 for Windows RVEA0011 1, 0, 0, 13)		9.1

### WTG sites

Terrain	UTM WGS84 S Zone: 35	East	North	Z	Reference site RIX	WTG RIX	Delta RIX (WTG site - Reference site)
				[m]	[%]	[%]	[%]
1 A	566,331	6,665,672	2,491.9	9.1	8.4	-0.7	
2 A	566,059	6,662,401	2,447.3	9.1	15.3	6.2	
3 A	565,507	6,665,979	2,485.5	9.1	7.2	-1.9	
4 A	565,186	6,663,019	2,470.0	9.1	12.1	3.0	
5 A	565,524	6,666,594	2,497.3	9.1	6.3	-2.8	
6 A	564,848	6,664,910	2,480.0	9.1	7.7	-1.4	
7 A	567,191	6,666,474	2,488.7	9.1	8.4	-0.8	
8 A	564,648	6,664,310	2,500.0	9.1	9.3	0.2	
9 A	564,748	6,664,610	2,490.0	9.1	8.3	-0.8	
10 A	566,550	6,665,871	2,522.1	9.1	8.2	-0.9	
11 A	565,420	6,666,346	2,521.8	9.1	6.4	-2.7	
12 A	565,885	6,662,196	2,466.8	9.1	14.8	5.7	
13 A	563,838	6,663,559	2,495.4	9.1	13.9	4.8	
14 A	564,548	6,664,010	2,489.8	9.1	10.1	1.0	
15 A	565,727	6,666,810	2,484.9	9.1	5.8	-3.3	
16 A	564,889	6,662,969	2,470.0	9.1	11.4	2.3	
17 A	566,972	6,666,292	2,509.3	9.1	8.2	-0.9	
18 A	563,908	6,663,908	2,505.8	9.1	11.6	2.5	
19 A	566,761	6,666,069	2,537.4	9.1	8.2	-0.9	
20 A	565,718	6,661,966	2,470.0	9.1	14.7	5.6	
21 A	565,252	6,661,962	2,470.0	9.1	14.9	5.8	
22 A	563,849	6,664,269	2,530.1	9.1	11.0	1.9	

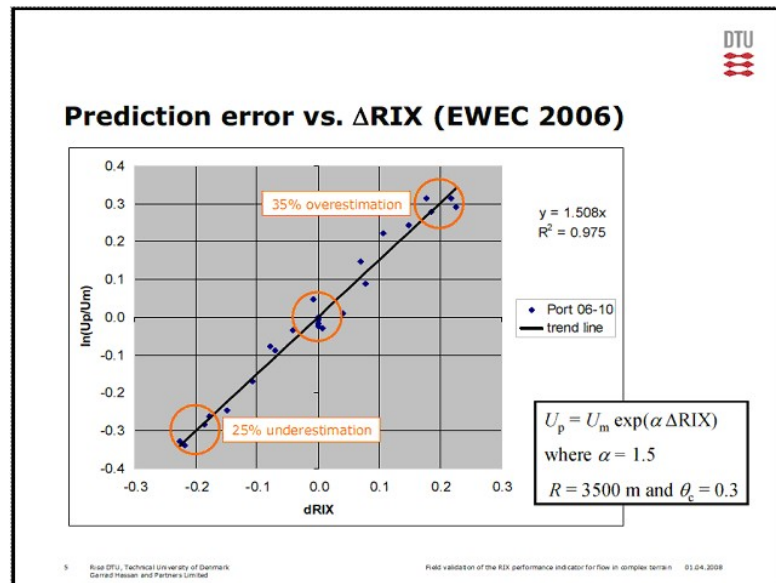
Project: SSI\_Fase2  
 Description: Potential wind farm site SSI

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## PARK - RIX calculation

**Calculation:** A South 1 optimizado

Latest research /Risø/ show that the threshold in RIX calculation typically work best with 40% (new default), and that delta Rix within +/- 5% should not give corrections. Cross predictions based on more mast can fine tune the threshold, see Cross predictor tool in WindPRO Meteo Analyzer. In WindPRO LOSS&&UNCERTAINTY module, RIX correction can be calculated automatically as a bias based on most recent recommended correction formulas, which can be found in EWEC2006 && 08 papers on Rix from Risø, see extract below:

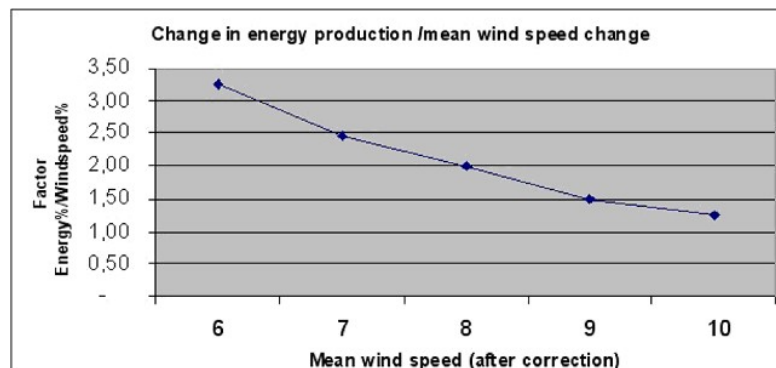


The main conclusion based on use of the RIX method is that if both reference site (measurement mast) and predicted site (WTG) are equally rugged (Delta RIX < 5%), very small calculation errors are expected.

If reference site (measurement mast) is very rugged, e.g. RIX = 0.2 and predicted site (WTG) are less rugged (e.g. RIX = 0), Delta RIX will be -0.2 and according to the graph, 30% too low wind speed prediction at WTG site could be expected. This could lead to around 60%\*) too low calculated energy production.

If the reference site is less rugged, e.g. RIX = 0, and the predicted site (WTG) are very rugged (e.g. RIX = 0.2), Delta RIX will be +0.2, and according to the graph, 30% too high wind speed prediction at WTG site could be expected. This could lead to around 60%\*) too high calculated energy production.

\*) Doubling of energy prediction error based on mean wind speed error is a rough conversion, which holds for wind speeds around 8 m/s. At 6-7 m/s tripling is more right, while only 1.5 factors should be used for 9 m/s, see graph below based on a typical WTG.



Source: EWEC06 paper:

### IMPROVING WaSP PREDICTIONS IN (TOO) COMPLEX TERRAIN

Niels G. Mortensen, Anthony J. Bowen and Ioannis Antoniou  
 Wind Energy Department, Risø National Laboratory

Project:

SSI\_Fase2

Description:

Potential wind farm site SSI

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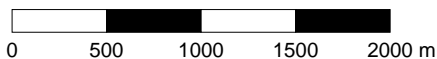
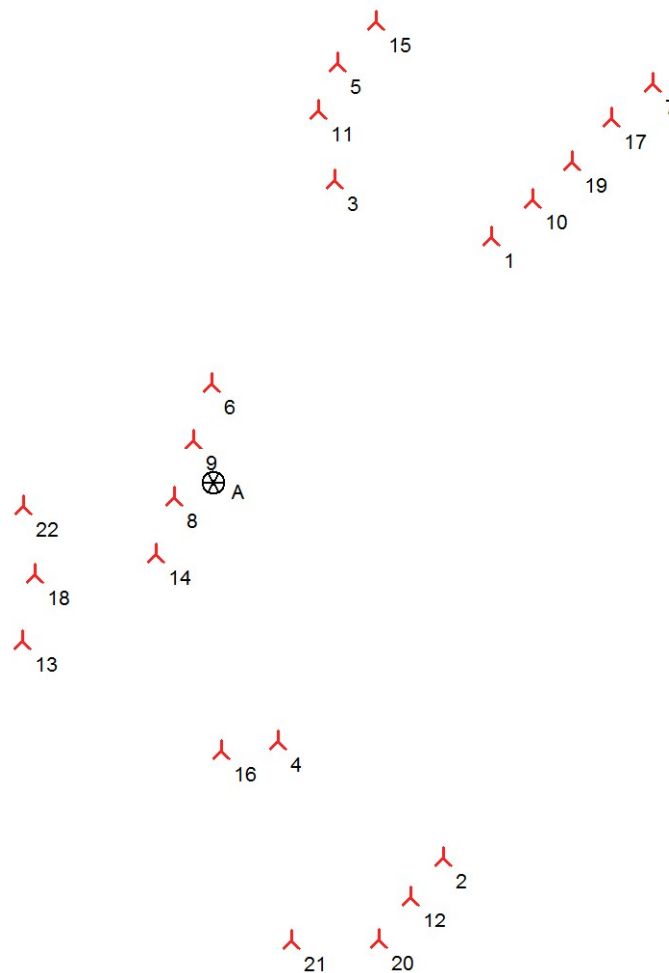
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**PARK - Mapa****Calculation:** A South 1 optimizado

Map: Mapa en blanco , Print scale 1:40,000, Map center UTM WGS 84 South Zone: 35 East: 565,515 North: 6,664,386



New WTG



Site Data

**LESOTHO POWER GENERATION MASTER PLAN**

**PROJECT # LEC/GEN/1-2009**

**FINAL MILESTONES REPORT**

**VOLUME 1 - PART 1.2**

**WIND POWER GENERATION OPTION**

**APPENDIX 1.2.2**

**B CENTER 1 WIND FARM**



July 2011

a. Area: B

Hyperlink: [c- Area B Potential Sites.KMZ](#)

b. RPD: B - Center 1 proposed Wind Farm

Hyperlink: [f- B Center 1.kmz](#)

Project: SSI\_Fase2  
Description: Potential wind farm site SSI

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## PARK - Main Result

### Calculation: B Center 1 Optimizado

#### Wake Model N.O. Jensen (RISØ/EMD)

##### Calculation Settings

Air density calculation mode Individual per WTG  
Result for WTG at hub altitude 0.908 kg/m³ to 0.919 kg/m³  
Air density relative to standard 74.7 %  
Hub altitude above sea level (asl) 2,651.8 m to 2,780.0 m  
Annual mean temperature at hub alt. 6.7 °C to 7.5 °C  
Pressure at WTGs 729.2 hPa to 740.7 hPa

##### Wake Model Parameters

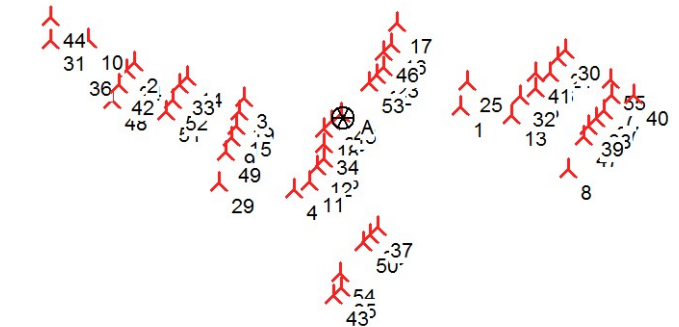
From angle To angle Terrain type Wake Decay Constant  
[°] [°]  
-180.0 180.0 Zona agrícola abierta 0.075

##### 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 data

Wind statistics	Distance [km]	Weight [%]
LS Zona B1 Central Area Mesoscale 2 to B3 - 80.00 m.wws	4	47
LS Zona B3 Mesoscale 1 - 80.00 m.wws	6	26
LS Zona B1 Central Area Mesoscale 1 to B3 - 80.00 m.wws	6	26



WASP version WASP 6-9 for Windows RVEA0011 1, 0, 0, 13

Non-default WASP parameters detailed information at the end of "Main results"

New WTG

Scale 1:200,000  
Site Data

### Key results for height 80.0 m above ground level

#### Terrain UTM WGS84 S Zone: 35

East	North	Name of wind distribution	Type	Wind energy [kWh/m²]	Mean wind speed [m/s]	Equivalent roughness
A 609,551	6,636,865	B Center 1 Rev to WASP	WASP (WASP 6-9 for Windows RVEA0011 1, 0, 0, 13)	3,192	7.1	0.5

### 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 [%]	Resultados específicos <sup>a)</sup>			Mean wind speed @hub height [m/s]
					Capacity factor [%]	Mean WTG result [MWh/y]	Full load hours [Hours/year]	
Wind farm	290,174.1	261,156.7	298,009.2	97.4	27.1	4,748.3	2,374	7.7

<sup>a)</sup> Basado en Result-10.0%

### Calculated Annual Energy for each of 55 new WTGs with total 110.0 MW rated power

WTG type	Terrain	Valid	Manufact.	Type-generator	Power, rated [kW]	Rotor diameter [m]	Hub height [m]	Power curve		Annual Energy		Park	
								Creator	Name	Result [MWh]	Result-10.0% [MWh]	Efficiency [%]	Mean wind speed [m/s]
1 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	80.0	EMD	Mode 0	4,760.0	4,284	96.8	7.28
2 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	80.0	EMD	Mode 0	5,797.5	5,218	96.3	8.21
3 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	80.0	EMD	Mode 0	5,288.7	4,760	96.7	7.72
4 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	80.0	EMD	Mode 0	5,753.5	5,178	97.6	8.14
5 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	80.0	EMD	Mode 0	5,610.3	5,049	97.3	8.00
6 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	80.0	EMD	Mode 0	5,545.1	4,991	95.5	8.04
7 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	80.0	EMD	Mode 0	5,550.9	4,996	96.6	7.99
8 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	80.0	EMD	Mode 0	4,841.3	4,357	98.2	7.31
9 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	80.0	EMD	Mode 0	4,695.3	4,226	96.4	7.21
10 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	80.0	EMD	Mode 0	5,704.7	5,134	97.1	8.08
11 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	80.0	EMD	Mode 0	5,419.5	4,878	96.6	7.87
12 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	80.0	EMD	Mode 0	5,469.3	4,922	97.2	7.88
13 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	80.0	EMD	Mode 0	5,556.0	5,000	97.4	7.96
14 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	80.0	EMD	Mode 0	5,502.4	4,952	96.4	7.93
15 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	80.0	EMD	Mode 0	4,830.7	4,348	96.1	7.35
16 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	80.0	EMD	Mode 0	5,515.9	4,964	98.9	7.82
17 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	80.0	EMD	Mode 0	5,511.3	4,960	99.2	7.80
18 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	80.0	EMD	Mode 0	5,418.2	4,876	97.6	7.82
19 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	80.0	EMD	Mode 0	4,910.2	4,419	96.1	7.42
20 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	80.0	EMD	Mode 0	5,474.0	4,927	97.3	7.90

To be continued on next page...

Project: SSI\_Fase2  
 Description: Potential wind farm site SSI

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## PARK - Main Result

Calculation: B Center 1 Optimizado

...continued from previous page

WTG type								Power curve		Annual Energy		Park	
Terrain	Valid	Manufact.	Type-generator	Power, rated [kW]	Rotor diameter [m]	Hub height [m]	Creator	Name	Result [MWh]	Result-10.0% [MWh]	Efficiency [%]	Mean wind speed [m/s]	
21 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,522.3	4,970	98.2	7.87	
22 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,512.9	4,962	98.6	7.85	
23 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,501.6	4,951	98.5	7.84	
24 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,444.8	4,900	96.9	7.85	
25 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,450.5	4,905	96.9	7.87	
26 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,297.9	4,768	97.0	7.73	
27 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,271.5	4,744	96.2	7.73	
28 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,343.0	4,809	97.6	7.75	
29 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,524.0	4,972	99.1	7.84	
30 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,437.6	4,894	98.1	7.80	
31 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,633.3	5,070	99.1	7.93	
32 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,352.2	4,817	97.2	7.77	
33 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,316.8	4,785	95.9	7.79	
34 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,209.5	4,689	97.2	7.64	
35 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,377.4	4,840	98.9	7.73	
36 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	4,781.6	4,303	98.1	7.25	
37 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,271.7	4,745	97.0	7.72	
38 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,131.9	4,619	96.2	7.61	
39 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,276.9	4,749	96.6	7.74	
40 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,106.2	4,596	94.3	7.70	
41 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,267.2	4,741	97.6	7.68	
42 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,216.0	4,694	96.9	7.66	
43 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,222.1	4,700	99.6	7.56	
44 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,544.8	4,990	99.3	7.83	
45 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	4,748.5	4,274	96.8	7.28	
46 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,259.0	4,733	99.0	7.60	
47 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	4,934.2	4,441	96.8	7.42	
48 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,223.2	4,701	98.6	7.59	
49 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	4,624.8	4,162	97.5	7.13	
50 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,077.0	4,569	98.2	7.50	
51 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	4,894.9	4,405	96.3	7.40	
52 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,068.1	4,561	95.7	7.57	
53 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,120.2	4,608	99.1	7.49	
54 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,067.6	4,561	99.1	7.46	
55 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	4,988.1	4,489	95.8	7.52	

## WTG siting

### UTM WGS84 S Zone: 35

	East	North	Z [m]	Row data/Description
UTM WGS84 S Zone: 35				
1 New	612,655	6,637,123	2,615.3	VESTAS V80-2.0MW 80.0 BC 1 - 40
2 New	604,038	6,638,387	2,580.0	VESTAS V80-2.0MW 80.0 BC 1 - 05
3 New	606,925	6,637,403	2,580.0	VESTAS V80-2.0MW 80.0 BC 1 - 13
4 New	608,238	6,634,987	2,698.4	VESTAS V80-2.0MW 80.0 BC 1 - 26
5 New	614,638	6,637,587	2,624.4	VESTAS V80-2.0MW 80.0 BC 1 - 45
6 New	615,038	6,637,987	2,640.0	VESTAS V80-2.0MW 80.0 BC 1 - 44
7 New	616,638	6,637,387	2,661.5	VESTAS V80-2.0MW 80.0 BC 1 - 50
8 New	615,475	6,635,438	2,678.1	VESTAS V80-2.0MW 80.0 BC 1 - 55
9 New	606,600	6,636,383	2,571.8	VESTAS V80-2.0MW 80.0 BC 1 - 16
10 New	602,838	6,638,987	2,600.0	VESTAS V80-2.0MW 80.0 BC 1 - 03
11 New	608,638	6,635,187	2,660.0	VESTAS V80-2.0MW 80.0 BC 1 - 25
12 New	608,838	6,635,587	2,640.0	VESTAS V80-2.0MW 80.0 BC 1 - 24
13 New	613,990	6,636,882	2,666.3	VESTAS V80-2.0MW 80.0 BC 1 - 47
14 New	605,438	6,637,987	2,580.0	VESTAS V80-2.0MW 80.0 BC 1 - 09
15 New	606,726	6,636,691	2,580.0	VESTAS V80-2.0MW 80.0 BC 1 - 15
16 New	610,838	6,638,787	2,599.5	VESTAS V80-2.0MW 80.0 BC 1 - 34

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Project: SSI\_Fase2  
 Description: Potential wind farm site SSI

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## PARK - Main Result

Calculation: B Center 1 Optimizado

...continued from previous page

### UTM WGS84 S Zone: 35

	East	North	Z	Row data/Description
	UTM WGS84 S Zone: 35		[m]	
17 New	610,990	6,639,356	2,580.0	VESTAS V80-2.0MW 80.0 BC 1 - 33
18 New	609,038	6,636,587	2,659.2	VESTAS V80-2.0MW 80.0 BC 1 - 21
19 New	606,789	6,637,054	2,580.0	VESTAS V80-2.0MW 80.0 BC 1 - 14
20 New	609,238	6,636,787	2,680.0	VESTAS V80-2.0MW 80.0 BC 1 - 20
21 New	615,238	6,638,387	2,620.0	VESTAS V80-2.0MW 80.0 BC 1 - 42
22 New	610,438	6,637,987	2,660.0	VESTAS V80-2.0MW 80.0 BC 1 - 37
23 New	610,638	6,638,187	2,639.4	VESTAS V80-2.0MW 80.0 BC 1 - 36
24 New	603,838	6,638,187	2,580.0	VESTAS V80-2.0MW 80.0 BC 1 - 06
25 New	612,838	6,637,787	2,620.0	VESTAS V80-2.0MW 80.0 BC 1 - 39
26 New	609,038	6,635,787	2,635.1	VESTAS V80-2.0MW 80.0 BC 1 - 23
27 New	616,438	6,636,987	2,606.9	VESTAS V80-2.0MW 80.0 BC 1 - 51
28 New	610,238	6,633,787	2,660.0	VESTAS V80-2.0MW 80.0 BC 1 - 28
29 New	606,238	6,635,187	2,680.0	VESTAS V80-2.0MW 80.0 BC 1 - 18
30 New	615,438	6,638,587	2,617.1	VESTAS V80-2.0MW 80.0 BC 1 - 41
31 New	601,838	6,638,987	2,640.0	VESTAS V80-2.0MW 80.0 BC 1 - 02
32 New	614,238	6,637,387	2,639.5	VESTAS V80-2.0MW 80.0 BC 1 - 46
33 New	605,238	6,637,787	2,580.0	VESTAS V80-2.0MW 80.0 BC 1 - 10
34 New	609,038	6,636,187	2,635.4	VESTAS V80-2.0MW 80.0 BC 1 - 22
35 New	609,438	6,632,387	2,700.0	VESTAS V80-2.0MW 80.0 BC 1 - 31
36 New	602,520	6,638,310	2,627.8	VESTAS V80-2.0MW 80.0 BC 1 - 04
37 New	610,438	6,633,987	2,660.0	VESTAS V80-2.0MW 80.0 BC 1 - 27
38 New	616,238	6,636,787	2,615.2	VESTAS V80-2.0MW 80.0 BC 1 - 52
39 New	616,038	6,636,587	2,657.6	VESTAS V80-2.0MW 80.0 BC 1 - 53
40 New	617,238	6,637,387	2,656.4	VESTAS V80-2.0MW 80.0 BC 1 - 49
41 New	614,638	6,637,987	2,640.0	VESTAS V80-2.0MW 80.0 BC 1 - 43
42 New	603,638	6,637,787	2,600.0	VESTAS V80-2.0MW 80.0 BC 1 - 07
43 New	609,238	6,632,187	2,700.0	VESTAS V80-2.0MW 80.0 BC 1 - 32
44 New	601,838	6,639,587	2,586.7	VESTAS V80-2.0MW 80.0 BC 1 - 01
45 New	609,503	6,636,968	2,660.0	VESTAS V80-2.0MW 80.0 BC 1 - 19
46 New	610,638	6,638,587	2,600.0	VESTAS V80-2.0MW 80.0 BC 1 - 35
47 New	615,911	6,636,300	2,633.9	VESTAS V80-2.0MW 80.0 BC 1 - 54
48 New	603,438	6,637,387	2,619.7	VESTAS V80-2.0MW 80.0 BC 1 - 08
49 New	606,426	6,636,002	2,607.7	VESTAS V80-2.0MW 80.0 BC 1 - 17
50 New	610,038	6,633,587	2,660.0	VESTAS V80-2.0MW 80.0 BC 1 - 29
51 New	604,873	6,637,088	2,580.0	VESTAS V80-2.0MW 80.0 BC 1 - 12
52 New	605,038	6,637,387	2,580.0	VESTAS V80-2.0MW 80.0 BC 1 - 11
53 New	610,238	6,637,787	2,656.9	VESTAS V80-2.0MW 80.0 BC 1 - 38
54 New	609,438	6,632,787	2,685.1	VESTAS V80-2.0MW 80.0 BC 1 - 30
55 New	616,638	6,637,787	2,622.7	VESTAS V80-2.0MW 80.0 BC 1 - 48

### Non-default WAsP parameters:

WAsP parameter	Minimum	Maximum	Default	Current value
Altura Estd. #4	5.0000	200.0000	100.0000	80.0000

Project: SSI\_Fase2  
Description: Potential wind farm site SSI

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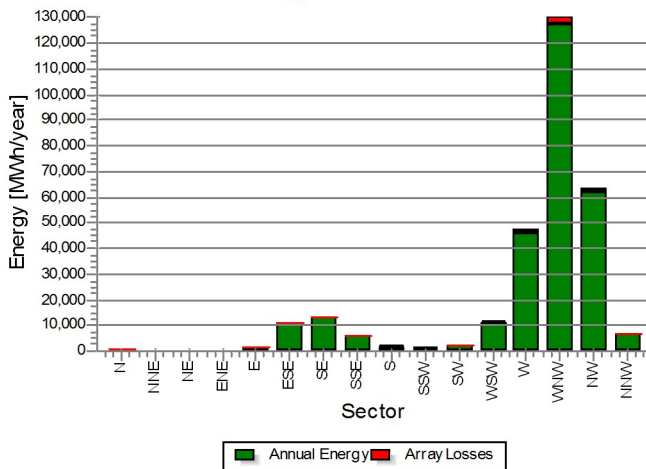
## PARK - Production Analysis

**Calculation:** B Center 1 Optimizado**WTG:** All new WTGs, Air density varies with WTG position 0.908 kg/m<sup>3</sup> - 0.919 kg/m<sup>3</sup>

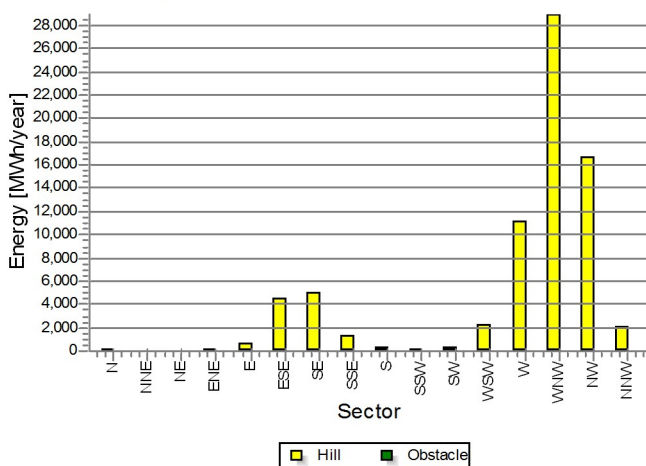
### Directional Analysis

Sector		0 N	1 NNE	2 NE	3 ENE	4 E	5 ESE	6 SE	7 SSE	8 S	9 SSW	10 SW	11 WSW	12 W	13 WNW	14 NW	15 NNW	Total
Roughness based energy	[MWh]	528.7	132.9	96.6	190.1	906.5	6,696.5	8,428.2	4,597.4	1,474.4	969.3	2,113.0	9,219.0	36,117.8	101,323.8	46,698.1	4,775.2	224,267.5
+Increase due to hills	[MWh]	148.4	28.3	26.4	85.2	624.7	4,505.4	4,999.3	1,319.9	362.6	195.5	347.8	2,278.7	11,089.7	28,933.3	16,674.4	2,122.0	73,741.8
-Decrease due to array losses	[MWh]	54.5	28.3	26.1	17.6	92.5	544.4	463.7	82.1	94.7	186.7	420.4	444.0	1,293.3	2,786.2	1,193.9	106.6	7,835.1
<b>Resulting energy</b>	<b>[MWh]</b>	<b>622.5</b>	<b>132.9</b>	<b>96.9</b>	<b>257.7</b>	<b>1,438.8</b>	<b>10,657.5</b>	<b>12,963.7</b>	<b>5,835.3</b>	<b>1,742.3</b>	<b>978.1</b>	<b>2,040.5</b>	<b>11,053.7</b>	<b>45,914.2</b>	<b>127,470.8</b>	<b>62,178.6</b>	<b>6,790.5</b>	<b>290,174.2</b>
Specific energy	[kWh/m <sup>2</sup> ]																	1,050
Specific energy	[kWh/kW]																	2,638
Increase due to hills	[%]	28.1	21.3	27.3	44.8	68.9	67.3	59.3	28.7	24.6	20.2	16.5	24.7	30.7	28.6	35.7	44.4	32.88
Decrease due to array losses	[%]	8.1	17.6	21.2	6.4	6.0	4.9	3.5	1.4	5.2	16.0	17.1	3.9	2.7	2.1	1.9	1.5	2.63
Utilization	[%]	33.8	26.7	23.5	30.1	35.4	37.5	36.4	30.3	33.7	32.3	32.6	35.7	28.0	22.6	24.7	33.8	25.5
Operational	[Hours/year]	98	59	63	102	209	563	477	220	132	124	192	481	1,117	2,137	1,172	289	7,434
Full Load Equivalent	[Hours/year]	6	1	1	2	13	97	118	53	16	9	19	100	417	1,159	565	62	2,638

Energy vs. sector



Impact of hills and obstacles vs. sector



Project: SSI\_Fase2  
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Marta Camps / mcamps@normawind.com  
Calculated:  
01/07/2011 10:44/2.7.487

## PARK - Power Curve Analysis

**Calculation:** B Center 1 Optimizado **WTG:** 1 - VESTAS V80-2.0MW 2000 80.0 !O! Mode 0, Hub height: 80.0 m

**Name:** Mode 0  
**Source:** Manufacturer

Source/Date	Created by	Created	Edited	Stop wind speed [m/s]	Power control	CT curve type
12/4/2009	EMD	12/07/2010	16/07/2010	25.0	Paso var. (Pitch)	Definido por usuario

Estimated power curve based on item n. 0004-7878 V03 04-12-2009.

**HP curve comparison** - Note: For standard air density and weibull k parameter = 2

Vmean	[m/s]	5	6	7	8	9	10
HP value	[MWh]	2,341	3,854	5,431	6,968	8,268	9,419
VESTAS V80-2.0MW 2000 80.0 !O! Mode 0	[MWh]	2,580	4,109	5,690	7,175	8,483	9,573
Check value	[%]	-9	-6	-5	-3	-3	-2

The table shows comparison between annual energy production calculated on basis of simplified "HP-curves" which assume that all WTGs performs quite similar - only specific power loading (kW/m<sup>2</sup>) and single/dual speed or stall/pitch decides the calculated values. Productions are without wake losses.

For further details, ask at the Danish Energy Agency for project report J.nr. 51171/00-0016 or see WindPRO manual chapter 3.5.2.

The method is refined in EMD report "20 Detailed Case Studies comparing Project Design Calculations and actual Energy Productions for Wind Energy Projects worldwide", jan 2003.

Use the table to evaluate if the given power curve is reasonable - if the check value are lower than -5%, the power curve probably is too optimistic due to uncertainty in power curve measurement.

### Power curve

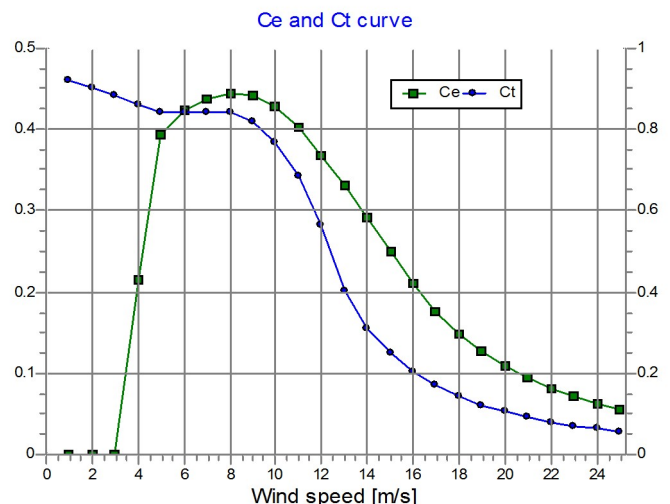
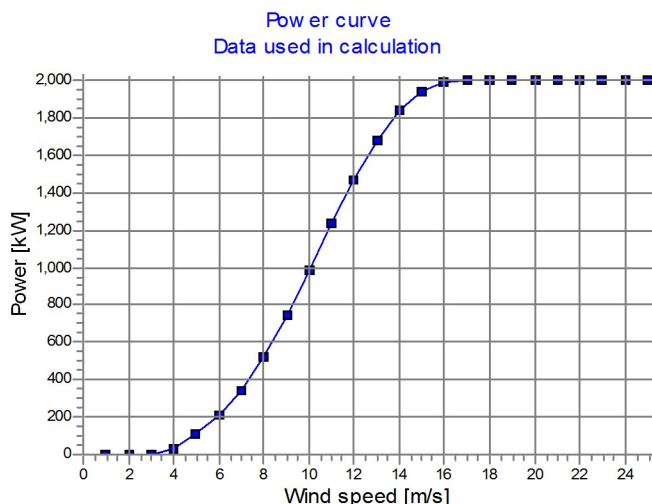
Original data from Windcat, Air density: 1.225 kg/m<sup>3</sup>

Wind speed [m/s]	Power [kW]	Ce	Wind speed [m/s]	Ct curve
4.0	66.0	0.33	4.0	0.86
5.0	156.0	0.41	5.0	0.84
6.0	285.0	0.43	6.0	0.84
7.0	467.0	0.44	7.0	0.84
8.0	706.0	0.45	8.0	0.84
9.0	1,001.0	0.45	9.0	0.82
10.0	1,329.0	0.43	10.0	0.77
11.0	1,652.0	0.40	11.0	0.68
12.0	1,892.0	0.36	12.0	0.56
13.0	1,982.0	0.29	13.0	0.40
14.0	2,000.0	0.24	14.0	0.31
15.0	2,000.0	0.19	15.0	0.25
16.0	2,000.0	0.16	16.0	0.20
17.0	2,000.0	0.13	17.0	0.17
18.0	2,000.0	0.11	18.0	0.14
19.0	2,000.0	0.09	19.0	0.12
20.0	2,000.0	0.08	20.0	0.10
21.0	2,000.0	0.07	21.0	0.09
22.0	2,000.0	0.06	22.0	0.08
23.0	2,000.0	0.05	23.0	0.07
24.0	2,000.0	0.05	24.0	0.06
25.0	2,000.0	0.04	25.0	0.06

### Power, Efficiency and energy vs. wind speed

Data used in calculation, Air density: 0.915 kg/m<sup>3</sup> Nuevo método WindPRO (método IEC ajustado, mejorado para que coincida con el control de la turbina) <RECOMENDADO>

Wind speed [m/s]	Power [kW]	Ce	Interval [m/s]	Energy [MWh]	Acc. Energy [MWh]	Relative [%]
1.0	0.0	0.00	0.50-1.50	0.0	0.0	0.0
2.0	0.0	0.00	1.50-2.50	0.0	0.0	0.0
3.0	0.0	0.00	2.50-3.50	0.0	0.0	0.0
4.0	31.6	0.21	3.50-4.50	30.3	30.3	0.6
5.0	113.0	0.39	4.50-5.50	94.8	125.1	2.6
6.0	211.0	0.42	5.50-6.50	171.8	296.9	6.2
7.0	345.2	0.44	6.50-7.50	262.1	559.0	11.7
8.0	522.7	0.44	7.50-8.50	355.1	914.1	19.2
9.0	741.6	0.44	8.50-9.50	435.1	1,349.2	28.3
10.0	987.8	0.43	9.50-10.50	486.7	1,835.9	38.6
11.0	1,234.5	0.40	10.50-11.50	503.4	2,339.3	49.1
12.0	1,464.2	0.37	11.50-12.50	486.4	2,825.7	59.4
13.0	1,675.0	0.33	12.50-13.50	442.1	3,267.8	68.7
14.0	1,836.2	0.29	13.50-14.50	381.3	3,649.1	76.7
15.0	1,939.0	0.25	14.50-15.50	311.5	3,960.6	83.2
16.0	1,988.0	0.21	15.50-16.50	240.5	4,201.1	88.3
17.0	2,000.0	0.18	16.50-17.50	178.3	4,379.5	92.0
18.0	2,000.0	0.15	17.50-18.50	128.5	4,507.9	94.7
19.0	2,000.0	0.13	18.50-19.50	90.2	4,598.2	96.6
20.0	2,000.0	0.11	19.50-20.50	61.8	4,660.0	97.9
21.0	2,000.0	0.09	20.50-21.50	41.3	4,701.3	98.8
22.0	2,000.0	0.08	21.50-22.50	26.9	4,728.3	99.3
23.0	2,000.0	0.07	22.50-23.50	17.1	4,745.4	99.7
24.0	2,000.0	0.06	23.50-24.50	10.6	4,756.0	99.9
25.0	2,000.0	0.06	24.50-25.50	4.0	4,760.0	100.0



Project:

**SSI\_Fase2**

Description:

Potential wind farm site SSI

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## PARK - Terrain

**Calculation:** B Center 1 Optimizado **Site Data:** A - B Center 1 Rev to WAsP

### Obstacles:

0 Obstacles used

### Roughness:

Calculation uses following MAP files:

\\Server-dell\modeliza\Proyecto SSI\_2\03 WINDPRO\Data\WP Data (Step 2)\ROUGHNESSLINE ZonaB3.wpo

Min X: 599,033, Max X: 623,924, Min Y: 6,621,642, Max Y: 6,644,342, Width: 24,891 m, Height: 22,700 m

### Orography:

Calculation uses following MAP files:

\\Server-dell\modeliza\Proyecto SSI\_2\03 WINDPRO\Data\WP Data (Step 2)\Curvas de nivel Zona B - III.wpo

Min X: 600,967, Max X: 622,330, Min Y: 6,623,858, Max Y: 6,643,125, Width: 21,363 m, Height: 19,267 m

Project:

SSI\_Fase2

Description:

Potential wind farm site SSI

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Calculated:

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**PARK - Wind Data Analysis****Calculation:** B Center 1 Optimizado **Wind data:** A - B Center 1 Rev to WAsP; Hub height: 80.0**Site Coordinates**

UTM WGS 84 South Zone: 35 East: 609,551 North: 6,636,865

**Wind data**

Wind statistics

LS Zona B1 Central Area Mesoscale 2 to B3 - 80.00 m.wws

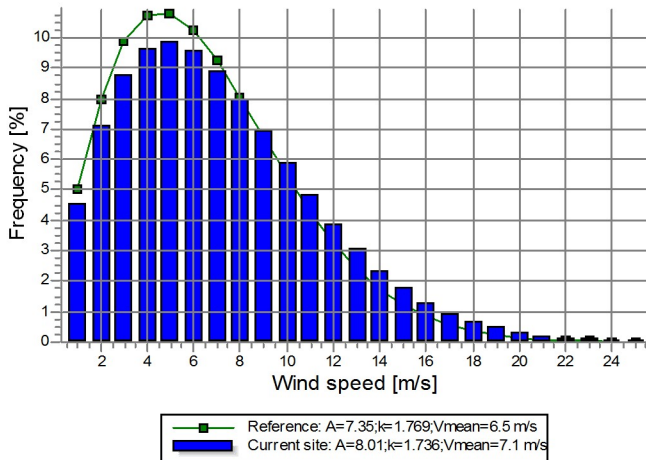
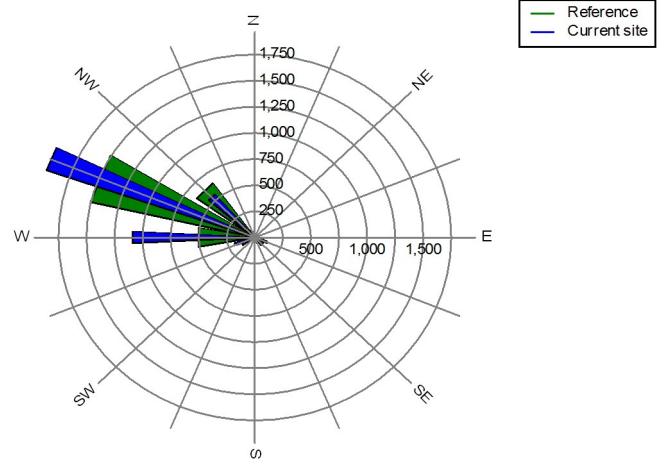
LS Zona B3 Mesoscale 1 - 80.00 m.wws

LS Zona B1 Central Area Mesoscale 1 to B3 - 80.00 m.wws

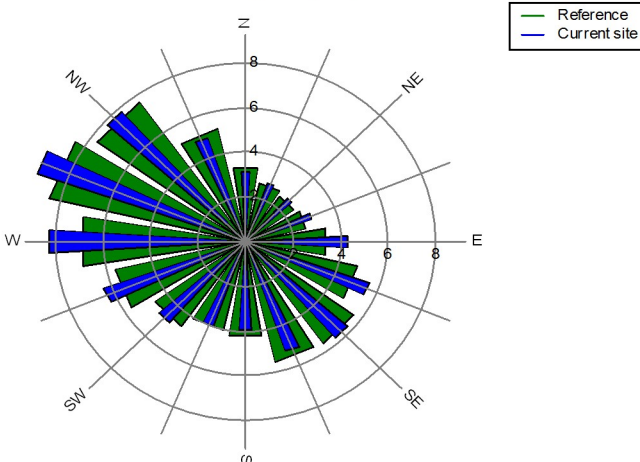
**Weibull Data**

Sector	Current site		k-	Frequency	Reference: Roughness class 1		Frequency
	A- parameter [m/s]	Wind speed [m/s]			A- parameter [m/s]	k- parameter	
0 N	3.41	3.08	1.482	1.2	3.64	1.483	1.5
1 NNE	3.07	2.75	1.568	0.9	3.03	1.628	0.9
2 NE	2.95	2.64	1.607	1.0	2.75	1.595	1.0
3 ENE	3.30	2.95	1.646	1.6	2.94	1.655	1.5
4 E	4.87	4.32	1.896	3.9	3.86	1.901	2.8
5 ESE	6.20	5.49	2.256	7.7	5.48	2.239	7.3
6 SE	6.45	5.71	2.229	5.2	6.29	2.347	6.0
7 SSE	5.81	5.21	1.619	2.5	6.13	1.628	3.0
8 S	4.38	3.96	1.486	1.6	4.69	1.487	1.9
9 SSW	4.51	4.01	1.807	1.6	4.60	1.881	1.8
10 SW	5.45	4.83	2.021	2.7	5.26	2.068	2.9
11 WSW	7.09	6.28	2.045	7.6	6.34	2.064	7.4
12 W	9.30	8.24	1.986	19.8	7.79	1.969	15.5
13 WNW	10.44	9.25	2.146	27.2	9.54	2.167	27.5
14 NW	8.76	7.76	2.041	12.1	8.68	2.096	14.9
15 NNW	5.53	4.91	1.877	3.4	5.82	1.891	4.1
All	8.01	7.14	1.736	100.0	7.35	1.769	100.0

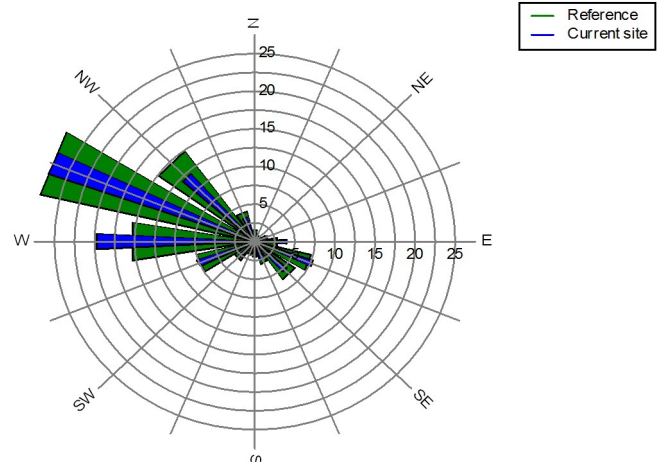
Weibull Distribution

Energy Rose (kWh/m<sup>2</sup>/year)

Mean wind speed (m/s)



Frequency (%)



Project:

SSI\_Fase2

Description:

Potential wind farm site SSI

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**PARK - Wind Data Analysis****Calculation:** B Center 1 Optimizado**Wind data:** A - B Center 1 Rev to WAsP; Hub height: 80.0**Site Coordinates**

UTM WGS 84 South Zone: 35 East: 612,655 North: 6,637,123

VESTAS V80-2.0MW 80.0 BC 1 - 40

**Wind data**

Wind statistics

LS Zona B1 Central Area Mesoscale 2 to B3 - 80.00 m.wws

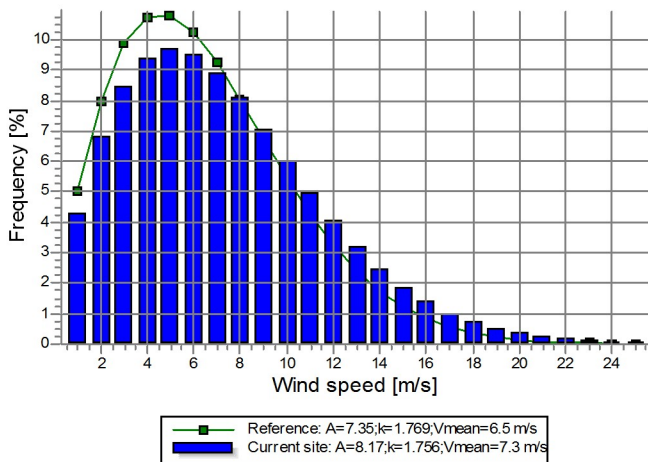
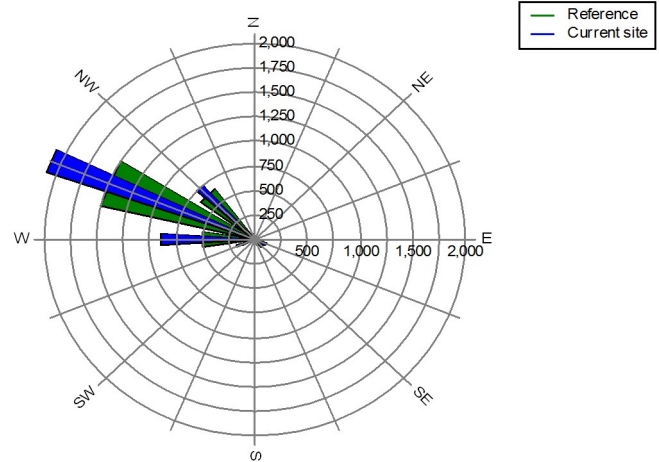
LS Zona B3 Mesoscale 1 - 80.00 m.wws

LS Zona B1 Central Area Mesoscale 1 to B3 - 80.00 m.wws

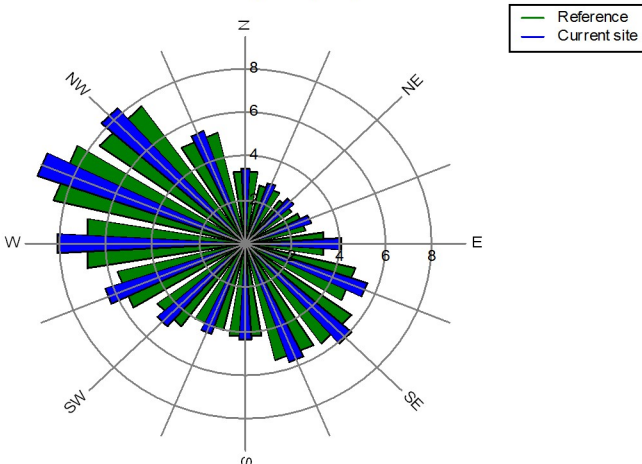
Distance  
[km]Weight  
[%]**Weibull Data**

Sector	Current site		Frequency [%]	Reference: Roughness class 1		Frequency [%]
	A- parameter [m/s]	Wind speed [m/s]		A- parameter [m/s]	k- parameter	
0 N	3.80	3.44	1.482	3.64	1.483	1.5
1 NNE	3.28	2.94	1.592	3.03	1.628	0.9
2 NE	3.05	2.74	1.604	2.75	1.595	1.0
3 ENE	3.32	2.97	1.654	2.94	1.655	1.5
4 E	4.64	4.12	1.881	3.86	1.901	2.8
5 ESE	6.22	5.51	2.240	5.48	2.239	7.3
6 SE	6.82	6.04	2.291	6.29	2.347	6.0
7 SSE	6.42	5.75	1.623	6.13	1.628	3.0
8 S	4.88	4.41	1.486	4.69	1.487	1.9
9 SSW	4.89	4.35	1.846	4.60	1.881	1.8
10 SW	5.74	5.08	2.053	5.26	2.068	2.9
11 WSW	7.15	6.34	2.061	6.34	2.064	7.4
12 W	9.07	8.04	1.975	7.79	1.969	15.5
13 WNW	10.65	9.43	2.166	9.54	2.167	27.5
14 NW	9.34	8.27	2.076	8.68	2.096	14.9
15 NNW	6.10	5.41	1.889	5.82	1.891	4.1
All	8.17	7.28	1.756	7.35	1.769	100.0

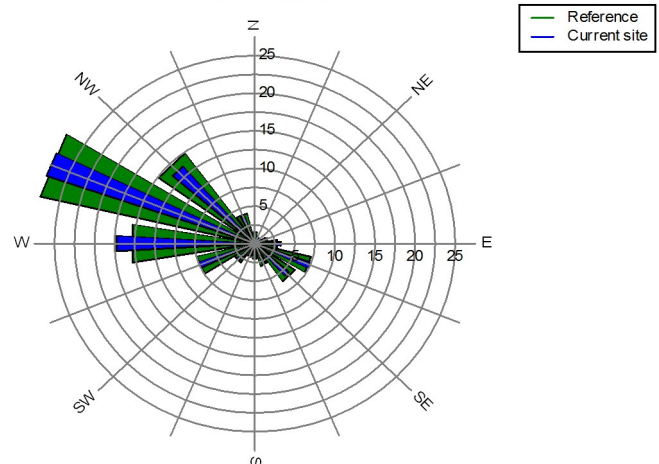
Weibull Distribution

Energy Rose (kWh/m<sup>2</sup>/year)

Mean wind speed (m/s)



Frequency (%)



Project: **SSI\_Fase2** Description: **Potential wind farm site SSI**

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## PARK - Park power curve

Calculation: B Center 1 Optimizado

Wind speed	Free WTGs	Park WTGs	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
[m/s]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4.5	3,963	3,520	3,356	2,683	2,609	3,550	3,542	3,540	3,612	3,786	3,434	2,656	2,674	3,546	3,538	3,533	3,616	3,792
5.5	8,437	7,891	7,608	6,803	6,481	7,939	7,933	7,933	8,018	8,225	7,782	6,786	6,528	7,932	7,927	7,924	8,023	8,232
6.5	14,788	13,881	13,422	12,157	11,790	13,960	13,942	13,935	14,079	14,430	13,730	12,122	11,879	13,947	13,932	13,921	14,087	14,442
7.5	23,472	22,011	21,320	19,332	18,805	22,148	22,106	22,082	22,317	22,887	21,810	19,282	18,946	22,125	22,091	22,059	22,329	22,907
8.5	34,580	32,472	31,481	28,664	27,912	32,684	32,606	32,564	32,909	33,738	32,205	28,592	28,089	32,653	32,584	32,531	32,929	33,767
9.5	47,474	44,913	43,547	40,096	39,044	45,177	45,088	45,049	45,475	46,474	44,543	40,000	39,240	45,140	45,061	45,008	45,498	46,509
10.5	61,012	58,438	56,663	53,116	51,767	58,693	58,646	58,637	59,062	60,048	57,953	53,010	51,941	58,654	58,620	58,596	59,087	60,082
11.5	74,398	72,139	70,064	67,064	65,629	72,381	72,364	72,364	72,741	73,593	71,661	66,976	65,745	72,346	72,344	72,326	72,752	73,614
12.5	86,420	84,728	82,544	80,854	79,638	84,945	84,914	84,912	85,197	85,832	84,419	80,789	79,671	84,915	84,900	84,885	85,213	85,854
13.5	96,439	95,478	93,155	93,178	92,269	95,610	95,610	95,620	95,771	96,118	95,272	93,150	92,317	95,599	95,601	95,606	95,781	96,131
14.5	104,607	104,123	101,565	102,596	102,044	104,138	104,217	104,267	104,331	104,485	103,883	102,593	102,105	104,138	104,216	104,263	104,322	104,483
15.5	108,559	108,257	105,828	107,684	107,468	108,317	108,313	108,313	108,358	108,465	108,233	107,673	107,486	108,313	108,310	108,308	108,361	108,468
16.5	109,740	109,659	107,244	109,583	109,522	109,697	109,696	109,696	109,704	109,724	109,682	109,580	109,525	109,696	109,696	109,695	109,705	109,724
17.5	110,000	109,968	107,556	109,999	109,989	110,000	110,000	110,000	110,000	110,000	110,000	109,999	109,989	110,000	110,000	110,000	110,000	110,000
18.5	110,000	109,968	107,556	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000
19.5	110,000	109,968	107,556	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000
20.5	110,000	109,968	107,556	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000
21.5	110,000	109,968	107,556	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000
22.5	110,000	109,968	107,556	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000
23.5	110,000	109,968	107,556	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000
24.5	110,000	109,968	107,556	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000
25.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

### Description:

The park power curve is similar to a WTG power curve, meaning that when a given wind speed appears in front of the park with same speed in the entire wind farm area (before influence from the park), the output from the park can be found in the park power curve. Another way to say this: The park power curve includes array losses, but do NOT include terrain given variations in the wind speed over the park area.

Measuring a park power curve is not as simple as measuring a WTG power curve due to the fact that the park power curve depends on the wind direction and that the same wind speed normally will not appear for the entire park area at the same time (only in very flat non-complex terrain). The idea with this version of the park power curve is not to use it for validation based on measurements. This would require at least 2 measurement masts at two sides of the park, unless only a few direction sectors should be tested, AND non complex terrain (normally only useable off shore). Another park power curve version for complex terrain is available in WindPRO.

### The park power curve can be used for:

1. Forecast systems, based on more rough (approximated) wind data, the park power curve would be an efficient way to make the connection from wind speed (and direction) to power.
2. Construction of duration curves, telling how often a given power output will appear, the park power curve can be used together with the average wind distribution for the Wind farm area in hub height. The average wind distribution can eventually be obtained based on the Weibull parameters for each WTG position. These are found at print menu: >Result to file< in the >Park result< which can be saved to file or copied to clipboard and pasted in Excel.
3. Calculation of wind energy index based on the PARK production (see below).
4. Estimation of the expected PARK production for an existing wind farm based on wind measurements at minimum 2 measurement masts at two sides of wind farm. The masts must be used for obtaining the free wind speed. The free wind speed is used in the simulation of expected energy production with the PARK power curve. This procedure will only work suitable in non complex terrains. For complex terrain another park power curve calculation is available in WindPRO (PPV-model).

### Note:

From the >Result to file< the >Wind Speeds Inside Wind farm< is also available. These can (e.g. via Excel) be used for extracting the wake induced reductions in measured wind speed.

Project: SSI\_Fase2  
Description: Potential wind farm site SSI

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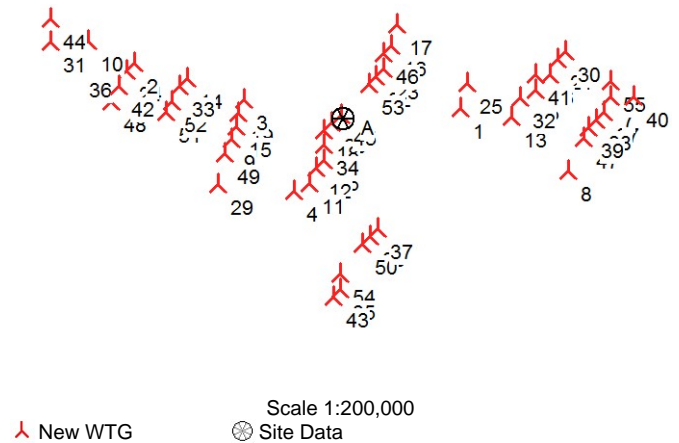
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Calculated:  
01/07/2011 10:44/2.7.487

## PARK - WTG distances

Calculation: B Center 1 Optimizado

### WTG distances

	Z	Nearest WTG	Z	Horizontal distance	Distance in
	[m]		[m]	[m]	rotor diameters
1	2,615.3	25	2,620.0	689	8.6
2	2,580.0	24	2,580.0	283	3.5
3	2,580.0	19	2,580.0	375	4.7
4	2,698.4	11	2,660.0	447	5.6
5	2,624.4	41	2,640.0	400	5.0
6	2,640.0	41	2,640.0	400	5.0
7	2,661.5	55	2,622.7	400	5.0
8	2,678.1	47	2,633.9	966	12.1
9	2,571.8	15	2,580.0	333	4.2
10	2,600.0	36	2,627.8	748	9.3
11	2,660.0	12	2,640.0	447	5.6
12	2,640.0	26	2,635.1	283	3.5
13	2,666.3	32	2,639.5	563	7.0
14	2,580.0	33	2,580.0	283	3.5
15	2,580.0	9	2,571.8	333	4.2
16	2,599.5	46	2,600.0	283	3.5
17	2,580.0	16	2,599.5	589	7.4
18	2,659.2	20	2,680.0	283	3.5
19	2,580.0	15	2,580.0	368	4.6
20	2,680.0	18	2,659.2	283	3.5
21	2,620.0	30	2,617.1	283	3.5
22	2,660.0	23	2,639.4	283	3.5
23	2,639.4	22	2,660.0	283	3.5
24	2,580.0	2	2,580.0	283	3.5
25	2,620.0	1	2,615.3	689	8.6
26	2,635.1	12	2,640.0	283	3.5
27	2,606.9	38	2,615.2	283	3.5
28	2,660.0	50	2,660.0	283	3.5
29	2,680.0	49	2,607.7	836	10.5
30	2,617.1	21	2,620.0	283	3.5
31	2,640.0	44	2,586.7	600	7.5
32	2,639.5	5	2,624.4	447	5.6
33	2,580.0	14	2,580.0	283	3.5
34	2,635.4	18	2,659.2	400	5.0
35	2,700.0	43	2,700.0	283	3.5
36	2,627.8	10	2,600.0	748	9.3
37	2,660.0	28	2,660.0	283	3.5
38	2,615.2	39	2,657.6	283	3.5
39	2,657.6	38	2,615.2	283	3.5
40	2,656.4	7	2,661.5	600	7.5
41	2,640.0	5	2,624.4	400	5.0
42	2,600.0	24	2,580.0	447	5.6
43	2,700.0	35	2,700.0	283	3.5
44	2,586.7	31	2,640.0	600	7.5
45	2,660.0	20	2,680.0	321	4.0
46	2,600.0	16	2,599.5	283	3.5
47	2,633.9	39	2,657.6	314	3.9
48	2,619.7	42	2,600.0	447	5.6
49	2,607.7	9	2,571.8	419	5.2
50	2,660.0	28	2,660.0	283	3.5
51	2,580.0	52	2,580.0	342	4.3
52	2,580.0	51	2,580.0	342	4.3
53	2,656.9	22	2,660.0	283	3.5
54	2,685.1	35	2,700.0	400	5.0
55	2,622.7	7	2,661.5	400	5.0



Project: SSI\_Fase2  
Description: Potential wind farm site SSI

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## PARK - RIX calculation

Calculation: B Center 1 Optimizado

### Assumptions

Radius for calculation 3,500 m  
Directional step 5 °  
Steepness threshold 40.0 % / 22 °  
Directional weight Equally distributed  
Height contours used Curvas de nivel Zona B3

### Reference sites

Terrain UTM WGS84 S Zone: 35

East	North	Z	Name of wind distribution	Type	Reference site RIX [%]
A 609,551	6,636,865	2643.0	B Center 1 Rev to WAsP	WAsP (WAsP 6-9 for Windows RVEA0011 1, 0, 0, 13)	0.5

### WTG sites

Terrain	East	North	Z	Reference site RIX [%]	WTG RIX [%]	Delta RIX (WTG site - Reference site) [%]
UTM WGS84 S Zone: 35						
1 A	612,655	6,637,123	2,615.3	0.5	0.4	-0.1
2 A	604,038	6,638,387	2,580.0	0.5	11.6	11.1
3 A	606,925	6,637,403	2,580.0	0.5	5.2	4.7
4 A	608,238	6,634,987	2,698.4	0.5	1.0	0.5
5 A	614,638	6,637,587	2,624.4	0.5	1.0	0.6
6 A	615,038	6,637,987	2,640.0	0.5	2.0	1.5
7 A	616,638	6,637,387	2,661.5	0.5	1.0	0.5
8 A	615,475	6,635,438	2,678.1	0.5	0.7	0.2
9 A	606,600	6,636,383	2,571.8	0.5	2.6	2.2
10 A	602,838	6,638,987	2,600.0	0.5	12.9	12.4
11 A	608,638	6,635,187	2,660.0	0.5	0.7	0.2
12 A	608,838	6,635,587	2,640.0	0.5	0.5	0.0
13 A	613,990	6,636,882	2,666.3	0.5	0.3	-0.2
14 A	605,438	6,637,987	2,580.0	0.5	8.1	7.6
15 A	606,726	6,636,691	2,580.0	0.5	3.0	2.5
16 A	610,838	6,638,787	2,599.5	0.5	2.5	2.1
17 A	610,990	6,639,356	2,580.0	0.5	3.7	3.2
18 A	609,038	6,636,587	2,659.2	0.5	0.5	0.0
19 A	606,789	6,637,054	2,580.0	0.5	3.6	3.2
20 A	609,238	6,636,787	2,680.0	0.5	0.5	0.0
21 A	615,238	6,638,387	2,620.0	0.5	1.7	1.3
22 A	610,438	6,637,987	2,660.0	0.5	0.8	0.4
23 A	610,638	6,638,187	2,639.4	0.5	1.3	0.9
24 A	603,838	6,638,187	2,580.0	0.5	10.2	9.7
25 A	612,838	6,637,787	2,620.0	0.5	1.1	0.6
26 A	609,038	6,635,787	2,635.1	0.5	0.3	-0.2
27 A	616,438	6,636,987	2,606.9	0.5	0.7	0.2
28 A	610,238	6,633,787	2,660.0	0.5	0.3	-0.2
29 A	606,238	6,635,187	2,680.0	0.5	1.9	1.5
30 A	615,438	6,638,587	2,617.1	0.5	2.0	1.6
31 A	601,838	6,638,987	2,640.0	0.5	8.7	8.3
32 A	614,238	6,637,387	2,639.5	0.5	0.9	0.5
33 A	605,238	6,637,787	2,580.0	0.5	6.9	6.4
34 A	609,038	6,636,187	2,635.4	0.5	0.2	-0.2
35 A	609,438	6,632,387	2,700.0	0.5	1.7	1.2
36 A	602,520	6,638,310	2,627.8	0.5	9.4	9.0
37 A	610,438	6,633,987	2,660.0	0.5	0.3	-0.2
38 A	616,238	6,636,787	2,615.2	0.5	0.6	0.1
39 A	616,038	6,636,587	2,657.6	0.5	0.5	0.0
40 A	617,238	6,637,387	2,656.4	0.5	0.6	0.2
41 A	614,638	6,637,987	2,640.0	0.5	1.5	1.1
42 A	603,638	6,637,787	2,600.0	0.5	8.3	7.8
43 A	609,238	6,632,187	2,700.0	0.5	1.8	1.3
44 A	601,838	6,639,587	2,586.7	0.5	11.8	11.3
45 A	609,503	6,636,968	2,660.0	0.5	0.5	0.0
46 A	610,638	6,638,587	2,600.0	0.5	2.3	1.8
47 A	615,911	6,636,300	2,633.9	0.5	0.3	-0.1
48 A	603,438	6,637,387	2,619.7	0.5	5.9	5.4
49 A	606,426	6,636,002	2,607.7	0.5	2.3	1.8
50 A	610,038	6,633,587	2,660.0	0.5	0.4	-0.1
51 A	604,873	6,637,088	2,580.0	0.5	4.7	4.3
52 A	605,038	6,637,387	2,580.0	0.5	5.3	4.8
53 A	610,238	6,637,787	2,656.9	0.5	0.8	0.3
54 A	609,438	6,632,787	2,685.1	0.5	1.9	1.4

To be continued on next page...

Project:

SSI\_Fase2

Description:

Potential wind farm site SSI

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**PARK - RIX calculation****Calculation:** B Center 1 Optimizado

...continued from previous page

Terrain	UTM WGS84 S Zone: 35	East	North	Z	Reference site RIX	WTG RIX	Delta RIX (WTG site - Reference site)
	UTM WGS84 S Zone: 35			[m]	[%]	[%]	[%]
55 A	616,638	6,637,787	2,622.7		0.5	1.2	0.8

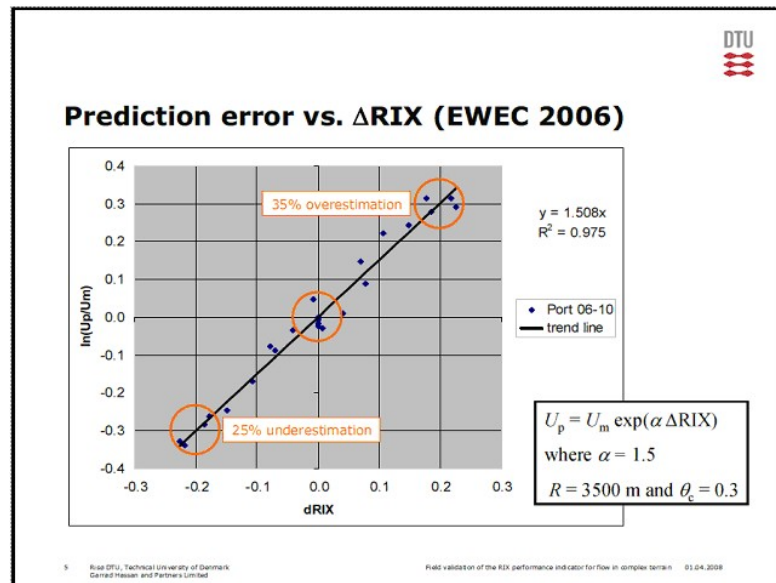
Project: SSI\_Fase2  
Description: Potential wind farm site SSI

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## PARK - RIX calculation

### Calculation: B Center 1 Optimizado

Latest research /Risø/ show that the threshold in RIX calculation typically work best with 40% (new default), and that delta Rix within +/- 5% should not give corrections. Cross predictions based on more mast can fine tune the threshold, see Cross predictor tool in WindPRO Meteo Analyzer. In WindPRO LOSS&&UNCERTAINTY module, RIX correction can be calculated automatically as a bias based on most recent recommended correction formulas, which can be found in EWEC2006 && 08 papers on Rix from Risø, see extract below:

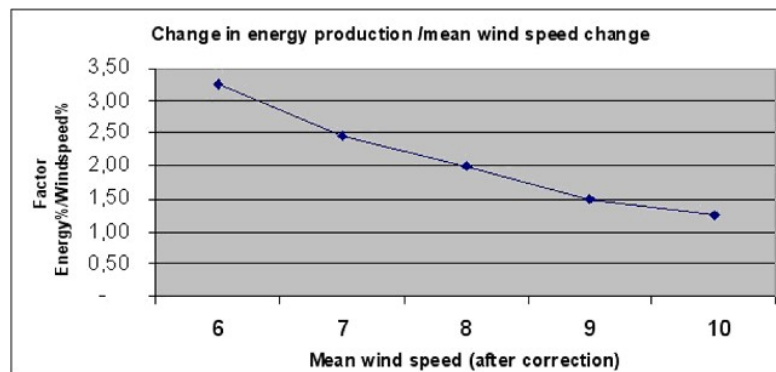


The main conclusion based on use of the RIX method is that if both reference site (measurement mast) and predicted site (WTG) are equally rugged (Delta RIX < 5%), very small calculation errors are expected.

If reference site (measurement mast) is very rugged, e.g. RIX = 0.2 and predicted site (WTG) are less rugged (e.g. RIX = 0), Delta RIX will be -0.2 and according to the graph, 30% too low wind speed prediction at WTG site could be expected. This could lead to around 60%\*) too low calculated energy production.

If the reference site is less rugged, e.g. RIX = 0, and the predicted site (WTG) are very rugged (e.g. RIX = 0.2), Delta RIX will be +0.2, and according to the graph, 30% too high wind speed prediction at WTG site could be expected. This could lead to around 60%\*) too high calculated energy production.

\*) Doubling of energy prediction error based on mean wind speed error is a rough conversion, which holds for wind speeds around 8 m/s. At 6-7 m/s tripling is more right, while only 1.5 factors should be used for 9 m/s, see graph below based on a typical WTG.



Source: EWEC06 paper:

#### IMPROVING WAsP PREDICTIONS IN (TOO) COMPLEX TERRAIN

Niels G. Mortensen, Anthony J. Bowen and Ioannis Antoniou  
Wind Energy Department, Risø National Laboratory

Project:

SSI\_Fase2

Description:

Potential wind farm site SSI

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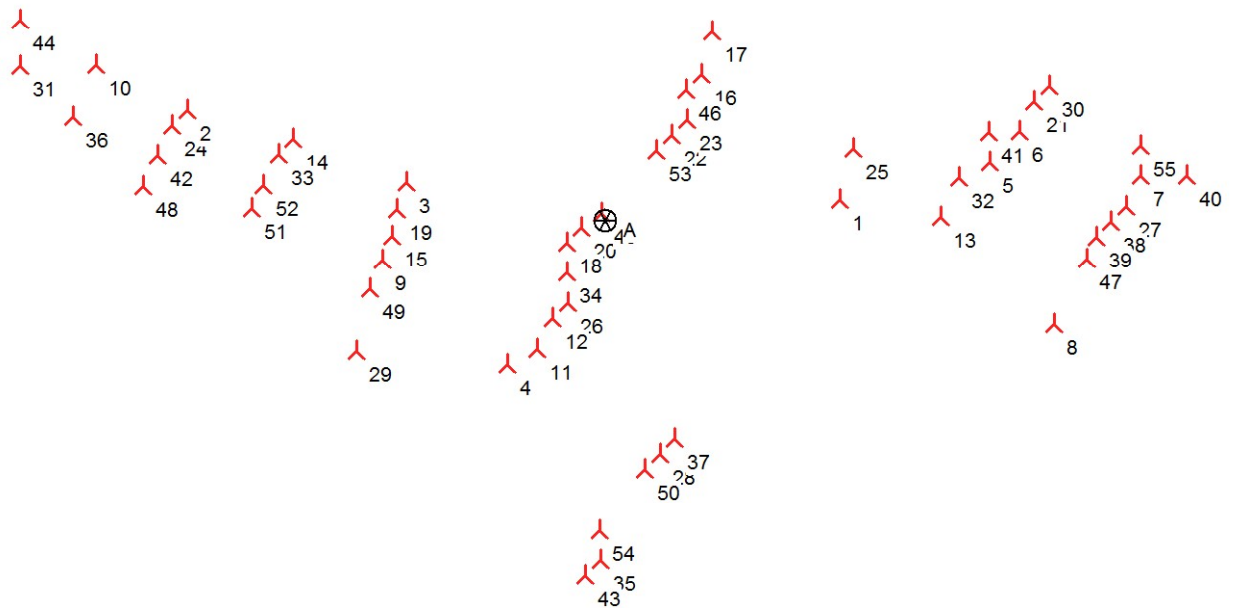
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**PARK - Mapa****Calculation:** B Center 1 Optimizado

Map: Mapa en blanco, Print scale 1:100,000, Map center UTM WGS 84 South Zone: 35 East: 609,538 North: 6,635,887



New WTG



Site Data

**LESOTHO POWER GENERATION MASTER PLAN**

**PROJECT # LEC/GEN/1-2009**

**FINAL MILESTONES REPORT**

**VOLUME 1 - PART 1.2**

**WIND POWER GENERATION OPTION**

**APPENDIX 1.2.3**

**B CENTER 2 WIND FARM**



July 2011

## HYPERLINK

- a. Area: B

Hyperlink: [c- Area B Potential Sites.KMZ](#)

- b. RPD: B – Center 2 proposed Wind Farm

Hyperlink: [g- B Center 2.kmz](#)

Project: **SSI\_Fase2**  
 Description: **Potential wind farm site SSI**

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## PARK - Main Result

Calculation: B Center 2 optimizado

Wake Model N.O. Jensen (RISØ/EMD)

### Calculation Settings

Air density calculation mode Individual per WTG  
 Result for WTG at hub altitude 0.908 kg/m³ to 0.915 kg/m³  
 Air density relative to standard 74.6 %  
 Hub altitude above sea level (asl) 2,700.0 m to 2,774.0 m  
 Annual mean temperature at hub alt. 6.8 °C to 7.2 °C  
 Pressure at WTGs 729.7 hPa to 736.4 hPa

### Wake Model Parameters

From angle To angle Terrain type Wake Decay Constant  
 [°] [°]  
 -180.0 180.0 Open farmland 0.075

### Wake calculation settings

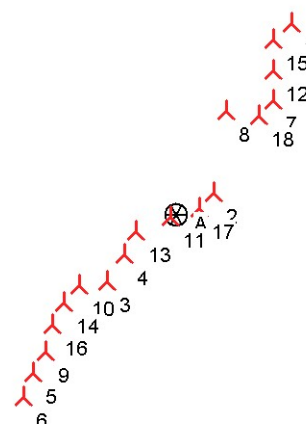
Angle [°] Wind speed [m/s]  
 start end step start end step  
 0.5 360.0 1.0 0.5 30.5 1.0

### Wind data

Wind statistics Distance Weight  
 [km] [%]  
 LS Zona B3 Mesoscale 1 - 80.00 m.wws 7 30  
 LS Zona B1 Central Area Mesoscale 2 to B3 - 80.00 m.wws 3 70

WASP version WASP 6-9 for Windows RVEA0011 1, 0, 0, 13

WASP parameters Detailed information at the end of "Main results"



Scale 1:100,000

Site Data

New WTG

## Key results for height 80.0 m above ground level

Terrain UTM WGS84 S Zone: 35

East	North	Name of wind distribution	Type	Wind energy [kWh/m²]	Mean wind speed [m/s]	Equivalent roughness
A 619,732	6,635,497	B Center 2 to WASP	WASP (WASP 6-9 for Windows RVEA0011 1, 0, 0, 13)	3,905	7.7	0.4

## 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 <sup>a)</sup>			Full load hours [Hours/year]	Mean wind speed @ hub height [m/s]
					Capacity factor [%]	Mean WTG result [MWh/y]			
Wind farm	107,174.6	96,457.1	108,122.2	99.1	30.6	5,358.7		2,679	8.2

<sup>a)</sup> Based on Result-10.0%

## Calculated Annual Energy for each of 18 new WTGs with total 36.0 MW rated power

WTG type	Terrain	Valid	Manufact.	Type-generator	Power, rated [kW]	Rotor diameter [m]	Hub height [m]	Power curve		Annual Energy		Park Efficiency [%]	Mean wind speed [m/s]
								Creator	Name	Result [MWh]	Result-10.0% [MWh]		
1 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0		5,760.1	5,184	99.5	8.01
2 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0		6,676.3	6,009	98.9	8.94
3 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0		6,298.1	5,668	98.1	8.60
4 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0		6,328.4	5,696	99.6	8.53
5 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0		5,857.7	5,272	99.6	8.09
6 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0		6,040.9	5,437	99.9	8.24
7 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0		5,958.4	5,363	98.8	8.22
8 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0		5,821.4	5,239	99.4	8.08
9 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0		6,081.7	5,473	99.5	8.30
10 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0		6,078.1	5,470	99.4	8.30
11 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0		5,426.3	4,884	99.2	7.73
12 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0		5,928.9	5,336	99.6	8.15
13 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0		6,062.6	5,456	99.6	8.27
14 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0		5,944.2	5,350	99.6	8.16
15 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0		5,825.5	5,243	99.6	8.07

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Project: **SSI\_Fase2**  
 Description: Potential wind farm site SSI

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## PARK - Main Result

Calculation: B Center 2 optimizado

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	WTG type			Power, rated	Rotor diameter	Hub height	Power curve		Annual Energy		Park	
	Terrain	Valid	Manufact.				Type-generator	Creator	Name	Result	Result-10.0%	Efficiency
				[kW]	[m]	[m]			[MWh]	[MWh]	[%]	[m/s]
16 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,985.7	5,387	99.8	8.19
17 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,653.5	5,088	98.1	7.99
18 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,446.7	4,902	96.0	7.91

## WTG siting

### UTM WGS84 S Zone: 35

	East	North	Z	Row data/Description
	UTM WGS84 S Zone: 35		[m]	
1 New	621,281	6,638,006	2,645.1	VESTAS V80-2.0MW 2000 80.0 BC 2 - 18
2 New	620,238	6,635,787	2,694.0	VESTAS V80-2.0MW 2000 80.0 BC 2 - 12
3 New	618,809	6,634,637	2,632.5	VESTAS V80-2.0MW 2000 80.0 BC 2 - 07
4 New	619,038	6,634,987	2,640.0	VESTAS V80-2.0MW 2000 80.0 BC 2 - 08
5 New	617,816	6,633,448	2,662.6	VESTAS V80-2.0MW 2000 80.0 BC 2 - 02
6 New	617,681	6,633,125	2,659.6	VESTAS V80-2.0MW 2000 80.0 BC 2 - 01
7 New	621,038	6,636,987	2,627.4	VESTAS V80-2.0MW 2000 80.0 BC 2 - 15
8 New	620,409	6,636,857	2,658.8	VESTAS V80-2.0MW 2000 80.0 BC 2 - 13
9 New	617,987	6,633,718	2,657.2	VESTAS V80-2.0MW 2000 80.0 BC 2 - 03
10 New	618,438	6,634,587	2,640.0	VESTAS V80-2.0MW 2000 80.0 BC 2 - 06
11 New	619,650	6,635,481	2,620.0	VESTAS V80-2.0MW 2000 80.0 BC 2 - 10
12 New	621,038	6,637,387	2,637.3	VESTAS V80-2.0MW 2000 80.0 BC 2 - 16
13 New	619,197	6,635,288	2,640.0	VESTAS V80-2.0MW 2000 80.0 BC 2 - 09
14 New	618,228	6,634,357	2,638.2	VESTAS V80-2.0MW 2000 80.0 BC 2 - 05
15 New	621,038	6,637,787	2,660.2	VESTAS V80-2.0MW 2000 80.0 BC 2 - 17
16 New	618,077	6,634,077	2,620.0	VESTAS V80-2.0MW 2000 80.0 BC 2 - 04
17 New	620,038	6,635,587	2,643.2	VESTAS V80-2.0MW 2000 80.0 BC 2 - 11
18 New	620,838	6,636,787	2,637.8	VESTAS V80-2.0MW 2000 80.0 BC 2 - 14

## Non-default WAsP parameters:

WAsP parameter	Minimum	Maximum	Default	Current value
Std. height #4	5.0000	200.0000	100.0000	80.0000

Project: **SSI\_Fase2**  
 Description: **Potential wind farm site SSI**

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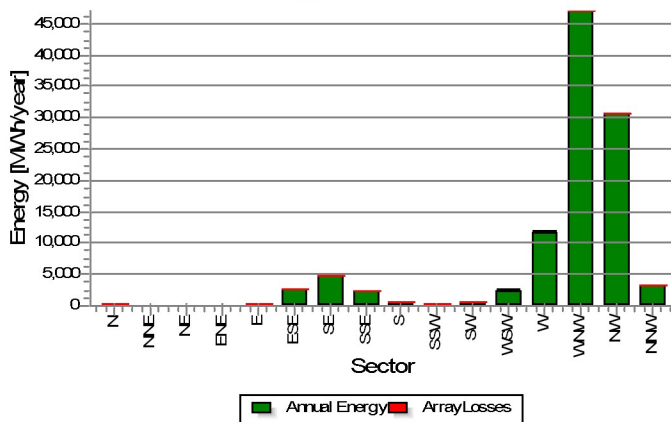
## PARK - Production Analysis

**Calculation:** B Center 2 optimizado **WTG:** All new WTGs, Air density varies with WTG position 0.908 kg/m<sup>3</sup> - 0.915 kg/m<sup>3</sup>

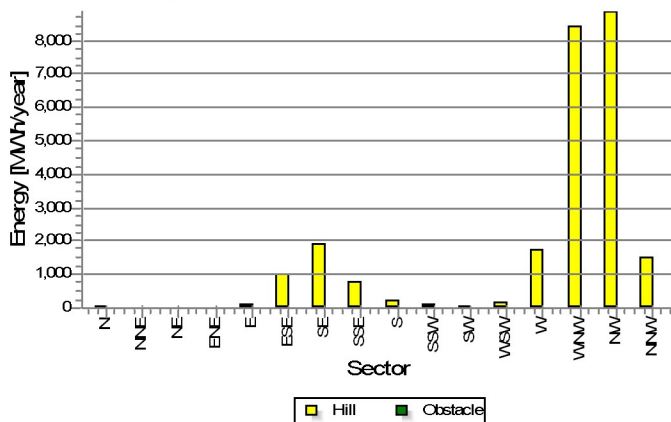
### Directional Analysis

Sector	0 N	1 NNE	2 NE	3 ENE	4 E	5 ESE	6 SE	7 SSE	8 S	9 SSW	10 SW	11 WSW	12 W	13 WNW	14 NW	15 NNW	Total
Roughness based energy [MWh]	169.7	43.9	27.2	62.2	304.2	1,792.8	2,763.2	1,609.1	473.5	314.8	637.0	2,499.1	10,264.7	38,548.3	21,764.0	1,854.8	83,128.5
+Increase due to hills [MWh]	74.9	8.4	4.0	8.5	95.8	1,009.5	1,896.7	781.1	211.3	96.2	74.7	179.0	1,726.6	8,450.7	8,878.2	1,498.2	24,993.6
-Decrease due to array losses [MWh]	16.9	14.8	8.9	7.3	15.5	21.2	0.0	2.0	30.9	88.9	148.0	202.9	245.6	142.5	0.0	2.2	947.6
<b>Resulting energy [MWh]</b>	<b>227.7</b>	<b>37.6</b>	<b>22.3</b>	<b>63.4</b>	<b>384.5</b>	<b>2,781.1</b>	<b>4,659.9</b>	<b>2,388.2</b>	<b>653.9</b>	<b>322.1</b>	<b>563.7</b>	<b>2,475.2</b>	<b>11,745.6</b>	<b>46,856.5</b>	<b>30,642.2</b>	<b>3,350.8</b>	<b>107,174.6</b>
Specific energy [kWh/m <sup>2</sup> ]																	1,185
Specific energy [kWh/kW]																	2,977
Increase due to hills [%]	44.2	19.2	14.6	13.6	31.5	56.3	68.6	48.5	44.6	30.5	11.7	7.2	16.8	21.9	40.8	80.8	30.07
Decrease due to array losses [%]	6.9	28.2	28.6	10.4	3.9	0.8	0.0	0.1	4.5	21.6	20.8	7.6	2.0	0.3	0.0	0.1	0.88
Utilization [%]	33.7	23.9	20.9	28.5	36.3	39.8	38.9	31.3	33.2	30.4	30.8	34.7	28.8	21.9	22.9	30.0	24.3
Operational [Hours/year]	87	54	55	84	169	469	542	266	139	121	175	380	905	2,273	1,544	323	7,587
Full Load Equivalent [Hours/year]	6	1	1	2	11	77	129	66	18	9	16	69	326	1,302	851	93	2,977

Energy vs. sector



Impact of hills and obstacles vs. sector



Project: SSI\_Fase2  
Description: Potential wind farm site SSI

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## PARK - Power Curve Analysis

**Calculation:** B Center 2 optimizado **WTG:** 1 - VESTAS V80-2.0MW 2000 80.0 !O! Mode 0, Hub height: 80.0 m

**Name:** Mode 0  
**Source:** Manufacturer

Source/Date	Created by	Created	Edited	Stop wind speed	Power control	CT curve type
12/4/2009	EMD	12/07/2010	16/07/2010	25.0	Pitch	User defined

Estimated power curve based on item n. 0004-7878 V03 04-12-2009.

**HP curve comparison** - Note: For standard air density and weibull k parameter = 2

Vmean	[m/s]	5	6	7	8	9	10
HP value	[MWh]	2,341	3,854	5,431	6,968	8,268	9,419
VESTAS V80-2.0MW 2000 80.0 !O! Mode 0	[MWh]	2,580	4,109	5,690	7,175	8,483	9,573
Check value	[%]	-9	-6	-5	-3	-3	-2

The table shows comparison between annual energy production calculated on basis of simplified "HP-curves" which assume that all WTGs performs quite similar - only specific power loading (kW/m<sup>2</sup>) and single/dual speed or stall/pitch decides the calculated values. Productions are without wake losses.

For further details, ask at the Danish Energy Agency for project report J.nr. 51171/00-0016 or see WindPRO manual chapter 3.5.2.

The method is refined in EMD report "20 Detailed Case Studies comparing Project Design Calculations and actual Energy Productions for Wind Energy Projects worldwide", jan 2003.

Use the table to evaluate if the given power curve is reasonable - if the check value are lower than -5%, the power curve probably is too optimistic due to uncertainty in power curve measurement.

### Power curve

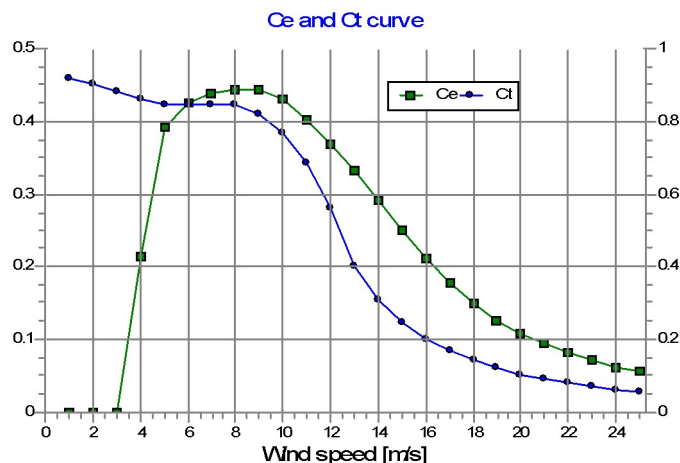
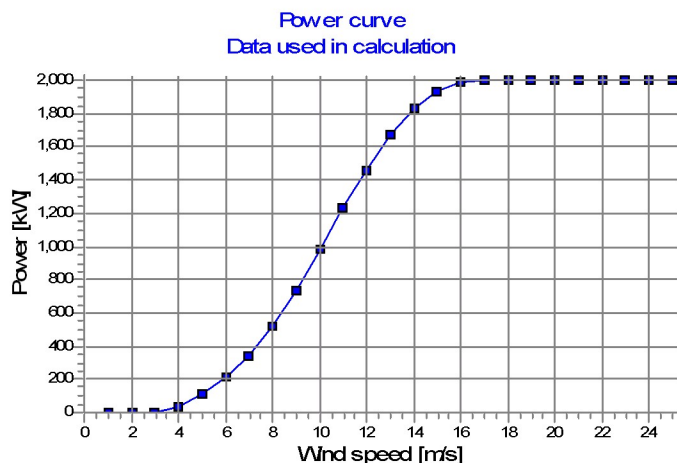
Original data from Windcat, Air density: 1.225 kg/m<sup>3</sup>

Wind speed	Power	Ce	Wind speed	Ct curve
[m/s]	[kW]		[m/s]	
4.0	66.0	0.33	4.0	0.86
5.0	156.0	0.41	5.0	0.84
6.0	285.0	0.43	6.0	0.84
7.0	467.0	0.44	7.0	0.84
8.0	706.0	0.45	8.0	0.84
9.0	1,001.0	0.45	9.0	0.82
10.0	1,329.0	0.43	10.0	0.77
11.0	1,652.0	0.40	11.0	0.68
12.0	1,892.0	0.36	12.0	0.56
13.0	1,982.0	0.29	13.0	0.40
14.0	2,000.0	0.24	14.0	0.31
15.0	2,000.0	0.19	15.0	0.25
16.0	2,000.0	0.16	16.0	0.20
17.0	2,000.0	0.13	17.0	0.17
18.0	2,000.0	0.11	18.0	0.14
19.0	2,000.0	0.09	19.0	0.12
20.0	2,000.0	0.08	20.0	0.10
21.0	2,000.0	0.07	21.0	0.09
22.0	2,000.0	0.06	22.0	0.08
23.0	2,000.0	0.05	23.0	0.07
24.0	2,000.0	0.05	24.0	0.06
25.0	2,000.0	0.04	25.0	0.06

### Power, Efficiency and energy vs. wind speed

Data used in calculation, Air density: 0.913 kg/m<sup>3</sup> New WindPRO method (adjusted IEC method, improved to match turbine control) <RECOMMENDED>

Wind speed	Power	Ce	Interval	Energy	Acc. Energy	Relative
[m/s]	[kW]		[m/s]	[MWh]	[MWh]	[%]
1.0	0.0	0.00	0.50-1.50	0.0	0.0	0.0
2.0	0.0	0.00	1.50-2.50	0.0	0.0	0.0
3.0	0.0	0.00	2.50-3.50	0.0	0.0	0.0
4.0	31.3	0.21	3.50-4.50	27.8	27.8	0.5
5.0	112.6	0.39	4.50-5.50	88.2	116.1	2.0
6.0	210.3	0.42	5.50-6.50	162.9	279.0	4.8
7.0	344.0	0.44	6.50-7.50	253.8	532.8	9.2
8.0	521.0	0.44	7.50-8.50	352.6	885.4	15.4
9.0	739.3	0.44	8.50-9.50	445.0	1,330.4	23.1
10.0	985.0	0.43	9.50-10.50	515.5	1,845.8	32.0
11.0	1,231.1	0.40	10.50-11.50	555.3	2,401.1	41.7
12.0	1,460.5	0.37	11.50-12.50	561.9	2,963.0	51.4
13.0	1,671.7	0.33	12.50-13.50	537.6	3,500.7	60.8
14.0	1,832.2	0.29	13.50-14.50	490.5	3,991.1	69.3
15.0	1,937.1	0.25	14.50-15.50	425.1	4,416.2	76.7
16.0	1,987.6	0.21	15.50-16.50	349.3	4,765.5	82.7
17.0	2,000.0	0.18	16.50-17.50	276.5	5,042.0	87.5
18.0	2,000.0	0.15	17.50-18.50	213.1	5,255.0	91.2
19.0	2,000.0	0.13	18.50-19.50	160.5	5,415.6	94.0
20.0	2,000.0	0.11	19.50-20.50	118.3	5,533.9	96.1
21.0	2,000.0	0.09	20.50-21.50	85.3	5,619.3	97.6
22.0	2,000.0	0.08	21.50-22.50	60.2	5,679.4	98.6
23.0	2,000.0	0.07	22.50-23.50	41.5	5,720.9	99.3
24.0	2,000.0	0.06	23.50-24.50	28.0	5,748.9	99.8
25.0	2,000.0	0.06	24.50-25.50	11.2	5,760.1	100.0



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## PARK - Terrain

**Calculation:** B Center 2 optimizado **Site Data:** A - B Center 2 to WAsP

### Obstacles:

0 Obstacles used

### Roughness:

Calculation uses following MAP files:

\\Server-dell\modeliza\Proyecto SSI\_2\03 WINDPRO\Data\WP Data (Step 2)\ROUGHNESSLINE ZonaB3.wpo

Min X: 599,033, Max X: 623,924, Min Y: 6,621,642, Max Y: 6,644,342, Width: 24,891 m, Height: 22,700 m

### Orography:

Calculation uses following MAP files:

\\Server-dell\modeliza\Proyecto SSI\_2\03 WINDPRO\Data\WP Data (Step 2)\Curvas de nivel Zona B - III.wpo

Min X: 600,967, Max X: 622,330, Min Y: 6,623,858, Max Y: 6,643,125, Width: 21,363 m, Height: 19,267 m

Project: SSI\_Fase2  
Description: Potential wind farm site SSI

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## PARK - Wind Data Analysis

Calculation: B Center 2 optimizado Wind data: A - B Center 2 to WAsP; Hub height: 80.0

### Site Coordinates

UTM WGS 84 South Zone: 35 East: 619,732 North: 6,635,497

### Wind data

Wind statistics

LS Zona B3 Mesoscale 1 - 80.00 m.wws  
LS Zona B1 Central Area Mesoscale 2 to B3 - 80.00 m.wws

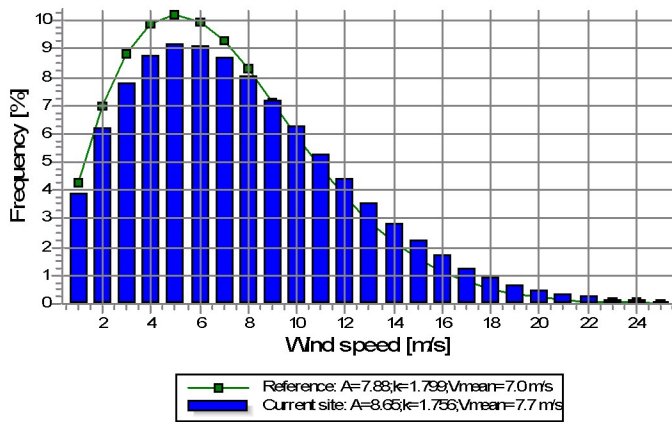
Distance [km] Weight [%]

7 30  
3 70

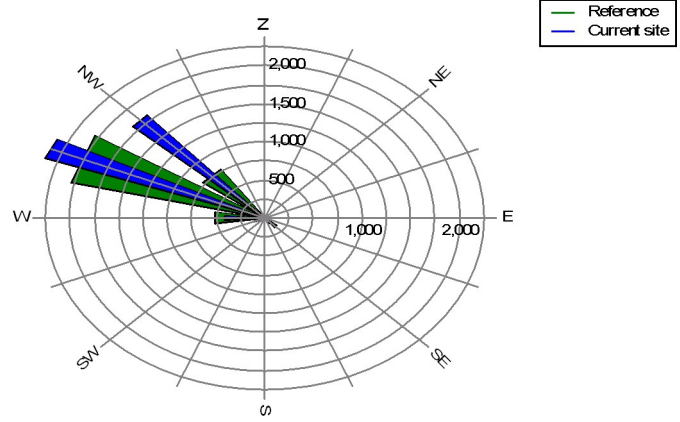
### Weibull Data

Sector	Current site		Frequency [%]	Reference: Roughness class 1		Frequency [%]
	A- parameter [m/s]	Wind speed [m/s]		A- parameter [m/s]	k- parameter	
0 N	3.95	3.58	1.455	3.75	1.478	1.2
1 NNE	2.98	2.68	1.561	3.06	1.579	0.8
2 NE	2.55	2.29	1.564	2.72	1.560	0.9
3 ENE	2.93	2.62	1.686	3.12	1.682	1.3
4 E	4.18	3.70	1.998	4.27	2.078	2.5
5 ESE	5.98	5.30	2.318	5.58	2.413	6.5
6 SE	7.02	6.23	2.424	6.14	2.456	6.2
7 SSE	6.76	6.05	1.643	5.96	1.679	3.2
8 S	5.03	4.53	1.529	4.62	1.468	1.8
9 SSW	4.81	4.27	1.982	4.72	1.981	1.6
10 SW	4.93	4.37	1.982	5.26	1.978	2.6
11 WSW	6.11	5.41	2.049	6.50	2.044	6.1
12 W	8.07	7.15	1.986	8.15	2.015	13.9
13 WNW	10.93	9.68	2.170	10.18	2.242	31.5
14 NW	10.89	9.64	2.174	9.16	2.153	16.1
15 NNW	6.88	6.11	1.885	6.04	1.940	3.8
All	8.65	7.70	1.756	7.88	1.799	100.0

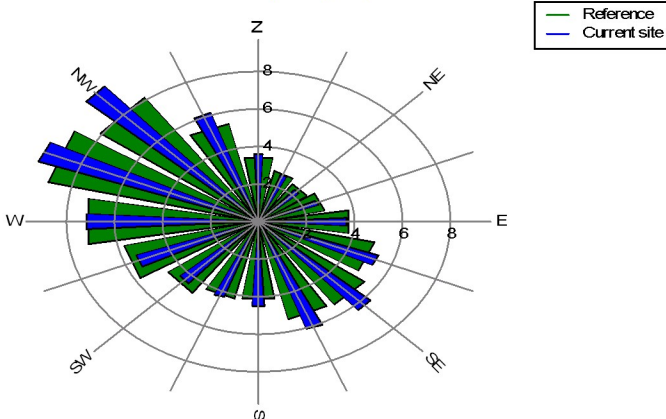
Weibull Distribution



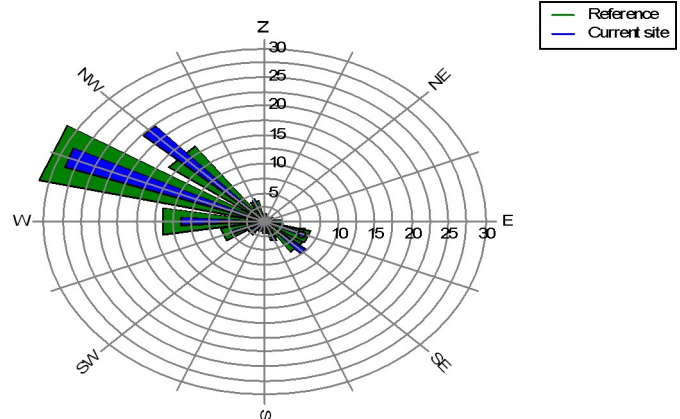
Energy Rose (kWh/m<sup>2</sup>/year)



Mean wind speed (m/s)



Frequency (%)



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## PARK - Wind Data Analysis

Calculation: B Center 2 optimizado Wind data: A - B Center 2 to WAsP; Hub height: 80.0

### Site Coordinates

UTM WGS 84 South Zone: 35 East: 621,281 North: 6,638,006  
 VESTAS V80-2.0MW 2000 80.0 BC 2 - 18

### Wind data

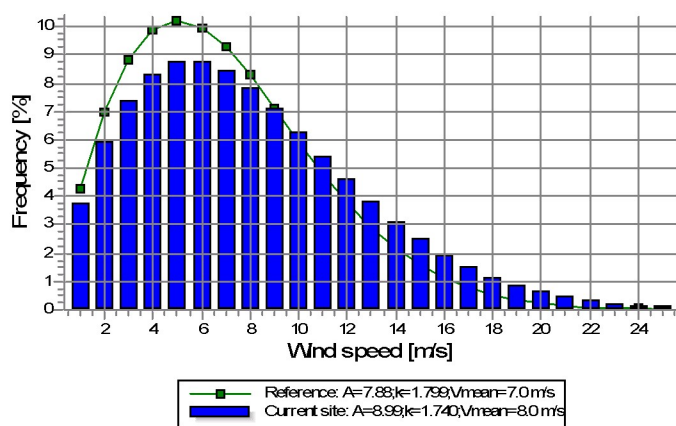
Wind statistics

LS Zona B3 Mesoscale 1 - 80.00 m.wws 7 30  
 LS Zona B1 Central Area Mesoscale 2 to B3 - 80.00 m.wws 3 70

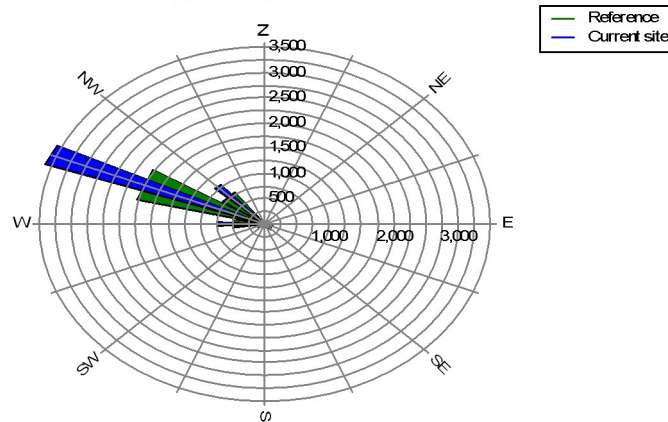
### Weibull Data

Sector	Current site		Frequency [%]	Reference: Roughness class 1		Frequency [%]
	A- parameter [m/s]	Wind speed [m/s]		A- parameter [m/s]	k- parameter	
0 N	3.55	3.21	1.475	3.75	1.478	1.2
1 NNE	2.82	2.53	1.580	3.06	1.579	0.8
2 NE	2.66	2.39	1.564	2.72	1.560	0.9
3 ENE	3.20	2.86	1.650	3.12	1.682	1.3
4 E	4.70	4.17	1.986	4.27	2.078	2.5
5 ESE	6.57	5.82	2.389	5.58	2.413	6.5
6 SE	6.93	6.14	2.311	6.14	2.456	6.2
7 SSE	5.99	5.36	1.623	5.96	1.679	3.2
8 S	4.43	4.00	1.498	4.62	1.468	1.8
9 SSW	4.36	3.87	1.986	4.72	1.981	1.6
10 SW	5.04	4.47	1.971	5.26	1.978	2.6
11 WSW	6.69	5.93	1.998	6.50	2.044	6.1
12 W	9.10	8.07	1.982	8.15	2.015	13.9
13 WNW	11.82	10.47	2.209	10.18	2.242	31.5
14 NW	10.19	9.03	2.088	9.16	2.153	16.1
15 NNW	6.11	5.43	1.854	6.04	1.940	3.8
All	8.99	8.01	1.740	7.88	1.799	100.0

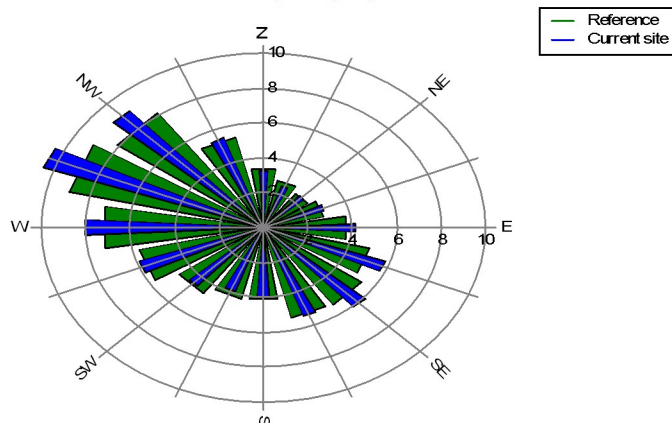
Weibull Distribution



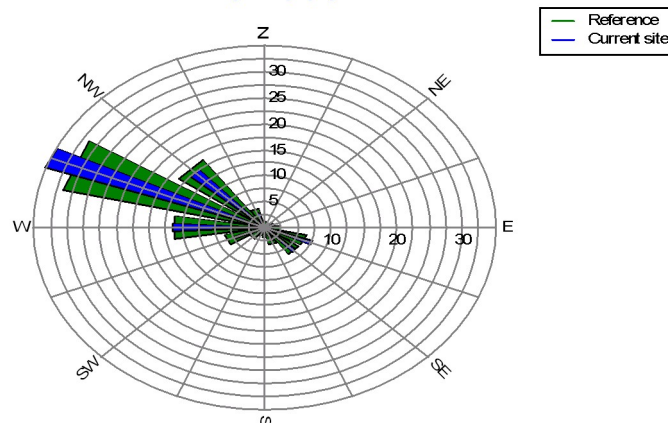
Energy Rose (kWh/m<sup>2</sup>/year)



Mean wind speed (m/s)



Frequency (%)



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**PARK - Park power curve****Calculation:** B Center 2 optimizado

Wind speed	Free WTGs	Park WTGs	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
[m/s]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4.5	1,297	1,223	1,101	803	714	1,043	1,183	1,272	1,294	1,290	1,130	793	725	1,049	1,182	1,272	1,294	1,290
5.5	2,761	2,667	2,487	2,086	1,986	2,453	2,622	2,732	2,758	2,753	2,547	2,080	1,993	2,458	2,621	2,732	2,758	2,753
6.5	4,840	4,688	4,393	3,782	3,614	4,334	4,614	4,791	4,834	4,826	4,499	3,770	3,628	4,341	4,612	4,791	4,834	4,826
7.5	7,682	7,443	6,978	6,021	5,749	6,882	7,327	7,605	7,672	7,660	7,148	6,003	5,773	6,896	7,324	7,604	7,672	7,659
8.5	11,317	10,976	10,302	8,933	8,541	10,179	10,813	11,207	11,303	11,285	10,552	8,910	8,573	10,202	10,808	11,207	11,303	11,285
9.5	15,537	15,112	14,237	12,535	12,065	14,134	14,918	15,401	15,518	15,496	14,579	12,501	12,099	14,160	14,912	15,401	15,518	15,496
10.5	19,968	19,514	18,503	16,703	16,240	18,501	19,327	19,825	19,945	19,923	18,941	16,659	16,268	18,520	19,321	19,825	19,945	19,923
11.5	24,348	23,928	22,864	21,253	20,882	23,022	23,779	24,218	24,324	24,305	23,398	21,208	20,900	23,033	23,775	24,218	24,324	24,305
12.5	28,283	27,956	26,937	25,869	25,650	27,296	27,865	28,178	28,253	28,239	27,560	25,834	25,659	27,302	27,862	28,178	28,253	28,239
13.5	31,562	31,357	30,425	30,097	30,013	30,985	31,306	31,491	31,535	31,527	31,121	30,075	30,023	30,989	31,304	31,491	31,535	31,527
14.5	34,235	34,105	33,203	33,349	33,267	33,871	34,070	34,192	34,221	34,217	33,961	33,336	33,271	33,869	34,071	34,192	34,221	34,218
15.5	35,528	35,457	34,613	35,137	35,100	35,355	35,446	35,500	35,513	35,511	35,401	35,135	35,103	35,357	35,445	35,500	35,513	35,511
16.5	35,915	35,894	35,094	35,840	35,837	35,883	35,899	35,909	35,912	35,911	35,891	35,841	35,838	35,883	35,899	35,909	35,912	35,911
17.5	36,000	35,991	35,200	35,997	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	35,998	35,999	36,000	36,000	36,000	36,000
18.5	36,000	35,991	35,200	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000
19.5	36,000	35,991	35,200	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000
20.5	36,000	35,991	35,200	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000
21.5	36,000	35,991	35,200	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000
22.5	36,000	35,991	35,200	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000
23.5	36,000	35,991	35,200	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000
24.5	36,000	35,991	35,200	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000
25.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

**Description:**

The park power curve is similar to a WTG power curve, meaning that when a given wind speed appears in front of the park with same speed in the entire wind farm area (before influence from the park), the output from the park can be found in the park power curve. Another way to say this: The park power curve includes array losses, but do NOT include terrain given variations in the wind speed over the park area.

Measuring a park power curve is not as simple as measuring a WTG power curve due to the fact that the park power curve depends on the wind direction and that the same wind speed normally will not appear for the entire park area at the same time (only in very flat non-complex terrain). The idea with this version of the park power curve is not to use it for validation based on measurements. This would require at least 2 measurement masts at two sides of the park, unless only a few direction sectors should be tested, AND non complex terrain (normally only useable off shore). Another park power curve version for complex terrain is available in WindPRO.

**The park power curve can be used for:**

1. Forecast systems, based on more rough (approximated) wind data, the park power curve would be an efficient way to make the connection from wind speed (and direction) to power.
2. Construction of duration curves, telling how often a given power output will appear, the park power curve can be used together with the average wind distribution for the Wind farm area in hub height. The average wind distribution can eventually be obtained based on the Weibull parameters for each WTG position. These are found at print menu: >Result to file< in the >Park result< which can be saved to file or copied to clipboard and pasted in Excel.
3. Calculation of wind energy index based on the PARK production (see below).
4. Estimation of the expected PARK production for an existing wind farm based on wind measurements at minimum 2 measurement masts at two sides of wind farm. The masts must be used for obtaining the free wind speed. The free wind speed is used in the simulation of expected energy production with the PARK power curve. This procedure will only work suitable in non complex terrains. For complex terrain another park power curve calculation is available in WindPRO (PPV-model).

**Note:**

From the >Result to file< the >Wind Speeds Inside Wind farm< is also available. These can (e.g. via Excel) be used for extracting the wake induced reductions in measured wind speed.

Project:

SSI\_Fase2

Description:

Potential wind farm site SSI

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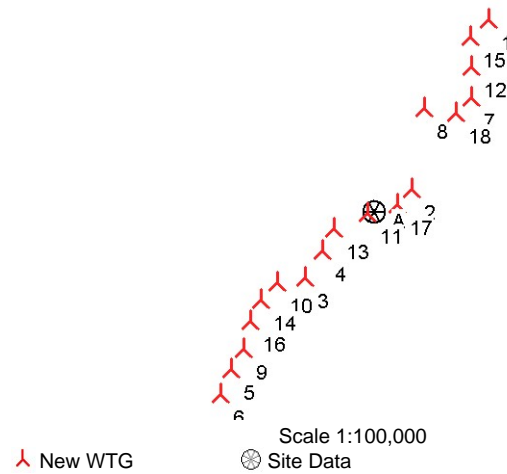
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**PARK - WTG distances****Calculation:** B Center 2 optimizado**WTG distances**

	Z	Nearest WTG	Z	Horizontal distance	Distance in
	[m]		[m]	[m]	rotor diameters
1	2,645.1	15	2,660.2	327	4.1
2	2,694.0	17	2,643.2	283	3.5
3	2,632.5	10	2,640.0	374	4.7
4	2,640.0	13	2,640.0	340	4.3
5	2,662.6	9	2,657.2	320	4.0
6	2,659.6	5	2,662.6	350	4.4
7	2,627.4	18	2,637.8	283	3.5
8	2,658.8	18	2,637.8	435	5.4
9	2,657.2	5	2,662.6	320	4.0
10	2,640.0	14	2,638.2	311	3.9
11	2,620.0	17	2,643.2	402	5.0
12	2,637.3	15	2,660.2	400	5.0
13	2,640.0	4	2,640.0	340	4.3
14	2,638.2	10	2,640.0	311	3.9
15	2,660.2	1	2,645.1	327	4.1
16	2,620.0	14	2,638.2	318	4.0
17	2,643.2	2	2,694.0	283	3.5
18	2,637.8	7	2,627.4	283	3.5



Project: SSI\_Fase2  
 Description: Potential wind farm site SSI

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## PARK - RIX calculation

Calculation: B Center 2 optimizado

### Assumptions

Radius for calculation 3,500 m  
 Directional step 5 °  
 Steepness threshold 40.0 % / 22 °  
 Directional weight Equally distributed  
 Height contours used Curvas de nivel Zona B3

### Reference sites

Terrain UTM WGS84 S Zone: 35

East	North	Z	Name of wind distribution	Type	Reference site RIX [%]
A 619,732	6,635,497	2620.0	B Center 2 to WAsP	WAsP (WAsP 6-9 for Windows RVEA0011 1, 0, 0, 13)	7.9

### WTG sites

Terrain	East	North	Z	Reference site RIX [%]	WTG RIX [%]	Delta RIX (WTG site - Reference site) [%]
UTM WGS84 S Zone: 35						
1 A	621,281	6,638,006	2,645.1	7.9	3.1	-4.8
2 A	620,238	6,635,787	2,694.0	7.9	7.4	-0.5
3 A	618,809	6,634,637	2,632.5	7.9	8.2	0.2
4 A	619,038	6,634,987	2,640.0	7.9	8.0	0.1
5 A	617,816	6,633,448	2,662.6	7.9	11.0	3.1
6 A	617,681	6,633,125	2,659.6	7.9	12.9	4.9
7 A	621,038	6,636,987	2,627.4	7.9	6.4	-1.5
8 A	620,409	6,636,857	2,658.8	7.9	5.7	-2.2
9 A	617,987	6,633,718	2,657.2	7.9	9.1	1.1
10 A	618,438	6,634,587	2,640.0	7.9	6.9	-1.0
11 A	619,650	6,635,481	2,620.0	7.9	8.2	0.2
12 A	621,038	6,637,387	2,637.3	7.9	4.4	-3.5
13 A	619,197	6,635,288	2,640.0	7.9	7.7	-0.2
14 A	618,228	6,634,357	2,638.2	7.9	6.5	-1.4
15 A	621,038	6,637,787	2,660.2	7.9	3.3	-4.6
16 A	618,077	6,634,077	2,620.0	7.9	6.9	-1.0
17 A	620,038	6,635,587	2,643.2	7.9	8.1	0.2
18 A	620,838	6,636,787	2,637.8	7.9	6.9	-1.0

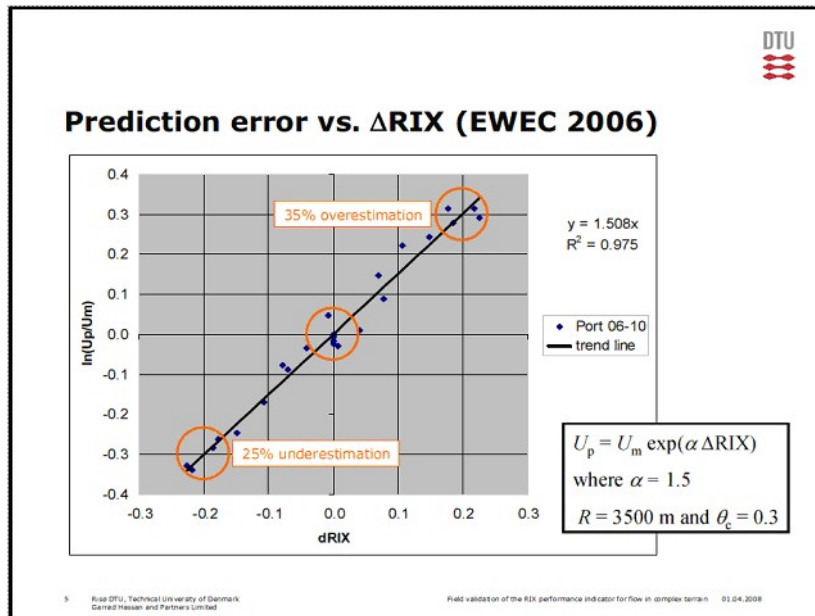
Project: SSI\_Fase2  
 Description: Potential wind farm site SSI

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## PARK - RIX calculation

Calculation: B Center 2 optimizado

Latest research /Risø/ show that the threshold in RIX calculation typically work best with 40% (new default), and that delta Rix within +/- 5% should not give corrections. Cross predictions based on more mast can fine tune the threshold, see Cross predictor tool in WindPRO Meteo Analyzer. In WindPRO LOSS&&UNCERTAINTY module, RIX correction can be calculated automatically as a bias based on most recent recommended correction formulas, which can be found in EWEC2006 && 08 papers on Rix from Risø, see extract below:

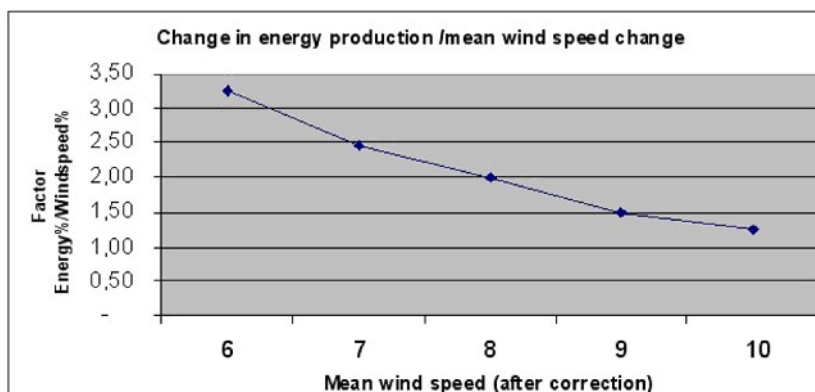


The main conclusion based on use of the RIX method is that if both reference site (measurement mast) and predicted site (WTG) are equally rugged (Delta RIX < 5%), very small calculation errors are expected.

If reference site (measurement mast) is very rugged, e.g. RIX = 0.2 and predicted site (WTG) are less rugged (e.g. RIX = 0), Delta RIX will be -0.2 and according to the graph, 30% too low wind speed prediction at WTG site could be expected. This could lead to around 60%\*) too low calculated energy production.

If the reference site is less rugged, e.g. RIX = 0, and the predicted site (WTG) are very rugged (e.g. RIX = 0.2), Delta RIX will be +0.2, and according to the graph, 30% too high wind speed prediction at WTG site could be expected. This could lead to around 60%\*) too high calculated energy production.

\*) Doubling of energy prediction error based on mean wind speed error is a rough conversion, which holds for wind speeds around 8 m/s. At 6-7 m/s tripling is more right, while only 1.5 factors should be used for 9 m/s, see graph below based on a typical WTG.



Source: EWEC06 paper:

**IMPROVING WAsP PREDICTIONS IN (TOO) COMPLEX TERRAIN**

Niels G. Mortensen, Anthony J. Bowen and Ioannis Antoniou  
 Wind Energy Department, Risø National Laboratory

Project:

SSI\_Fase2

Description:

Potential wind farm site SSI

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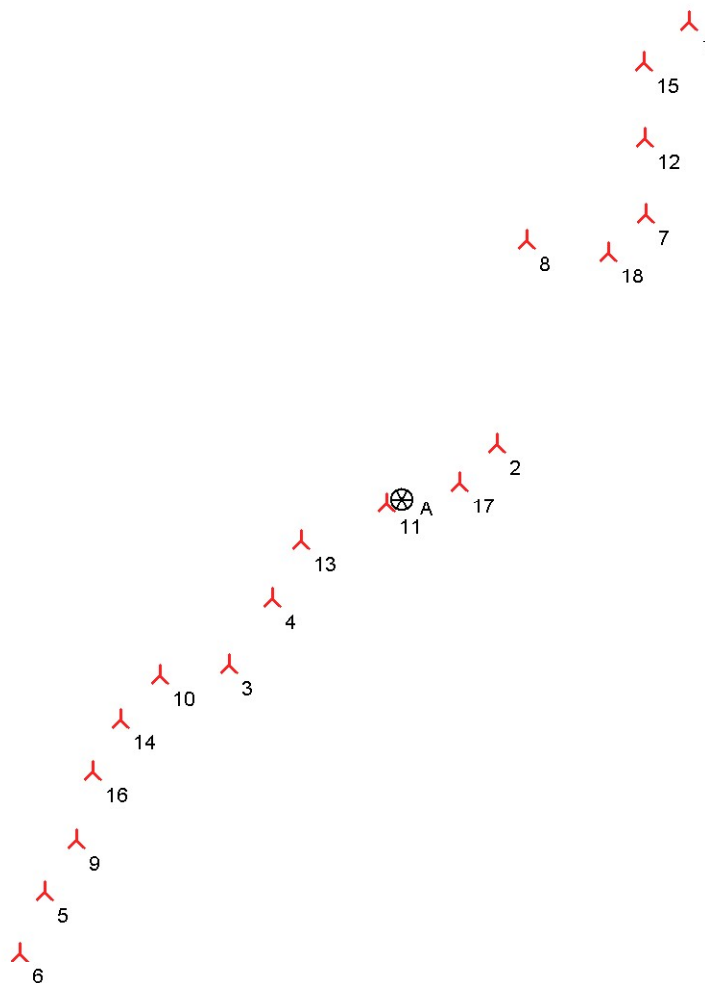
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**PARK - Map****Calculation:** B Center 2 optimizado

New WTG

Site Data

Map: Blank map , Print scale 1:40,000, Map center UTM WGS 84 South Zone: 35 East: 619,481 North: 6,635,566

# LESOTHO POWER GENERATION MASTER PLAN

PROJECT # LEC/GEN/1-2009

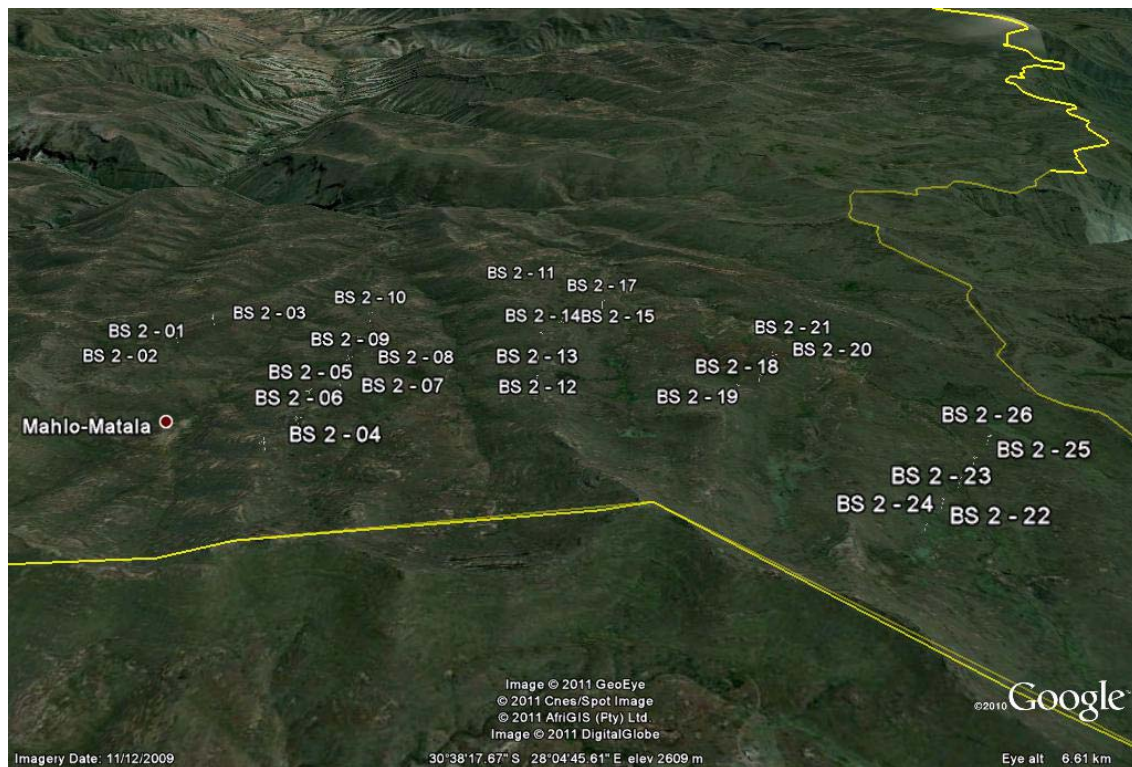
FINAL MILESTONES REPORT

VOLUME 1 - PART 1.2

WIND POWER GENERATION OPTION

## APPENDIX 1.2.4

### B SOUTH 2 WIND FARM



July 2011

# HYPERLINK

- a. Area: B

Hyperlink: [c- Area B Potential Sites.KMZ](#)

- b. RPD: B - South 2 proposed Wind Farm

Hyperlink: [h- B South 2.kmz](#)

Project: SSI\_Fase2  
Description: Potential wind farm site SSI

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## PARK - Main Result

Calculation: B South 2 optimizado

Wake Model N.O. Jensen (RISØ/EMD)

### Calculation Settings

Air density calculation mode Individual per WTG  
Result for WTG at hub altitude 0.912 kg/m³ to 0.918 kg/m³  
Air density relative to standard 74.8 %  
Hub altitude above sea level (asl) 2,666.6 m to 2,738.2 m  
Annual mean temperature at hub alt. 6.9 °C to 7.4 °C  
Pressure at WTGs 732.9 hPa to 739.3 hPa

### Wake Model Parameters

From angle To angle Terrain type Wake Decay Constant  
[°] [°]  
-180.0 180.0 Zona agrícola abierta 0.075

### 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

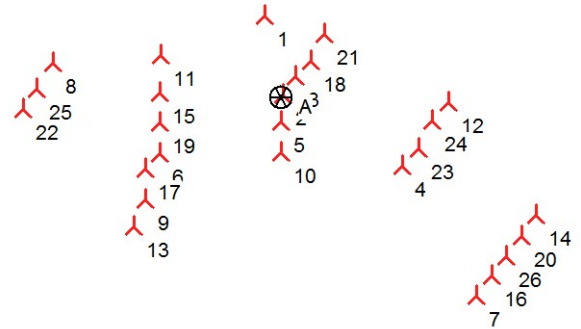
LS Zona B5 Mesoscale 1 - 80.00 m.wws

### WASP version

WASP 6-9 for Windows RVEA0011 1, 0, 0, 13

### WASP parameters

Non-default WASP parameters - detailed information at the end of "Main results"



▲ New WTG

Scale 1:100,000  
⊗ Site Data

## Key results for height 80.0 m above ground level

Terrain UTM WGS84 S Zone: 35

East	North	Name of wind distribution	Type	Wind energy [kWh/m²]	Mean wind speed [m/s]	Equivalent roughness
A 603,120	6,610,743	B South 2 to WASP	WASP (WASP 6-9 for Windows RVEA0011 1, 0, 0, 13)	4,074	8.0	0.0

## Calculated Annual Energy for Wind Farm

WTG combination	Result		GROSS (no loss)	Park efficiency	Resultados específicos <sup>a)</sup>			Mean wind speed @hub height
	PARK [MWh/y]	Result-10.0% [MWh]			Capacity factor [%]	Mean WTG result [MWh/y]	Full load hours [Hours/year]	
Wind farm	134,370.5	120,933.4	138,675.5	96.9	26.5	4,651.3	2,326	7.6

<sup>a)</sup> Basado en Result-10.0%

## Calculated Annual Energy for each of 26 new WTGs with total 52.0 MW rated power

WTG type								Power curve		Annual Energy		Park	
Terrain	Valid	Manufact.	Type-generator	Power, rated [kW]	Rotor diameter [m]	Hub height [m]	Creator	Name	Result [MWh]	Result-10.0% [MWh]	Efficiency [%]	Mean wind speed [m/s]	
1 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	6,065.3	5,459	98.8	8.28	
2 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,793.5	5,214	96.8	8.16	
3 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,803.2	5,223	96.9	8.16	
4 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,635.8	5,072	96.0	8.06	
5 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,633.4	5,070	96.3	8.05	
6 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,589.0	5,030	96.2	8.00	
7 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	3,944.9	3,550	97.5	6.66	
8 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,604.2	5,044	98.8	7.88	
9 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,503.1	4,953	97.9	7.86	
10 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,419.3	4,877	96.1	7.88	
11 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,514.4	4,963	98.1	7.84	
12 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	4,800.2	4,320	96.2	7.35	
13 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,614.5	5,053	98.9	7.91	
14 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	4,327.3	3,895	95.2	7.03	
15 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,392.7	4,853	97.0	7.80	
16 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	4,124.8	3,712	96.3	6.84	
17 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,352.0	4,817	97.0	7.77	
18 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,222.8	4,701	96.0	7.70	
19 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,264.4	4,738	96.5	7.72	
20 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	4,180.9	3,763	95.4	6.91	
21 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,047.6	4,543	95.9	7.56	
22 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,341.1	4,807	99.4	7.66	

To be continued on next page...

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 Description: Potential wind farm site SSI

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## PARK - Main Result

Calculation: B South 2 optimizado

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	WTG type			Power, rated [kW]	Rotor diameter [m]	Hub height [m]	Power curve		Annual Energy		Park	
	Terrain	Valid	Manufact.				Type-generator	Creator	Name	Result	Result-10.0%	Efficiency
									[MWh]	[MWh]	[%]	[m/s]
23 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	4,927.1	4,434	94.9	7.51
24 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	4,881.3	4,393	95.7	7.44
25 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,211.8	4,691	98.8	7.57
26 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	4,175.9	3,758	95.7	6.90

## WTG siting

UTM WGS84 S Zone: 35				
	East	North	Z	Row data/Description
	UTM WGS84 S Zone: 35		[m]	
1 New	602,915	6,611,829	2,629.3	VESTAS V80-2.0MW 80.0 BS 2 - 11
2 New	603,148	6,610,790	2,638.9	VESTAS V80-2.0MW 80.0 BS 2 - 14
3 New	603,315	6,611,029	2,642.9	VESTAS V80-2.0MW 80.0 BS 2 - 15
4 New	604,715	6,609,829	2,658.2	VESTAS V80-2.0MW 80.0 BS 2 - 18
5 New	603,115	6,610,429	2,640.2	VESTAS V80-2.0MW 80.0 BS 2 - 12
6 New	601,515	6,610,029	2,630.0	VESTAS V80-2.0MW 80.0 BS 2 - 07
7 New	605,676	6,608,119	2,611.8	VESTAS V80-2.0MW 80.0 BS 2 - 22
8 New	600,115	6,611,229	2,596.8	VESTAS V80-2.0MW 80.0 BS 2 - 03
9 New	601,317	6,609,428	2,634.0	VESTAS V80-2.0MW 80.0 BS 2 - 06
10 New	603,115	6,610,029	2,633.5	VESTAS V80-2.0MW 80.0 BS 2 - 13
11 New	601,530	6,611,317	2,586.6	VESTAS V80-2.0MW 80.0 BS 2 - 10
12 New	605,339	6,610,663	2,602.4	VESTAS V80-2.0MW 80.0 BS 2 - 21
13 New	601,163	6,609,068	2,654.6	VESTAS V80-2.0MW 80.0 BS 2 - 04
14 New	606,480	6,609,166	2,601.2	VESTAS V80-2.0MW 80.0 BS 2 - 26
15 New	601,515	6,610,829	2,600.0	VESTAS V80-2.0MW 80.0 BS 2 - 08
16 New	605,877	6,608,383	2,610.0	VESTAS V80-2.0MW 80.0 BS 2 - 23
17 New	601,315	6,609,829	2,617.1	VESTAS V80-2.0MW 80.0 BS 2 - 05
18 New	603,515	6,611,229	2,610.0	VESTAS V80-2.0MW 80.0 BS 2 - 16
19 New	601,515	6,610,429	2,605.7	VESTAS V80-2.0MW 80.0 BS 2 - 09
20 New	606,277	6,608,894	2,600.0	VESTAS V80-2.0MW 80.0 BS 2 - 25
21 New	603,698	6,611,573	2,596.6	VESTAS V80-2.0MW 80.0 BS 2 - 17
22 New	599,715	6,610,629	2,624.3	VESTAS V80-2.0MW 80.0 BS 2 - 01
23 New	604,931	6,610,053	2,623.0	VESTAS V80-2.0MW 80.0 BS 2 - 19
24 New	605,115	6,610,429	2,610.9	VESTAS V80-2.0MW 80.0 BS 2 - 20
25 New	599,892	6,610,893	2,595.2	VESTAS V80-2.0MW 80.0 BS 2 - 02
26 New	606,079	6,608,632	2,606.0	VESTAS V80-2.0MW 80.0 BS 2 - 24

## Non-default WAsP parameters:

WAsP parameter	Minimum	Maximum	Default	Current value
Altura Estd. #4	5.0000	200.0000	100.0000	80.0000

Project: SSI\_Fase2  
Description: Potential wind farm site SSI

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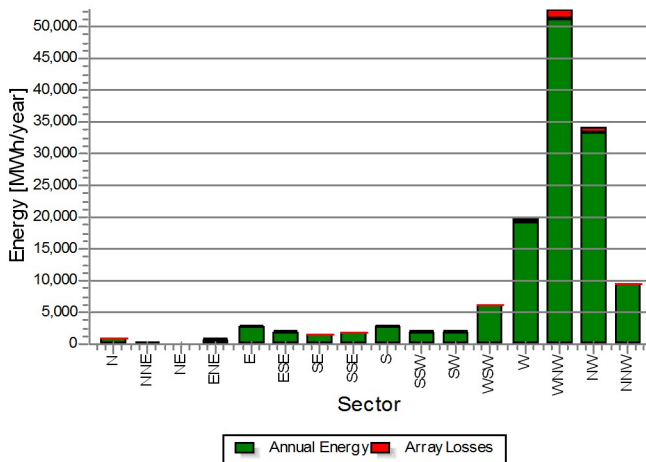
## PARK - Production Analysis

**Calculation:** B South 2 optimizado **WTG:** All new WTGs, Air density varies with WTG position 0.912 kg/m<sup>3</sup> - 0.918 kg/m<sup>3</sup>

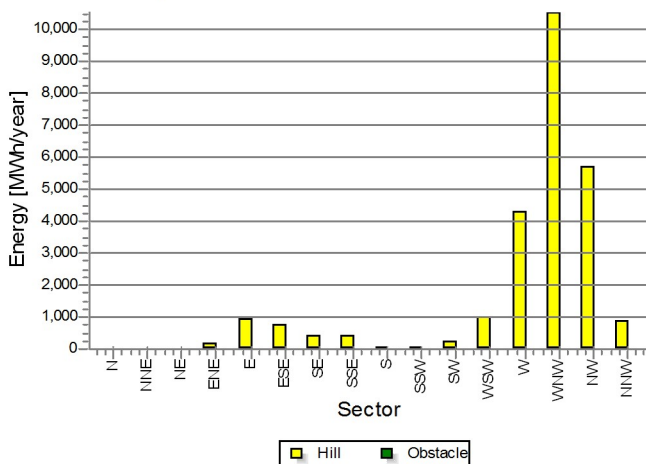
### Directional Analysis

Sector	0 N	1 NNE	2 NE	3 ENE	4 E	5 ESE	6 SE	7 SSE	8 S	9 SSW	10 SW	11 WSW	12 W	13 WNW	14 NW	15 NNW	Total
Roughness based energy [MWh]	810.7	142.8	97.5	574.6	1,938.3	1,251.3	982.5	1,269.3	2,862.8	1,863.0	1,951.3	5,208.7	15,238.6	42,049.7	28,230.2	8,642.0	113,113.4
+Increase due to hills [MWh]	26.1	14.6	22.4	168.1	940.6	774.5	438.3	386.7	67.1	51.1	237.1	1,007.8	4,304.6	10,550.5	5,712.8	859.7	25,562.1
-Decrease due to array losses [MWh]	97.8	28.0	27.3	30.9	145.9	126.3	74.9	35.6	207.3	240.2	366.0	160.4	473.7	1,356.0	790.4	144.3	4,305.0
<b>Resulting energy [MWh]</b>	<b>738.9</b>	<b>129.4</b>	<b>92.6</b>	<b>711.8</b>	<b>2,733.1</b>	<b>1,899.5</b>	<b>1,346.0</b>	<b>1,620.4</b>	<b>2,722.6</b>	<b>1,673.9</b>	<b>1,822.5</b>	<b>6,056.2</b>	<b>19,069.4</b>	<b>51,244.2</b>	<b>33,152.6</b>	<b>9,357.4</b>	<b>134,370.4</b>
Specific energy [kWh/m <sup>2</sup> ]																	1,028
Specific energy [kWh/kW]																	2,584
Increase due to hills [%]	3.2	10.2	23.0	29.3	48.5	61.9	44.6	30.5	2.3	2.7	12.2	19.3	28.2	25.1	20.2	9.9	22.60
Decrease due to array losses [%]	11.7	17.8	22.8	4.2	5.1	6.2	5.3	2.1	7.1	12.5	16.7	2.6	2.4	2.6	2.3	1.5	3.10
Utilization [%]	33.6	30.6	26.3	37.5	38.6	37.0	38.0	35.4	30.6	32.3	32.4	31.8	27.2	26.8	29.7	31.1	28.8
Operational [Hours/year]	115	52	64	157	422	381	238	186	206	178	228	446	1,048	2,103	1,350	494	7,669
Full Load Equivalent [Hours/year]	14	2	2	14	53	37	26	31	52	32	35	116	367	985	638	180	2,584

Energy vs. sector



Impact of hills and obstacles vs. sector



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## PARK - Power Curve Analysis

**Calculation:** B South 2 optimizado **WTG:** 1 - VESTAS V80-2.0MW 2000 80.0 !O! Mode 0, Hub height: 80.0 m

**Name:** Mode 0  
**Source:** Manufacturer

Source/Date	Created by	Created	Edited	Stop wind speed [m/s]	Power control	CT curve type
12/4/2009	EMD	12/07/2010	16/07/2010	25.0	Paso var. (Pitch)	Definido por usuario

Estimated power curve based on item n. 0004-7878 V03 04-12-2009.

**HP curve comparison** - Note: For standard air density and weibull k parameter = 2

Vmean	[m/s]	5	6	7	8	9	10
HP value	[MWh]	2,341	3,854	5,431	6,968	8,268	9,419
VESTAS V80-2.0MW 2000 80.0 !O! Mode 0	[MWh]	2,580	4,109	5,690	7,175	8,483	9,573
Check value	[%]	-9	-6	-5	-3	-3	-2

The table shows comparison between annual energy production calculated on basis of simplified "HP-curves" which assume that all WTGs performs quite similar - only specific power loading (kW/m<sup>2</sup>) and single/dual speed or stall/pitch decides the calculated values. Productions are without wake losses.

For further details, ask at the Danish Energy Agency for project report J.nr. 51171/00-0016 or see WindPRO manual chapter 3.5.2.

The method is refined in EMD report "20 Detailed Case Studies comparing Project Design Calculations and actual Energy Productions for Wind Energy Projects worldwide", jan 2003.

Use the table to evaluate if the given power curve is reasonable - if the check value are lower than -5%, the power curve probably is too optimistic due to uncertainty in power curve measurement.

### Power curve

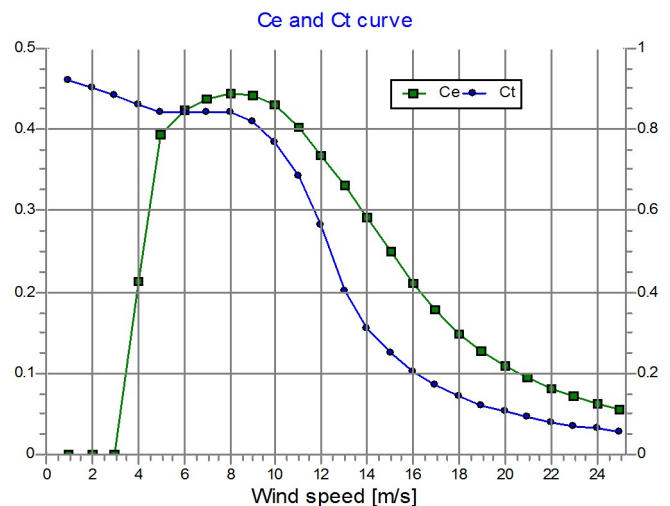
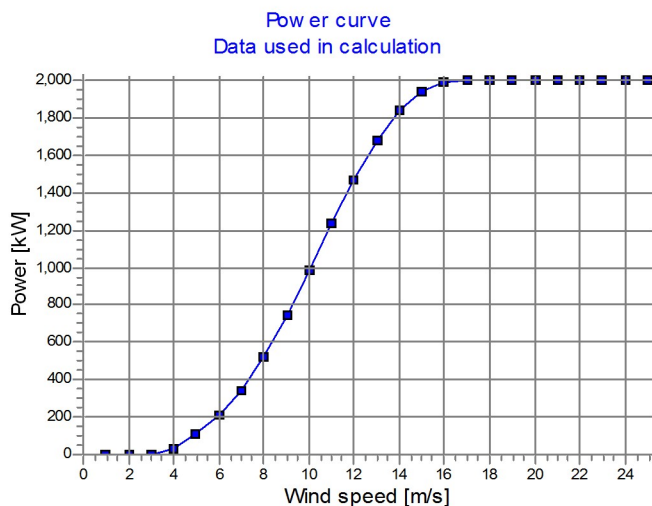
Original data from Windcat, Air density: 1.225 kg/m<sup>3</sup>

Wind speed [m/s]	Power [kW]	Ce	Wind speed [m/s]	Ct curve
4.0	66.0	0.33	4.0	0.86
5.0	156.0	0.41	5.0	0.84
6.0	285.0	0.43	6.0	0.84
7.0	467.0	0.44	7.0	0.84
8.0	706.0	0.45	8.0	0.84
9.0	1,001.0	0.45	9.0	0.82
10.0	1,329.0	0.43	10.0	0.77
11.0	1,652.0	0.40	11.0	0.68
12.0	1,892.0	0.36	12.0	0.56
13.0	1,982.0	0.29	13.0	0.40
14.0	2,000.0	0.24	14.0	0.31
15.0	2,000.0	0.19	15.0	0.25
16.0	2,000.0	0.16	16.0	0.20
17.0	2,000.0	0.13	17.0	0.17
18.0	2,000.0	0.11	18.0	0.14
19.0	2,000.0	0.09	19.0	0.12
20.0	2,000.0	0.08	20.0	0.10
21.0	2,000.0	0.07	21.0	0.09
22.0	2,000.0	0.06	22.0	0.08
23.0	2,000.0	0.05	23.0	0.07
24.0	2,000.0	0.05	24.0	0.06
25.0	2,000.0	0.04	25.0	0.06

### Power, Efficiency and energy vs. wind speed

Data used in calculation, Air density: 0.914 kg/m<sup>3</sup> Nuevo método WindPRO (método IEC ajustado, mejorado para que coincida con el control de la turbina) <RECOMENDADO>

Wind speed [m/s]	Power [kW]	Ce	Interval [m/s]	Energy [MWh]	Acc. Energy [MWh]	Relative [%]
1.0	0.0	0.00	0.50-1.50	0.0	0.0	0.0
2.0	0.0	0.00	1.50-2.50	0.0	0.0	0.0
3.0	0.0	0.00	2.50-3.50	0.0	0.0	0.0
4.0	31.4	0.21	3.50-4.50	26.6	26.6	0.4
5.0	112.8	0.39	4.50-5.50	87.3	113.8	1.9
6.0	210.7	0.42	5.50-6.50	168.1	282.0	4.6
7.0	344.7	0.44	6.50-7.50	271.2	553.2	9.1
8.0	522.0	0.44	7.50-8.50	386.9	940.0	15.5
9.0	740.6	0.44	8.50-9.50	497.6	1,437.7	23.7
10.0	986.7	0.43	9.50-10.50	583.0	2,020.7	33.3
11.0	1,233.1	0.40	10.50-11.50	629.9	2,650.6	43.7
12.0	1,462.7	0.37	11.50-12.50	633.8	3,284.4	54.2
13.0	1,673.7	0.33	12.50-13.50	597.1	3,881.5	64.0
14.0	1,834.6	0.29	13.50-14.50	531.3	4,412.8	72.8
15.0	1,938.2	0.25	14.50-15.50	445.3	4,858.1	80.1
16.0	1,987.9	0.21	15.50-16.50	351.2	5,209.4	85.9
17.0	2,000.0	0.18	16.50-17.50	265.1	5,474.4	90.3
18.0	2,000.0	0.15	17.50-18.50	193.9	5,668.3	93.5
19.0	2,000.0	0.13	18.50-19.50	138.1	5,806.5	95.7
20.0	2,000.0	0.11	19.50-20.50	96.1	5,902.6	97.3
21.0	2,000.0	0.09	20.50-21.50	65.4	5,968.0	98.4
22.0	2,000.0	0.08	21.50-22.50	43.6	6,011.6	99.1
23.0	2,000.0	0.07	22.50-23.50	28.5	6,040.0	99.6
24.0	2,000.0	0.06	23.50-24.50	18.2	6,058.3	99.9
25.0	2,000.0	0.06	24.50-25.50	7.1	6,065.4	100.0



Project:

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**PARK - Terrain****Calculation:** B South 2 optimizado **Site Data:** A - B South 2 to WAsP**Obstacles:**

0 Obstacles used

**Roughness:**

Calculation uses following MAP files:

\\Server-dell\modeliza\Proyecto SSI\_2\03 WINDPRO\Data\WP Data (Step 2)\ROUGHNESSLINE B5.wpo

Min X: 584,208, Max X: 612,704, Min Y: 6,602,426, Max Y: 6,620,326, Width: 28,496 m, Height: 17,900 m

Limited by a square on 40.0 km x 40.0 km around the current site

**Orography:**

Calculation uses following MAP files:

\\Server-dell\modeliza\Proyecto SSI\_2\03 WINDPRO\Data\WP Data (Step 2)\Curvas de Nivel Zona B - V.wpo

Min X: 586,071, Max X: 611,650, Min Y: 6,603,498, Max Y: 6,619,434, Width: 25,579 m, Height: 15,936 m

Limited by a square on 10.0 km x 10.0 km around the current site

Project: SSI\_Fase2  
Description: Potential wind farm site SSI

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## PARK - Wind Data Analysis

Calculation: B South 2 optimizado Wind data: A - B South 2 to WAsP; Hub height: 80.0

### Site Coordinates

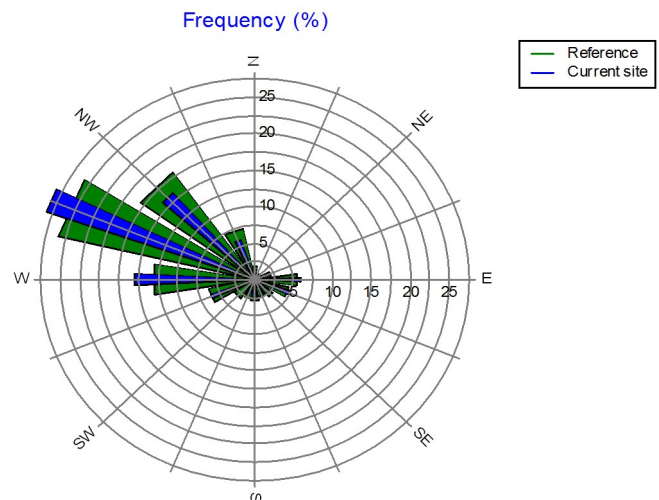
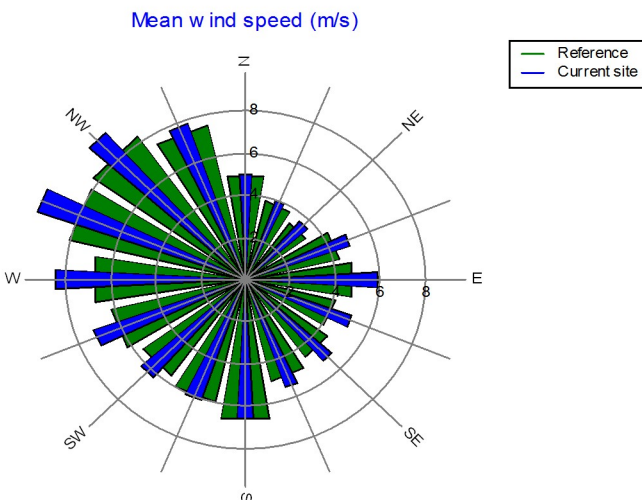
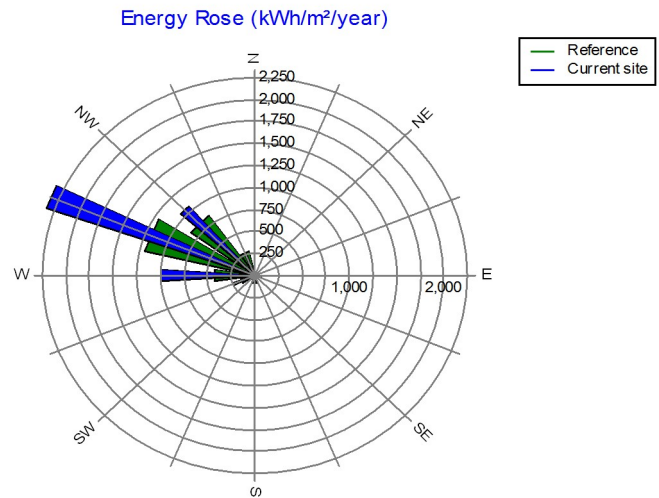
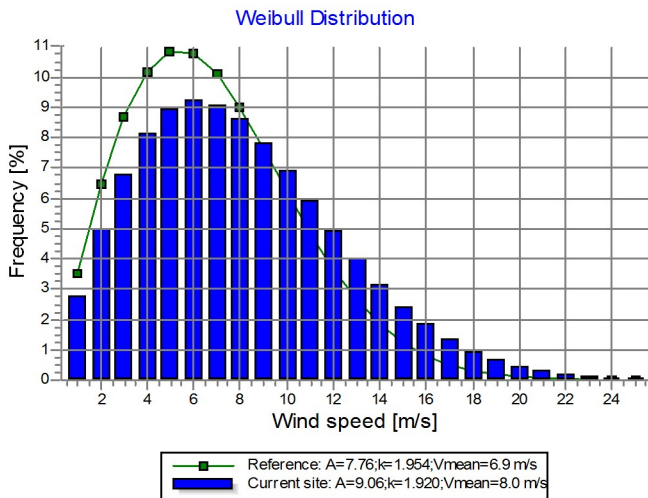
UTM WGS 84 South Zone: 35 East: 603,120 North: 6,610,743

### Wind statistics

LS Zona B5 Mesoscale 1 - 80.00 m.wws

### Weibull Data

Sector	Current site		Frequency	Reference: Roughness class 1		Frequency
	A- parameter [m/s]	Wind speed [m/s]		A- parameter [m/s]	k- parameter	
0 N	5.61	4.99	1.818	5.65	1.820	1.7
1 NNE	4.52	4.01	1.885	4.30	1.970	0.7
2 NE	4.16	3.68	2.021	3.74	2.040	0.9
3 ENE	5.58	4.94	2.119	4.83	2.180	2.2
4 E	6.62	5.88	2.596	5.42	2.670	5.4
5 ESE	5.70	5.04	2.088	4.64	2.040	4.6
6 SE	5.86	5.19	2.260	5.12	2.470	3.0
7 SSE	6.07	5.41	1.740	5.52	1.760	2.4
8 S	7.45	6.62	1.861	7.50	1.860	3.0
9 SSW	6.85	6.08	1.959	6.71	1.970	2.6
10 SW	6.97	6.18	2.162	6.37	2.210	3.2
11 WSW	8.10	7.19	1.857	6.94	1.850	6.1
12 W	9.60	8.52	1.877	7.67	1.850	13.0
13 WNW	11.09	9.83	2.303	9.13	2.270	25.9
14 NW	10.53	9.35	2.518	9.36	2.580	18.0
15 NNW	8.82	7.81	2.135	8.51	2.170	7.3
All	9.06	8.04	1.920	7.76	1.954	100.0



Project: SSI\_Fase2  
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## PARK - Wind Data Analysis

Calculation: B South 2 optimizado Wind data: A - B South 2 to WAsP; Hub height: 80.0

### Site Coordinates

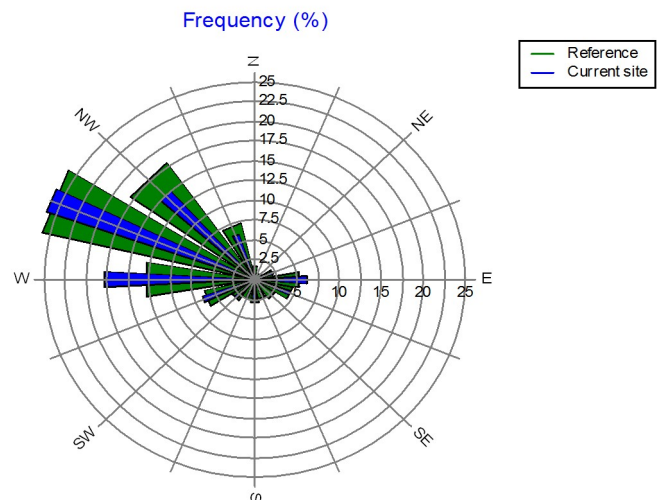
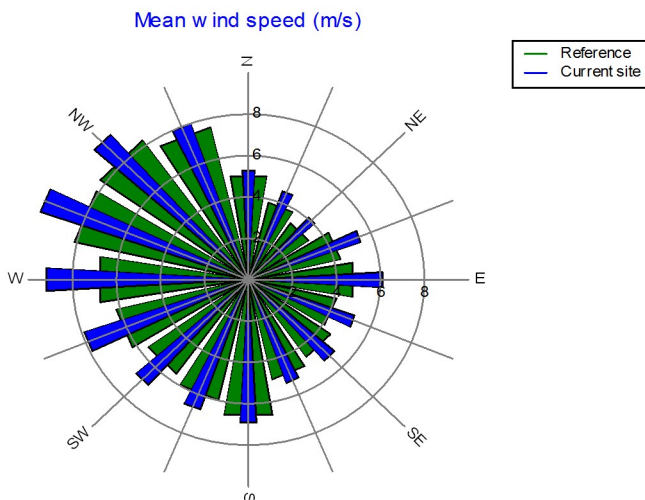
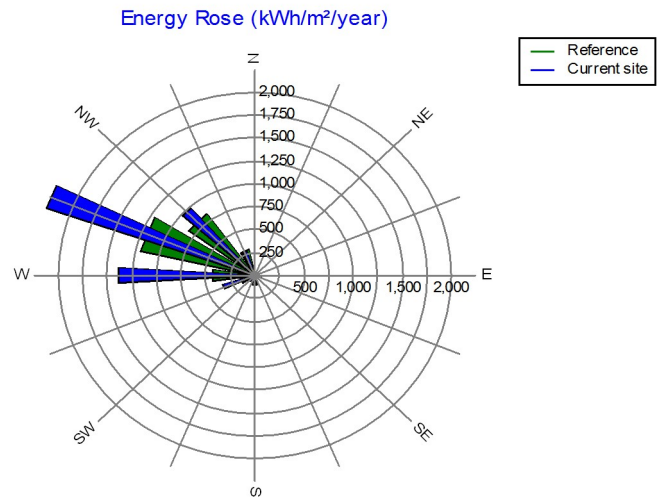
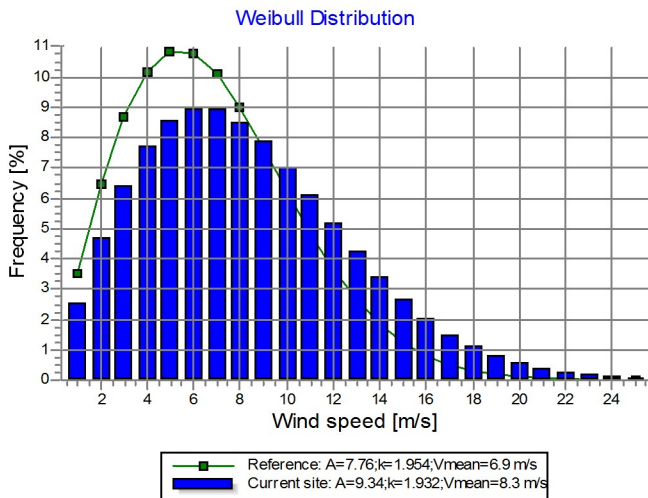
UTM WGS 84 South Zone: 35 East: 602,915 North: 6,611,829  
VESTAS V80-2.0MW 80.0 BS 2 - 11

### Wind statistics

LS Zona B5 Mesoscale 1 - 80.00 m.wws

### Weibull Data

Sector	Current site		k-	Frequency	Reference: Roughness class 1		Frequency
	A- parameter [m/s]	Wind speed [m/s]			A- parameter [m/s]	k- parameter	
0 N	5.89	5.23	1.818	1.4	5.65	1.820	1.7
1 NNE	5.12	4.54	1.842	0.8	4.30	1.970	0.7
2 NE	4.59	4.07	2.021	0.9	3.74	2.040	0.9
3 ENE	6.09	5.40	2.135	2.3	4.83	2.180	2.2
4 E	6.91	6.13	2.553	6.3	5.42	2.670	5.4
5 ESE	5.80	5.14	2.100	4.5	4.64	2.040	4.6
6 SE	5.88	5.21	2.279	2.7	5.12	2.470	3.0
7 SSE	5.93	5.29	1.744	2.1	5.52	1.760	2.4
8 S	7.82	6.94	1.861	2.4	7.50	1.860	3.0
9 SSW	7.52	6.67	1.943	2.4	6.71	1.970	2.6
10 SW	7.68	6.80	2.154	3.2	6.37	2.210	3.2
11 WSW	8.83	7.85	1.861	6.6	6.94	1.850	6.1
12 W	10.35	9.18	1.939	17.7	7.67	1.850	13.0
13 WNW	11.27	9.99	2.307	26.1	9.13	2.270	25.9
14 NW	10.57	9.38	2.525	14.8	9.36	2.580	18.0
15 NNW	8.98	7.95	2.162	5.9	8.51	2.170	7.3
All	9.34	8.28	1.932	100.0	7.76	1.954	100.0



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**PARK - Park power curve**

Calculation: B South 2 optimizado

Power																		
Wind speed	Free WTGs	Park WTGs	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
[m/s]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4.5	1,916	1,661	1,457	1,299	1,208	1,741	1,712	1,670	1,705	1,781	1,489	1,290	1,201	1,735	1,706	1,669	1,704	1,778
5.5	4,040	3,724	3,411	3,245	2,997	3,830	3,795	3,745	3,787	3,879	3,491	3,236	2,994	3,823	3,789	3,744	3,786	3,875
6.5	7,078	6,554	6,065	5,806	5,489	6,723	6,664	6,579	6,650	6,805	6,209	5,791	5,484	6,711	6,653	6,578	6,648	6,798
7.5	11,237	10,394	9,645	9,245	8,768	10,661	10,564	10,425	10,541	10,793	9,875	9,217	8,758	10,640	10,546	10,423	10,537	10,782
8.5	16,558	15,334	14,254	13,698	13,007	15,721	15,576	15,377	15,546	15,911	14,595	13,658	12,993	15,691	15,550	15,374	15,540	15,895
9.5	22,729	21,214	19,760	19,122	18,192	21,699	21,521	21,287	21,489	21,928	20,232	19,079	18,174	21,662	21,490	21,283	21,481	21,910
10.5	29,192	27,609	25,823	25,275	24,132	28,125	27,952	27,724	27,919	28,352	26,439	25,234	24,116	28,090	27,922	27,721	27,913	28,335
11.5	35,552	34,086	32,150	31,853	30,619	34,566	34,420	34,226	34,391	34,763	32,918	31,822	30,609	34,537	34,395	34,223	34,385	34,748
12.5	41,327	40,054	38,243	38,343	37,229	40,434	40,321	40,179	40,301	40,581	39,149	38,320	37,228	40,411	40,302	40,177	40,297	40,570
13.5	46,006	45,141	43,577	44,106	43,298	45,377	45,316	45,237	45,305	45,457	44,577	44,093	43,296	45,365	45,306	45,236	45,303	45,451
14.5	49,664	49,227	47,736	48,540	48,099	49,361	49,347	49,308	49,337	49,397	48,832	48,541	48,103	49,356	49,342	49,310	49,335	49,394
15.5	51,536	51,191	49,934	50,938	50,748	51,267	51,248	51,224	51,245	51,292	51,072	50,933	50,755	51,263	51,245	51,223	51,244	51,290
16.5	51,929	51,841	50,682	51,807	51,758	51,869	51,866	51,861	51,865	51,874	51,834	51,807	51,763	51,868	51,865	51,861	51,865	51,873
17.5	52,000	51,982	50,844	51,998	51,992	52,000	52,000	52,000	52,000	52,000	52,000	51,999	51,993	52,000	52,000	52,000	52,000	52,000
18.5	52,000	51,983	50,844	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000
19.5	52,000	51,983	50,844	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000
20.5	52,000	51,983	50,844	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000
21.5	52,000	51,983	50,844	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000
22.5	52,000	51,983	50,844	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000
23.5	52,000	51,983	50,844	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000
24.5	52,000	51,983	50,844	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000
25.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

**Description:**

The park power curve is similar to a WTG power curve, meaning that when a given wind speed appears in front of the park with same speed in the entire wind farm area (before influence from the park), the output from the park can be found in the park power curve. Another way to say this: The park power curve includes array losses, but do NOT include terrain given variations in the wind speed over the park area.

Measuring a park power curve is not as simple as measuring a WTG power curve due to the fact that the park power curve depends on the wind direction and that the same wind speed normally will not appear for the entire park area at the same time (only in very flat non-complex terrain). The idea with this version of the park power curve is not to use it for validation based on measurements. This would require at least 2 measurement masts at two sides of the park, unless only a few direction sectors should be tested, AND non complex terrain (normally only useable off shore). Another park power curve version for complex terrain is available in WindPRO.

**The park power curve can be used for:**

- Forecast systems, based on more rough (approximated) wind data, the park power curve would be an efficient way to make the connection from wind speed (and direction) to power.
- Construction of duration curves, telling how often a given power output will appear, the park power curve can be used together with the average wind distribution for the Wind farm area in hub height. The average wind distribution can eventually be obtained based on the Weibull parameters for each WTG position. These are found at print menu: >Result to file< in the >Park result< which can be saved to file or copied to clipboard and pasted in Excel.
- Calculation of wind energy index based on the PARK production (see below).
- Estimation of the expected PARK production for an existing wind farm based on wind measurements at minimum 2 measurement masts at two sides of wind farm. The masts must be used for obtaining the free wind speed. The free wind speed is used in the simulation of expected energy production with the PARK power curve. This procedure will only work suitable in non complex terrains. For complex terrain another park power curve calculation is available in WindPRO (PPV-model).

**Note:**

From the >Result to file< the >Wind Speeds Inside Wind farm< is also available. These can (e.g. via Excel) be used for extracting the wake induced reductions in measured wind speed.

Project: **SSI\_Fase2** Description: Potential wind farm site SSI

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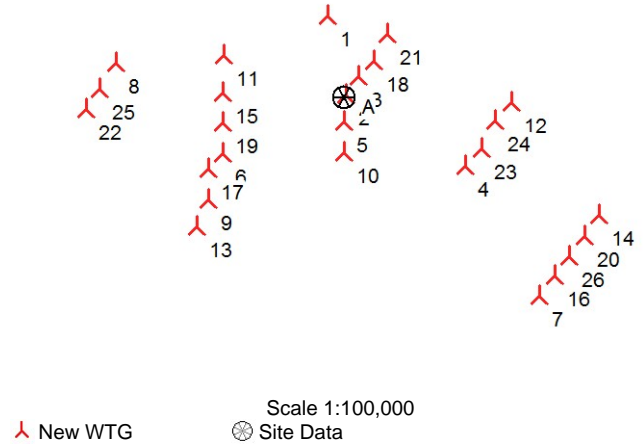
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## PARK - WTG distances

Calculation: B South 2 optimizado

### WTG distances

Z	Nearest WTG	Z	Horizontal distance	Distance in
[m]		[m]	[m]	rotor diameters
1 2,629.3	21 2,596.6		824	10.3
2 2,638.9	3 2,642.9		292	3.6
3 2,642.9	18 2,610.0		283	3.5
4 2,658.2	23 2,623.0		311	3.9
5 2,640.2	2 2,638.9		363	4.5
6 2,630.0	17 2,617.1		283	3.5
7 2,611.8	16 2,610.0		332	4.1
8 2,596.8	25 2,595.2		403	5.0
9 2,634.0	13 2,654.6		392	4.9
10 2,633.5	5 2,640.2		400	5.0
11 2,586.6	15 2,600.0		488	6.1
12 2,602.4	24 2,610.9		324	4.0
13 2,654.6	9 2,634.0		392	4.9
14 2,601.2	20 2,600.0		339	4.2
15 2,600.0	19 2,605.7		400	5.0
16 2,610.0	26 2,606.0		321	4.0
17 2,617.1	6 2,630.0		283	3.5
18 2,610.0	3 2,642.9		283	3.5
19 2,605.7	6 2,630.0		400	5.0
20 2,600.0	26 2,606.0		328	4.1
21 2,596.6	18 2,610.0		390	4.9
22 2,624.3	25 2,595.2		318	4.0
23 2,623.0	4 2,658.2		311	3.9
24 2,610.9	12 2,602.4		324	4.0
25 2,595.2	22 2,624.3		318	4.0
26 2,606.0	16 2,610.0		321	4.0



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## PARK - RIX calculation

Calculation: B South 2 optimizado

### Assumptions

Radius for calculation 3,500 m  
 Directional step 5 °  
 Steepness threshold 40.0 % / 22 °  
 Directional weight Equally distributed  
 Height contours used Curvas de Nivel B5

### Reference sites

Terrain	UTM WGS84 S Zone: 35	East	North	Z [m]	Name of wind distribution	Type	Reference site RIX [%]
A	603,120	6,610,743	2630.9	B South 2 to WAsP	WAsP (WAsP 6-9 for Windows RVEA0011 1, 0, 0, 13)		0.6

### WTG sites

Terrain	UTM WGS84 S Zone: 35	East	North	Z [m]	Reference site RIX [%]	WTG RIX [%]	Delta RIX (WTG site - Reference site) [%]
1 A	602,915	6,611,829	2,629.3	0.6	1.6	1.0	
2 A	603,148	6,610,790	2,638.9	0.6	0.6	0.0	
3 A	603,315	6,611,029	2,642.9	0.6	0.8	0.2	
4 A	604,715	6,609,829	2,658.2	0.6	0.0	-0.6	
5 A	603,115	6,610,429	2,640.2	0.6	0.3	-0.3	
6 A	601,515	6,610,029	2,630.0	0.6	0.1	-0.5	
7 A	605,676	6,608,119	2,611.8	0.6	0.1	-0.5	
8 A	600,115	6,611,229	2,596.8	0.6	1.4	0.8	
9 A	601,317	6,609,428	2,634.0	0.6	0.1	-0.5	
10 A	603,115	6,610,029	2,633.5	0.6	0.3	-0.3	
11 A	601,530	6,611,317	2,586.6	0.6	1.4	0.8	
12 A	605,339	6,610,663	2,602.4	0.6	0.5	-0.1	
13 A	601,163	6,609,068	2,654.6	0.6	0.3	-0.3	
14 A	606,480	6,609,166	2,601.2	0.6	3.7	3.1	
15 A	601,515	6,610,829	2,600.0	0.6	0.7	0.1	
16 A	605,877	6,608,383	2,610.0	0.6	0.7	0.1	
17 A	601,315	6,609,829	2,617.1	0.6	0.1	-0.5	
18 A	603,515	6,611,229	2,610.0	0.6	0.7	0.1	
19 A	601,515	6,610,429	2,605.7	0.6	0.3	-0.3	
20 A	606,277	6,608,894	2,600.0	0.6	2.8	2.1	
21 A	603,698	6,611,573	2,596.6	0.6	0.9	0.3	
22 A	599,715	6,610,629	2,624.3	0.6	0.5	-0.1	
23 A	604,931	6,610,053	2,623.0	0.6	0.2	-0.4	
24 A	605,115	6,610,429	2,610.9	0.6	0.3	-0.3	
25 A	599,892	6,610,893	2,595.2	0.6	0.5	-0.1	
26 A	606,079	6,608,632	2,606.0	0.6	1.7	1.1	

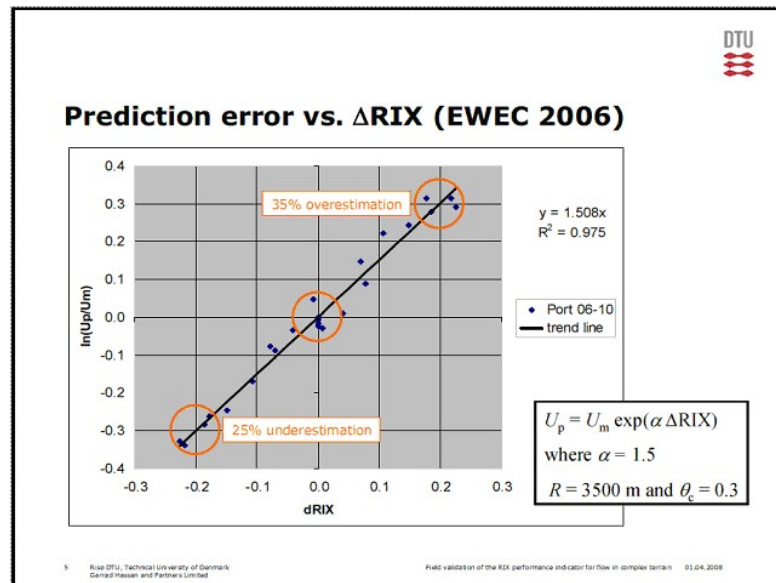
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 Description: Potential wind farm site SSI

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## PARK - RIX calculation

Calculation: B South 2 optimizado

Latest research /Risø/ show that the threshold in RIX calculation typically work best with 40% (new default), and that delta Rix within +/- 5% should not give corrections. Cross predictions based on more mast can fine tune the threshold, see Cross predictor tool in WindPRO Meteo Analyzer. In WindPRO LOSS&&UNCERTAINTY module, RIX correction can be calculated automatically as a bias based on most recent recommended correction formulas, which can be found in EWEC2006 && 08 papers on Rix from Risø, see extract below:

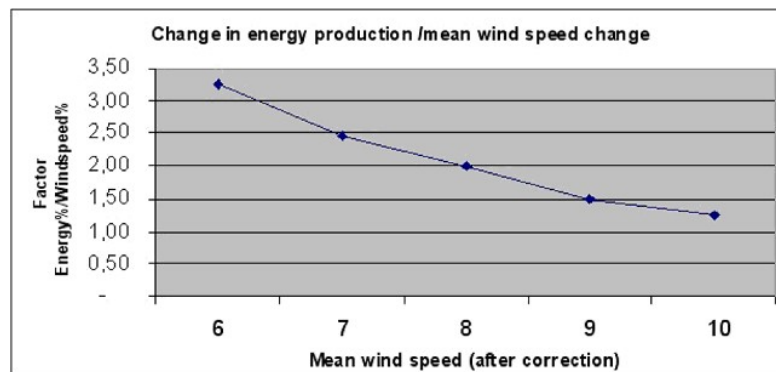


The main conclusion based on use of the RIX method is that if both reference site (measurement mast) and predicted site (WTG) are equally rugged (Delta RIX < 5%), very small calculation errors are expected.

If reference site (measurement mast) is very rugged, e.g. RIX = 0.2 and predicted site (WTG) are less rugged (e.g. RIX = 0), Delta RIX will be -0.2 and according to the graph, 30% too low wind speed prediction at WTG site could be expected. This could lead to around 60%\*) too low calculated energy production.

If the reference site is less rugged, e.g. RIX = 0, and the predicted site (WTG) are very rugged (e.g. RIX = 0.2), Delta RIX will be +0.2, and according to the graph, 30% too high wind speed prediction at WTG site could be expected. This could lead to around 60%\*) too high calculated energy production.

\*) Doubling of energy prediction error based on mean wind speed error is a rough conversion, which holds for wind speeds around 8 m/s. At 6-7 m/s tripling is more right, while only 1.5 factors should be used for 9 m/s, see graph below based on a typical WTG.



Source: EWEC06 paper:

### IMPROVING WAsP PREDICTIONS IN (TOO) COMPLEX TERRAIN

Niels G. Mortensen, Anthony J. Bowen and Ioannis Antoniou  
 Wind Energy Department, Risø National Laboratory

Project:

SSI\_Fase2

Description:

Potential wind farm site SSI

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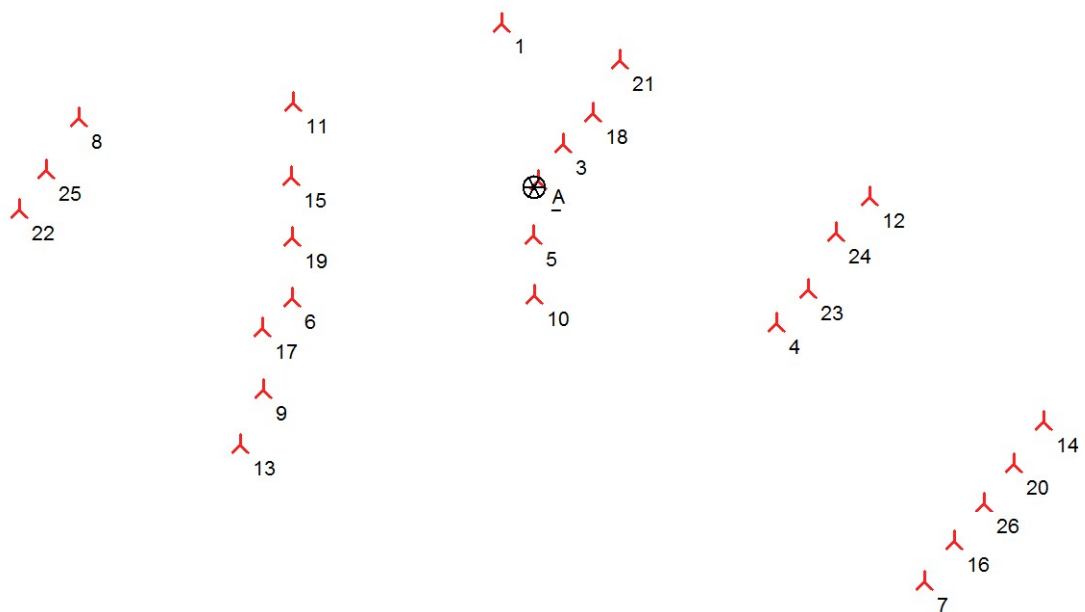
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**PARK - Mapa****Calculation:** B South 2 optimizado

0 500 1000 1500 2000 m

Map: Mapa en blanco , Print scale 1:50,000, Map center UTM WGS 84 South Zone: 35 East: 603,098 North: 6,609,974

 New WTG

 Site Data

# LESOTHO POWER GENERATION MASTER PLAN

PROJECT # LEC/GEN/1-2009

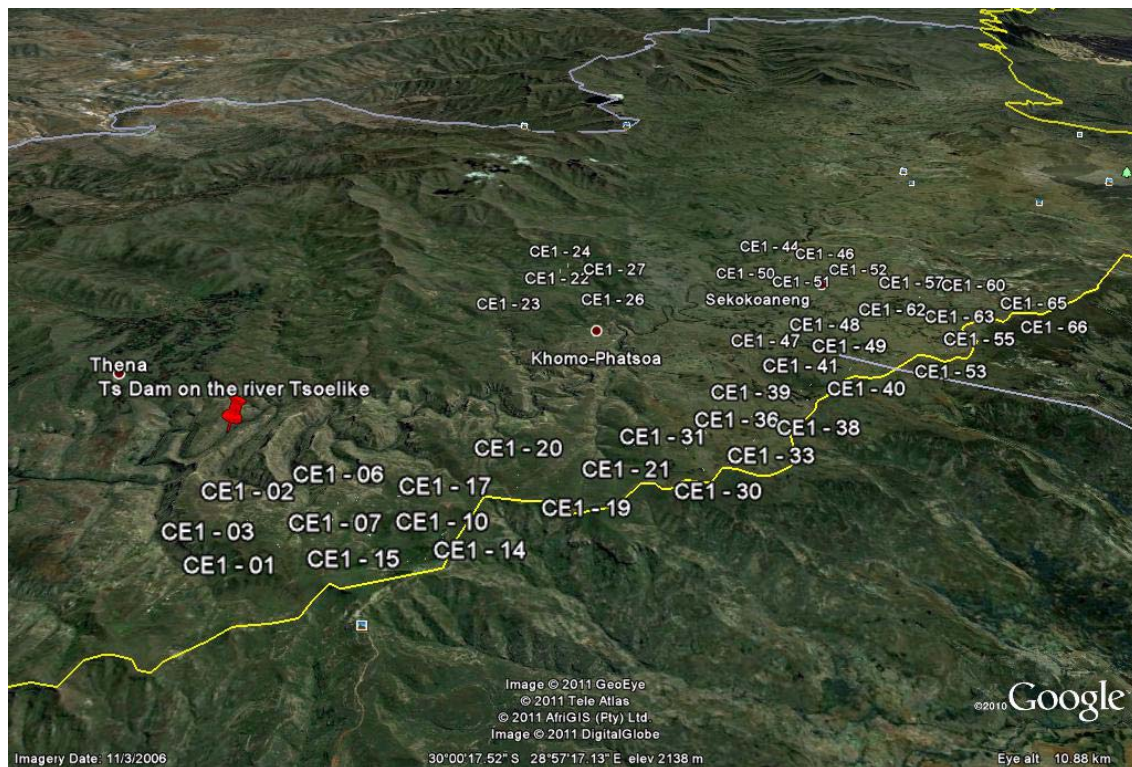
FINAL MILESTONES REPORT

VOLUME 1 - PART 1.2

WIND POWER GENERATION OPTION

## APPENDIX 1.2.5

### C EAST 1 WIND FARM



July 2011

# HYPERLINK

a. Area: c

Hyperlink: [d- Area C Potential Sites.KMZ](#)

b. RPD: C - East 1 proposed Wind Farm

Hyperlink: [i- C East 1.kmz](#)

Project: SSI\_Fase2  
Description: Potential wind farm site SSI

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## PARK - Main Result

Calculation: C East 1 optimizado

Wake Model N.O. Jensen (RISØ/EMD)

### Calculation Settings

Air density calculation mode Individual per WTG  
Result for WTG at hub altitude 0.925 kg/m³ to 0.945 kg/m³  
Air density relative to standard 77.1 %  
Hub altitude above sea level (asl) 2,320.0 m to 2,533.7 m  
Annual mean temperature at hub alt. 10.3 °C to 11.7 °C  
Pressure at WTGs 752.9 hPa to 772.5 hPa

### Wake Model Parameters

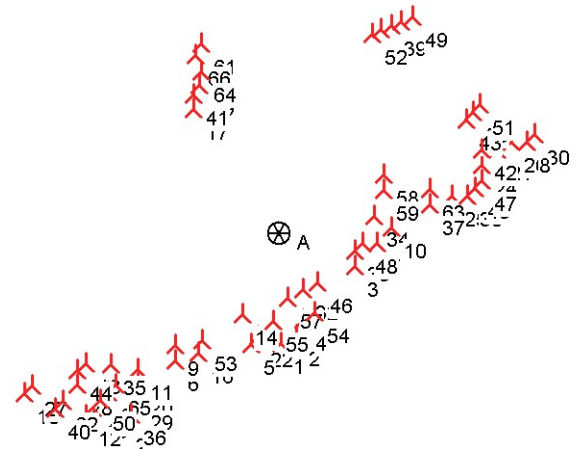
From angle To angle Terrain type Wake Decay Constant  
[°] [°]  
-180.0 180.0 Zona agrícola abierta 0.075

### 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 data

Wind statistics	Distance [km]	Weight [%]
LS Zona C2 Mesoscale 2 - 80.00 m.wws	4	25
LS Zona C2 Mesoscale 3 - 80.00 m.wws	4	25
LS Zona C2 Mesoscale 4 - 80.00 m.wws	2	50



New WTG

Scale 1:200,000  
Site Data

WAsP version WAsP 6-9 for Windows RVEA0011 1, 0, 0, 13  
WAsP parameters detailed information at the end of "Main results"

## Key results for height 80.0 m above ground level

Terrain UTM WGS84 S Zone: 35

East	North	Name of wind distribution	Type
A 690,420	6,679,047	Zona C East 1 to WAsP	WAsP (WAsP 6-9 for Windows RVEA0011 1, 0, 0, 13)

Wind energy [kWh/m²]	Mean wind speed [m/s]	Equivalent roughness
3,589	7.0	1.7

## 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 [%]	Capacity factor [%]	Mean WTG result [MWh/y]	Full load hours [Hours/year]	Mean wind speed @hub height [m/s]	Resultados específicos*)	
									Mean WTG result [MWh/y]	Full load hours [Hours/year]
Wind farm	371,530.1	334,377.1	383,424.9	96.9	28.5	4,990.7	2,495	8.3		

\*) Basado en Result-10.0%

## Calculated Annual Energy for each of 67 new WTGs with total 134.0 MW rated power

Terrain	Valid	WTG type	Manuf.	Type-generator	Power, rated [kW]	Rotor diameter [m]	Hub height [m]	Power curve Creator	Name	Annual Energy		Park Efficiency [%]	Mean wind speed [m/s]
										Result [MWh]	Result-10.0% [MWh]		
1 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	6,188.5	5,570	95.6	9.44	
2 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	6,326.2	5,694	95.8	9.51	
3 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	6,374.9	5,737	98.2	9.32	
4 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	6,117.9	5,506	95.9	9.06	
5 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,980.2	5,382	97.2	8.83	
6 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,958.7	5,363	98.1	8.68	
7 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,862.1	5,276	97.0	8.83	
8 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,790.0	5,211	95.5	8.71	
9 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	6,055.7	5,450	98.5	8.86	
10 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,923.2	5,331	96.4	8.80	
11 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,894.2	5,305	96.9	8.61	
12 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,913.3	5,322	94.8	8.84	
13 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,369.3	4,832	97.9	7.95	
14 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	6,047.8	5,443	98.6	8.59	

To be continued on next page...

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## PARK - Main Result

Calculation: C East 1 optimizado

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WTG type			Type-generator	Power, rated	Rotor diameter	Hub height	Power curve		Annual Energy		Park	
Terrain	Valid	Manufact.					Creator	Name	Result	Result-10.0%	Efficiency	Mean wind speed
				[kW]	[m]	[m]			[MWh]	[MWh]	[%]	[m/s]
15 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,709.8	5,139	94.2	8.66
16 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,676.2	5,109	96.7	8.38
17 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	6,064.5	5,458	99.4	8.64
18 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,802.6	5,222	98.1	8.27
19 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	6,073.7	5,466	98.2	8.61
20 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,582.4	5,024	95.3	8.52
21 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,429.0	4,886	94.9	8.24
22 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,550.7	4,996	95.9	8.26
23 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,464.4	4,918	93.6	8.45
24 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,590.6	5,032	97.0	8.32
25 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,519.4	4,967	96.4	8.23
26 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,446.2	4,902	96.3	8.19
27 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,790.8	5,212	98.7	8.30
28 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,771.8	5,195	97.5	8.39
29 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,490.4	4,941	94.2	8.51
30 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,457.6	4,912	97.4	8.12
31 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,368.5	4,832	97.4	7.91
32 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,137.7	4,624	98.1	7.70
33 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,615.0	5,053	97.5	8.29
34 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,451.6	4,906	98.4	7.99
35 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,171.1	4,654	97.2	7.79
36 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,355.5	4,820	93.5	8.30
37 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,458.7	4,913	97.5	8.13
38 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,295.9	4,766	95.5	8.05
39 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,050.5	4,545	96.2	7.64
40 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,433.8	4,890	95.4	8.14
41 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,808.0	5,227	98.5	8.35
42 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,403.9	4,864	96.8	8.01
43 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,512.7	4,961	96.3	8.10
44 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,738.8	5,165	97.7	8.42
45 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,324.2	4,792	96.9	8.04
46 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,558.1	5,002	98.4	8.19
47 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,465.1	4,919	97.7	8.16
48 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,443.0	4,899	98.2	8.06
49 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	4,671.5	4,204	97.6	7.20
50 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,305.7	4,775	93.4	8.22
51 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,240.0	4,716	97.4	7.79
52 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,631.5	5,068	98.8	8.14
53 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,633.2	5,070	98.1	8.23
54 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,426.5	4,884	95.8	8.18
55 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,385.9	4,847	97.2	8.02
56 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,287.3	4,759	95.9	7.92
57 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,489.5	4,941	98.0	8.00
58 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,513.4	4,962	98.8	8.05
59 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,533.6	4,980	98.7	8.08
60 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	4,469.1	4,022	96.3	7.08
61 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	4,873.9	4,387	99.3	7.33
62 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,213.4	4,692	96.9	7.85
63 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,225.3	4,703	97.8	7.85
64 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,444.2	4,900	98.0	7.99
65 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,135.8	4,622	94.9	7.92
66 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,080.9	4,573	98.8	7.54
67 A	Yes	VESTAS	V80-2.0MW-2,000	2,000	80.0	80.0	EMD	Mode 0	5,155.1	4,640	93.8	8.01

Project: SSI\_Fase2  
Description: Potential wind farm site SSI

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## PARK - Main Result

Calculation: C East 1 optimizado

### WTG siting

UTM WGS84 S Zone: 35				
	East	North	Z	Row data/Description
	UTM WGS84 S Zone: 35		[m]	
1 New	690,427	6,676,155	2,384.0	VESTAS V80-2.0MW 80.0m CE1 - 33
2 New	690,827	6,676,355	2,400.0	VESTAS V80-2.0MW 80.0m CE1 - 35
3 New	692,427	6,678,155	2,384.6	VESTAS V80-2.0MW 80.0m CE1 - 40
4 New	691,027	6,676,755	2,379.2	VESTAS V80-2.0MW 80.0m CE1 - 36
5 New	689,627	6,676,155	2,340.0	VESTAS V80-2.0MW 80.0m CE1 - 30
6 New	687,627	6,675,755	2,331.1	VESTAS V80-2.0MW 80.0m CE1 - 19
7 New	693,007	6,678,755	2,357.3	VESTAS V80-2.0MW 80.0m CE1 - 45
8 New	697,027	6,681,355	2,453.7	VESTAS V80-2.0MW 80.0m CE1 - 66
9 New	687,627	6,676,155	2,320.1	VESTAS V80-2.0MW 80.0m CE1 - 20
10 New	693,417	6,679,155	2,390.0	VESTAS V80-2.0MW 80.0m CE1 - 49
11 New	686,627	6,675,555	2,327.3	VESTAS V80-2.0MW 80.0m CE1 - 16
12 New	685,227	6,674,355	2,330.7	VESTAS V80-2.0MW 80.0m CE1 - 07
13 New	685,263	6,675,712	2,240.0	VESTAS V80-2.0MW 80.0m CE1 - 08
14 New	689,427	6,676,955	2,320.0	VESTAS V80-2.0MW 80.0m CE1 - 29
15 New	685,427	6,674,555	2,305.4	VESTAS V80-2.0MW 80.0m CE1 - 09
16 New	688,227	6,675,955	2,317.5	VESTAS V80-2.0MW 80.0m CE1 - 21
17 New	688,227	6,682,355	2,360.0	VESTAS V80-2.0MW 80.0m CE1 - 22
18 New	683,627	6,674,955	2,272.4	VESTAS V80-2.0MW 80.0m CE1 - 01
19 New	688,372	6,682,996	2,399.4	VESTAS V80-2.0MW 80.0m CE1 - 26
20 New	686,627	6,675,155	2,279.8	VESTAS V80-2.0MW 80.0m CE1 - 17
21 New	696,227	6,681,155	2,416.5	VESTAS V80-2.0MW 80.0m CE1 - 64
22 New	689,827	6,676,355	2,328.5	VESTAS V80-2.0MW 80.0m CE1 - 31
23 New	686,227	6,674,155	2,252.5	VESTAS V80-2.0MW 80.0m CE1 - 14
24 New	695,827	6,680,755	2,393.3	VESTAS V80-2.0MW 80.0m CE1 - 61
25 New	695,027	6,679,955	2,380.0	VESTAS V80-2.0MW 80.0m CE1 - 55
26 New	696,627	6,681,355	2,421.4	VESTAS V80-2.0MW 80.0m CE1 - 65
27 New	683,827	6,675,155	2,260.0	VESTAS V80-2.0MW 80.0m CE1 - 02
28 New	685,027	6,675,155	2,286.8	VESTAS V80-2.0MW 80.0m CE1 - 05
29 New	686,627	6,674,755	2,247.3	VESTAS V80-2.0MW 80.0m CE1 - 18
30 New	697,227	6,681,555	2,428.3	VESTAS V80-2.0MW 80.0m CE1 - 67
31 New	693,222	6,684,390	2,286.4	VESTAS V80-2.0MW 80.0m CE1 - 46
32 New	691,043	6,677,566	2,265.3	VESTAS V80-2.0MW 80.0m CE1 - 37
33 New	692,427	6,678,555	2,334.5	VESTAS V80-2.0MW 80.0m CE1 - 41
34 New	692,949	6,679,458	2,338.8	VESTAS V80-2.0MW 80.0m CE1 - 43
35 New	685,915	6,675,672	2,240.0	VESTAS V80-2.0MW 80.0m CE1 - 12
36 New	686,427	6,674,355	2,240.0	VESTAS V80-2.0MW 80.0m CE1 - 15
37 New	694,427	6,679,755	2,354.0	VESTAS V80-2.0MW 80.0m CE1 - 53
38 New	695,427	6,679,955	2,369.4	VESTAS V80-2.0MW 80.0m CE1 - 56
39 New	693,493	6,684,466	2,276.6	VESTAS V80-2.0MW 80.0m CE1 - 50
40 New	684,427	6,674,555	2,282.9	VESTAS V80-2.0MW 80.0m CE1 - 03
41 New	688,227	6,682,755	2,364.6	VESTAS V80-2.0MW 80.0m CE1 - 23
42 New	695,827	6,681,155	2,400.0	VESTAS V80-2.0MW 80.0m CE1 - 62
43 New	695,427	6,681,955	2,400.0	VESTAS V80-2.0MW 80.0m CE1 - 57
44 New	685,027	6,675,555	2,254.7	VESTAS V80-2.0MW 80.0m CE1 - 06
45 New	695,627	6,680,155	2,352.9	VESTAS V80-2.0MW 80.0m CE1 - 58
46 New	691,427	6,677,755	2,277.8	VESTAS V80-2.0MW 80.0m CE1 - 39
47 New	695,827	6,680,355	2,362.6	VESTAS V80-2.0MW 80.0m CE1 - 63
48 New	692,627	6,678,755	2,325.1	VESTAS V80-2.0MW 80.0m CE1 - 42
49 New	694,058	6,684,695	2,245.8	VESTAS V80-2.0MW 80.0m CE1 - 52
50 New	685,627	6,674,755	2,268.7	VESTAS V80-2.0MW 80.0m CE1 - 10
51 New	695,803	6,682,347	2,375.3	VESTAS V80-2.0MW 80.0m CE1 - 60
52 New	692,974	6,684,258	2,280.0	VESTAS V80-2.0MW 80.0m CE1 - 44
53 New	688,346	6,676,285	2,300.0	VESTAS V80-2.0MW 80.0m CE1 - 25
54 New	691,337	6,676,963	2,321.4	VESTAS V80-2.0MW 80.0m CE1 - 38
55 New	690,227	6,676,755	2,311.9	VESTAS V80-2.0MW 80.0m CE1 - 32

To be continued on next page...

Project: **SSI\_Fase2**  
 Description: Potential wind farm site SSI

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## PARK - Main Result

Calculation: C East 1 optimizado

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### UTM WGS84 S Zone: 35

	East	North	Z	Row data/Description
	UTM WGS84 S Zone: 35			[m]
56 New	695,627	6,682,155	2,392.4	VESTAS V80-2.0MW 80.0m CE1 - 59
57 New	690,627	6,677,355	2,305.6	VESTAS V80-2.0MW 80.0m CE1 - 34
58 New	693,227	6,680,555	2,307.2	VESTAS V80-2.0MW 80.0m CE1 - 47
59 New	693,227	6,680,155	2,324.3	VESTAS V80-2.0MW 80.0m CE1 - 48
60 New	693,754	6,684,564	2,245.2	VESTAS V80-2.0MW 80.0m CE1 - 51
61 New	688,457	6,684,072	2,329.7	VESTAS V80-2.0MW 80.0m CE1 - 28
62 New	684,627	6,674,755	2,257.2	VESTAS V80-2.0MW 80.0m CE1 - 04
63 New	694,427	6,680,155	2,330.3	VESTAS V80-2.0MW 80.0m CE1 - 54
64 New	688,427	6,683,355	2,355.0	VESTAS V80-2.0MW 80.0m CE1 - 27
65 New	686,027	6,675,155	2,240.0	VESTAS V80-2.0MW 80.0m CE1 - 13
66 New	688,285	6,683,785	2,340.0	VESTAS V80-2.0MW 80.0m CE1 - 24
67 New	685,827	6,674,955	2,245.3	VESTAS V80-2.0MW 80.0m CE1 - 11

### Non-default WAsP parameters:

WAsP parameter	Minimum	Maximum	Default	Current value
Altura Estd. #4	5.0000	200.0000	100.0000	80.0000

Project: SSI\_Fase2  
Description: Potential wind farm site SSI

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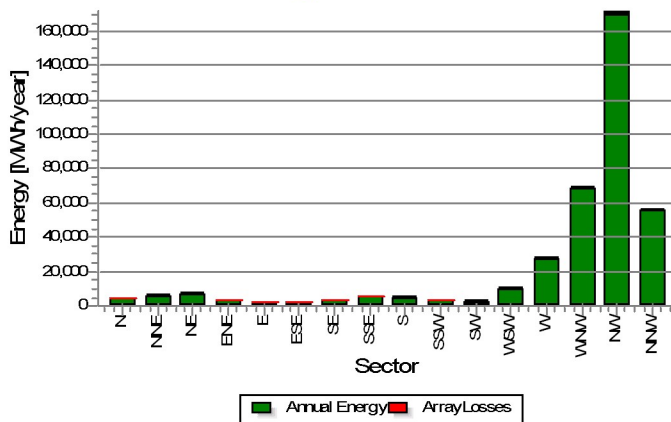
## PARK - Production Analysis

**Calculation:** C East 1 optimizado **WTG:** All new WTGs, Air density varies with WTG position 0.925 kg/m<sup>3</sup> - 0.945 kg/m<sup>3</sup>

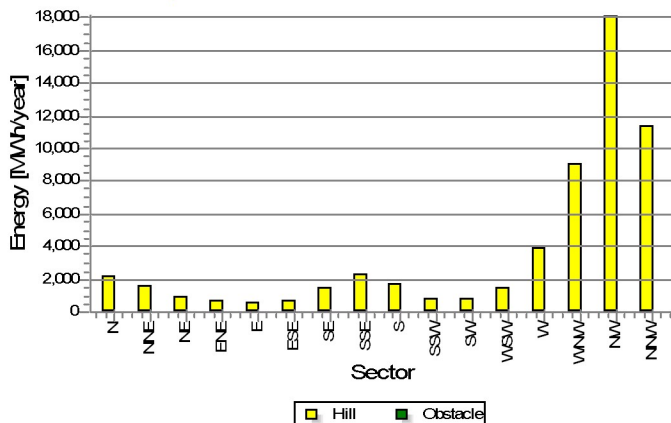
### Directional Analysis

Sector		0 N	1 NNE	2 NE	3 ENE	4 E	5 ESE	6 SE	7 SSE	8 S	9 SSW	10 SW	11 WSW	12 W	13 WNW	14 NW	15 NNW	Total
Roughness based energy	[MWh]	2,411.2	4,540.0	6,691.1	2,719.4	1,418.3	1,299.5	2,003.0	3,251.0	3,177.7	2,862.0	2,498.7	9,286.3	24,632.1	60,297.4	153,448.7	45,185.4	325,721.7
+Increase due to hills	[MWh]	2,157.6	1,601.6	965.0	648.6	568.3	690.5	1,475.7	2,331.5	1,755.8	819.4	778.4	1,457.2	3,897.9	9,047.2	18,171.0	11,337.0	57,702.8
-Decrease due to array losses	[MWh]	403.1	495.5	1,474.4	512.1	181.9	125.3	142.7	220.3	455.8	322.4	638.0	1,354.9	1,337.8	1,449.4	1,877.3	904.0	11,894.8
<b>Resulting energy</b>	<b>[MWh]</b>	<b>4,165.7</b>	<b>5,646.1</b>	<b>6,181.7</b>	<b>2,856.0</b>	<b>1,804.7</b>	<b>1,864.8</b>	<b>3,336.0</b>	<b>5,362.3</b>	<b>4,477.8</b>	<b>3,359.0</b>	<b>2,639.1</b>	<b>9,388.6</b>	<b>27,192.2</b>	<b>67,895.2</b>	<b>169,742.3</b>	<b>55,618.5</b>	<b>371,530.3</b>
Specific energy	[kWh/m <sup>2</sup> ]																	1,103
Specific energy	[kWh/kW]																	2,773
Increase due to hills	[%]	89.5	35.3	14.4	23.9	40.1	53.1	73.7	71.7	55.3	28.6	31.2	15.7	15.8	15.0	11.8	25.1	17.72
Decrease due to array losses	[%]	8.8	8.1	19.3	15.2	9.2	6.3	4.1	3.9	9.2	8.8	19.5	12.6	4.7	2.1	1.1	1.6	3.10
Utilization	[%]	28.4	35.8	32.7	34.4	35.9	36.9	38.0	38.5	36.3	36.5	31.8	33.8	29.1	19.1	15.9	19.9	19.1
Operational	[Hours/year]	211	284	295	193	150	151	267	376	303	221	212	377	597	1,016	1,856	752	7,260
Full Load Equivalent	[Hours/year]	31	42	46	21	13	14	25	40	33	25	20	70	203	507	1,267	415	2,773

Energy vs. sector



Impact of hills and obstacles vs. sector



Project: SSI\_Fase2  
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## PARK - Power Curve Analysis

**Calculation:** C East 1 optimizado **WTG:** 1 - VESTAS V80-2.0MW 2000 80.0 !O! Mode 0, Hub height: 80.0 m

**Name:** Mode 0  
**Source:** Manufacturer

Source/Date	Created by	Created	Edited	Stop wind speed	Power control	CT curve type
12/4/2009	EMD	12/07/2010	16/07/2010	25.0	Paso var. (Pitch)	Definido por usuario

Estimated power curve based on item n. 0004-7878 V03 04-12-2009.

**HP curve comparison** - Note: For standard air density and weibull k parameter = 2

Vmean	[m/s]	5	6	7	8	9	10
HP value	[MWh]	2,341	3,854	5,431	6,968	8,268	9,419
VESTAS V80-2.0MW 2000 80.0 !O! Mode 0	[MWh]	2,580	4,109	5,690	7,175	8,483	9,573
Check value	[%]	-9	-6	-5	-3	-3	-2

The table shows comparison between annual energy production calculated on basis of simplified "HP-curves" which assume that all WTGs performs quite similar - only specific power loading (kW/m<sup>2</sup>) and single/dual speed or stall/pitch decides the calculated values. Productions are without wake losses.

For further details, ask at the Danish Energy Agency for project report J.nr. 51171/00-0016 or see WindPRO manual chapter 3.5.2.

The method is refined in EMD report "20 Detailed Case Studies comparing Project Design Calculations and actual Energy Productions for Wind Energy Projects worldwide", jan 2003.

Use the table to evaluate if the given power curve is reasonable - if the check value are lower than -5%, the power curve probably is too optimistic due to uncertainty in power curve measurement.

## Power curve

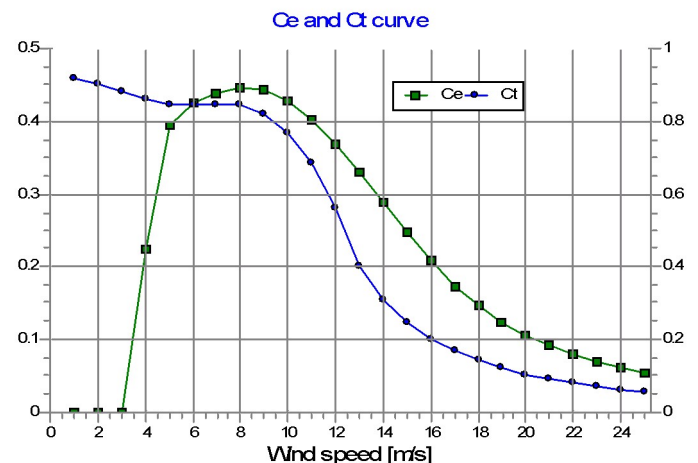
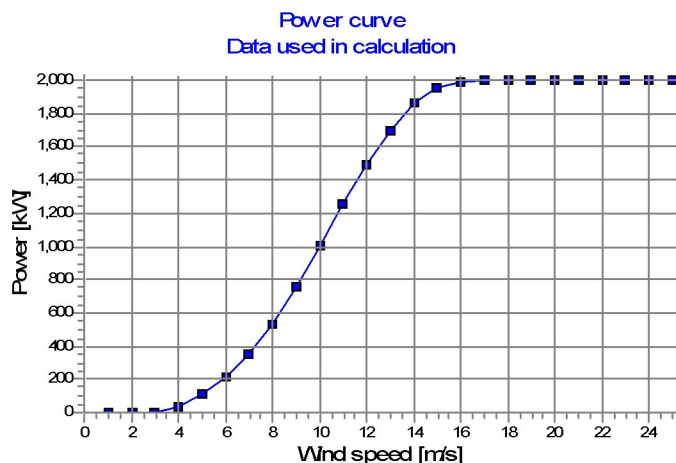
Original data from Windcat, Air density: 1.225 kg/m<sup>3</sup>

Wind speed	Power	Ce	Wind speed	Ct curve
[m/s]	[kW]		[m/s]	
4.0	66.0	0.33	4.0	0.86
5.0	156.0	0.41	5.0	0.84
6.0	285.0	0.43	6.0	0.84
7.0	467.0	0.44	7.0	0.84
8.0	706.0	0.45	8.0	0.84
9.0	1,001.0	0.45	9.0	0.82
10.0	1,329.0	0.43	10.0	0.77
11.0	1,652.0	0.40	11.0	0.68
12.0	1,892.0	0.36	12.0	0.56
13.0	1,982.0	0.29	13.0	0.40
14.0	2,000.0	0.24	14.0	0.31
15.0	2,000.0	0.19	15.0	0.25
16.0	2,000.0	0.16	16.0	0.20
17.0	2,000.0	0.13	17.0	0.17
18.0	2,000.0	0.11	18.0	0.14
19.0	2,000.0	0.09	19.0	0.12
20.0	2,000.0	0.08	20.0	0.10
21.0	2,000.0	0.07	21.0	0.09
22.0	2,000.0	0.06	22.0	0.08
23.0	2,000.0	0.05	23.0	0.07
24.0	2,000.0	0.05	24.0	0.06
25.0	2,000.0	0.04	25.0	0.06

## Power, Efficiency and energy vs. wind speed

Data used in calculation, Air density: 0.932 kg/m<sup>3</sup> Nuevo método WindPRO (método IEC ajustado, mejorado para que coincida con el control de la turbina)  
<RECOMENDADO>

Wind speed	Power	Ce	Interval	Energy	Acc. Energy	Relative
[m/s]	[kW]		[m/s]	[MWh]	[MWh]	[%]
1.0	0.0	0.00	0.50-1.50	0.0	0.0	0.0
2.0	0.0	0.00	1.50-2.50	0.0	0.0	0.0
3.0	0.0	0.00	2.50-3.50	0.0	0.0	0.0
4.0	33.6	0.22	3.50-4.50	27.2	27.2	0.4
5.0	115.5	0.39	4.50-5.50	86.9	114.1	1.8
6.0	215.3	0.43	5.50-6.50	160.1	274.2	4.4
7.0	352.3	0.44	6.50-7.50	243.9	518.1	8.4
8.0	533.3	0.44	7.50-8.50	325.1	843.3	13.6
9.0	755.5	0.44	8.50-9.50	390.8	1,234.0	19.9
10.0	1,004.5	0.43	9.50-10.50	433.5	1,667.5	26.9
11.0	1,255.4	0.40	10.50-11.50	455.6	2,123.1	34.3
12.0	1,487.2	0.37	11.50-12.50	463.5	2,586.6	41.8
13.0	1,695.6	0.33	12.50-13.50	459.9	3,046.5	49.2
14.0	1,860.5	0.29	13.50-14.50	446.2	3,492.7	56.4
15.0	1,951.0	0.25	14.50-15.50	421.7	3,914.4	63.3
16.0	1,990.7	0.21	15.50-16.50	386.5	4,300.9	69.5
17.0	2,000.0	0.17	16.50-17.50	347.2	4,648.1	75.1
18.0	2,000.0	0.15	17.50-18.50	308.8	4,956.9	80.1
19.0	2,000.0	0.12	18.50-19.50	272.5	5,229.4	84.5
20.0	2,000.0	0.11	19.50-20.50	238.4	5,467.8	88.4
21.0	2,000.0	0.09	20.50-21.50	206.7	5,674.6	91.7
22.0	2,000.0	0.08	21.50-22.50	177.6	5,852.1	94.6
23.0	2,000.0	0.07	22.50-23.50	151.1	6,003.2	97.0
24.0	2,000.0	0.06	23.50-24.50	127.3	6,130.5	99.1
25.0	2,000.0	0.05	24.50-25.50	58.0	6,188.5	100.0



Project:

**SSI\_Fase2**

Description:

Potential wind farm site SSI

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## PARK - Terrain

**Calculation:** C East 1 optimizado **Site Data:** A - Zona C East 1 to WAsP

### Obstacles:

0 Obstacles used

### Roughness:

Calculation uses following MAP files:

\\Server-dell\modeliza\Proyecto SSI\_2\03 WINDPRO\Data\WP Data C East 1\ROUGHNESSLINE Zona C2.wpo

Min X: 666,318, Max X: 699,468, Min Y: 6,668,173, Max Y: 6,689,453, Width: 33,150 m, Height: 21,280 m

### Orography:

Calculation uses following MAP files:

\\Server-dell\modeliza\Proyecto SSI\_2\03 WINDPRO\Data\WP Data C East 1\Curvas de nivel Zona C - II.wpo

Min X: 667,710, Max X: 698,897, Min Y: 6,668,688, Max Y: 6,688,292, Width: 31,187 m, Height: 19,604 m

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Description: Potential wind farm site SSI

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## PARK - Wind Data Analysis

Calculation: C East 1 optimizado Wind data: A - Zona C East 1 to WAsP; Hub height: 80.0

### Site Coordinates

UTM WGS 84 South Zone: 35 East: 690,420 North: 6,679,047

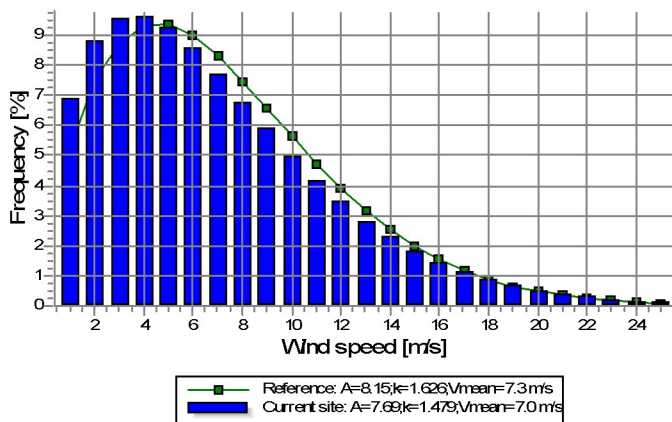
### Wind data

Wind statistics	Distance [km]	Weight [%]
LS Zona C2 Mesoscale 2 - 80.00 m.wws	4	25
LS Zona C2 Mesoscale 3 - 80.00 m.wws	4	25
LS Zona C2 Mesoscale 4 - 80.00 m.wws	2	50

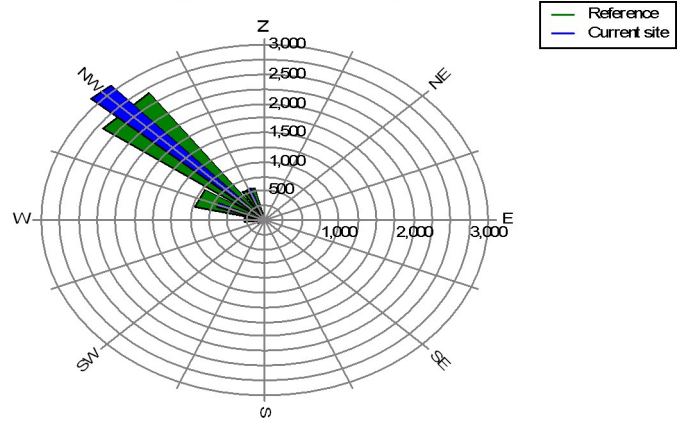
### Weibull Data

Sector	Current site		Frequency [%]	Reference: Roughness class 1		Frequency [%]
	A- parameter [m/s]	Wind speed [m/s]		A- parameter [m/s]	k- parameter	
0 N	4.28	3.84	1.600	4.27	1.394	2.5
1 NNE	4.66	4.13	2.139	5.48	2.014	4.0
2 NE	4.88	4.33	2.619	6.46	2.623	4.6
3 ENE	4.30	3.82	2.643	5.58	2.660	2.8
4 E	4.20	3.73	2.451	4.87	2.362	2.1
5 ESE	4.38	3.88	2.248	4.66	2.222	2.0
6 SE	4.78	4.25	2.678	4.1	2.764	3.5
7 SSE	4.91	4.36	2.639	4.87	2.715	4.9
8 S	4.64	4.11	2.365	5.00	2.357	4.2
9 SSW	4.29	3.80	2.322	5.32	2.400	3.2
10 SW	3.81	3.37	2.150	5.04	2.150	3.0
11 WSW	4.94	4.37	2.264	6.48	2.270	5.7
12 W	6.34	5.62	1.947	7.81	1.994	8.8
13 WNW	8.57	7.64	1.701	9.52	1.740	14.0
14 NW	11.81	10.46	2.096	11.91	2.175	25.5
15 NNW	9.29	8.24	1.889	9.55	2.008	9.4
All	7.69	6.95	1.479	8.15	1.626	100.0

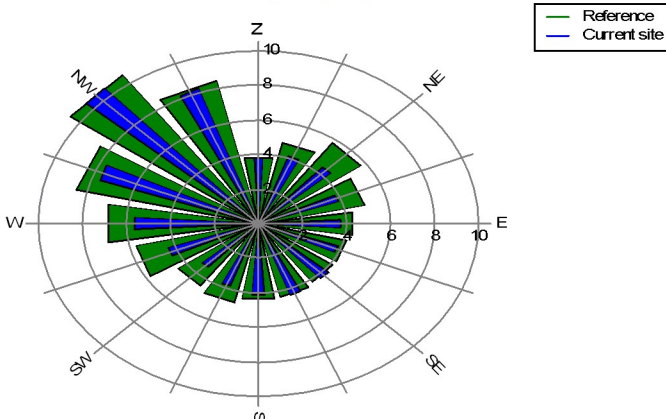
Weibull Distribution



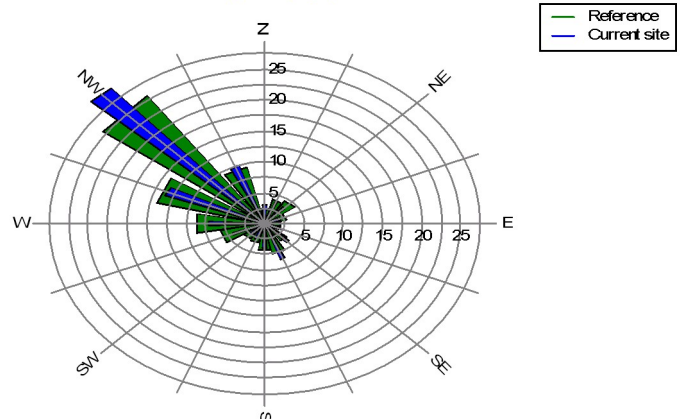
Energy Rose (kWh/m<sup>2</sup>/year)



Mean wind speed (m/s)



Frequency (%)



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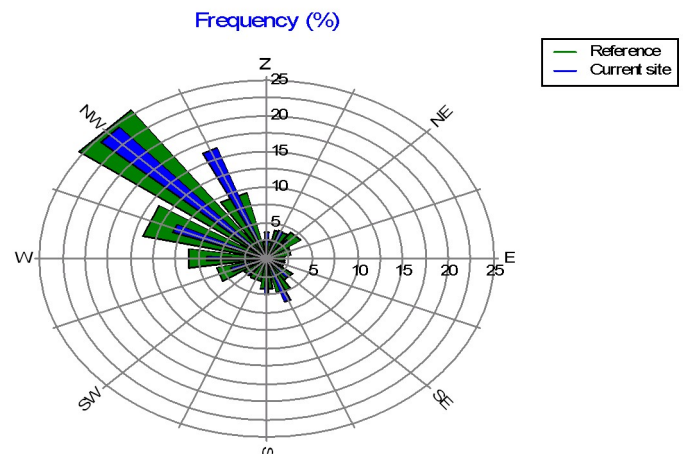
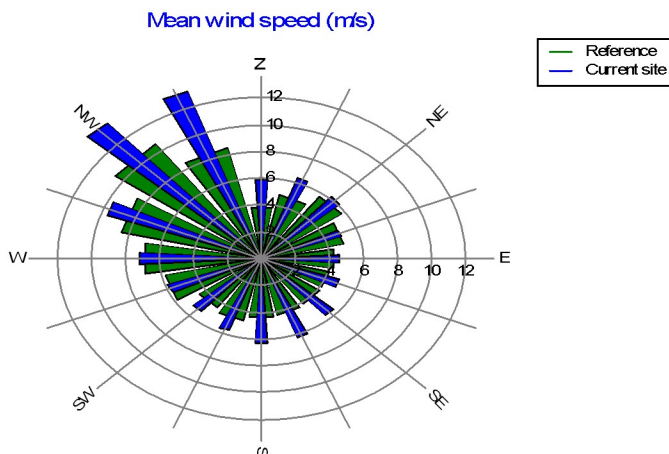
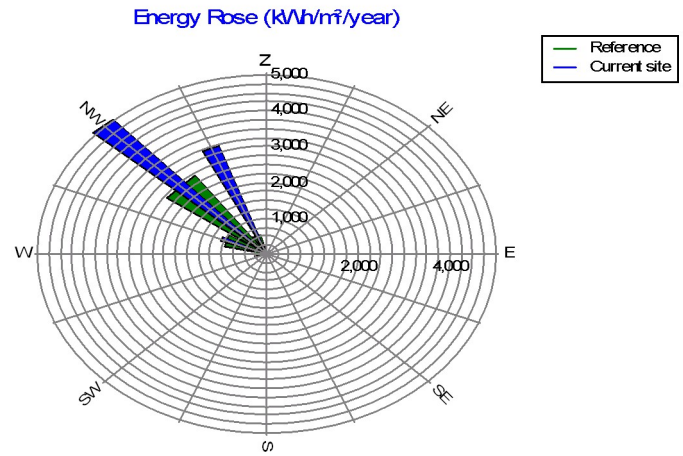
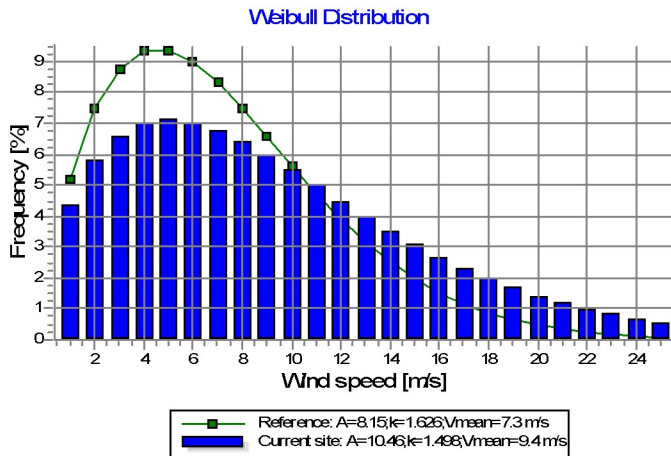
**PARK - Wind Data Analysis****Calculation:** C East 1 optimizado **Wind data:** A - Zona C East 1 to WAsP; Hub height: 80.0**Site Coordinates**UTM WGS 84 South Zone: 35 East: 690,427 North: 6,676,155  
VESTAS V80-2.0MW 80.0m CE1 - 33**Wind data**

Wind statistics

	Distance [km]	Weight [%]
LS Zona C2 Mesoscale 2 - 80.00 m.wws	4	25
LS Zona C2 Mesoscale 3 - 80.00 m.wws	4	25
LS Zona C2 Mesoscale 4 - 80.00 m.wws	2	50

**Weibull Data**

Sector	Current site		Frequency [%]	Reference: Roughness class 1		
	A- parameter [m/s]	Wind speed [m/s]	k- parameter	A- parameter [m/s]	k- parameter	Frequency [%]
0 N	6.55	5.88	1.588	4.27	1.394	2.5
1 NNE	7.16	6.34	2.205	5.48	2.014	4.0
2 NE	6.96	6.18	2.549	6.46	2.623	4.6
3 ENE	5.62	4.99	2.658	5.58	2.660	2.8
4 E	5.21	4.62	2.396	4.87	2.362	2.1
5 ESE	5.49	4.86	2.240	4.66	2.222	2.0
6 SE	6.31	5.61	2.600	4.70	2.764	3.5
7 SSE	7.05	6.27	2.678	4.87	2.715	4.9
8 S	7.09	6.29	2.369	5.00	2.357	4.2
9 SSW	6.42	5.69	2.256	5.32	2.400	3.2
10 SW	5.96	5.28	2.166	5.04	2.150	3.0
11 WSW	6.52	5.78	2.271	6.48	2.270	5.7
12 W	8.11	7.19	1.982	7.81	1.994	8.8
13 WNW	10.73	9.58	1.689	9.52	1.740	14.0
14 NW	15.35	13.60	2.014	11.91	2.175	25.5
15 NNW	14.88	13.19	2.021	9.55	2.008	9.4
All	10.46	9.44	1.498	8.15	1.626	100.0



Project: **SSI\_Fase2**  
 Description: **Potential wind farm site SSI**

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## PARK - Park power curve

Calculation: C East 1 optimizado

Wind speed	Free WTGs	Park WTGs	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
[m/s]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4.5	5,061	4,313	3,925	4,122	3,226	3,580	4,161	4,487	4,658	4,600	4,009	4,130	3,141	3,609	4,170	4,480	4,660	4,599
5.5	10,612	9,645	9,093	9,434	7,965	8,668	9,500	9,899	10,103	10,034	9,298	9,439	7,902	8,704	9,514	9,892	10,110	10,036
6.5	18,498	16,952	16,036	16,601	14,431	15,408	16,697	17,337	17,682	17,568	16,398	16,610	14,311	15,461	16,718	17,322	17,685	17,563
7.5	29,379	26,910	25,476	26,352	23,029	24,477	26,490	27,495	28,052	27,877	26,057	26,359	22,838	24,564	26,526	27,471	28,058	27,868
8.5	43,295	39,740	37,657	38,956	34,156	36,210	39,129	40,588	41,381	41,136	38,527	38,970	33,870	36,341	39,185	40,554	41,391	41,126
9.5	59,427	55,041	52,320	54,102	47,811	50,552	54,328	56,156	57,113	56,811	53,521	54,127	47,475	50,718	54,390	56,113	57,127	56,804
10.5	76,282	71,706	68,521	70,789	63,493	66,819	71,071	72,987	73,961	73,647	70,079	70,819	63,163	66,976	71,126	72,944	73,973	73,641
11.5	92,780	88,645	85,258	87,925	80,549	83,998	88,202	89,916	90,778	90,499	87,203	87,954	80,269	84,130	88,247	89,876	90,782	90,489
12.5	107,935	104,638	101,341	104,219	97,951	100,843	104,410	105,697	106,334	106,138	103,654	104,235	97,756	100,967	104,451	105,670	106,343	106,136
13.5	119,822	117,823	114,708	117,673	113,648	115,617	117,793	118,512	118,861	118,750	117,323	117,682	113,531	115,690	117,813	118,498	118,866	118,748
14.5	128,623	127,660	124,560	127,618	125,445	126,672	127,735	128,098	128,241	128,177	127,389	127,632	125,423	126,669	127,716	128,080	128,237	128,170
15.5	132,949	132,517	129,486	132,534	131,666	132,180	132,604	132,754	132,826	132,792	132,443	132,546	131,651	132,159	132,587	132,735	132,809	132,773
16.5	133,970	133,768	130,850	133,840	133,648	133,746	133,846	133,883	133,903	133,896	133,824	133,841	133,649	133,750	133,847	133,882	133,902	133,895
17.5	134,000	133,913	131,022	134,000	133,992	133,998	134,000	134,000	134,000	134,000	134,000	134,000	133,994	133,998	134,000	134,000	134,000	134,000
18.5	134,000	133,913	131,022	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000
19.5	134,000	133,913	131,022	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000
20.5	134,000	133,913	131,022	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000
21.5	134,000	133,913	131,022	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000
22.5	134,000	133,913	131,022	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000
23.5	134,000	133,913	131,022	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000
24.5	134,000	133,913	131,022	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000	134,000
25.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

### Description:

The park power curve is similar to a WTG power curve, meaning that when a given wind speed appears in front of the park with same speed in the entire wind farm area (before influence from the park), the output from the park can be found in the park power curve. Another way to say this: The park power curve includes array losses, but do NOT include terrain given variations in the wind speed over the park area.

Measuring a park power curve is not as simple as measuring a WTG power curve due to the fact that the park power curve depends on the wind direction and that the same wind speed normally will not appear for the entire park area at the same time (only in very flat non-complex terrain). The idea with this version of the park power curve is not to use it for validation based on measurements. This would require at least 2 measurement masts at two sides of the park, unless only a few direction sectors should be tested, AND non complex terrain (normally only useable off shore). Another park power curve version for complex terrain is available in WindPRO.

### The park power curve can be used for:

1. Forecast systems, based on more rough (approximated) wind data, the park power curve would be an efficient way to make the connection from wind speed (and direction) to power.
2. Construction of duration curves, telling how often a given power output will appear, the park power curve can be used together with the average wind distribution for the Wind farm area in hub height. The average wind distribution can eventually be obtained based on the Weibull parameters for each WTG position. These are found at print menu: >Result to file< in the >Park result< which can be saved to file or copied to clipboard and pasted in Excel.
3. Calculation of wind energy index based on the PARK production (see below).
4. Estimation of the expected PARK production for an existing wind farm based on wind measurements at minimum 2 measurement masts at two sides of wind farm. The masts must be used for obtaining the free wind speed. The free wind speed is used in the simulation of expected energy production with the PARK power curve. This procedure will only work suitable in non complex terrains. For complex terrain another park power curve calculation is available in WindPRO (PPV-model).

### Note:

From the >Result to file< the >Wind Speeds Inside Wind farm< is also available. These can (e.g. via Excel) be used for extracting the wake induced reductions in measured wind speed.

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Description: Potential wind farm site SSI

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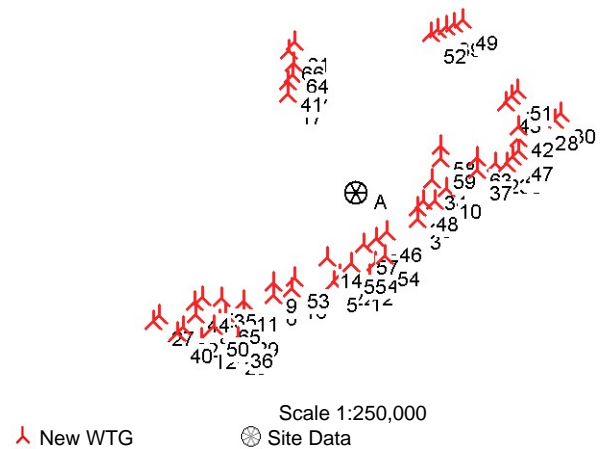
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## PARK - WTG distances

Calculation: C East 1 optimizado

### WTG distances

Z	Nearest WTG	Z	Horizontal distance	Distance in
[m]		[m]	[m]	rotor diameters
1 2,384.0	2 2,400.0		447	5.6
2 2,400.0	4 2,379.2		447	5.6
3 2,384.6	33 2,334.5		400	5.0
4 2,379.2	54 2,321.4		373	4.7
5 2,340.0	22 2,328.5		283	3.5
6 2,331.1	9 2,320.1		400	5.0
7 2,357.3	48 2,325.1		380	4.8
8 2,453.7	30 2,428.3		283	3.5
9 2,320.1	6 2,331.1		400	5.0
10 2,390.0	34 2,338.8		558	7.0
11 2,327.3	20 2,279.8		400	5.0
12 2,330.7	15 2,305.4		283	3.5
13 2,240.0	44 2,254.7		283	3.5
14 2,320.0	22 2,328.5		721	9.0
15 2,305.4	12 2,330.7		283	3.5
16 2,317.5	53 2,300.0		351	4.4
17 2,360.0	41 2,364.6		400	5.0
18 2,272.4	27 2,260.0		283	3.5
19 2,399.4	41 2,364.6		281	3.5
20 2,279.8	11 2,327.3		400	5.0
21 2,416.5	42 2,400.0		400	5.0
22 2,328.5	5 2,340.0		283	3.5
23 2,252.5	36 2,240.0		283	3.5
24 2,393.3	42 2,400.0		400	5.0
25 2,380.0	38 2,369.4		400	5.0
26 2,421.4	8 2,453.7		400	5.0
27 2,260.0	18 2,272.4		283	3.5
28 2,286.8	44 2,254.7		400	5.0
29 2,247.3	20 2,279.8		400	5.0
30 2,428.3	8 2,453.7		283	3.5
31 2,286.4	52 2,280.0		281	3.5
32 2,265.3	46 2,277.8		428	5.3
33 2,334.5	48 2,325.1		283	3.5
34 2,338.8	10 2,390.0		558	7.0
35 2,240.0	65 2,240.0		529	6.6
36 2,240.0	23 2,252.5		283	3.5
37 2,354.0	63 2,330.3		400	5.0
38 2,369.4	45 2,352.9		283	3.5
39 2,276.6	60 2,245.2		279	3.5
40 2,282.9	62 2,257.2		283	3.5
41 2,364.6	19 2,399.4		281	3.5
42 2,400.0	24 2,393.3		400	5.0
43 2,400.0	56 2,392.4		283	3.5
44 2,254.7	13 2,240.0		283	3.5
45 2,352.9	38 2,369.4		283	3.5
46 2,277.8	32 2,265.3		428	5.3
47 2,362.6	45 2,352.9		283	3.5
48 2,325.1	33 2,334.5		283	3.5
49 2,245.8	60 2,245.2		331	4.1
50 2,268.7	67 2,245.3		283	3.5
51 2,375.3	56 2,392.4		260	3.3
52 2,280.0	31 2,286.4		281	3.5
53 2,300.0	16 2,317.5		351	4.4
54 2,321.4	4 2,379.2		373	4.7
55 2,311.9	22 2,328.5		566	7.1



To be continued on next page...

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**PARK - WTG distances****Calculation:** C East 1 optimizado

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Z	Nearest WTG	Z	Horizontal distance	Distance in
[m]		[m]	[m]	rotor diameters
56 2,392.4	51 2,375.3	260	3.3	
57 2,305.6	32 2,265.3	466	5.8	
58 2,307.2	59 2,324.3	400	5.0	
59 2,324.3	58 2,307.2	400	5.0	
60 2,245.2	39 2,276.6	279	3.5	
61 2,329.7	66 2,340.0	335	4.2	
62 2,257.2	40 2,282.9	283	3.5	
63 2,330.3	37 2,354.0	400	5.0	
64 2,355.0	19 2,399.4	363	4.5	
65 2,240.0	67 2,245.3	283	3.5	
66 2,340.0	61 2,329.7	335	4.2	
67 2,245.3	50 2,268.7	283	3.5	

Project:

SSI\_Fase2

Description:

Potential wind farm site SSI

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**PARK - RIX calculation**

Calculation: C East 1 optimizado

**Assumptions**

Radius for calculation 3,500 m  
 Directional step 5 °  
 Steepness threshold 40.0 % / 22 °  
 Directional weight Equally distributed  
 Height contours used Curvas de nivel Zona C2

**Reference sites**

Terrain UTM WGS84 S Zone: 35

East	North	Z	Name of wind distribution	Type	Reference site RIX [%]
A 690,420	6,679,047	2160.0	Zona C East 1 to WAsP	WAsP (WAsP 6-9 for Windows RVEA0011 1, 0, 0, 13)	1.1

**WTG sites**

Terrain	UTM WGS84 S Zone: 35	East	North	Z	Reference site RIX	WTG RIX	Delta RIX (WTG site - Reference site)
	UTM WGS84 S Zone: 35			[m]	[%]	[%]	[%]
1 A	690,427	6,676,155	2,384.0	1.1	2.8	1.8	
2 A	690,827	6,676,355	2,400.0	1.1	3.7	2.6	
3 A	692,427	6,678,155	2,384.6	1.1	2.4	1.3	
4 A	691,027	6,676,755	2,379.2	1.1	3.3	2.2	
5 A	689,627	6,676,155	2,340.0	1.1	2.1	1.0	
6 A	687,627	6,675,755	2,331.1	1.1	2.2	1.1	
7 A	693,007	6,678,755	2,357.3	1.1	1.9	0.8	
8 A	697,027	6,681,355	2,453.7	1.1	1.8	0.7	
9 A	687,627	6,676,155	2,320.1	1.1	2.7	1.6	
10 A	693,417	6,679,155	2,390.0	1.1	1.9	0.8	
11 A	686,627	6,675,555	2,327.3	1.1	2.9	1.9	
12 A	685,227	6,674,355	2,330.7	1.1	2.2	1.1	
13 A	685,263	6,675,712	2,240.0	1.1	6.2	5.2	
14 A	689,427	6,676,955	2,320.0	1.1	1.9	0.8	
15 A	685,427	6,674,555	2,305.4	1.1	2.3	1.2	
16 A	688,227	6,675,955	2,317.5	1.1	1.9	0.8	
17 A	688,227	6,682,355	2,360.0	1.1	1.1	0.1	
18 A	683,627	6,674,955	2,272.4	1.1	5.2	4.1	
19 A	688,372	6,682,996	2,399.4	1.1	1.8	0.7	
20 A	686,627	6,675,155	2,279.8	1.1	2.0	1.0	
21 A	696,227	6,681,155	2,416.5	1.1	1.6	0.5	
22 A	689,827	6,676,355	2,328.5	1.1	2.1	1.0	
23 A	686,227	6,674,155	2,252.5	1.1	1.4	0.3	
24 A	695,827	6,680,755	2,393.3	1.1	2.1	1.0	
25 A	695,027	6,679,955	2,380.0	1.1	2.8	1.7	
26 A	696,627	6,681,355	2,421.4	1.1	1.5	0.4	
27 A	683,827	6,675,155	2,260.0	1.1	5.5	4.4	
28 A	685,027	6,675,155	2,286.8	1.1	4.4	3.3	
29 A	686,627	6,674,755	2,247.3	1.1	1.6	0.5	
30 A	697,227	6,681,555	2,428.3	1.1	1.2	0.1	
31 A	693,222	6,684,390	2,286.4	1.1	2.1	1.0	
32 A	691,043	6,677,566	2,265.3	1.1	2.4	1.3	
33 A	692,427	6,678,555	2,334.5	1.1	2.0	0.9	
34 A	692,949	6,679,458	2,338.8	1.1	1.4	0.3	
35 A	685,915	6,675,672	2,240.0	1.1	4.5	3.4	
36 A	686,427	6,674,355	2,240.0	1.1	1.3	0.2	
37 A	694,427	6,679,755	2,354.0	1.1	2.1	1.0	
38 A	695,427	6,679,955	2,369.4	1.1	3.2	2.1	
39 A	693,493	6,684,466	2,276.6	1.1	1.2	0.1	
40 A	684,427	6,674,555	2,282.9	1.1	4.2	3.1	
41 A	688,227	6,682,755	2,364.6	1.1	1.7	0.6	
42 A	695,827	6,681,155	2,400.0	1.1	1.6	0.5	
43 A	695,427	6,681,955	2,400.0	1.1	0.4	-0.6	
44 A	685,027	6,675,555	2,254.7	1.1	5.7	4.6	
45 A	695,627	6,680,155	2,352.9	1.1	3.1	2.0	
46 A	691,427	6,677,755	2,277.8	1.1	2.5	1.4	
47 A	695,827	6,680,355	2,362.6	1.1	2.5	1.4	
48 A	692,627	6,678,755	2,325.1	1.1	1.8	0.7	
49 A	694,058	6,684,695	2,245.8	1.1	1.6	0.5	
50 A	685,627	6,674,755	2,268.7	1.1	2.2	1.1	
51 A	695,803	6,682,347	2,375.3	1.1	0.6	-0.5	
52 A	692,974	6,684,258	2,280.0	1.1	2.8	1.7	
53 A	688,346	6,676,285	2,300.0	1.1	2.1	1.0	
54 A	691,337	6,676,963	2,321.4	1.1	3.2	2.1	
55 A	690,227	6,676,755	2,311.9	1.1	2.5	1.4	
56 A	695,627	6,682,155	2,392.4	1.1	0.6	-0.4	
57 A	690,627	6,677,355	2,305.6	1.1	2.6	1.5	
58 A	693,227	6,680,555	2,307.2	1.1	1.0	-0.1	
59 A	693,227	6,680,155	2,324.3	1.1	1.0	-0.1	
60 A	693,754	6,684,564	2,245.2	1.1	1.3	0.3	
61 A	688,457	6,684,072	2,329.7	1.1	1.5	0.4	
62 A	684,627	6,674,755	2,257.2	1.1	3.7	2.6	
63 A	694,427	6,680,155	2,330.3	1.1	2.0	0.9	
64 A	688,427	6,683,355	2,355.0	1.1	1.3	0.2	
65 A	686,027	6,675,155	2,240.0	1.1	2.7	1.6	

To be continued on next page...

Project: **SSI\_Fase2**  
Description: Potential wind farm site SSI

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## PARK - RIX calculation

Calculation: C East 1 optimizado

...continued from previous page

UTM WGS84 S Zone: 35							
Terrain	East	North	Z	Reference site RIX	WTG RIX	Delta RIX (WTG site - Reference site)	
	UTM WGS84 S Zone: 35		[m]	[%]	[%]	[%]	
66 A	688,285	6,683,785	2,340.0	1.1	1.6	0.5	
67 A	685,827	6,674,955	2,245.3	1.1	2.3	1.2	

Project: SSI\_Fase2  
Description: Potential wind farm site SSI

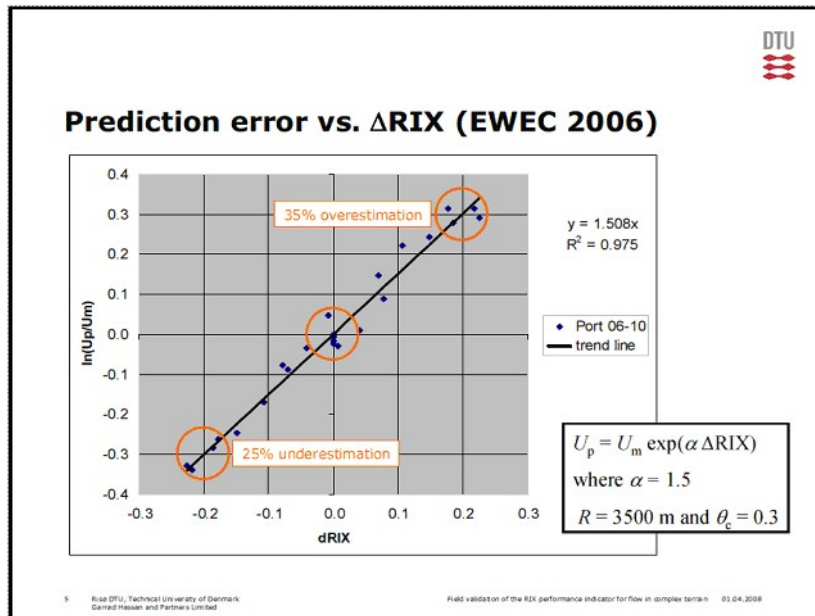
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## PARK - RIX calculation

Calculation: C East 1 optimizado

Latest research /Risø/ show that the threshold in RIX calculation typically work best with 40% (new default), and that delta Rix within +/- 5% should not give corrections. Cross predictions based on more mast can fine tune the threshold, see Cross predictor tool in WindPRO Meteo Analyzer. In WindPRO LOSS&&UNCERTAINTY module, RIX correction can be calculated automatically as a bias based on most recent recommended correction formulas, which can be found in EWEC2006 && 08 papers on Rix from Risø, see extract below:

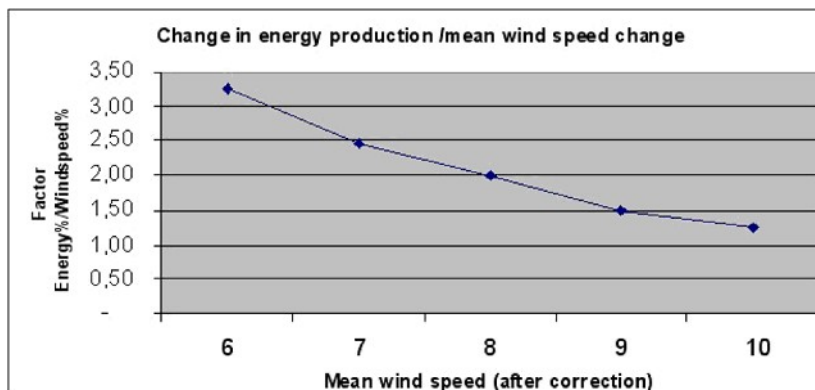


The main conclusion based on use of the RIX method is that if both reference site (measurement mast) and predicted site (WTG) are equally rugged (Delta RIX < 5%), very small calculation errors are expected.

If reference site (measurement mast) is very rugged, e.g. RIX = 0.2 and predicted site (WTG) are less rugged (e.g. RIX = 0), Delta RIX will be -0.2 and according to the graph, 30% too low wind speed prediction at WTG site could be expected. This could lead to around 60%\*) too low calculated energy production.

If the reference site is less rugged, e.g. RIX = 0, and the predicted site (WTG) are very rugged (e.g. RIX = 0.2), Delta RIX will be +0.2, and according to the graph, 30% too high wind speed prediction at WTG site could be expected. This could lead to around 60%\*) too high calculated energy production.

\*) Doubling of energy prediction error based on mean wind speed error is a rough conversion, which holds for wind speeds around 8 m/s. At 6-7 m/s tripling is more right, while only 1.5 factors should be used for 9 m/s, see graph below based on a typical WTG.



Source: EWEC06 paper:

**IMPROVING WAsP PREDICTIONS IN (TOO) COMPLEX TERRAIN**

Niels G. Mortensen, Anthony J. Bowen and Ioannis Antoniou

WindPRO is developed by EMD International A/S, Niels Jernesvej 10, DK-9220 Ålborg Ø, Tlf. +45 96 35 44 44, Fax +45 96 35 44 46, e-mail: windpro@emd.dk  
Wind Energy Department, Risø National Laboratory

Project:

SSI\_Fase2

Description:

Potential wind farm site SSI

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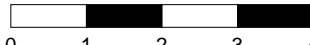
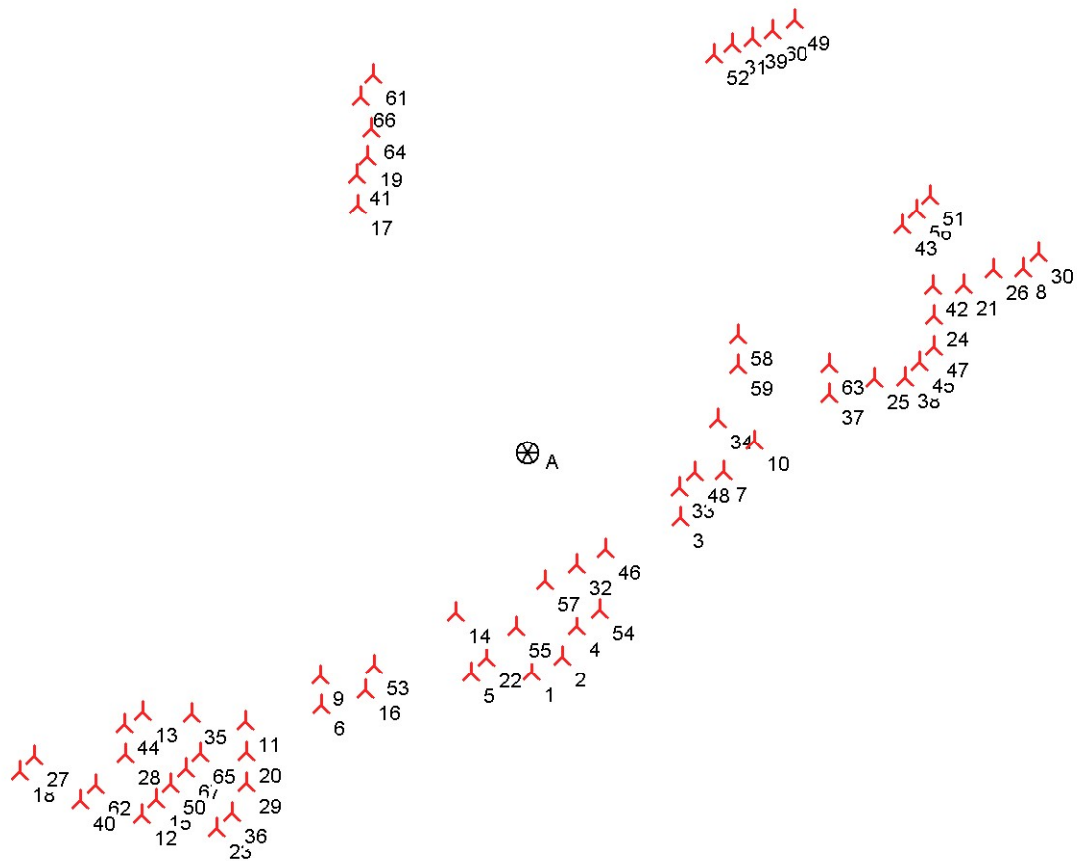
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**PARK - Mapa****Calculation:** C East 1 optimizado

0 1 2 3 4 km

Map: Mapa en blanco , Print scale 1:100,000, Map center UTM WGS 84 South Zone: 35 East: 690,427 North: 6,679,425



New WTG



Site Data