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Aknowledgment

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Abstract

Renewable energy sources are increasing in order to provide power with minimal environmental impact. The most commercially advanced of these at present is wind power. The production and use of wind energy opens new opportunities for Latin American countries to limit the emissions of carbon dioxide. It will provide a cleaner, sustainable, efficient and competitive energy matrix. According to the Latin American Wind Energy Association (LAWEA), Latin America has an installed capacity of only 1274 MW but more projects are under construction: Their combined development portfolio could reach in some countries like Mexico 2,600 MW in Oaxaca province and 1,000 MW in Baja California over the period from 2008-2012. There is a capacity addition of an average of 1 GW per year for the next five years expected, bringing the total installed wind capacity up to 5.7 GW by 2013. The growth will mainly be driven by Brazil, Mexico and Chile. In order to provide optimal sitting of wind turbines, a reliable estimate of the wind resource over a given area is required. This thesis shows the performance of the models, WAsP and WindPRO in predicting the power production of individual turbines. The prediction accuracy is determined as function of wind direction, terrain, roughness, turbine spacing and turbulence. A detailed comparison has been made for the predictions for wind speed, power density, turbine yield and wind farm performance for different representative sites in Brazil and Mexico.

Key words: wind farm, Latin America, simulation, wind resource.

Nomenclature

σ_0	Turbulence intensity [%]
$\bar{v}_w$	Mean wind speed [m/s]
σ_v	Standard deviation of the wind speed
ϕ	Distribution function
e	Logarithmic base (the natural log, e = 2,781)
A	Scaling factor
k	Form parameter
a	Scaling factor
a.s.l.	Above see level
AC	Alternative Current
AMDEE	Asociación Mexicana De Energía Eólica
ANEEL	Agencia Nacional de Energia Eletrica (Brazil)
AWEA	American Wind Energy Association
CEPEL	Centro de Pesquisas de Energia Elétrica (Brazil)
CFD	Computational Fluid Dynamic
CIRES	Cooperative Institute for Research in Environmental Science
Cp	Power coefficient
CRESESB	Centro de Referência para as Energias Solar e Eólica Sérgio de Salvo Brito
D	Diameter
DC	Discontinue current
e	Logarithmic base
FUNCEME	Fundação Cearense de Meteorologia e Recursos Hídricos
GE	General Electric
GH	Garrad Hassan
GW	Gigawatt

GWEC	Global Wind Energy Council
HH	Hub Height
IBGE	Instituto Brasileiro de Geografia e Estatística (Brazil)
IEC	International Electrotechnical Commission
INEGI	Instituto Nacional de estatistica y geografia (Mexico)
k	Form Parameter
kW	Kilowatt
LAWEA	Latin American Wind Energy Association
m	Meter
m/s	Meter per second
MCP	Measure-Correlate-Predict tool
MME	Ministério de Minas e Energia (Brazil)
MW	Megawatt
MWh/y	Megawatt houres per year
NARR	North American Regional Reanalysis
NCAR	National Center for Atmospheric Research
NCEP	National Center for Environmental Prediction
NREL	National Renewable Energy Laboratory
NSA	noise sensitive areas
PCD	Plataforma de Coleta de Dados
Pel	Electrical power [xW]
PROINFA	Programa de Incentivo às Fontes Alternativas de Energia Elétrica (Brazil)
RAM	Revista del Aficionado a la Meteorologia
RD	Rotor Diameter
SENER	Secretaría de Energía (Mexico)
SRTM	Shuttle Radar Topography Mission
t	Time [s]
W	Watt

WF	Wind Farm
WTG	Wind Turbine Generators
WWEA	World Wind Energy Association
ZVI	Zone of Visual Impact

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1 Introduction

When in 1973 important events took place on the world's oil market, the preoccupations on the provision and future price of the energy resurged. As a consequence, the consuming countries faced the high costs of the oil and an almost en-tire dependency on this one energy. They had to modify customs and look for options to reduce their dependency on non renewable sources.

Between the options to reduce the dependency on oil, like principal source of energy, they had to reconsider the best use of the solar energy and the diverse sources of energy like wind, hydraulic power, Geothermic and diverse forms of biomass.

In the Eighties, appeared evidences of an increase in gas concentrations that are responsible for the greenhouse effect in the terrestrial atmosphere, which have been attributed, to a great extent, to the fossil fuel burning fire.

This brought a world-wide call to look for alternatives of reduction of the present concentrations of these gases. As a result of this call, many countries, particularly more developed, have established commitments to limit and to reduce the gas emissions responsible for the greenhouse effect. They have renewed their interest in applying policies of promotion of the renewable energies.

Nowadays, 30 years after the oil crisis, many of the technologies of use of renewable energies have matured and evolved, increasing their reliability and improving their profitability for many applications.

Many Latin American countries count on a very high potential in question of renewable energy resources, whose development will allow this region to count on a greater diversification of power plants, to extend the industrial base in an area that can have strategic value in the future, and to attenuate the environmental impacts caused by the production, distribution and final use of the conventional forms of energy.

The technology of extracting electricity from wind has evolved enormously over the last decades. Wind turbines have been developed from a few kilowatt turbines in the 1980's to multi-megawatt turbines installed nowadays. Wind is one of the most economically promising renewable energy resources and has established itself as one of the most competitive forms of renewable energy available at the moment.

In order to provide optimal sitting of wind turbines, a reliable estimate of the wind resource over a given area is required. This thesis shows the performance of the models, WAsP and WindPRO in predicting the power production of individual turbines. The prediction accuracy is determined as function of wind direction, terrain, roughness, turbine spacing and wind turbine class. A detailed comparison will be made for the predictions for wind speed, power density, turbine yield and wind farm performance for different representative sites in the countries of Brazil and Mexico.

1.1 Objectives

Performance analysis of resource assessment software for different type of wind sites taking in account the changes of elevation, roughness changes and the different wind turbine class.

Comparison of the accuracy of the wind resource assessment software.

Study of wind farms located in different wind site.

1.2 Outlines

The thesis consists mainly of four parts. The first part gives a basic knowledge of the wind energy technology and describes the actual wind power installed in the world. The second part describes the modelling software used in the wind energy industry. The third and main part explains all the input and output parameters which are necessary to analyse and validate the results. Finally in the fourth part, the performance of the resource assessment software will be evaluated showing the accuracy of the wind energy production for different wind sites in Brazil and Mexico

2 The basics of wind turbine technology

2.1 How does a Turbine work?

A wind turbine actually does two things:

1. It **extracts** energy from wind with a rotor;
2. It **converts** this extracted mechanical energy into electrical energy using a generator and a drive train.

All other components in a wind turbine are there to make sure that these two things are done as efficient as possible. This section is divided into two subsections that cover these two topics.

2.1.1 Energy extraction

A wind turbine extracts energy from the wind with its rotor. As wind speed increases, the energy that is extracted from the wind also increases. The theoretical maximum amount of energy that can be extracted from the wind is called the Betz Limit, which is 59% of the kinetic energy of the wind. The amount of power that a wind turbine actually extracts depends on the rotor's size and the power rating of the generator.[3]

The maximum power $P_{\max}$ (Watt) which can be extracted from the wind is defined by the following equation:

$$P_{\max} = C_{p\max} \cdot \frac{1}{2} \cdot \rho \cdot S \cdot v_1^3$$

$C_{p\max}$ is the maximum power coefficient. The power coefficient C_p is the ratio between the mechanical power extracted by the converter and that of the undisturbed air stream.($C_{p\max} = \frac{16}{27} = 0{,}59$ =59%)

ρ is the air density (kg/m³)

S is the swept area of the rotor (m²)

v_1^3 is the wind velocity (m/s)

The following figure shows us the relation between the Power coefficient C_p and the wind speed for various actual WTG.

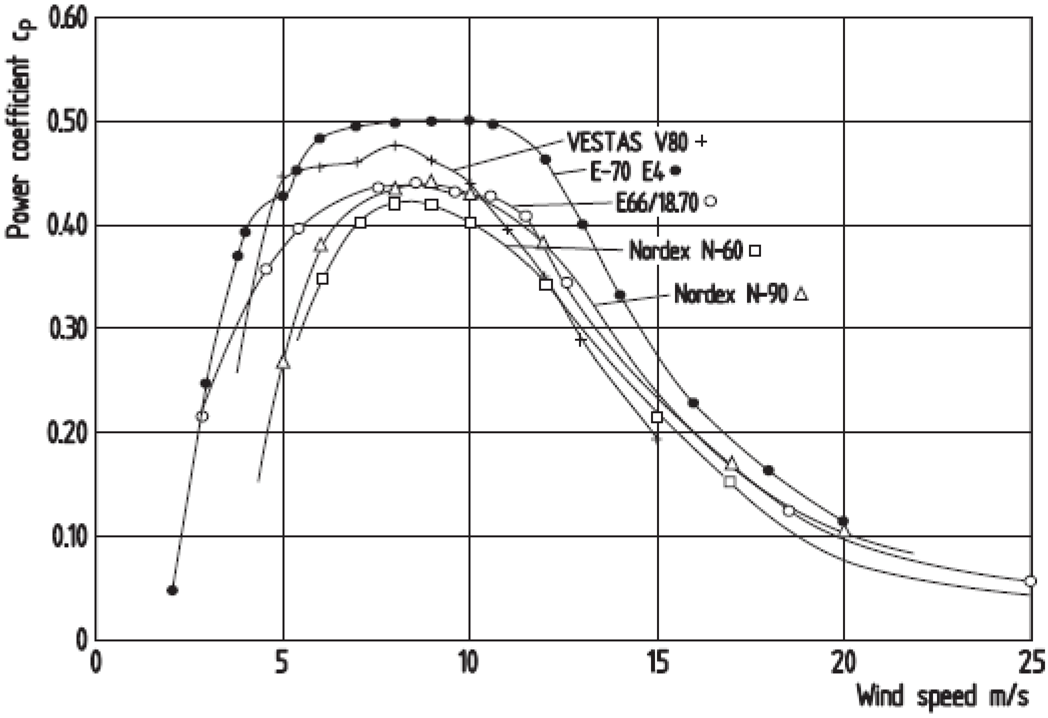


Figure 2.1 Power coefficient of actual WTG [3]

Figure 2.2 shows a power curve of a wind turbine, which represents the mechanical power extraction as a function of wind speed. Two regions can be defined:

1. **Power Optimization** - for these wind speed the rated generator power has not been reached yet: the goal is to extract as much power from the wind as possible. Rated wind speed depends on the proportion between rotor area and generator size. A typical value is 12 m/s;

2. **Power Limitation** - for these wind speed the maximum generator power has been reached, the power that is extracted from the wind has to be limited in order to avoid generator overloading.

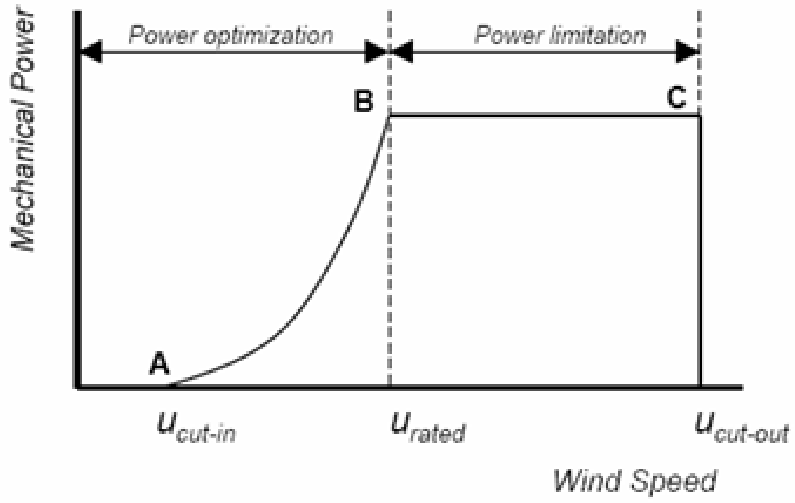


Figure 2.2 Power extraction curve of a wind turbine [3]

In the power optimization region, energy extraction should be maximized. This can be achieved with the following two principles:

1. **Variable speed operation** - Making optimal use of wind gusts by allowing the rotor to speed up during wind gusts;

2. **Pitch regulation** - Ensuring maximum power capture by pitching the blades at the optimal angle. There is an optimal blade angle for every wind speed. In the power limitation region, the blades are pitched to a different angle for lower energy capture.

In practice variable speed operation and pitch regulation often go together in a wind turbine concept. The main drawbacks of the extra energy capture are that the turbine needs two additional systems: a blade pitch system and a more costly energy conversion system. The alternative is to operate a wind turbine at fixed rotor speed and without pitch regulation. This turbine concept is cheaper because it does not have costly extra systems, but has the drawback of less energy production [3]. The difference between fixed- versus variable- speed operation will further be discussed in the next subsection.[4]

2.1.2 Energy conversion

The electricity that a wind turbine feeds into the power grid needs to be of the same voltage and frequency as the power grid's voltage and frequency. The voltage can easily be adapted to the grid voltage using transformers. The frequency can be adapted to the grid frequency using AC-DC-AC converters. However, these converters are relatively expensive components. There are two options that can be applied in a wind turbine to make sure that the frequency matches the grid frequency:

1. **Without a converter** - this means that the generator, and therefore the rotor, needs to be operated at a fixed speed that corresponds to the frequency of the power grid;

2. **With a converter** - this means that the turbine's output frequency can be adjusted to match the grid frequency and is therefore independent of the generator and rotor speed.

As one can conclude from above, for each turbine design a trade off has to be made between variable- and fixed- speed operation. Variable speed operation requires more expensive components but allows a higher energy capture whereas fixed speed operation requires less expensive components but therefore captures less energy.

At the present moment, almost all commercial wind turbines available in the market are variable speed operated. [2]

2.1.3 Turbine components

Figure 2.3 shows a schematic overview of a GE1.5 wind turbine, which are:

1. **Wind vane and anemometer** - sensors that measure wind direction and wind speed respectively;

2. **Ground frame** - frame that provides stiffness and strength to the complete *nacelle* (machine head), all components are mounted on this frame;

3. **Generator** - converts the rotating energy of the drive train into electricity;

4. **Control box** - contains computers that control the wind turbine;

5. **Hub** - the iron structure to which the blades are bolted;

6. **Gearbox** - the rotor rotates at low rotational speed while the generator requires high rotational speed: the gearbox converts the low rotational speed with high torque on the rotor side into high rotational speed with low torque on the generator side;

7. **Oil cooler** - friction in the gearbox leads to increased temperature in the gearbox, by cooling the oil, overheating is prevented;

8. **Yaw system** - the turbine needs to be kept facing the wind actively, this is done by the yaw system;

9. **Drive shaft** - shaft that connects the rotor with the gearbox;

10. **Pitch system** - system that rotates the blades over their longitudinal axis, to increase or decrease power capture;

11. **Blade flange** - flange to connect the blades with the hub;

12. **Heat exchanger** - to cool the generator during operation;

13. **Rotor blade** - structure to capture the energy from the wind flow and convert it into rotation;

14. **Nacelle enclosure** - enclosure of the machine head.

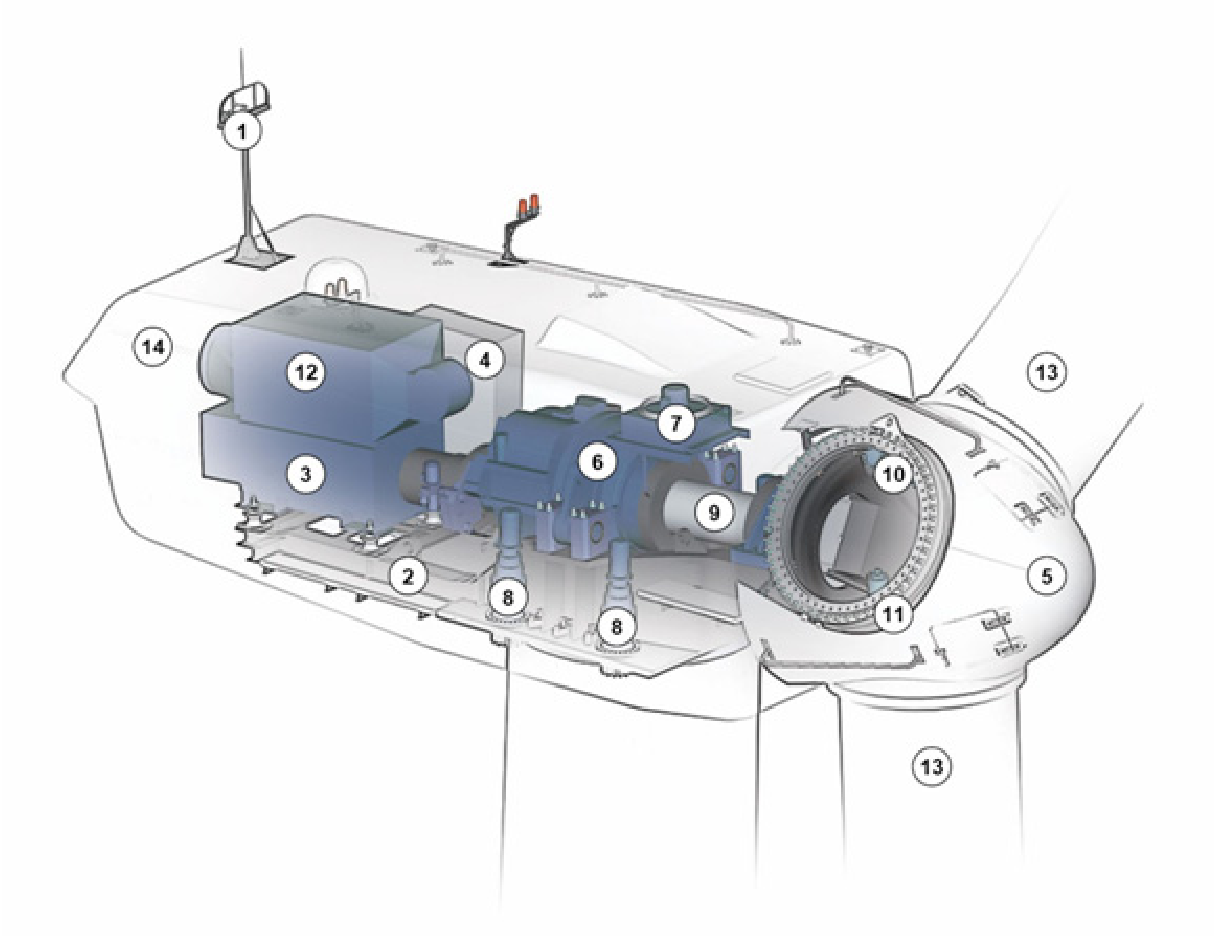


Figure 2.3 Schematic overview of the GE1.5 wind turbine.[7]

2.2 Enercon E-126 WTG

Actually the biggest installed WTG is the E-126 with a Rated power of 7.5MW, from the manufacturer Enercon. The soil has to support the weight of 7000t which is composed of:

- 3 Rotor blades of 63m and a hub with a total weight of 320t
- Nacelle of 120t
- Generator of 220t
- The tower with a height of 130m, a diameter of 16.5m at the bottom and a weight of 2800t
- The foundation of 3500t and a volume of 14000m³ high strength armoured concrete

The E-126 WTG has been installed in Belgium and the total cost was 11 million Euro. It can produce 15000 -18000 MWh/y and can deliver 15000 till 18000 standard European households with electricity. [31]

Figure 2.4 Enercon E-126 [34]

3 State of wind energy

3.1 Worldwide

In 2009, 37.466 MW of new wind energy capacity were added summing up to a global installed capacity of 157.899 MW by the end of December 2009. The added capacity equals a growth rate of 31,1 %, after 28,1 % in 2008. By the end of 2008, the installed wind power capacity generates 260 TWh per year, equalling 1,5 % of the global electricity consumption – in some countries and regions, wind energy already contributes 40 % and more. The wind industry employs today 440.000 people worldwide, after 300.000 employees in 2006. [1]

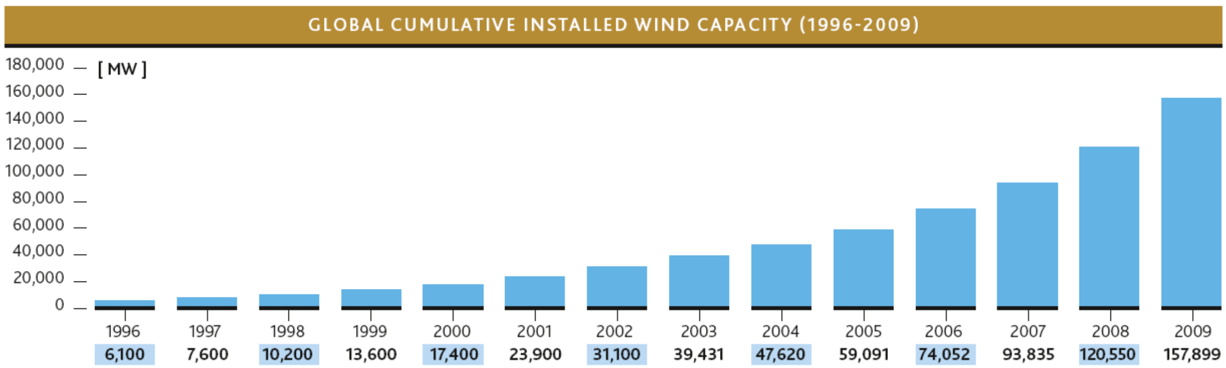


Figure 3.1 Global cumulative installed wind capacity (1996-2009) [1]

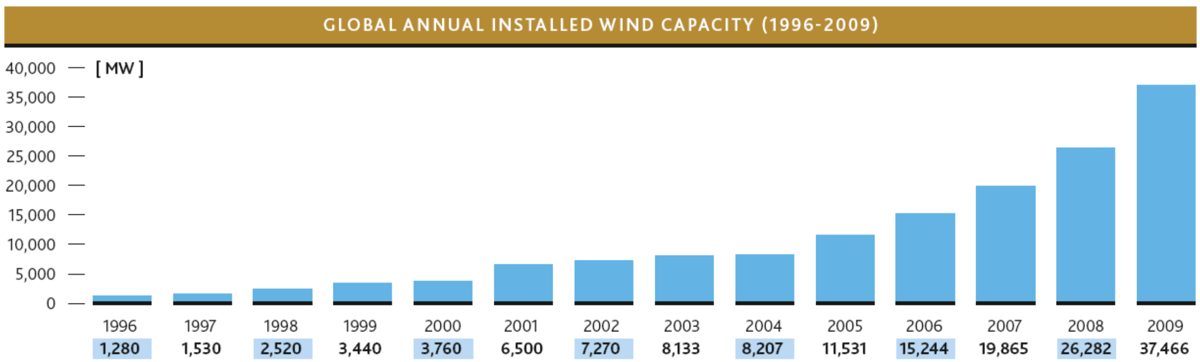
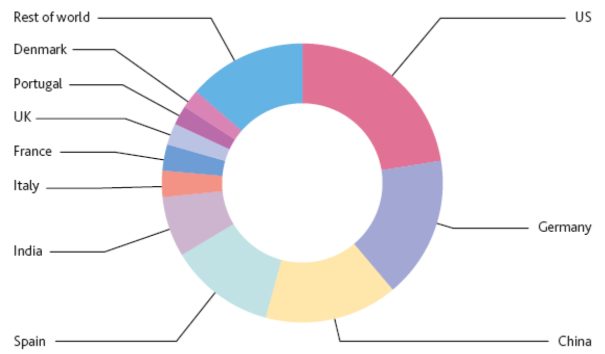


Figure 3.2 Global annual installed wind capacity [1]

Compared with 2008 when 26.282 MW were added, the year 2009 brought another new record in new installations. Mainly the booming wind markets in China with 13.000 MW of new capacity installed capacity doubled again – for the fourth year in a row, USA with 9.922 MW and Spain with 2.459 MW contributed to this record. China with a growth rate of

107 % showed the greatest performance of the top five wind countries. Germany defended clearly its position as number 2 country in terms of overall capacity with 25.777 MW installed. With additional capacity of 1.917 MW, Germany as well as India (1.271 MW added) kept their positions as leading markets, however, both countries clearly decreased in new installations. Only two countries (after five in the year 2008) added between 500 MW and 1.000 MW and showed strong growth rates: France (888 MW, 56,7 % growth) and Italy (603 MW, 28,4 %). The most dynamic market in 2007 was Turkey adding 142 MW up to a total of 207 MW which equals a growth rate of more than 200 %.[1]

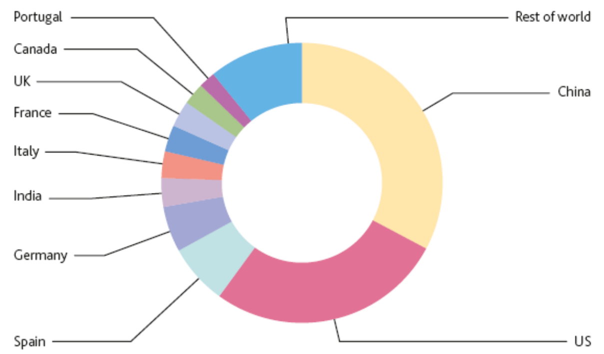
TOP 10 CUMULATIVE CAPACITY DEC. 2009



	MW	%
US	35,159	22.3
Germany	25,777	16.3
China	25,104	15.9
Spain	19,149	12.1
India	10,926	6.9
Italy	4,850	3.1
France	4,492	2.8
UK	4,051	2.6
Portugal	3,535	2.2
Denmark	3,465	2.2
Total top 10	**136,508**	**86.5**
Rest of the world	**21,391**	**13.5**
World total	**157,899**	**100**

Figure 3.3 Top 10 cumulative capacity 12.2009 [1]

TOP 10 NEW INSTALLED CAPACITY JAN.-DEC. 2009



	MW	%
China	13.000	34.7
US	9,922	26.5
Spain	2,459	6.6
Germany	1,917	5.1
India	1,271	3.4
Italy	1,114	3.0
France	1,088	2.9
UK	1,077	2.9
Canada	950	2.5
Portugal	673	1.8
Total top 10	33,471	89.3
Rest of the world	**3,994**	**10.7**
World total	**37,466**	**100**

Figure 3.4 Top 10 new installed capacity 12.2009 [1]

The market for new wind turbines reached an overall size of 37.466 MW, after 26.282 MW in 2008 which shows an increase of 42 %.

The Latin American market, despite the tremendous wind resources in the region, saw only slow growth in 2009. The only countries installing substantial new capacity were Brazil, which added 264 MW of wind energy across wind farms, mostly located in Ceará in the north east of the country, followed by Mexico which added 117 MW and Chile with 148 MW. [1]

LATIN AMERICA & CARIBBEAN	Brazil	341	264	606
	Mexico	85	117	202
	Chile	20	148	168
	Costa Rica	74	50	123
	Nicaragua	0	40	40
	Caribbean	35	0	35
	Argentina	29	2	31
	Uruguay	20	0	20
	Jamaica	22	1	23
	Colombia	20	0	20
	Others (5)	6	0	6
	Total	**653**	**622**	**1,274**

Table 3.1 Installed capacity in Latin America, 12.2009 [1]

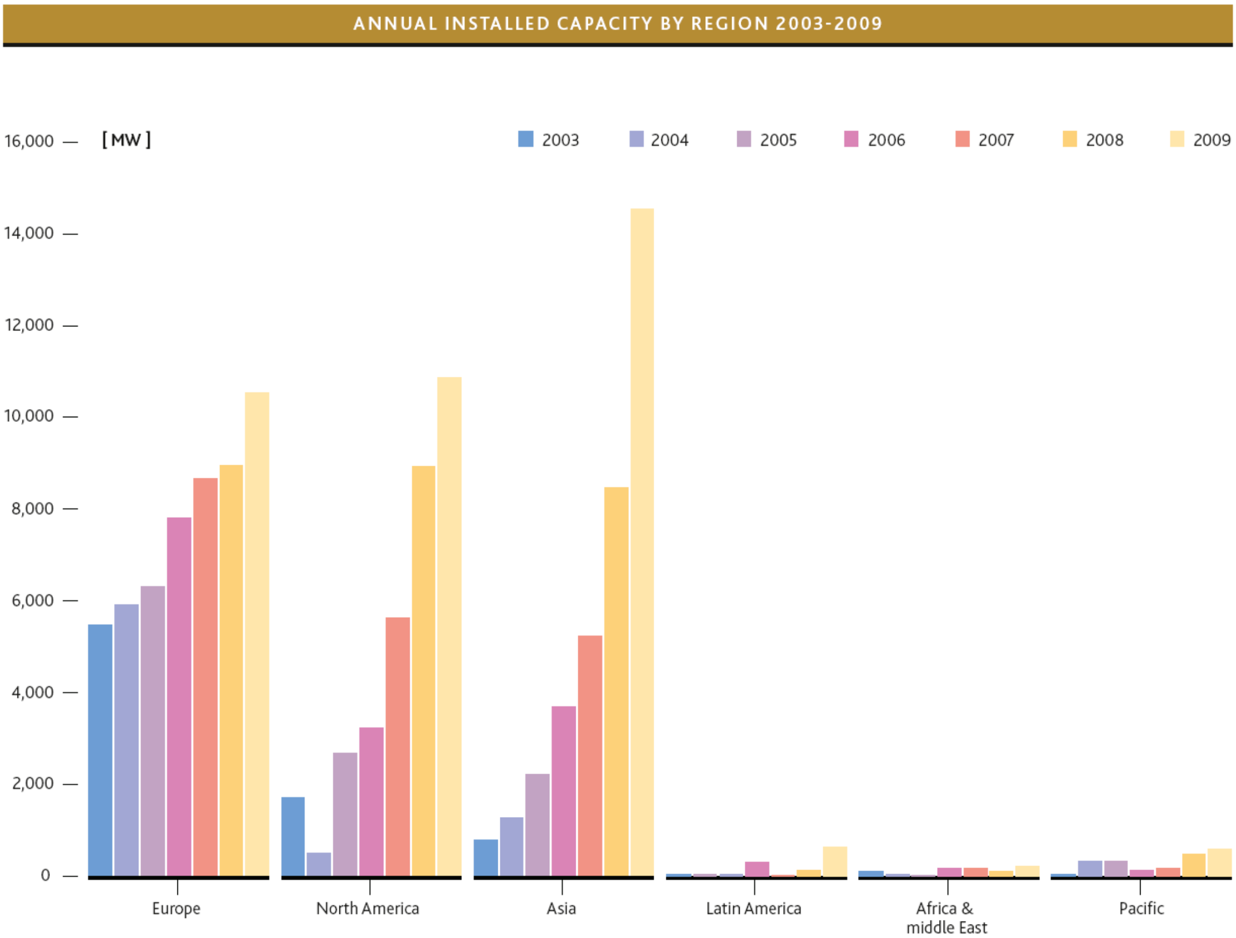


Figure 3.5 Annual installed capacity by region 2003-2009 [1]

3.2 Brazil

Brazil has a total electrical generation capacity of 105,4 GW at the end of 2007. The part coming from renewable sources includes large and small hydro power, wind and biomass reached 73% in the year 2007.

The best wind resources in terms of wind speed and capacity factor are the North/Northeast region, in particular, in the states of Rio Grande do Norte, Ceara, Pernambuco and Bahia. The South/Southeast region also has good quality resources (Rio Grande do Sul and Santa Catarina).[1] and [11]

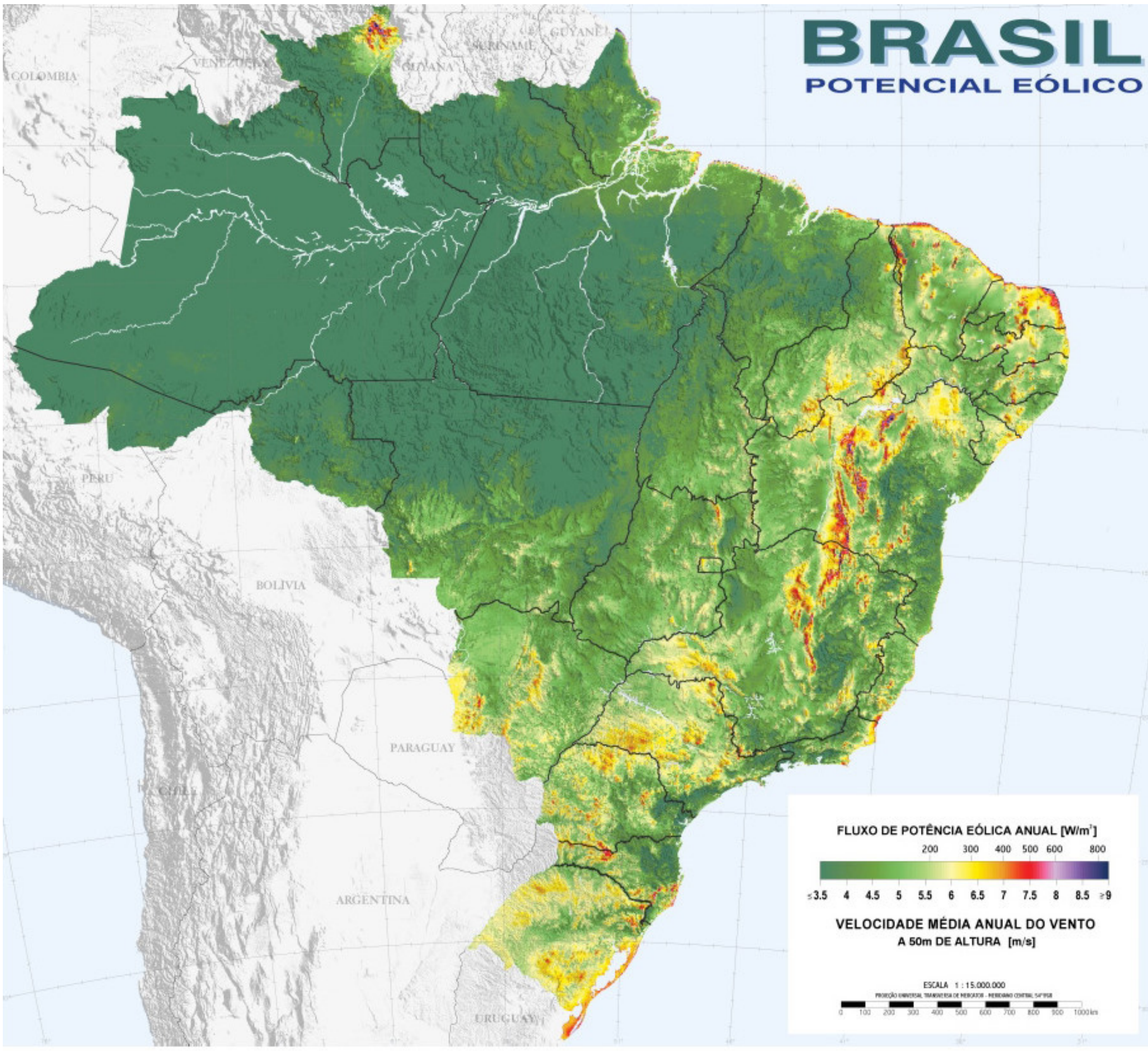


Figure 3.6 Wind energy potential of Brazil at 50 heights [18]

To increase the share of renewable energy in Brazil's electricity supply, the brazilian government established the "Programa de Incentivo às Fontes Alternativas de Energia Elétrica" (PROINFA). In December 2009, the Brazilian energy regulator, Agencia Nacional de Energia Eletrica (ANEEL), hosted the first wind only auction. Through that auction, 71 wind energy projects were contracted for a total capacity of 1,800 MW, awarded in the following regions [1]:

Rio Grande do Norte – 657 MW in 23 wind farms

Ceará – 542 MW in 21 wind farms

Bahia – 390 MW in 18 wind farms

Rio Grande do Sul – 189 MW in eight wind farms

Sergipe – 30 MW in one wind farm

3.3 Mexico

Mexico has around 50 GW of total installed electricity generation capacity, which is made up of 49% petroleum products, 21.6% hydro, 19% natural gas, 10% coal, 2.8% nuclear and 2% geothermal power. The installed and operational wind capacity was only 202 MW at the end of 2008 despite a technical potential of 40 GW.

Oaxaca's Isthmus of Tehuantepec zone has a world-class wind resource where average wind speed often exceeds 10 m/s, and the exploitable wind power potential exceeds 6,000 MW. Other excellent sites are located in Baja California, Zacatecas, Hidalgo, Veracruz, Sinaloa and Yucatan. [1] and [10]

Proyectos Eólicos en México

Proyectos Eólicos en México

Proyectos Eólicos en Operación

Proyecto	Ubicación	Esquema	Desarrollador	Turbinas	FOC	MW
La Venta	Oaxaca	OPF	CFE	Vestas	1994	1.6
La Venta II	Oaxaca	OPF	CFE	Gamesa	2006	83.3
Parques Ecológicos de México	Oaxaca	Autoabastecimiento	Iberdrola	Gamesa	2009	79.9
Eurus, 1st Phase	Oaxaca	Autoabastecimiento	Cemex/Acciona	Acciona	2009	37.5
Eurus 2nd Phase	Oaxaca	Autoabastecimiento	Cemex/Acciona	Acciona	2010	212.5
Gobierno Baja California	Baja California	OPF	GBC/Turbo Power Services	Gamesa	2010	10
Bii Nee Stipa I	Oaxaca	Autoabastecimiento	Cisa-Gamesa	Gamesa	2010	26.35
La Mata - La Ventosa	Oaxaca	Autoabastecimiento	Electrica del Valle de México (EDF-EN)	Clipper	2010	67.5
						518.63

Proyectos Eólicos Bajo Construcción

Proyecto	Ubicación	Esquema	Desarrollador	Turbinas	FOC	MW
Fuerza Eólica del Istmo	Oaxaca	Autoabastecimiento	Peñoles	Clipper	2010-2011	50
La Venta III	Oaxaca	PIE	CFE/Iberdrola	Gamesa	2011	101
Oaxaca II, III y IV	Oaxaca	PIE	CFE/Acciona	Acciona	2011-2012	304.2
Oaxaca I	Oaxaca	PIE	CFE/EYRA	Vestas	2010	101
Los Vergeles	Tamaulipas	Autoabastecimiento	GSEER	Siemens	2010-2011	161
						717.2

Proyectos Eólicos en Desarrollo

Proyecto	Ubicación	Esquema	Desarrollador	Turbinas	FOC	MW
Vientos del Istmo	Oaxaca	Autoabastecimiento	Preneal	Por Definir	2011-2014	395.9
Fuerza Eólica del Istmo	Oaxaca	Autoabastecimiento	Peñoles	Clipper	2011-2012	30
Bií Hioxio	Oaxaca	Autoabastecimiento	Unión Fenosa	Por Definir	2011-2014	227.5
Bii Stinú	Oaxaca	Autoabastecimiento	Eoliatec del Istmo (Eolia)	Por Definir	2011-2013	164
Santo Domingo	Oaxaca	Autoabastecimiento	Eoliatec del Pacífico (Eolia)	Por Definir	2011-2014	160
Bii Nee Stipa	Oaxaca	Autoabastecimiento	Cisa-Gamesa	Gamesa	2011-2014	288
Desarrollo Eólicos Mexicanos	Oaxaca	Autoabastecimiento	Renovalia	Por Definir	2011-2014	227.5
Union Fenosa	Baja California	Exportación	Gas Natural/Union Fenosa	Por Definir	2011-2014	400
Sempra	Baja California	Exportación	Sempra	Por Definir	2011-2014	1200
Fuerza Eolica	Baja California	Exportación	Fuerza Eolica	Por Definir	2011-2014	400
						3,492.9
					Total MW	4,728.7

OPF: Obra Pública Financiada
FOC: Fecha de Operación Comercial
PIE: Productor Independiente de Energía

Table 3.2 Wind energy projects in Mexico [36]

4 Methodology

4.1 Evaluated software

At the beginning of this work, the initial idea was to compare the different resource assessment software, used actually in the market. Unfortunately it was just possible to get a student version of the software WindPRO and WAsP. It was not possible to work with the software WindFarm and WindSim due to the license restrictions. WindPRO is used in the preparation part and WAsP is used in the simulation part.

4.1.1 WASP

WAsP is a PC program for predicting wind climates, wind resources and power productions from wind turbines and wind farms. The predictions are based on wind data measured at stations in the same region. The program includes a complex terrain flow model, a roughness change model and a model for sheltering obstacles. WAsP can be used in the WindPRO interface to estimate and optimise the WF production and efficiency, for the wind resources mapping, generation of wind atlas and for digitalising information on maps like height contours or the mean wind speed.[12]

This software uses the wind atlas model which is a linear model combining 2 models [34]:

- The physical model, based on the atmospheric stability, roughness changes, shelters and the landscape orography
- The statistical model based on the Weibull distribution on the wind analysis

WAsP is developed and distributed by the Wind Energy Division at Risø DTU, Denmark. There are currently more than 2900 users in over 110 countries and territories.[12]

4.1.2 WindPRO

WindPRO is a module-based software package suited for project design and planning of both single WTG and large wind farms. It consists of a number of modules organised in energy, environment, visualisation, grid & planning and Economy [19].

The software is used for different purposes like digitizing height contours or power density, energy estimation of single WTG and WF, calculation of noise and shadow generation, photo montages and video of the landscape with the WTGs.[19]

Figure 4.1 WindPRO modules [19]

4.2 Method of Calculation

4.2.1 Background map and Topography

The background map is the first step for the implementation of a wind farm. It gives the user the possibility to visualize the surrounding area to collocate the right roughness and obstacles. The maps can be implemented from private maps or from the online source from WindPRO which are satellite images based on the US Geo-Cover database.

The topographic map or height contour lines are essential for almost all the calculation of a wind farm. Orographic elements such as hills, valleys, cliffs, escarpments and ridges have an additional influence on the wind. Near the summit or crest of these features the wind will accelerate while near the foot and in valleys it will decelerate. The elevation data are downloaded via the online option in a Line Object with the purpose set to “Height contour lines”. The source is the SRTM Shuttle DTM Dataset which are digital terrain model, based on the Shuttle Radar Topography Mission (SRTM) data. It has a near global coverage with more than 80% of the land surface covered. All positions between 60 degrees north and 56 degrees south are covered. [20], [21]

Another way to access to the topographical maps is to download the maps from the Mexican INEGI, Instituto Nacional de estatistica y geografia or from the Brazilian IBGE, Instituto

Brasileiro de Geografia e Estatística. In these sites it is sometimes also possible to download satellite images more actual than the Google Earth images.

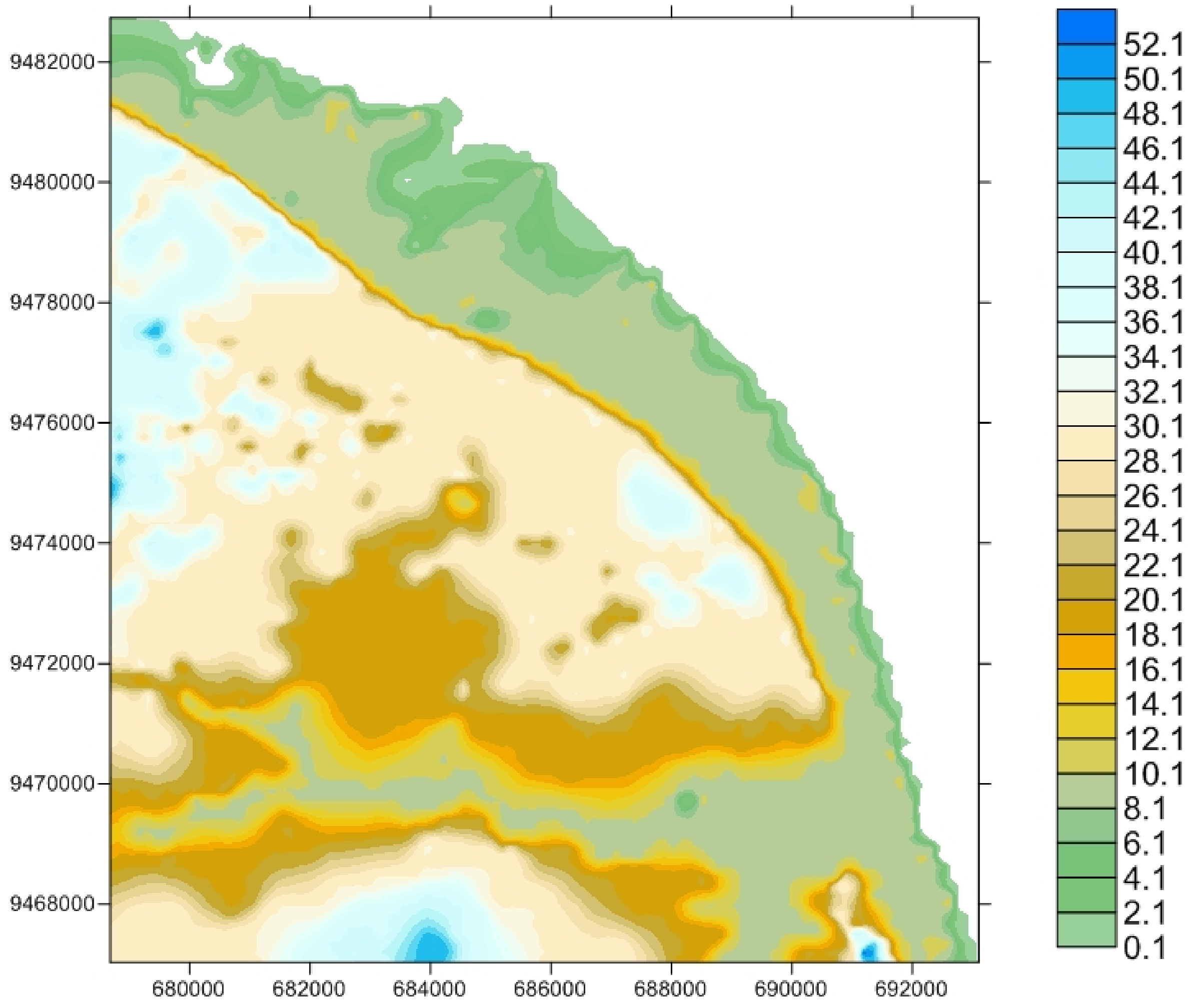


Figure 4.2 Elevation map Icapui [22]

4.2.2 Roughness

There are two ways of doing the roughness classification in WindPRO. The first method is to make manually a wind rose from the roughness classification, where the area around the wind turbine is divided into 12 sectors. The other way is to set a background roughness and all landscapes types that differ from the background are delimited and set with a predetermined roughness class. The software produces a wind rose automatically from the background roughness and the area objects.

The roughness classes are defined as roughness length in meter (z0), which results to the height above ground level where the wind speed is theoretical zero.

Roughness Class	Roughness Length, z_0 in m	Energy Index (%)	Landscape
0	0.0002	100	Water surface
0.5	0.0024	73	Open terrain with smooth surface i.e. runways
1	0.03	52	Agricultural area, no fences or hedges, scattered buildings,
1.5	0.055	45	Agricultural area, some houses, hedges with min. 1250m distance
2	0.1	39	Agricultural area, couple of houses, hedges with min. 500m distance
2.5	0.2	31	Agricultural area with houses, shrubs, trees and hedges with min. 250m distance
3	0.4	24	Villages, small towns forests or very rough and uneven terrain
3.5	0.8	18	Lager cities with tall buildings
4	1.6	13	Very large cities with tall buildings

Table 4.1 Roughness classification [23]

4.2.3 Wind Atlas

The Wind Atlas is a set of wind statistics and regional wind climates based on the measured wind speed and direction. The data must be cleaned with respect to the local terrain conditions around the measure mast, like the surrounding obstacles, the roughness and the orography of the landscape. A regional Wind Atlas constitutes a complete description of the governing wind conditions for a region, and consists of a table that contains the following data:

		Roughness Class				
Height	Parameter	0,00 m	0,03 m	0,10 m	0,40 m	1,50 m
10,0 m	Weibull A [m/s]	8,4	5,8	5,0	3,9	2,6
	Weibull k	4,50	3,97	3,92	3,67	3,76
	Mean speed [m/s]	7,70	5,26	4,53	3,52	2,34
	Power density [W/m²]	333	110	71	34	10
25,0 m	Weibull A [m/s]	9,1	6,9	6,2	5,1	3,9
	Weibull k	4,57	4,21	4,14	3,86	3,93
	Mean speed [m/s]	8,34	6,29	5,60	4,64	3,54
	Power density [W/m²]	421	185	131	77	34
50,0 m	Weibull A [m/s]	9,6	8,0	7,2	6,2	5,0
	Weibull k	4,60	4,59	4,48	4,14	4,18
	Mean speed [m/s]	8,82	7,28	6,57	5,61	4,55
	Power density [W/m²]	496	279	206	132	70
100,0 m	Weibull A [m/s]	10,2	9,4	8,6	7,5	6,3
	Weibull k	4,37	4,80	4,79	4,54	4,63
	Mean speed [m/s]	9,27	8,65	7,84	6,81	5,72
	Power density [W/m²]	584	462	345	230	135
200,0 m	Weibull A [m/s]	10,7	11,8	10,6	9,3	7,9
	Weibull k	4,00	4,65	4,63	4,39	4,52
	Mean speed [m/s]	9,68	10,75	9,72	8,47	7,24
	Power density [W/m²]	685	896	662	446	275

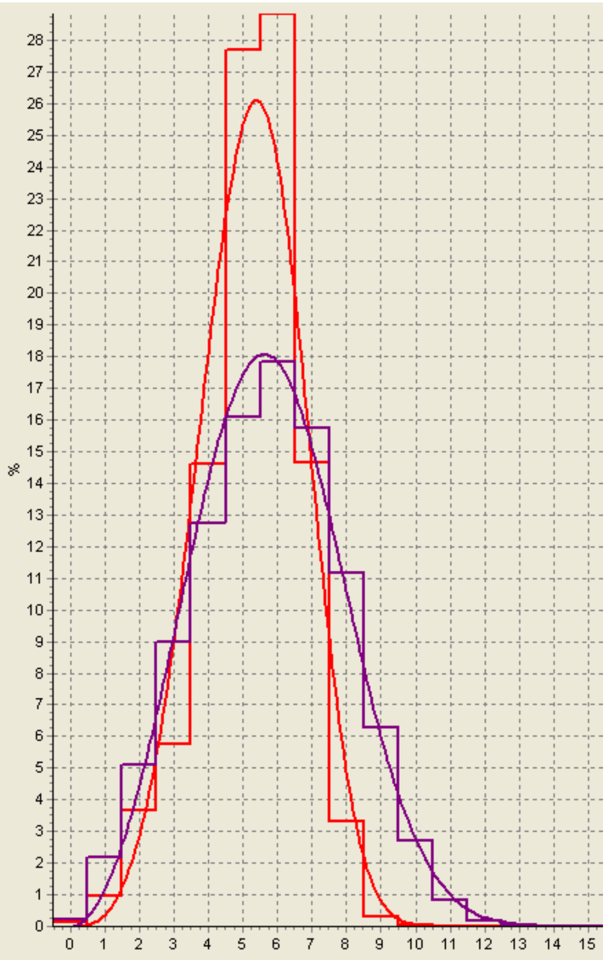
Table 4.2 Wind Atlas of Icapui [24]

The wind atlas table contain the mean wind speed and mean power density for 25 different standard classes, defined by the height above ground level and the roughness length [24]:

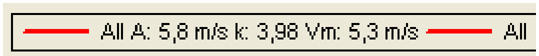
- the Weibull wind distribution parameter A and k
- the mean wind speed and the power density for 5 reference roughness lengths (0,000 m, 0,030 m, 0,100 m, 0,400 m, 1,500 m) and 5 reference heights (10 m, 25 m, 50 m, 100 m, 200 m) above ground level.

4.2.4 Measure-Correlate-Predict tools (MCP)

The MCP tool in Windpro enables the user to calculate long term corrected wind data. WindPRO has an access to NCEP/NCAR long-term reference data from the United States National Centers for Environmental Prediction and The National Center for Atmospheric Research. The data are saved as time series, tables or Weibull distribution parameters. To ensure a good correlation it is important to have two overlapping time series from a local site data measurements and a concurrent time series for long term reference data as we can see in the following charts [20].



PCD Local site data measurements:



NCAR Long term reference data:

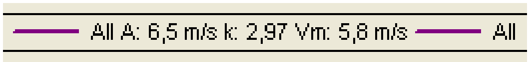


Figure 4.3 NCAR and PCD Wind distributions [25]

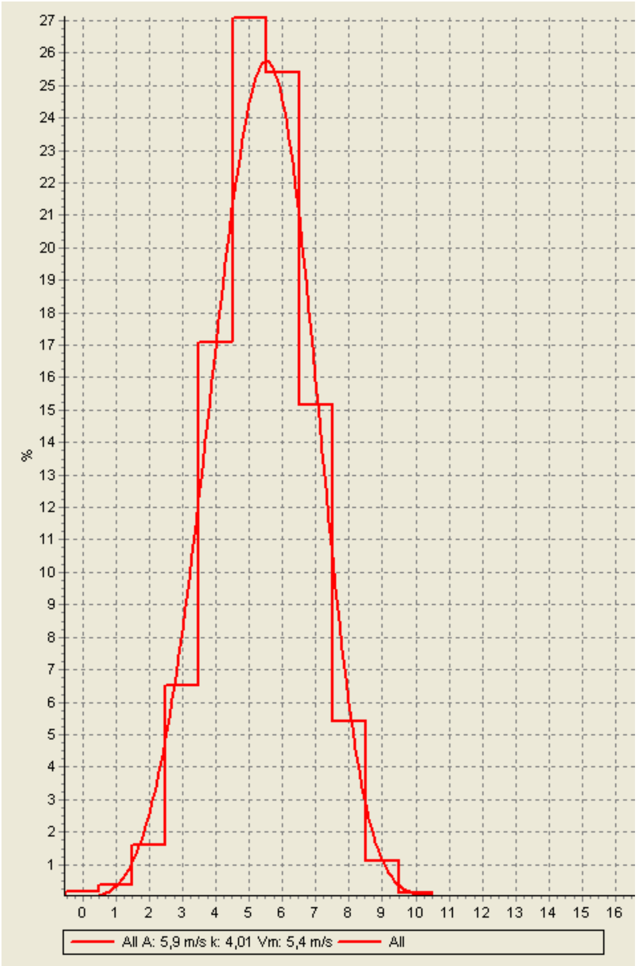


Figure 4.4 MCP correlated wind data [25]

The MCP analysis gives a result in form of a wind statistic generated with WASP or can be saved in Meteo-object located at the same position as the one holding the short-term site measurements. The Meteo-object is a data container and data analysis tool for meteorological data screening focused on wind speed and wind direction for wind energy calculation [20].

4.2.5 Resource grid

A wind resource map is useful for planning wind energy projects. It helps to evaluate the wind energy potential in a specific region. The purpose is to support the wind farm layout to find the best sites within a very large area as well as small areas. With the software WindPRO, it is possible to handle very large areas with different map files, like roughness and orography and it can work with several wind statistics that are changed and weighted according to the sites characteristics. The calculation engine used is WAsP. To calculate a resource grid for a specific region, we need a site data with the wind statistic, a roughness map and the topographical map [20].

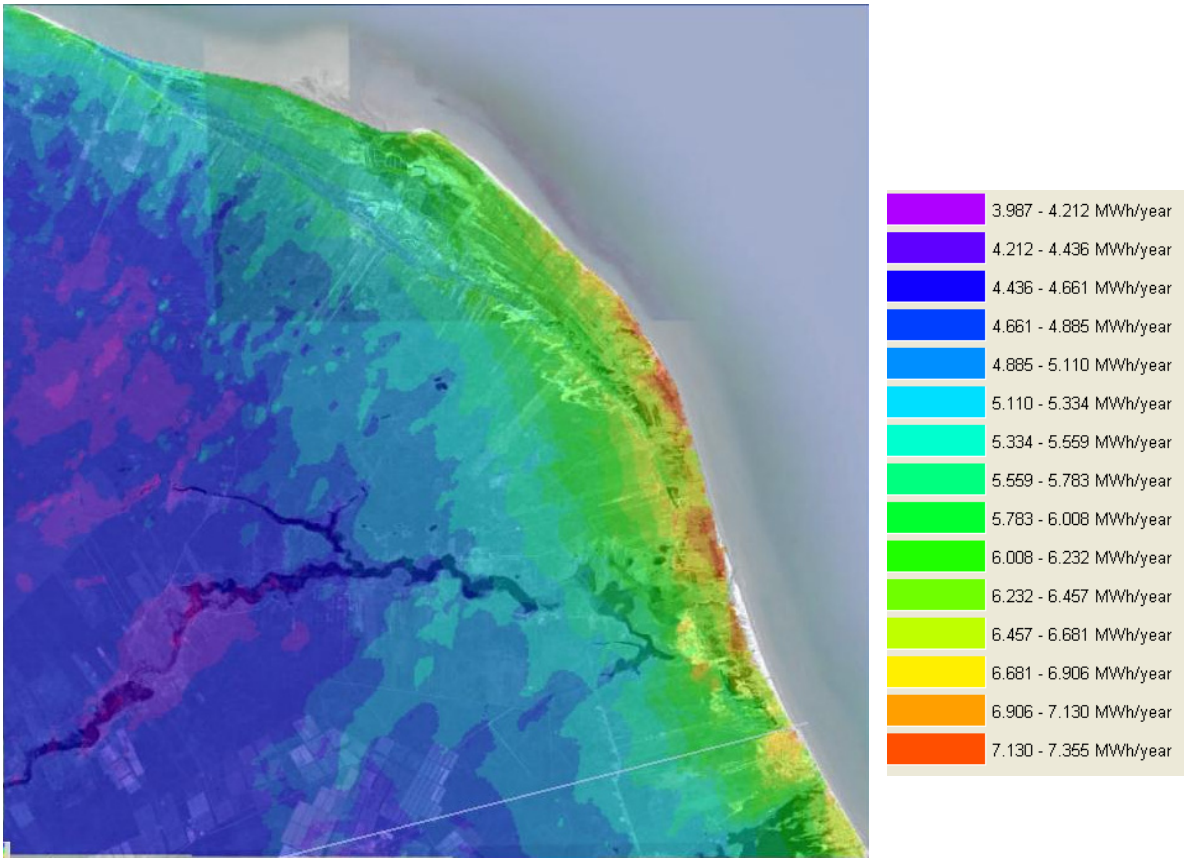


Figure 4.5 AEP resource grid of Icapui at 67m height [25] [26]

4.2.6 Environmental calculation

4.2.6.1 Noise calculation

The sound emitted by wind turbines is caused by aerodynamic noises primarily emitted by the rotor. The flow around the rotor blades generates a sound similar to the flow around an aircraft wing. The second sound source is a mechanical noise emitted mainly by the meshing of individual teeth of the several gearbox located in the top of the tower in the nacelle [27].

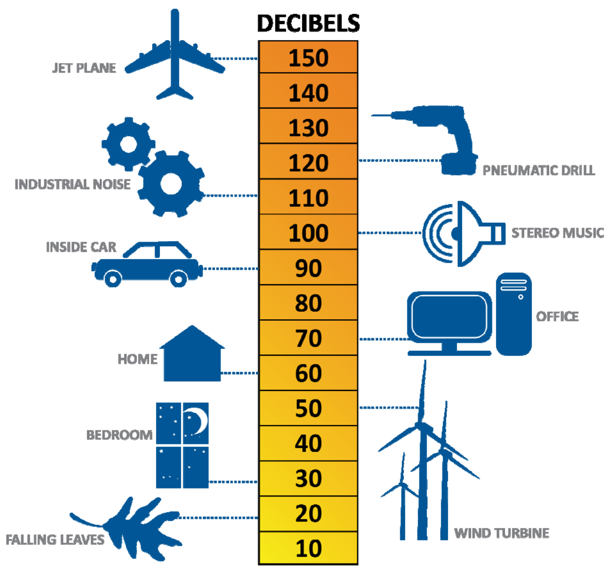


Figure 4.6 Decibel scale [27]

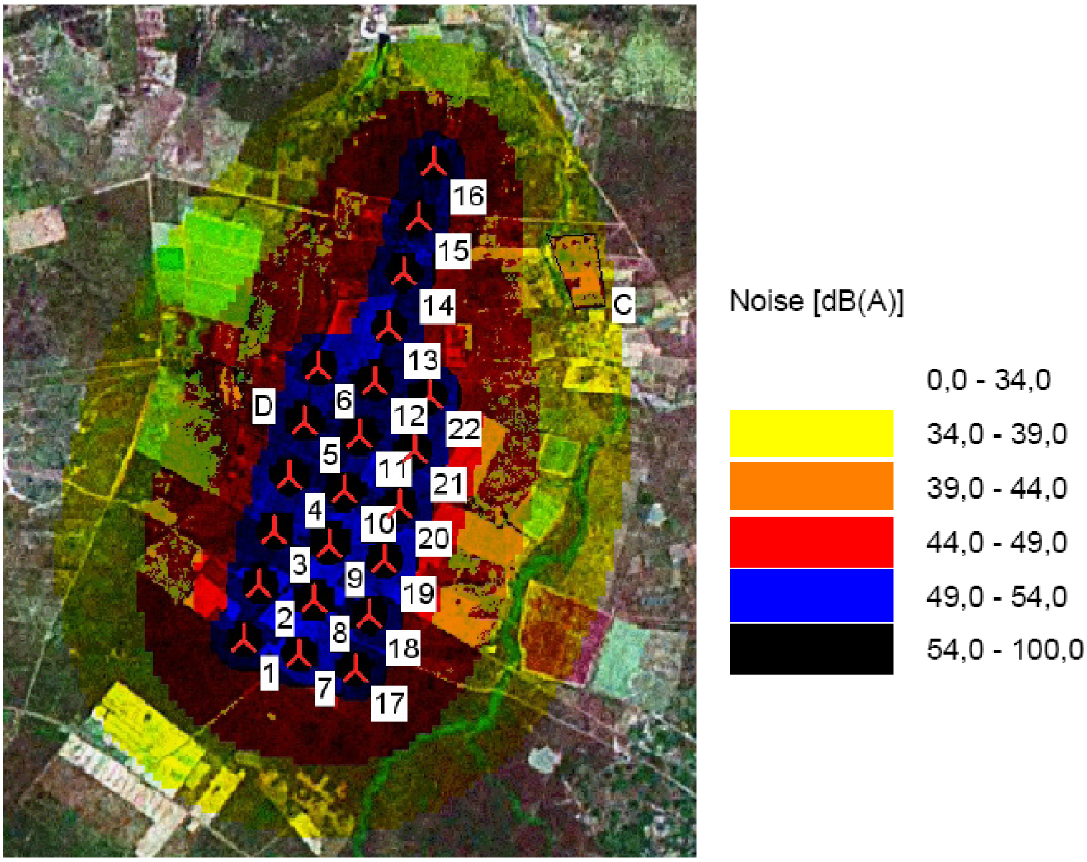


Figure 4.7 Decibel map [25]

4.2.6.2 Shadow flicker

Wind turbines can reach heights of 140m and the tendency is increasing and when the sun shines, they can cast their shadow over a very large surrounding area. To calculate the shadow flicker, it is important to have several input parameters like the coordinate of the wind turbines, a topographic map, the rotor diameter, the hub height, the wind speed and frequency distribution and the monthly sunshine hours of the specific area. The shadow impact on a house or farm near the wind farm are explained in hours per year or minutes per day of astronomical shadow captured by a shadow receptor placed on the critical places [20].

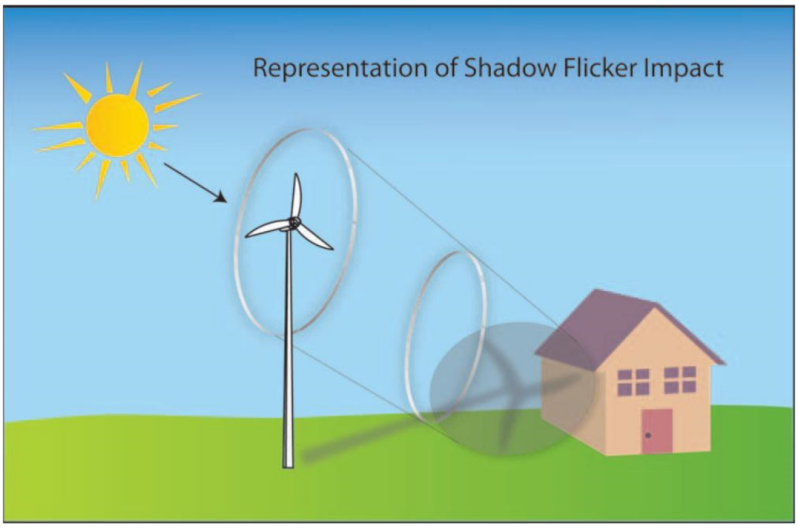


Figure 4.8 Shadow flicker impact [17]

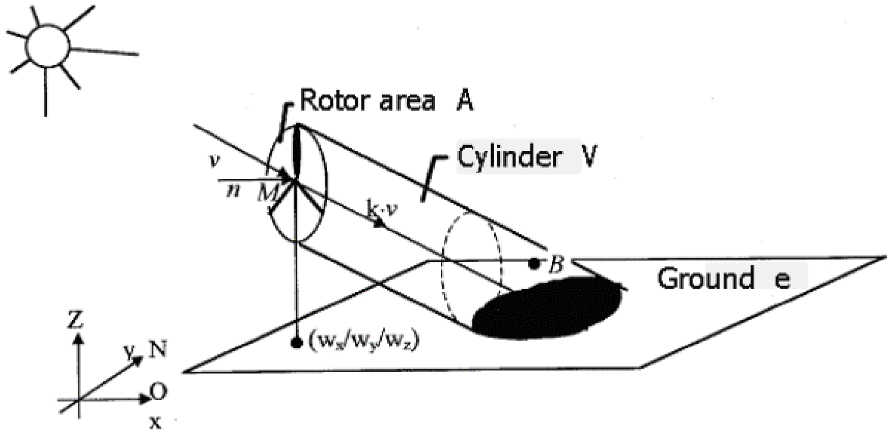


Figure 4.9 Shadow projection [20]

4.2.6.3 Visual impact

Wind farms have a visual impact on the surrounding landscape. Depending of the wind turbines size and the topography of the environment, they can be seen from long distances until 30 km.

The ZVI module calculate the theoretical visibility of wind turbine generators on the landscape and the generated maps are used as a background material for an environmental impact assessment project.

The calculations are based on a digital 3D model of the landscape established from digital height contours. To calculate the visual impact, it is important to have several input parameters like the position, the hub height and rotor diameter of the wind turbines, a digital height contour map, the local obstacles and the surface objects (forests, cities) with defined elevations above the terrain [20].

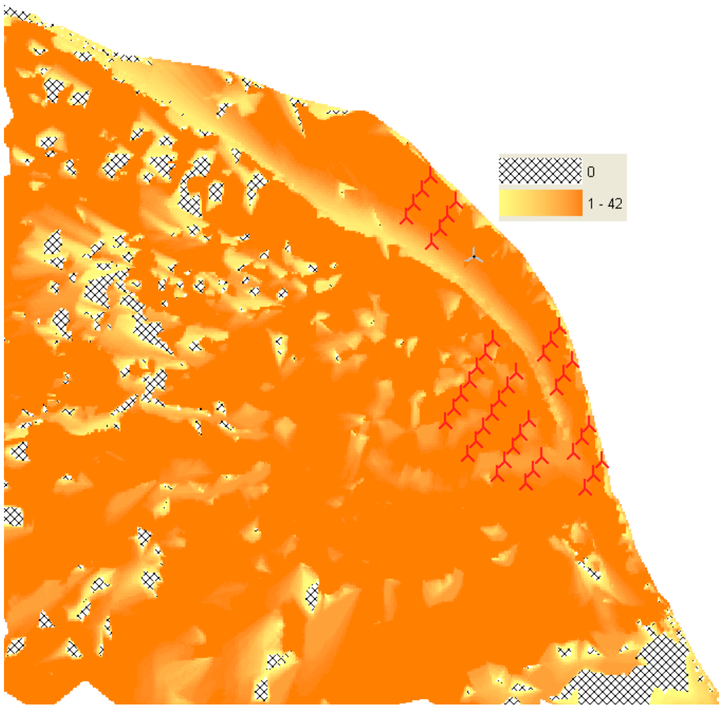


Figure 4.10 Zone of visual impact of the Icapui WF in a radius of 20km

4.2.7 Wind park energy calculation

Calculating the energy production for a wind energy project is one of the most important tasks. The annual energy production for a specific turbine can vary by several hundred percent depending on the micrositing.

WindPRO offers a range of options for calculating the energy production. It allows the user to combine any format of wind data with different type of wind turbines.

The METEO module calculates the energy production based on measured wind data on a specific location. If the measurements are taken at a height other than the proposed WTG hub height, the data can be extrapolated.

The ATLAS module permits the user to calculate the energy production based on the simple ATLAS model (Wind Atlas method), based on a terrain description (roughness, elevation and obstacles) and a Wind Statistic [20].

5 Conceptual framework

5.1 Input variables

5.1.1 Site location

To make a complete analysis, it is important to choose various sites with different topography. Wind farms can be constructed in those following sites:

Mountainous (very complex)

Hilly (moderately complex)

Flat-rough

Flat-smooth

Flat-coastal

Mountainous-coastal

Every site has different properties and the wind flow is different for each kind of this sites. The acceleration effects depend on the shape and the orientation of the ridge. Hilly terrain will lead to generally higher turbulence levels.

5.1.2 Turbulence class

The wind's turbulence causes the fluctuating part of the wind speed. The characteristics of the turbulences depend on geographical and meteorological factors.

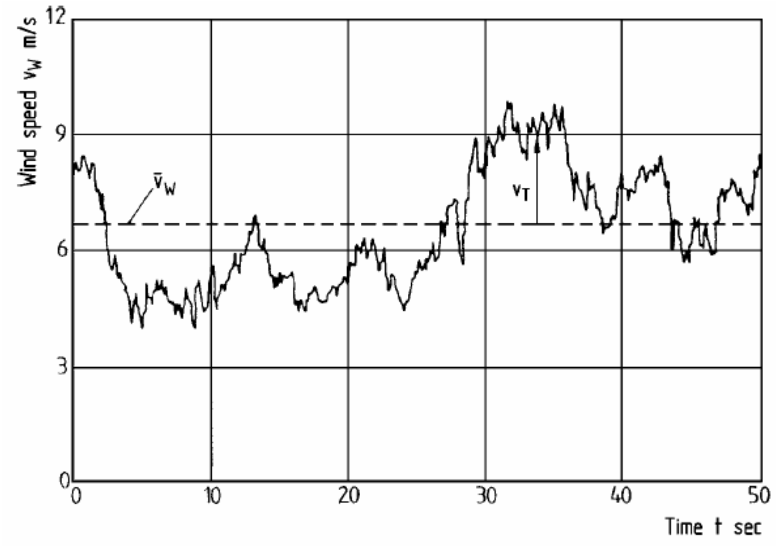


Figure 5.1 Measured time history of wind speed [3]

To characterise the turbulence, the term of turbulence intensity is used which is occasionally also called the degree of turbulence. The turbulence intensity σ_0 is defined as the ratio of the standard deviation σ_v of the wind speed to the mean wind speed $\bar{v}_w$ in a certain averaging time and is specified in percent:

$$\sigma_0 = \frac{\sigma_v}{\bar{v}_w} \quad [\%]$$

The turbulence intensity changes with the mean wind speed, with the surface roughness, with the atmospheric stability and with the topographic features. The lowest values are measured over the open sea (5% and less) whereas the highest values (20% and more) occur over densely settled areas or forest areas. [3]

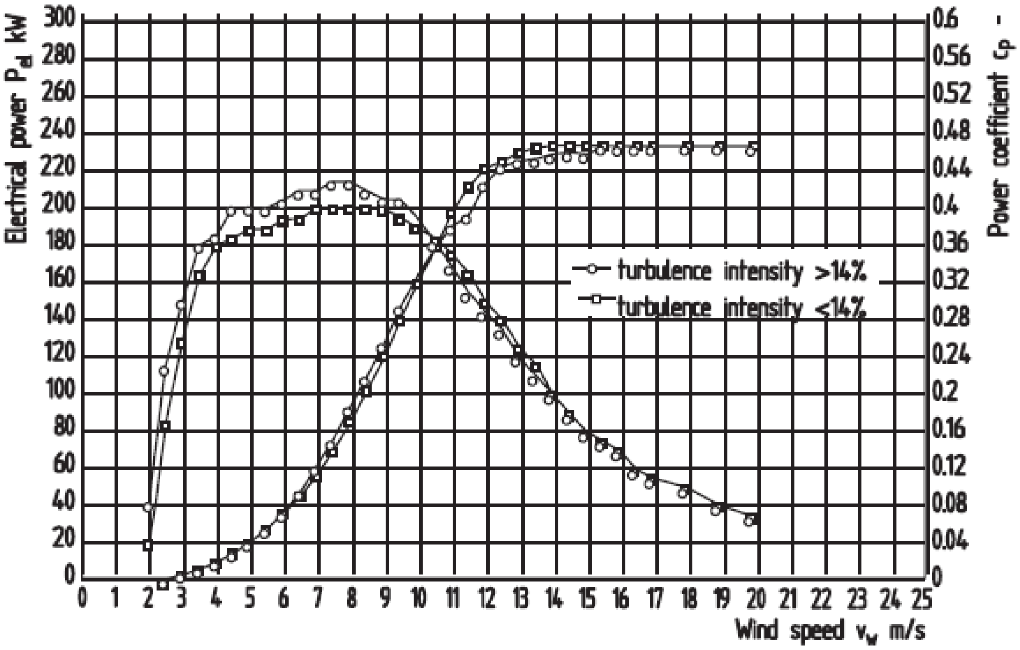


Figure 5.2 Measurements of the power curve and Power coefficient at different turbulence intensities on the example of an Enercon E-30 [3]

5.1.3 Wind turbine class

Wind turbines are divided into four classes defined by wind speed and turbulence data. The wind data is characterised by the mean annual wind speed $\bar{v}_w$ and the maximum wind speed to be expected as a mean value over 10 min, called reference wind speed velocity v_{eref} . The next parameters for wind turbine design is the turbulence intensity, which is defined as the ratio of the standard deviation of wind speed fluctuations to the mean.(see 9.1.2). The turbulence intensity is divided in 2 categories, the higher level A with 18% where I_{15} is the turbulence intensity at a mean wind speed of 15 m/s and the longitudinal wind velocity a equal 2. The level B is for a lower turbulence intensity by I_{15} equal 16% and a equal 3 [3].

WT Classes		I	II	III	IV	S
$v_{\mathrm{e\,ref}}$ (m/s)		50	42.5	37.5	30	
$\bar{v}_{\mathrm{w}}$ (m/s)		10	8.5	7.5	6.0	
$v_{\mathrm{G50}} = 1.4 v_{\mathrm{e\,ref}}$		70	59.5	52.5	42	values to be specified by the designer
$v_{\mathrm{G1}} = 1.05 v_{\mathrm{G50}}$		52.5	44.6	39.4	31.5	
A	I_{15}	0.18	0.18	0.18	0.18	
	a	2	2	2	2	
B	I_{15}	0.16	0.16	0.16	0.16	
	a	3	3	3	3	

Table 5.1 Basic wind parameters at rotor hub height for wind type classes [3]

5.1.4 Turbine spacing

The turbine spacing is a very important factor for the future power production of a wind farm. This investigation is done in the micrositting process which is a resource assessment tool to determine the exact position of one or more wind turbines on a limited area to maximize the annual energy production. In the following figure we can see the influence of turbine spacing in the efficiency of a wind farm.

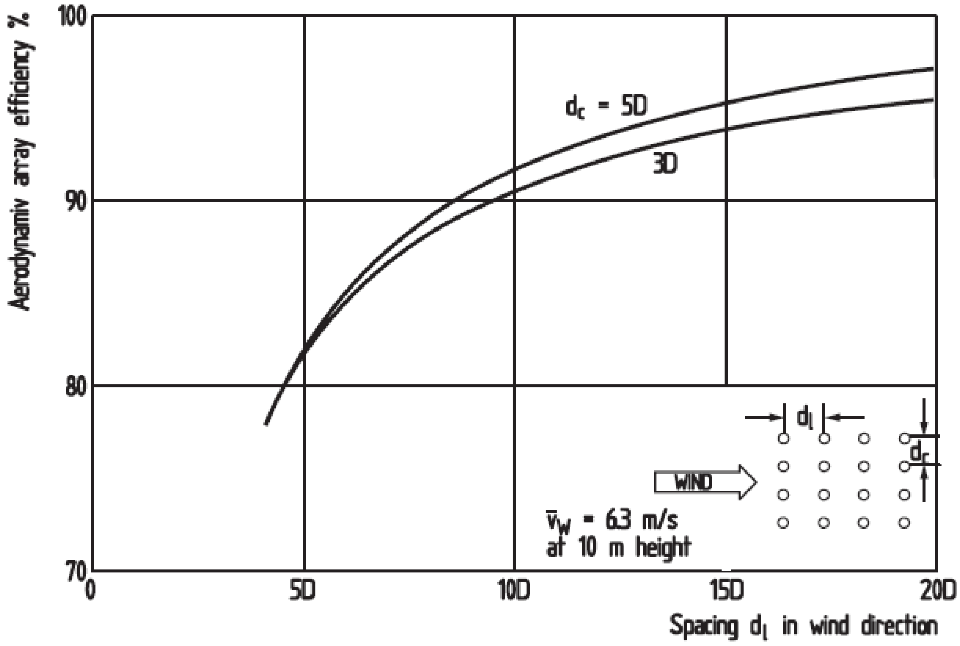


Figure 5.3 Aerodynamic array efficiency as a function of rotor distance in the wind direction, calculated for an array of 16 turbines [3]

5.1.5 Wake model

The wake effect depends on the turbine spacing in a wind park area and from the turbine characteristics. Behind a turbine, a wake effect is generated which is characterized by a reduced wind speeds and increased level of turbulence. The turbines operating in this wake will produce less energy and will be confronted to greater structural load than the turbines operating at the free stream. The prediction of the wake profiles downstream of a wind turbine can be calculated with means of different wake models: The N.O. Jensen model, the Ainslie model (Eddy Viscosity) and the G.C.Larsen model (Prandtl BL-equations) [3] and [4].

The maximum deceleration in the rotor wake's centre with respect to the surrounding wind velocity can be seen in Fig. 5.4, for example. It is:

- approx. 60% at a distance from the rotor of 2 rotor diameters,
- approx. 30% at a distance from the rotor of 4 diameters, and

approx. 20% at a distance from the rotor of 6 diameters. [3]

Figure 5.4 Wake effect [9]

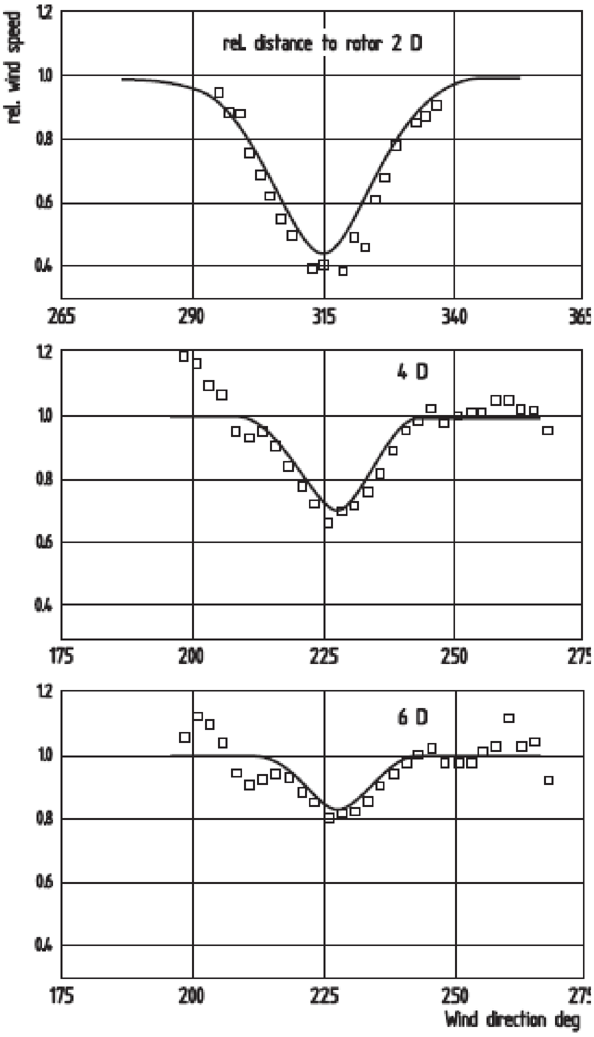


Figure 5.5 Horizontal speed profile in the wake of a wind turbine of the Enercon E-16 type, referred to the surrounding wind speed [3]

5.1.6 Wind regime

5.1.6.1 Very directional vs. relatively isotropic

The wind regimes can be easily showed with help of a wind rose.

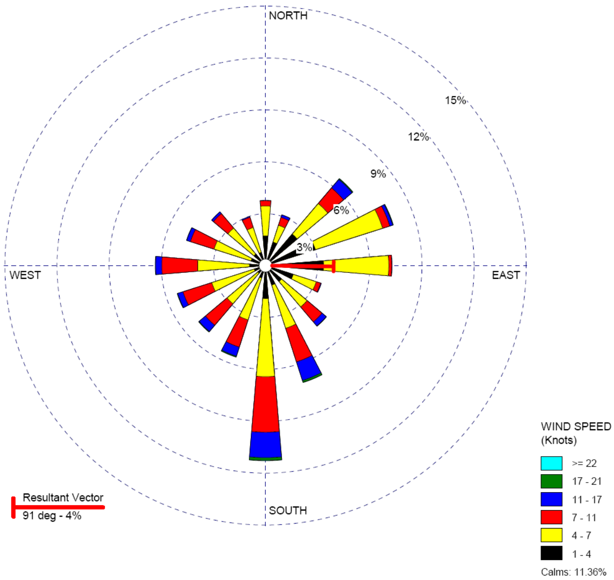


Figure 5.6 Isotropic wind regime [5]

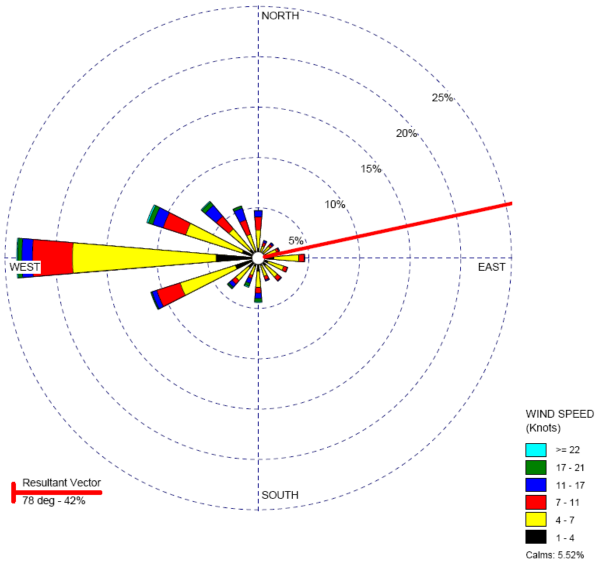


Figure 5.7 Very directional wind regime [5]

5.1.6.2 Weibull form parameter

Mean Annual Wind Speed and Wind Speed Frequency Distribution are two important parameters for wind prediction.

The frequency distribution of the annual wind speeds can be derived from data measured at a given elevation. The relative frequency distribution indicates the occurrence of the most frequent wind speeds.

The mathematical approximation for the distribution curve will be provided by a Weibull function. See Fig. 5.8. The equation is defined as:

$$\phi = 1 - e^{-\left(\frac{v_w}{A}\right)^k}$$

Where: ϕ = Distribution function

e = Logarithmic base (the natural log, e = 2,781)

A = Scaling factor

k = form parameter

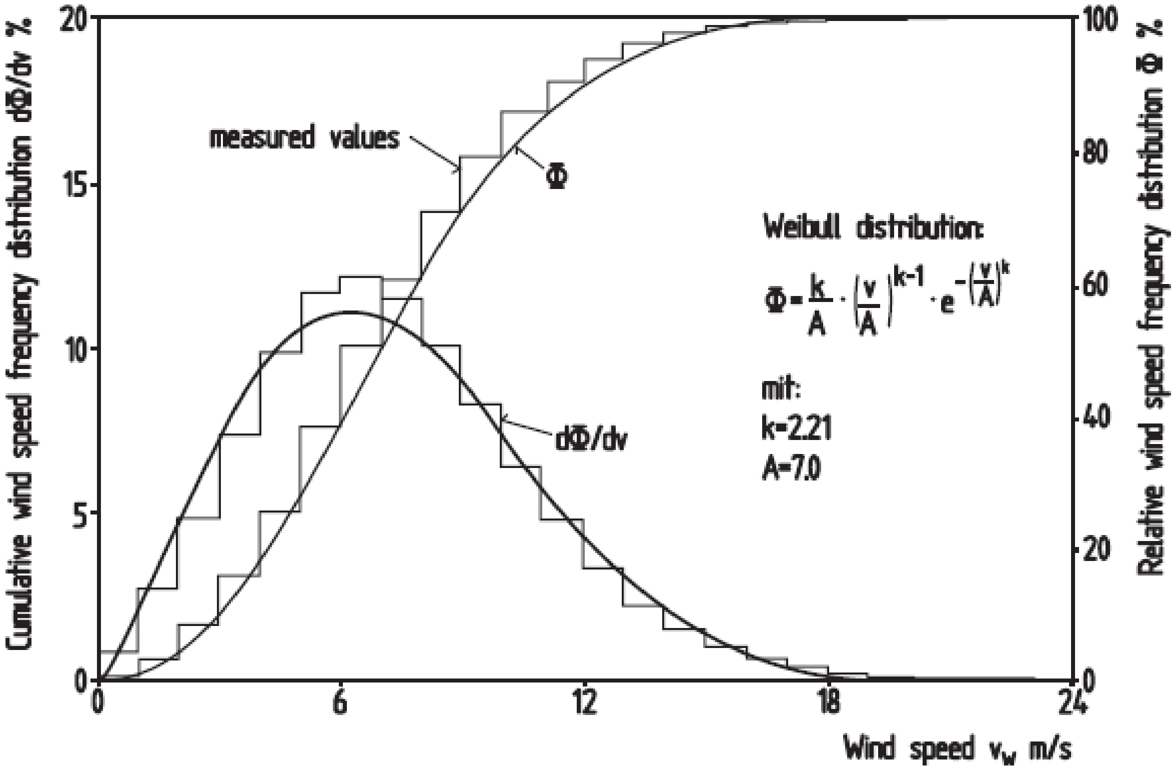


Figure 5.8 Approximation of the measured wind frequency distribution on the island of Sylt by a mathematical distribution function according to Weibull [3]

6 Case studies

6.1 Vale de Rio Jaguaribe – Brazil

The valley of jaguaribe river is situated in the North-East of Brazil in the state of Ceara which have a very high wind energy potential. A wind called Aracati, blows through this valley and reaches Ceara's countryside. It was possible to get wind data from the PCDs (Plataforma de Coleta de Dados), which are meteorological weather stations installed by the FUNCEME (Fundação Cearense de Meteorologia e Recursos Hídricos). They collect data on air temperature, relative humidity, atmospheric pressure, rainfall, solar radiation, soil temperature, soil moisture, wind speed and direction at 10m height.

A first investigation about the wind energy potential of the region has been made by the student Camylla Maria Narciso de Melo from the UECE (Universidade Estadual do CEará). She analyzed the wind potential at 50m and 80m height in Icapui, Jaguaribe and Morada Nova, three towns situated in the Jaguaribe river valley. Therefore she used the wind datas from the PCDs and the simulation results from RAMS, the Regional Atmospheric Modeling System developed at Colorado State University for numerical simulations of atmospheric meteorology.

An investigation will be made with the wind resource assessment software WASP, and WindPRO to calculate the wind energy potential of this region.

The energy consumption of the main cities are listed in the following table

City	Energy consumption [MWh/y]
Icapuí	42,049
Jaguaruana	33,929
Morada Nova	34,919

Table 6.1 Energy consumption of the main cities in Vale do Jaguaribe [28]

6.1.1 Icapui

The wind farm is located near the city of Icapui in a flat, coastal terrain type. The location is -4°43' latitude, -37°20' longitude, 20m above sea level. With a mean wind speed of 8.4m/s at a height of 67m, it is a strong wind site with very directional wind regime (see Fig.6.7). The wind farm contains 42 wind turbine generators from the company Vestas with 67 hub height, with 528m distance in the main wind direction; about 8RD and 264m distance in the lateral spacing; about 4RD.

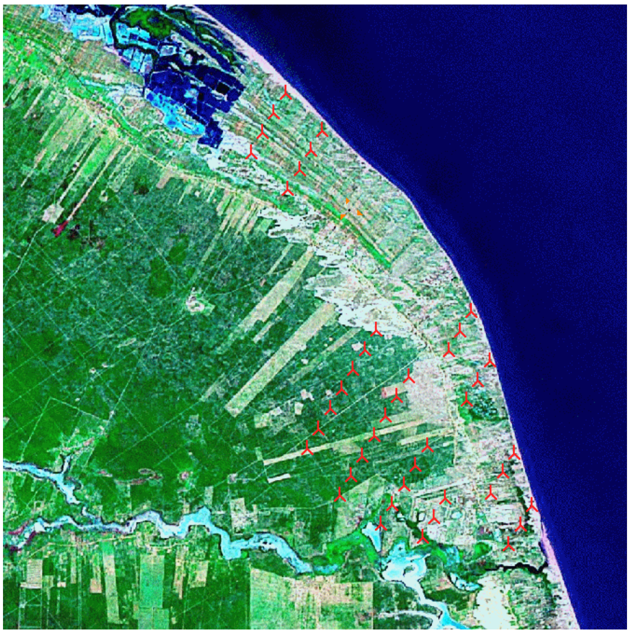


Figure 6.1 Background map with the Icapui wind farm [25]

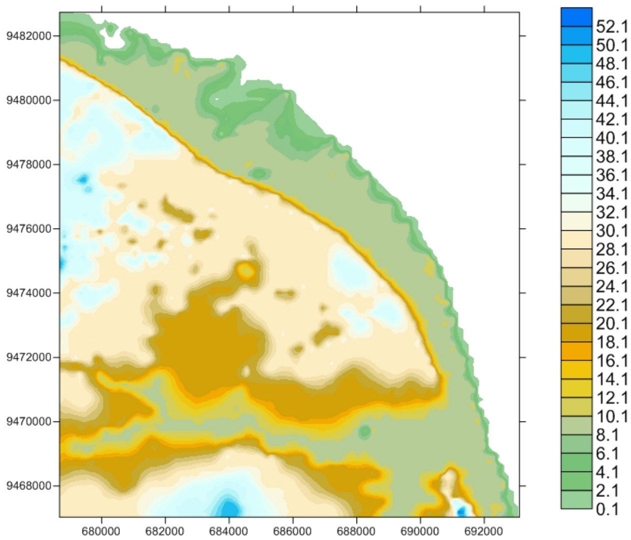


Figure 6.2 Icapui elevation map [22]

The roughness around the wind farm is dominated by a vegetation of canopy with a roughness class of 2,0. The main wind direction (E – ESE) comes from the ocean which has a roughness class of 0,2.

Color	Name	Height	Roughness class	Roughness length
	0,0005m(cl.0,2) Inland Water or Ocean	0,0	0,2	0,0005
	0,0300m(cl.1,0) BACKGROUND	0,0	1,0	0,0300
	0,0382m(cl.1,2) Canopy Cover = 0 %	0,0	1,2	0,0382
	0,1000m(cl.2,0) Canopy Cover = 1 - 25 %	2,5	2,0	0,1000
	0,3031m(cl.2,8) Canopy Cover = 26 - 50 %	5,0	2,8	0,3031
	0,4000m(cl.3,0) Canopy Cover = 51 - 75 %	7,5	3,0	0,4000

Figure 6.3 Roughness class of the area around Icapui [25]

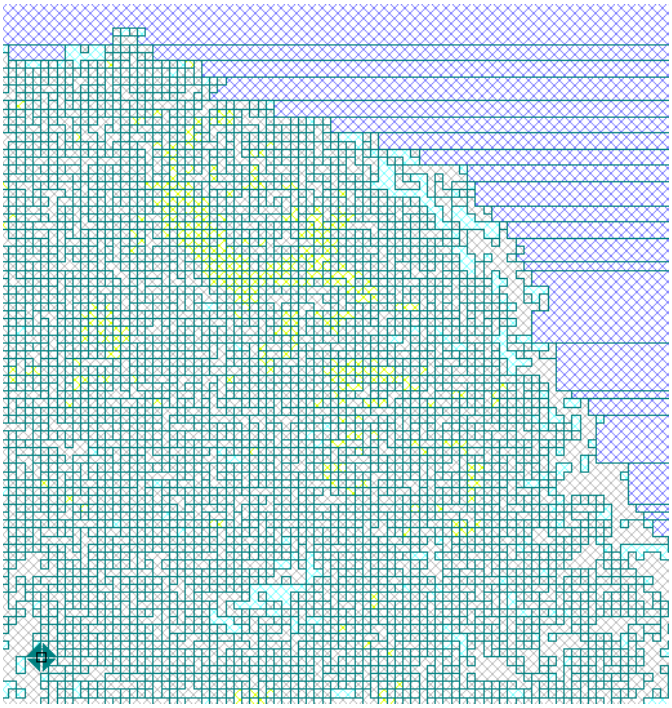


Figure 6.4 Roughness map of the region of Icapui, 500m resolution [windpro]

The next figures below illustrate the wind distribution of the region of Icapui. The results have been extracted from the wind Atlas generated from the correlation of the wind measurements of the PCD Meteorological mast and from the NCAR satellite wind data located at -4,7° latitude, -37,3 longitude.

Figure 6.5 Location of the Meteorological measurements site in Icapui [26]

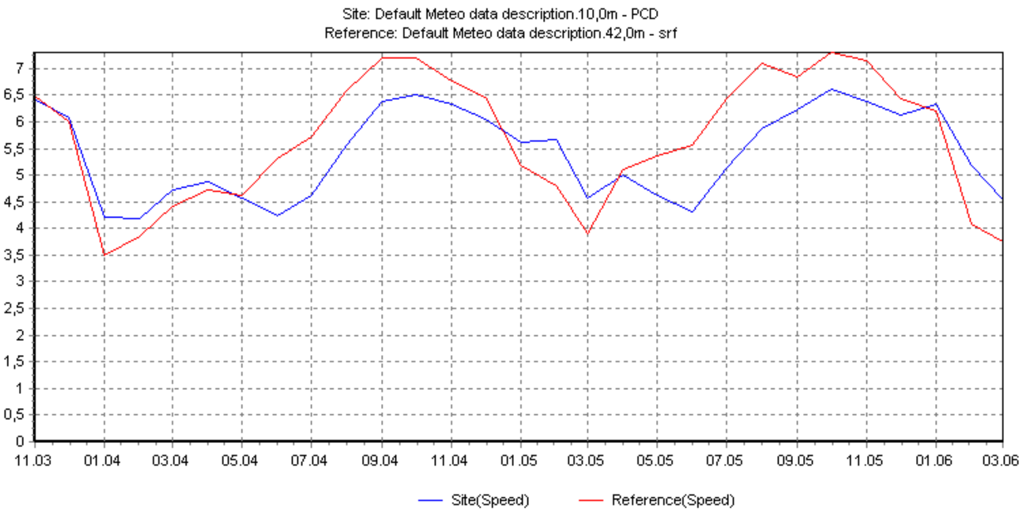


Figure 6.6 MCP Correlation of PCD and NCAR wind data for Icapui [25]

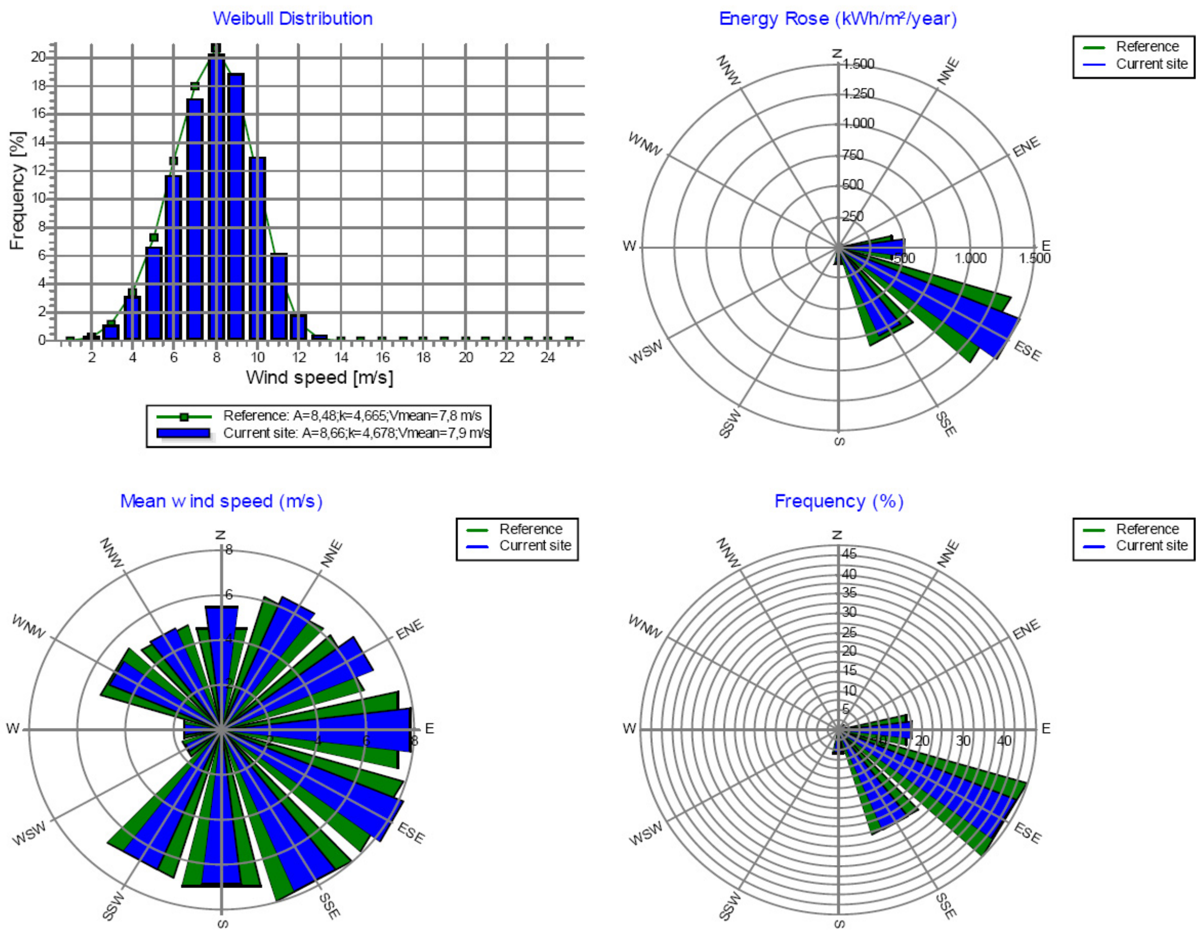


Figure 6.7 Icapui wind atlas [25]

At the following picture, we can see the AEP resource grid at 67 height:

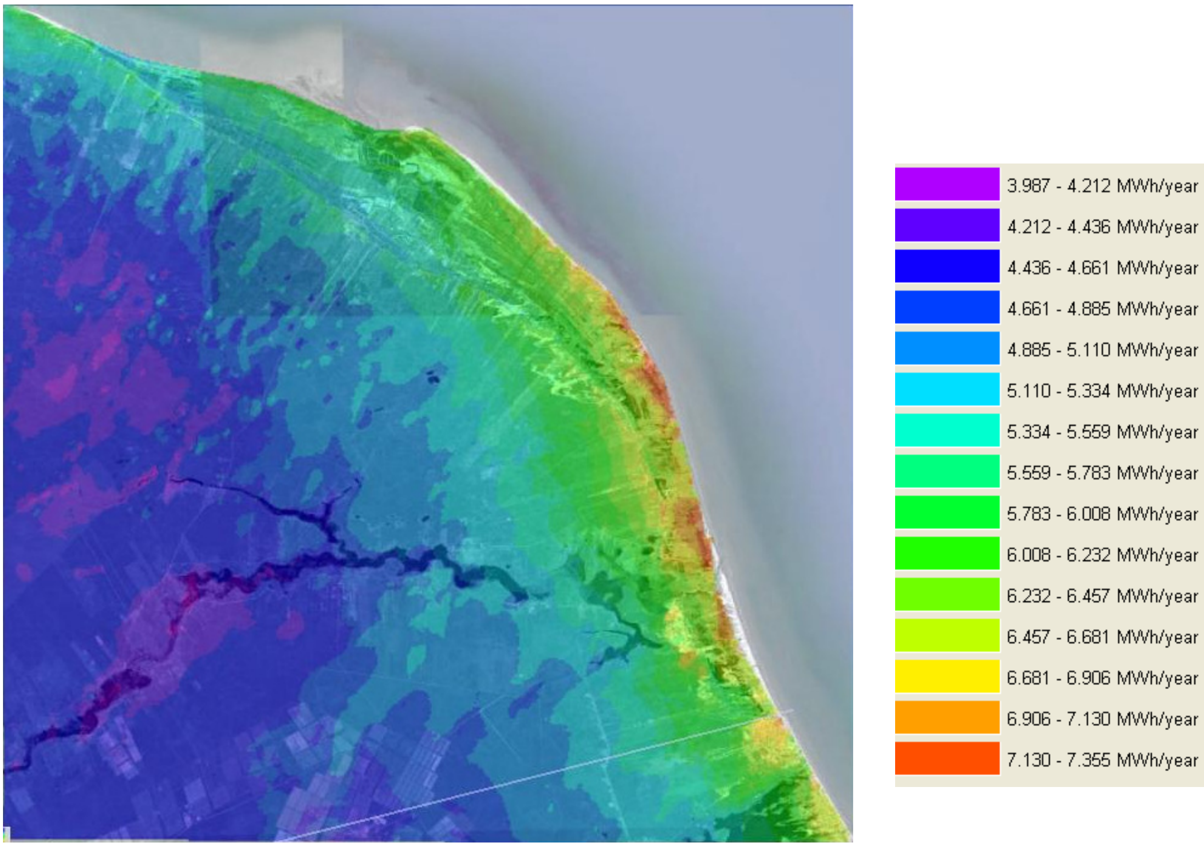


Figure 6.8 AEP resource grid of Icapui at 67m height [25] and [26]

The directional analysis of the wind farm shows us that the main lost due to the Wake effect are predominated from the E – ESE and SSE sectors. The array losses of the WF reach a value of 9233 MWh/y.

Sector		0 N	1 NNE	2 ENE	3 E	4 ESE	5 SSE	6 S	7 SSW	8 WSW	9 W	10 WNW	11 NNW	Total
Roughness based energy	[MWh]	86,3	551,1	9.413,7	67.949,4	77.917,7	55.270,4	6.047,6	393,2	19,3	3,4	1,8	12,1	217.666,0
-Decrease due to array losses	[MWh]	2,6	83,4	187,7	2.454,4	3.143,3	3.050,6	224,7	84,8	0,9	0,3	0,2	0,8	9.233,8
Resulting energy	**[MWh]**	**83,6**	**467,7**	**9.226,1**	**65.495,0**	**74.774,4**	**52.219,8**	**5.822,9**	**308,4**	**18,5**	**3,0**	**1,6**	**11,2**	**208.432,2**
Specific energy	[kWh/m²]													1.451
Specific energy	[kWh/kW]													2.481
Decrease due to array losses	[%]	3,0	15,1	2,0	3,6	4,0	5,5	3,7	21,6	4,5	10,1	10,0	6,8	4,2
Utilization	[%]	39,2	34,7	40,7	39,6	39,2	39,5	39,1	25,2	14,3	7,9	11,5	29,9	39,4
Operational	[Hours/year]	9	42	368	2.183	2.618	2.477	649	210	70	35	9	9	8.679
Full Load Equivalent	[Hours/year]	1	6	110	780	890	622	69	4	0	0	0	0	2.481

Table 6.2 Energy and wake lost distribution per sector [25]

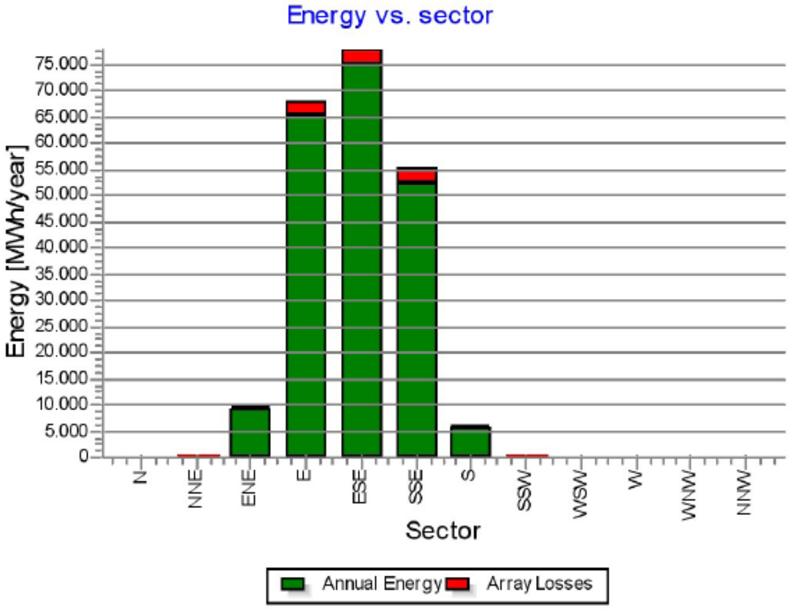


Figure 6.9 Directional analysis of the WF in Icapui with array losses [25]

In the three following pictures, we can see the environmental impact analysis of the wind farm on the surrounding area.

The noise sensitive areas (NSA) like farms or small towns are symbolised by the following figure . According to the German ISO 9613-2 noise calculation model and the German TA Lärm, the NSA in this site are general residential areas and the noise can not exceed 40dB.

The area affected with the Shadow of the WTG is illustrated in the flicker map. The limit according to the German law is max. 30min shadow per day.

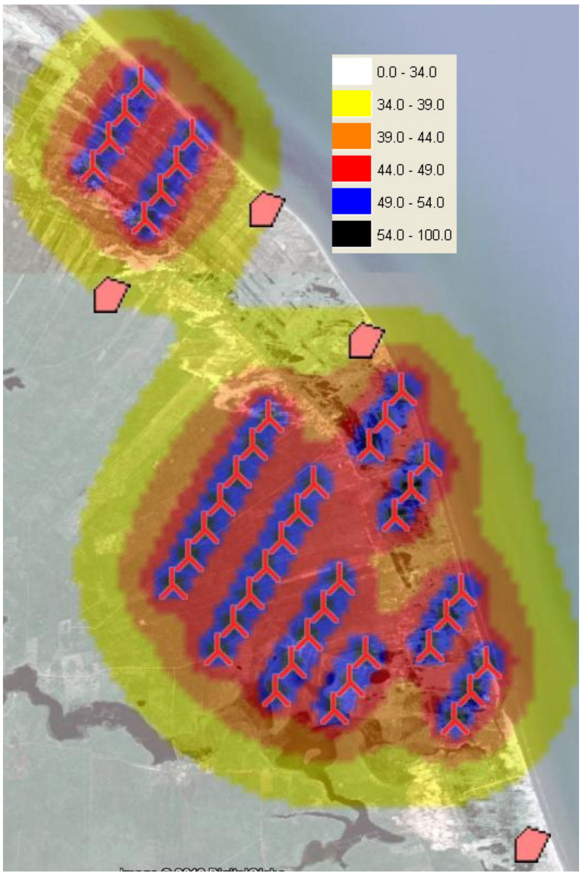


Figure 6.10 Noise map of Icapui wind farm [25] [26]

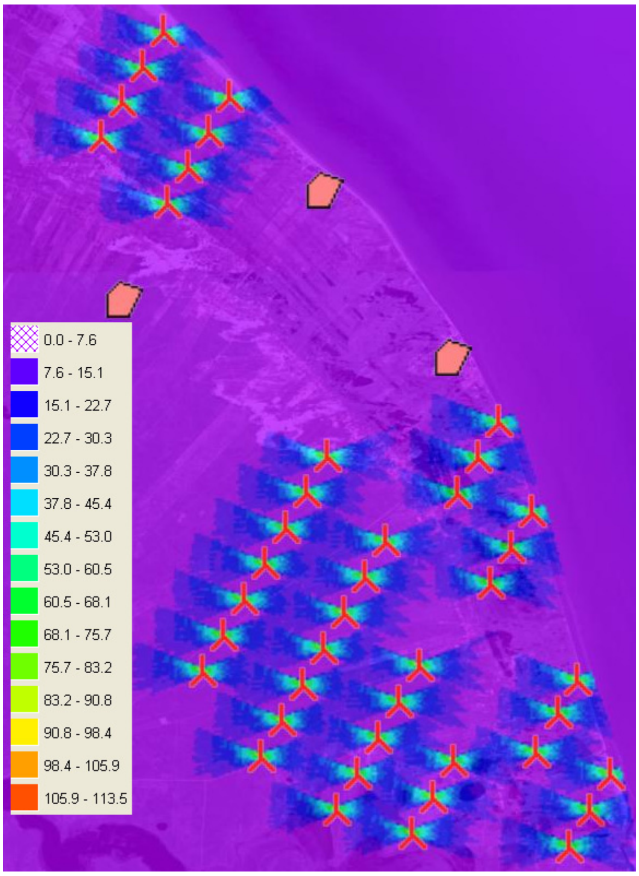


Figure 6.11 Shadow map of Icapui wind farm [25] [26]

The wind farm can be seen from a radius of 15 km due to the flat land of the region.

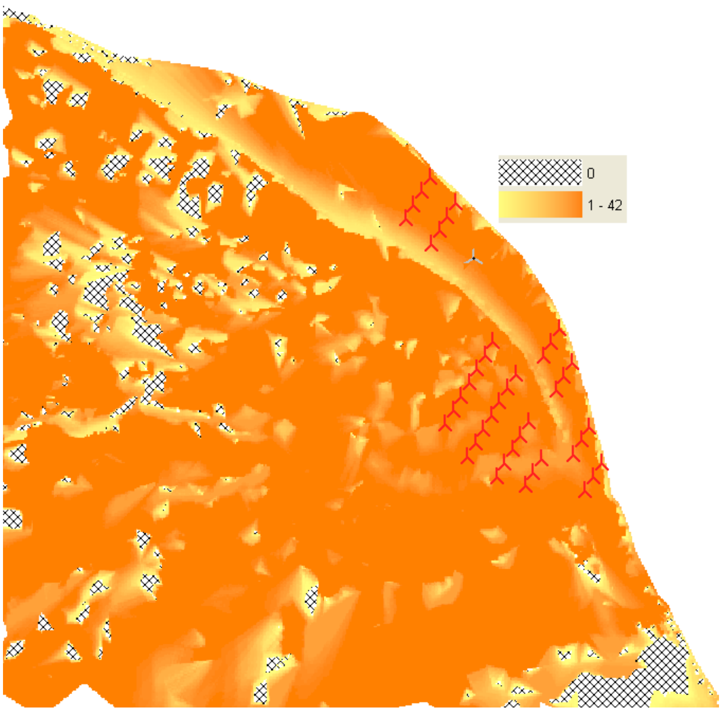


Figure 6.12 Zone of visibility in Icapui [25]

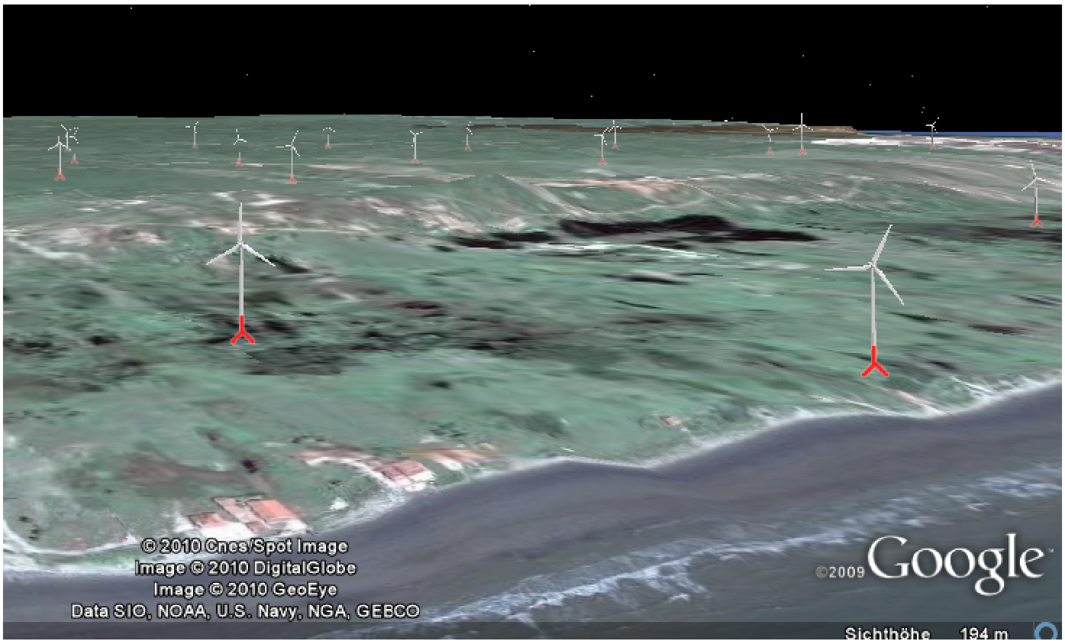


Figure 6.13 Google earth view from the Icapui wind farm [26]

6.1.1.1 Results of the Icapui wind farm

The results of the wind farm energy production show us a high energy production with a mean WTG energy production of nearly 5000 MWh/y. The Park efficiency is by 95.8% and a Capacity factor of 28.3%. The WTG positioned on the coast have a better efficiency with a capacity factor of nearly 40%.

Calculated Annual Energy for Wind Farm							
			Specific results¤)				
WTG combination	Result PARK [MWh/y]	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]
Wind farm	208.432,3	217.666,0	95,8	28,3	4.962,7	2.481	8,4

Table 6.3 AEP for the Icapui wind farm [25]

The energy production of the Icapui wind farm will be enough to cover the electricity consumption of the main cities situated on the Vale de Jaguaribe.

Before planning a wind project, various issues need to be considered. The WTG has to be placed in order to take advantage of the best wind resource but in the same way, the impact on the surrounding region and on the environment must be minimized.

It is also necessary to check the soil and underlying rock to see if they are capable to support the weight of a wind turbine which can varies from 500t until 7000t.

Actually there are more than 300 WTG in the market produced by more than 30 manufacturer's world wide. [32]

Three factors will contribute to the size of the WTG [33]:

- The amount of energy needed
- The amount of wind energy available
- The investment costs

6.1.2 Wind turbine class study in Icapui

The wind turbine manufacturer General electric has 5 different types of wind turbines with a rated power of 1.5 MW. They were produced to fit the different wind sites with the different wind classes. 9 wind turbines of each model will be tested in the wind site of Icapui to see which one will fit as best the wind conditions of this region.

On the next two figures we can see the characteristics and the power curve of each turbine model:

Technical Data	1.5s	1.5se	1.5sl (50Hz only)	1.5sle	1.5xle
Operating data					
• Rated capacity:	1,500 kW	1,500 kW	1,500 kW	1,500 kW	1,500 kW
• Cut-in wind speed:	4 m/s	4 m/s	3,5 m/s	3,5 m/s	3,5 m/s
• Cut-out wind speed (10 min. avg.):	25 m/s	25 m/s	20 m/s	25 m/s	20 m/s
• Rated wind speed:	13 m/s	13 m/s	14 m/s	14 m/s	12,5 m/s
• Wind Class - IEC:	IIa	Ib	–	IIa V_{e50} = 55 m/s	IIIb V_{ave} = 8.0 m/s
• Wind Class - DIBt WZ:	II/III	–	II	–	II
Rotor					
• Number of rotor blades:	3	3	3	3	3
• Rotor diameter:	70,5 m	70,5 m	77 m	77 m	82,5 m
• Swept area:	3904 m²	3904 m²	4657 m²	4657 m²	5346 m²
• Rotor speed (variable):	12,0 – 22,2 rpm	12,0 – 22,2 rpm	11,0 – 20,4 rpm	11,0 – 20,4 rpm	10,1 – 18,7 rpm
Tower					
• Hub heights - IEC:	64,7 m	54,7/64,7 m	–	61,4/64,7/80 m	58,7/80/100 m
• Hub heights - DIBt:	64,7 m	–	61,4 to 100 m	61,4/64,7/80/85/100 m	58,7/80/100 m

Table 6.4 Technical data of the GE 1.5 model [7]

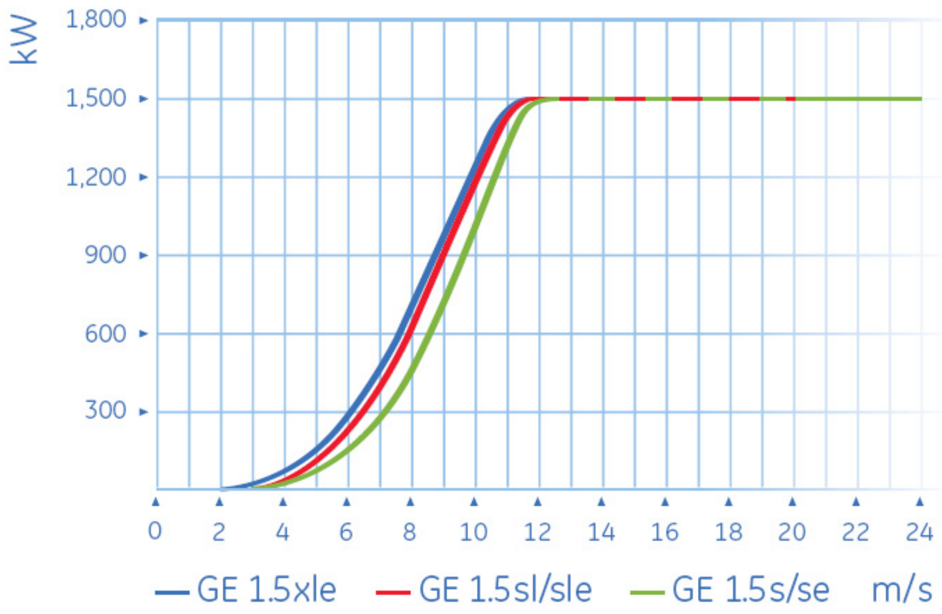


Figure 6.14 Power curve of the GE 1.5 model [7]

According to the AEP results of the simulation (see figure below), the GE1.5xle model, with a 58.7 Hub Height tower, 82.5m RD (Rotor Diameter) and a RP (rated Power) by 13m/s wind velocity would better fit in the region of Icapui. This WTG is a wind turbine class IIIb according to the IEC regulations. The capacity factor would reach by some WTG 47% by an annual energy production of more than 6000 MWh/y. It was not possible to choose the same HH (Hub Height) for the 5 WTG. The HH is varying from 58m till 64m.

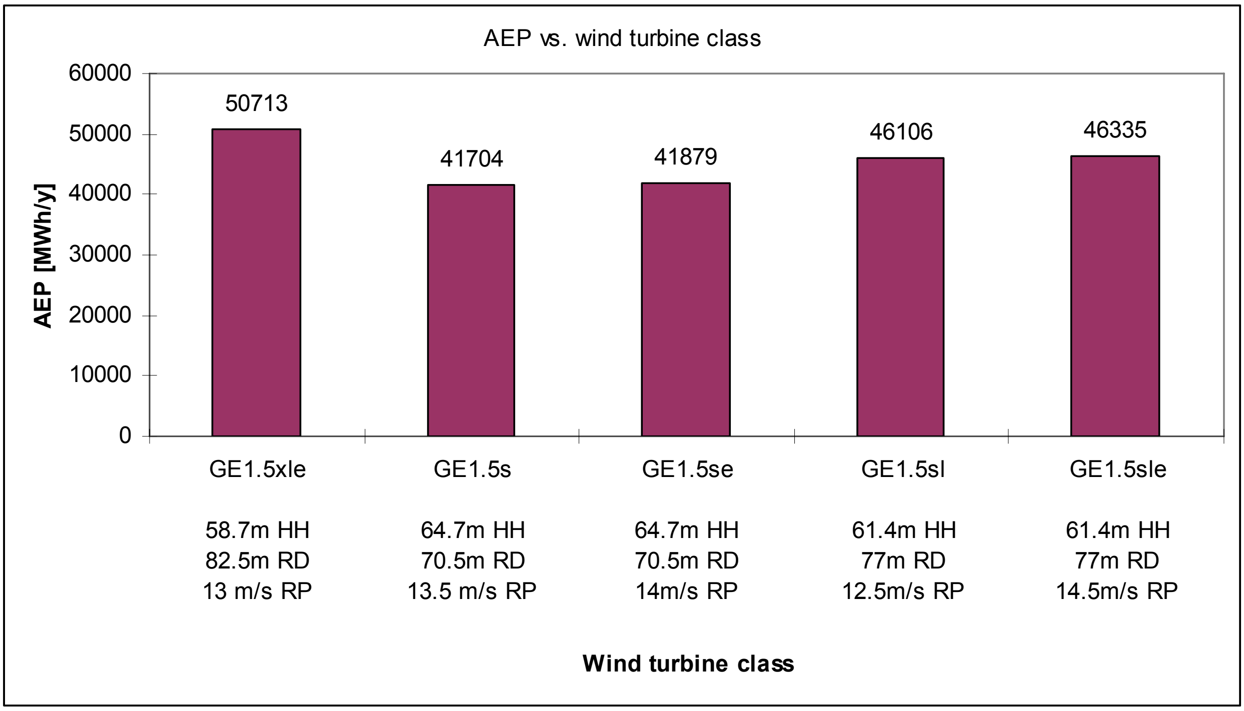


Figure 6.15 AEP vs. Wind turbine class

6.1.3 Jaguaruana

The WTG are situated in the east of the city of Jaguaruana at -4°84 latitude, -37,68 longitude at the hill top where the mean wind speed is 7,1m/s at 67m height. The surroundings are flat with max 150 m elevation within 10 km radius of the wind farm. The wind regime is very directional and comes mainly from the direction E – ESE. The surrounding area is dominated by canopy vegetation with a roughness class of 2,0.

The wind farm contains 22 wind turbine generators from the company Vestas with 67 hub height and a 67m rotor diameter, with 528m distance in the main wind direction; about 8RD and 264m distance in the lateral spacing; about 4RD.

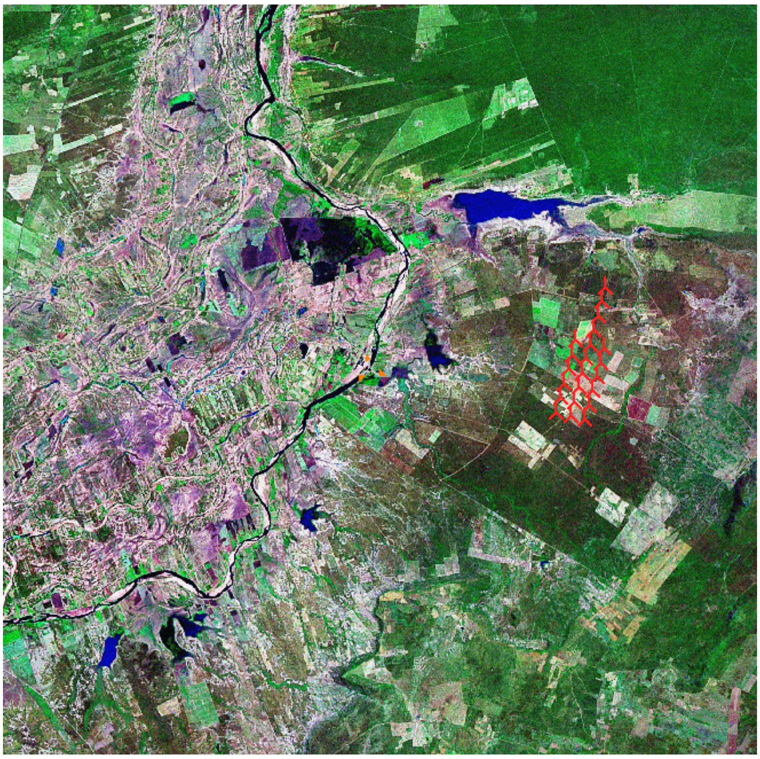


Figure 6.16 Jaguaruana background map and location of the WTG [25]

At the following picture, we can see the AEP resource grid at 67 height and the location of the WF:

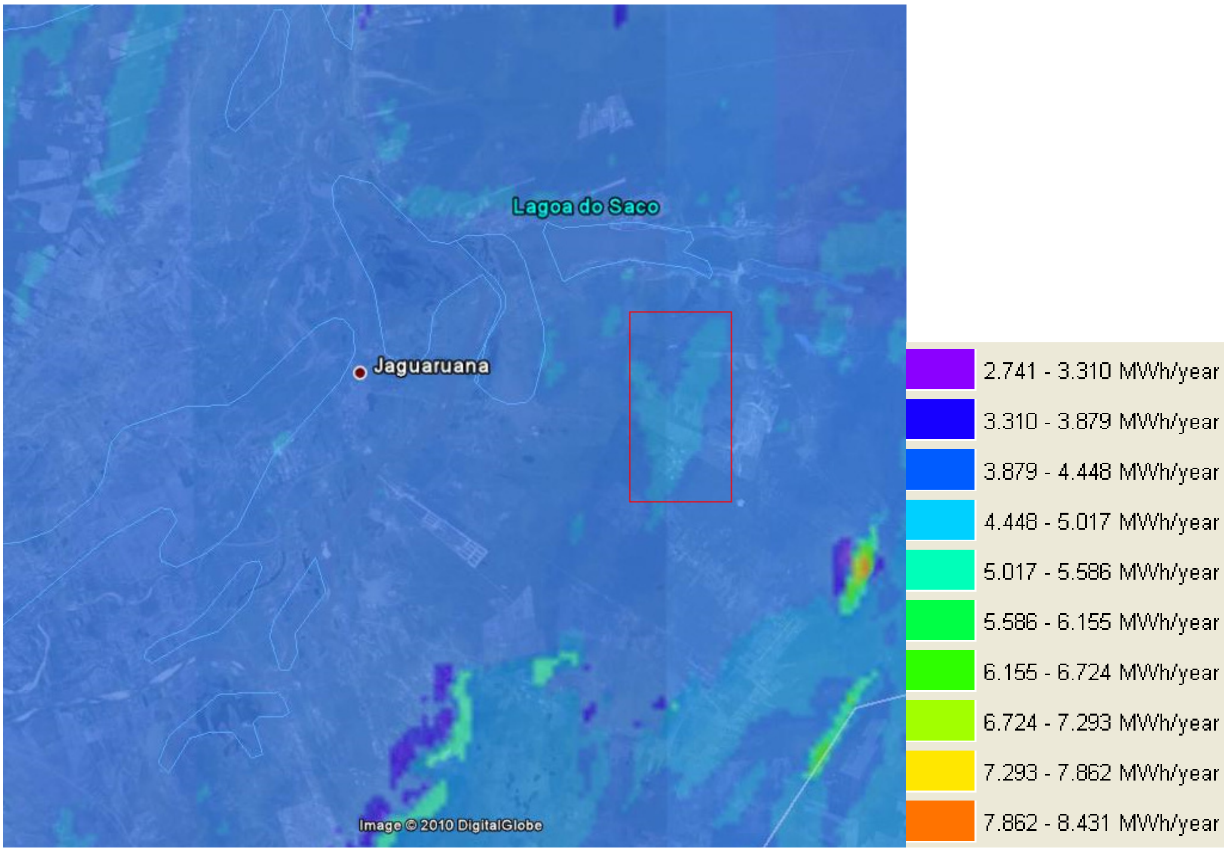


Figure 6.17 Jaguaruana ressource grid at 67m hub height [25]

In the three following pictures, we can see the environmental impact analysis of the wind farm on the surrounding area. The populated areas like farms or small towns are symbolised by the following figure . The WTG has been positioned on a small hill where their production would reach 4000 to 5000 MWh/y. The WTG would not affect the neighboured houses by the generated shadow, but unfortunately it would be to loud for the residential area on the left of the wind farm where the noise would exceed the allowed limit of 40dB. In this case we should choose smaller WTG or move the WTG which are near the populated area.

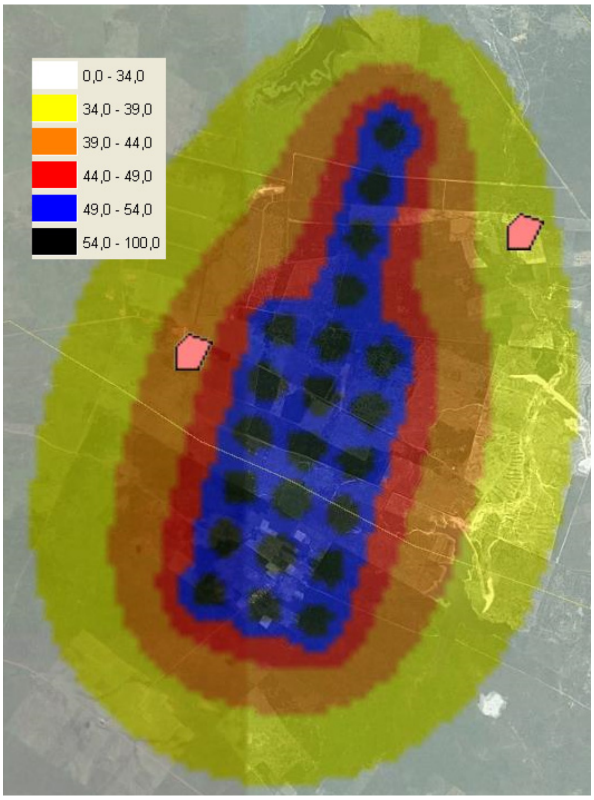


Figure 6.18 Jaguaruana noise map [25]

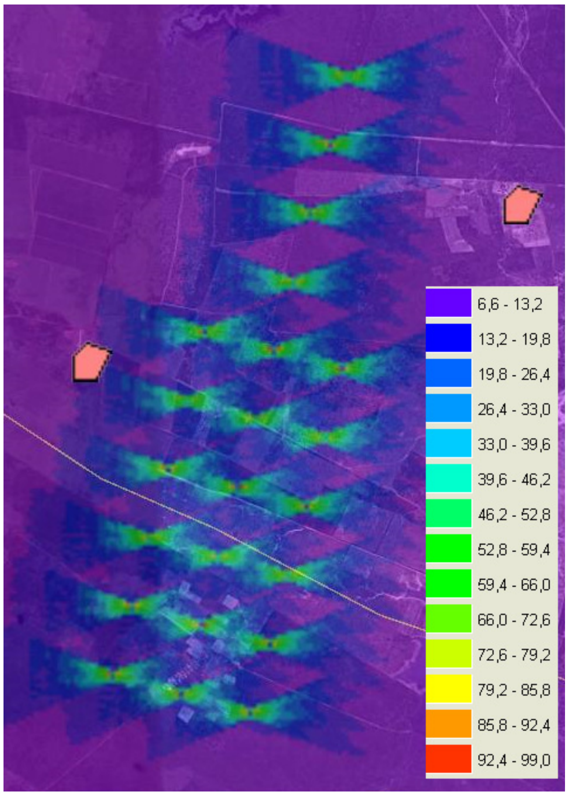


Figure 6.19 Jaguaruana shadow map [25]

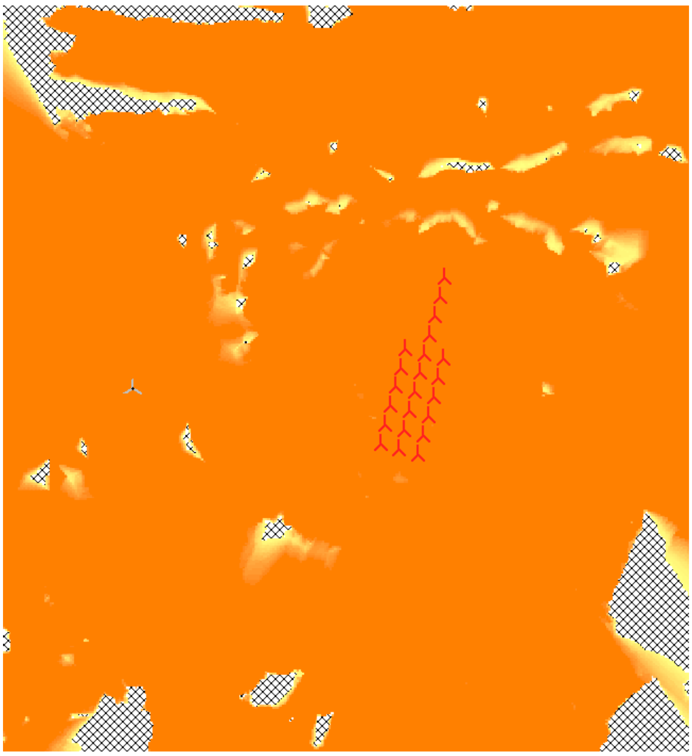


Figure 6.20 Zone of visibility of Jaguaruanas widn farm [25]

The next figures below illustrate the wind distribution of the region of Jaguaruana. The results have been extracted from the wind Atlas generated from the correlation of the wind measurements of the PCD Meteorological mast and from the NCAR satellite wind data located at -4,8° latitude, -37,7 longitude.

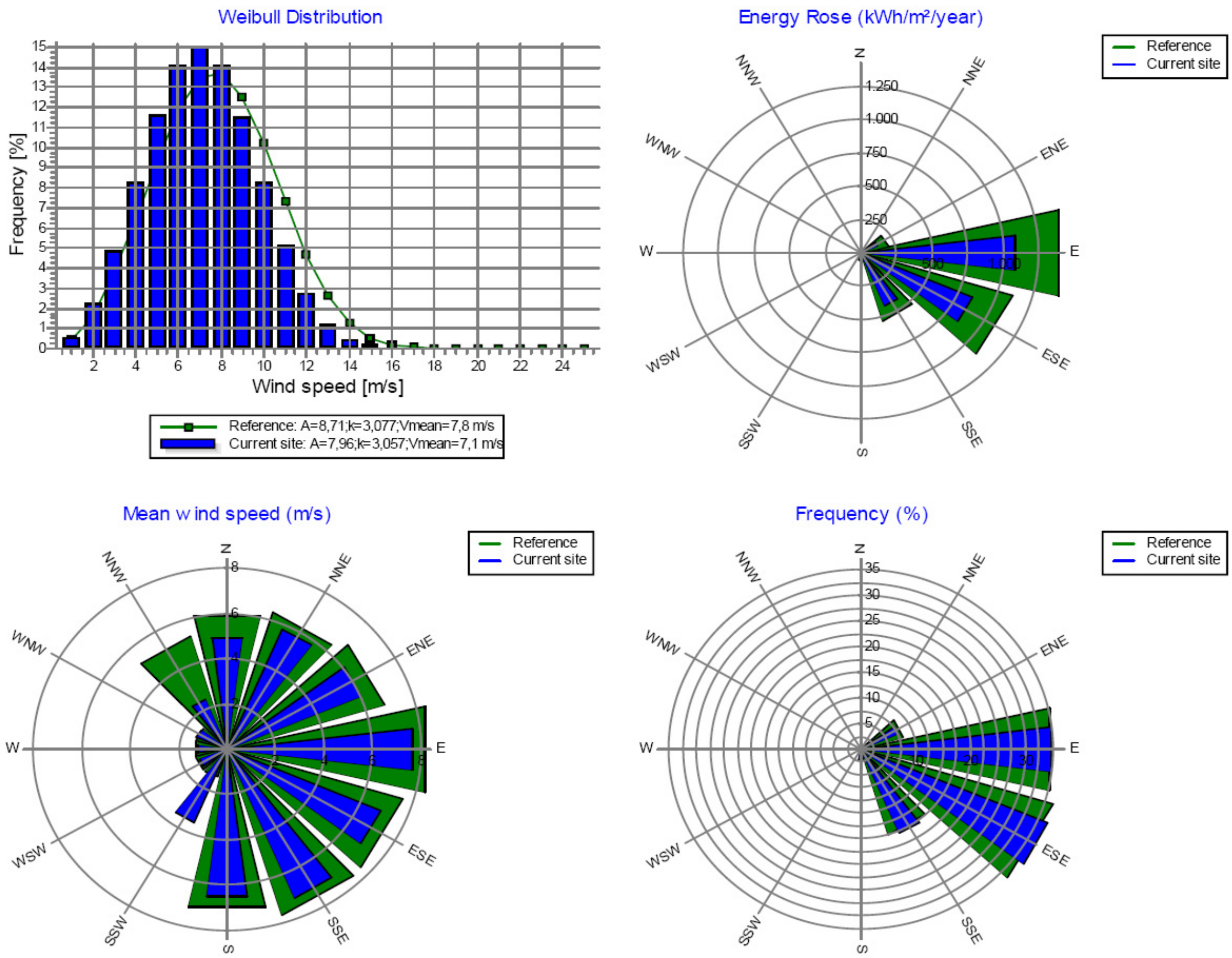


Figure 6.21 Jaguaruana wind atlas [25]

The wind farm energy production shows lower results than the Icapui wind farm. The mean WTG energy production lies by 3300 MWh/y. This has to do with the mean wind speed of 7,1 m/s which is less than the Icapui region. This has to do with the fact that the wind coming from the coast is getting weaker by crossing the countryside.

				Specific results¤)			
WTG combination	Result PARK [MWh/y]	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]
Wind farm	73.537,6	77.798,9	94,5	19,1	3.342,6	1.671	7,1

Table 6.5 Jaguaruana wind farm energy production [25]

6.1.4 Morada nova

In the region surrounding the city of Morada Nova, the wind conditions are weaker than the other wind sites. It would not be efficient enough to build a Wind farm. The mean wind speed at 67 HH would be around 4 m/s according to the Wind atlas generated for this region.

				Specific results¤)			
WTG combination	Result PARK [MWh/y]	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]
Wind farm	14.989,9	16.058,0	93,3	3,9	681,4	341	3,9

Figure 6.22 Wind farm energy production in morada Nova [25]

6.2 Istmo de Tehuantepec – Mexico

The narrowness of the Isthmus, and the gap in the Sierra Madre, allow the winds of the Gulf of Mexico to blow across the Pacific Ocean. These particularly strong winds, known as Tehuano, are caused by a wave of denser cold high pressure air from the gulf of Mexico and a warmer low pressure air over the gulf of Tehuantepec which are accelerated through the Chivela pass [30]. (see the two figures below)

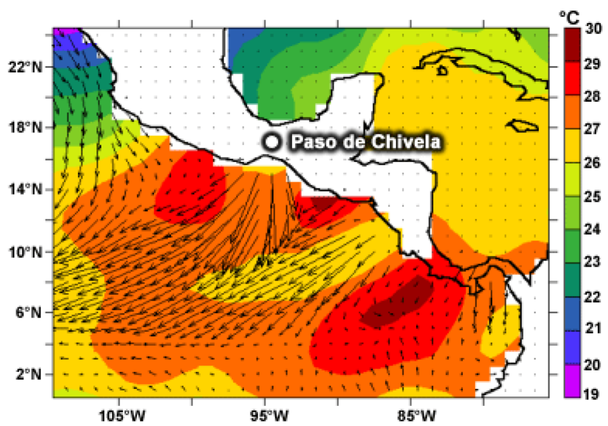


Figure 6.23 Paso de chivela and surrounding temperature [29]

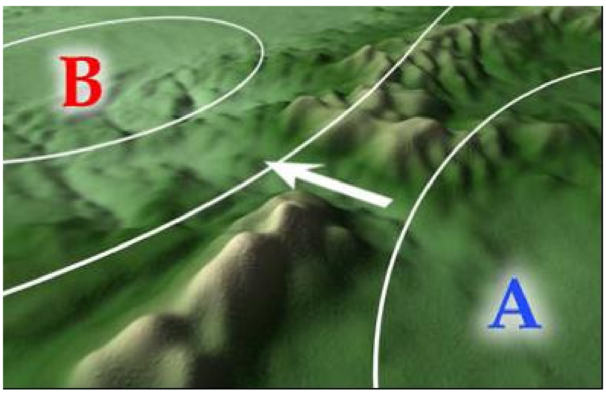


Figure 6.24 Acceleration of the wind through the chivela pass [29]

6.2.1 La venta

The best wind resource areas in Oaxaca are concentrated in the south-eastern region of the state in the southern part of the Isthmus of Tehuantepec. The windy Isthmus region extends from the coast northward approximately 60 km and approximately 60 km to 80 km from east to west. The isthmus region has excellent wind resource near the ridges, coast and foothills like La venta. Strong winds coming from the North are frequent in this region, particularly from November through February [30].

In the region of La Venta, a study will be done to see the influence of the turbine spacing and the wake models on the AEP.

The wind farm is made of nine 1.75 MW WTG from the Wind turbine manufacturer Vestas, with a 66m RD (Rotor Diameter) and a 66m HH (hub height).

The wind atlas used for the calculations has been created from the wind data of the IIE meteorological mast and from the nearest NARR satellite wind data. As shown in the following figures, the wind distribution is dominated by winds coming from the NNW sector.

Weibull Data

Sector	A- parameter [m/s]	Wind speed [m/s]	k- parameter	Frequency [%]	Wind gradient exponent
0 N	9,05	8,03	1,859	11,3	0,123
1 NNE	1,75	1,55	2,194	1,2	0,074
2 ENE	1,40	1,25	2,653	0,8	0,079
3 E	1,44	1,27	2,371	1,0	0,107
4 ESE	2,35	2,09	1,901	2,8	0,124
5 SSE	7,29	6,46	2,255	32,0	0,148
6 S	4,47	3,99	1,723	4,2	0,175
7 SSW	1,46	1,30	2,003	0,5	0,108
8 WSW	1,14	1,01	2,176	0,3	0,123
9 W	1,22	1,08	2,155	0,4	0,120
10 WNW	1,77	1,58	1,854	0,9	0,096
11 NNW	14,46	12,86	2,700	44,5	0,162
All	10,06	8,99	1,645	100,0	

Figure 6.25 Weibull data of la Venta [25]

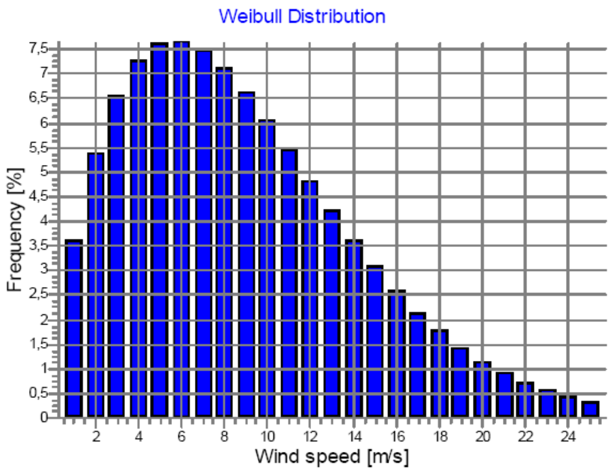


Figure 6.26 Weibull wind distribution of la Venta [25]

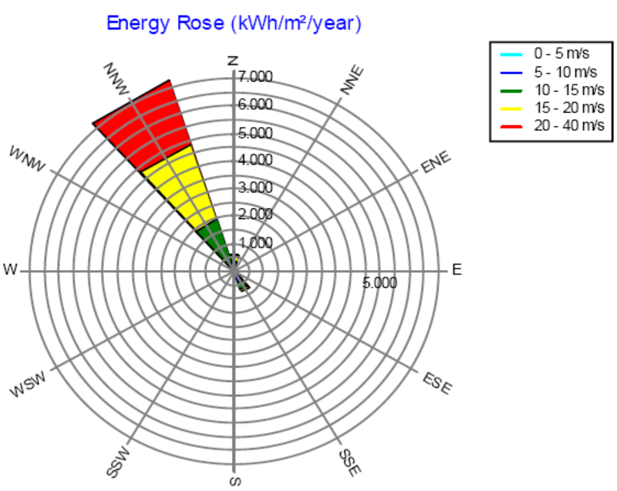


Figure 6.27 Energy rose of the Venta wind farm [25]

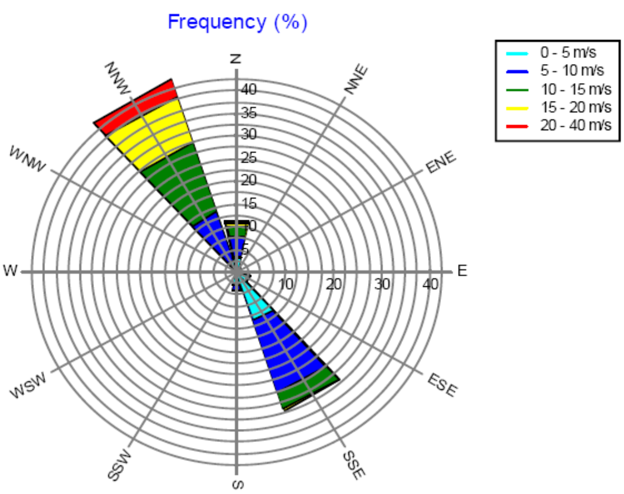


Figure 6.28 Frequency rose of the Venta wind farm [25]

6.2.2 Turbine spacing study

In the following table we can see the results of the AEP in relation to the Turbine spacing.

Turbine spacing	Wind Farm annual energy production							
	WTG combination	Result PARK [MWh/y]	GROSS (no loss) Free WTGs [MWh/y]	Park efficiency [%]	Specific results¤) Capacity factor [%]	Mean WTG result [MWh/y]	Full load hours [Hours/year]	Mean wind speed @hub height [m/s]
16x8 RD	Wind farm	90.927,4	92.677,6	98,1	39,5	6.061,8	3.464	9,0
12x6 RD	Wind farm	89.888,1	92.676,1	97,0	39,1	5.992,5	3.424	9,0
10x5 RD	Wind farm	89.117.4	92.676.0	96.2	38.7	5.941.2	3.395	9.0
8x4 RD	Wind farm	87.786,4	92.676,2	94,7	38,2	5.852,4	3.344	9,0
6x3 RD	Wind farm	85.749,3	92.676,1	92,5	37,3	5.716,6	3.267	9,0

Table 6.6 AEP in relation to the turbine spacing [25]

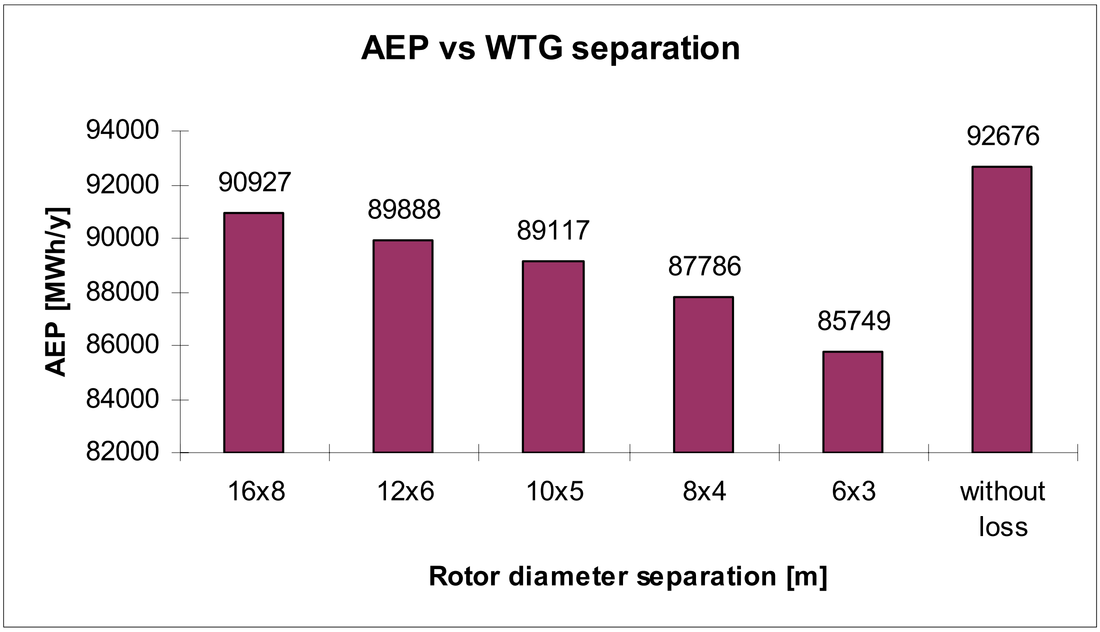


Figure 6.29 AEP vs. WTG separation

The AEP without loss would be 92676 MWh/y; even with a distance of 16 RD in the main wind direction the wind farm would produce 90927 MWh/y. This implies a Park efficiency of 98,1% with a main capacity factor of 39,5%. For the simulations, the used wake model is the N.O. Jensen (RISØ/EMD), which is recommended by the WindPRO software. According to the results of this study, we can see how important it is to plan a WF, depending on the available area, the RD and the HH of the WTG.

Figure 6.30 Turbine spacing [26]

6.2.3 Wake models study

To see the influence of the different Wake models, the WF was created with a WTG separation of 10x5 RD for all the models. The results are shown in the following table and figure:

Wake model	Wind Farm annual energy production							
	Specific results¤)							
	WTG combination	Result PARK [MWh/y]	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]
N.O. Jensen (RISØ/EMD)	Wind farm	89.117,4	92.676,0	96,2	38,7	5.941,2	3.395	9,0
N.O. Jensen (EMD) : 2005	Wind farm	88.800,1	92.676,1	95,8	38,6	5.920,0	3.383	9,0
EWTS II (G.C.Larsen): 2008	Wind farm	90.470.6	92.676.1	97.6	39.3	6.031.4	3.446	9.0
EWTS II (G.C.Larsen) : 1999	Wind farm	90.470.6	92.676.1	97.6	39.3	6.031.4	3.446	9.0

	Specific results¤)							
	WTG combination	Result PARK [MWh/y]	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]
Eddy Viscosity Model (J.F. Ainslie) : 1986	Wind farm	90.304.6	92.676.1	97.4	39.2	6.020.3	3.440	9.0

Table 6.7 AEP in relation to the wake models [25]

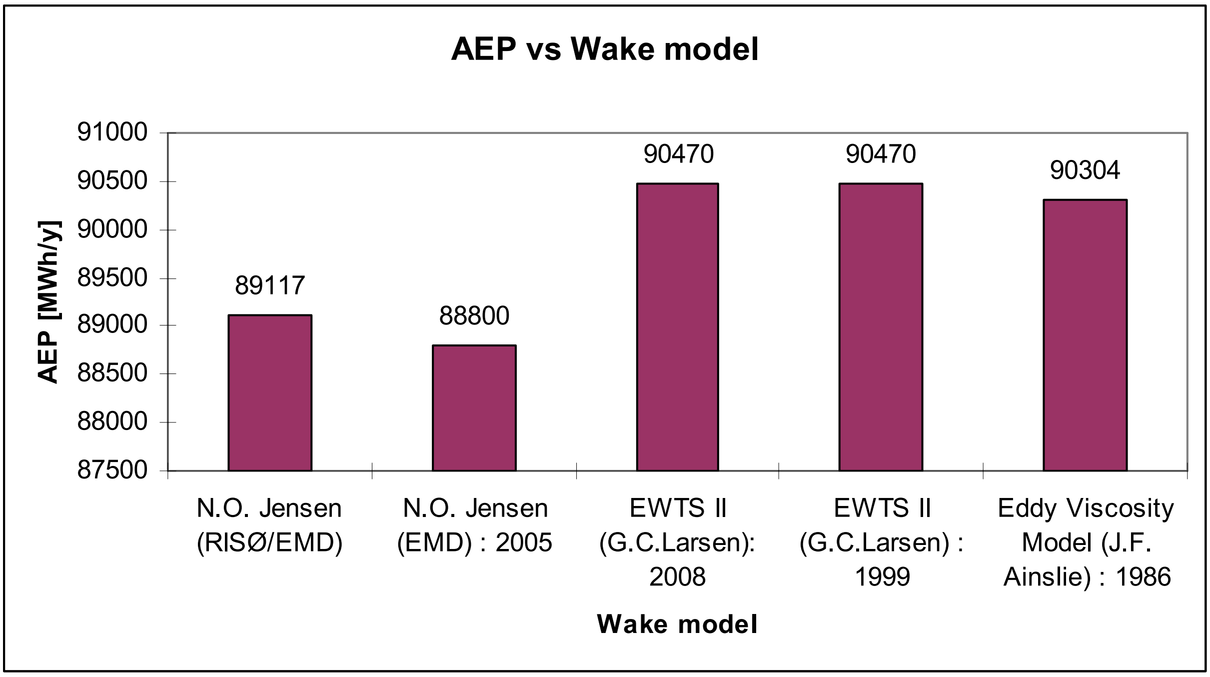


Figure 6.31 AEP vs Wake model

According to the result of the AEP, the (G.C. Larsen) 2008 and 1999 have the most optimistic results regarding energy yield, efficiency and capacity factor. The wake model recommended by EMD, N.O. Jensen (RISO/EMD), has a prognostic of 89117 MWh/y which are 1353 MWh/y less than the EWTS II model from Larsen.

6.3 State of Tamaulipas – Mexico

6.3.1 Francisco Villa

In this wind site, a study will be done to see the Influence of the resolution and source of the topographic map and roughness data on the results of the wind farm energy production. In the following figure, we can see the 3D elevation map of the area surrounding Francisco Villa. The topography is varying from 0m to 150m.

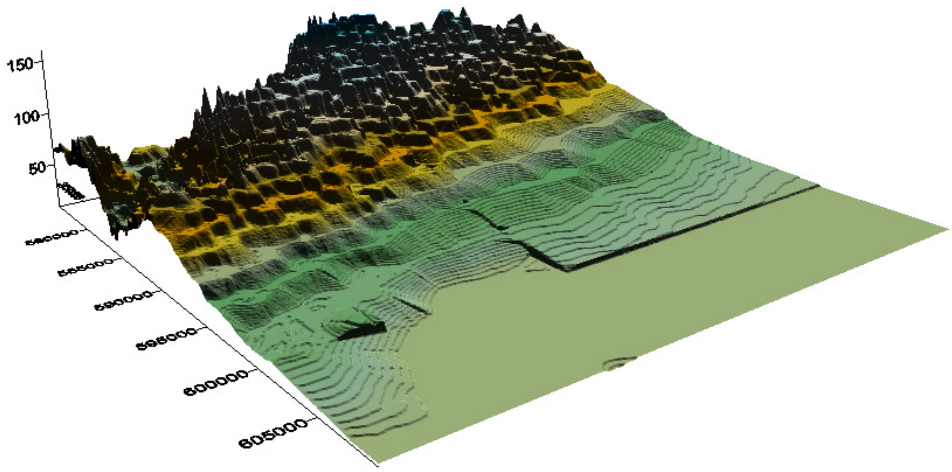


Figure 6.32 Elevation map of Francisco Villa [22]

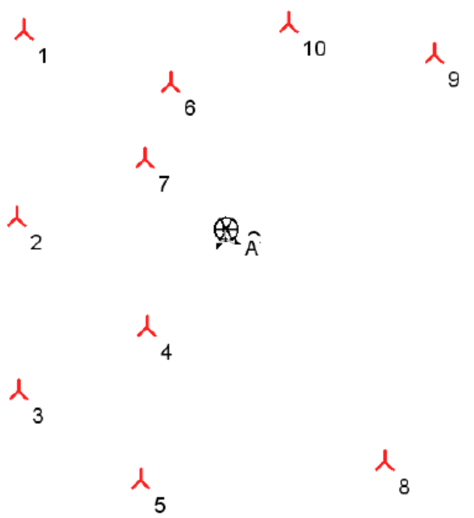


Figure 6.33 Position of the Wind Turbines [25]

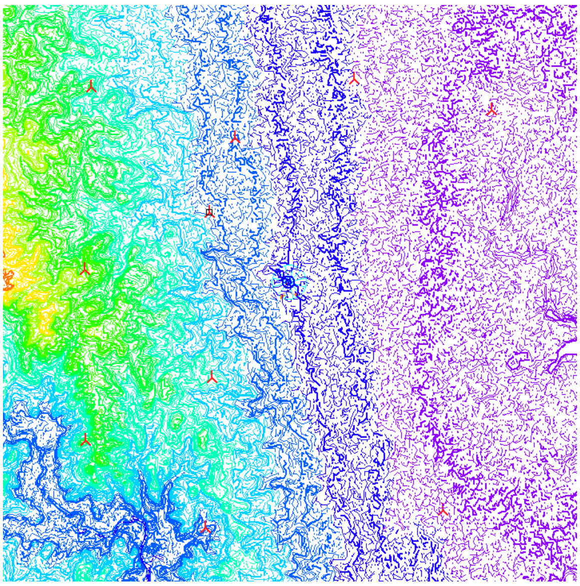


Figure 6.34 Position of the Wind turbines with elevation map [25]

For this study case, we used the wind data coming from the Meteorological mast of the IIE situated at +25,01, -98,01 at 20 and 40m height, 32m a.s.l.(above see level).

The wind atlas generated for this region is for a height of 60m and is dominated by a wind coming from the SSE sector with a mean wind speed of 8,7m/s.

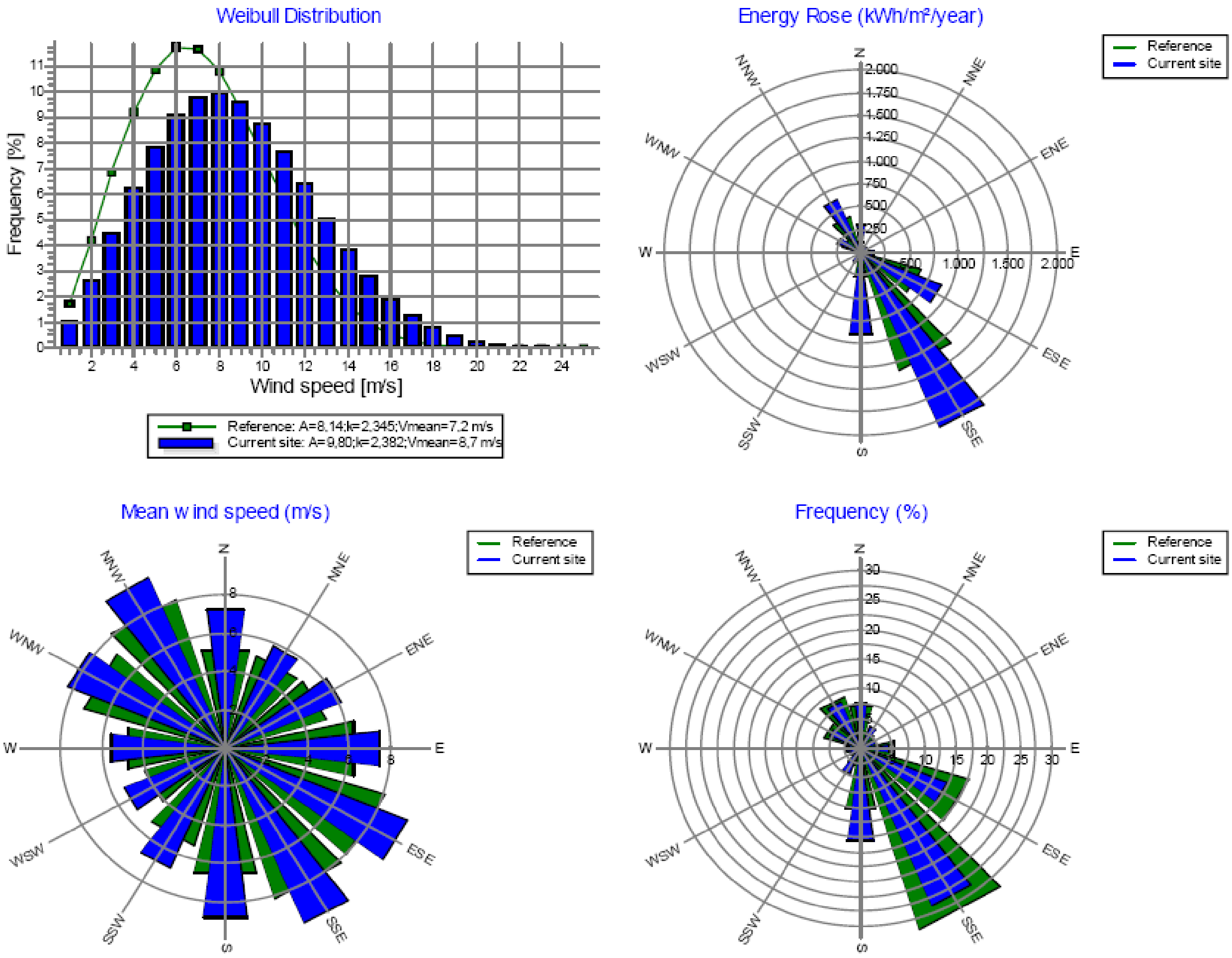


Figure 6.35 Wind Atlas of Francisco Villa [25]

6.3.2 Elevation and roughness study

6.3.2.1 Influence of the elevation resolution on the AEP

The first comparison will be done between the elevation map of the SRTM with a resolution of 2m and 10m resolution lines and the INEGI with a 2m contour line resolution. For all simulation, a roughness class of 2 has been chosen for the whole area.

According to the results of the energy production, the WTG number 2 shows a great difference in the energy production. By using the SRTM map with a resolution of 2m, it has an

AEP of 6228 MWh and with the other 2 maps it produce just 3127 MWh. But regarding the other WTG, the tendency shows that the INEGI simulation gives a higher AEP if we keep apart the result of WTG 2. This can be seen in the second chart with the results of the AEP of the whole WF without WTG number 2.

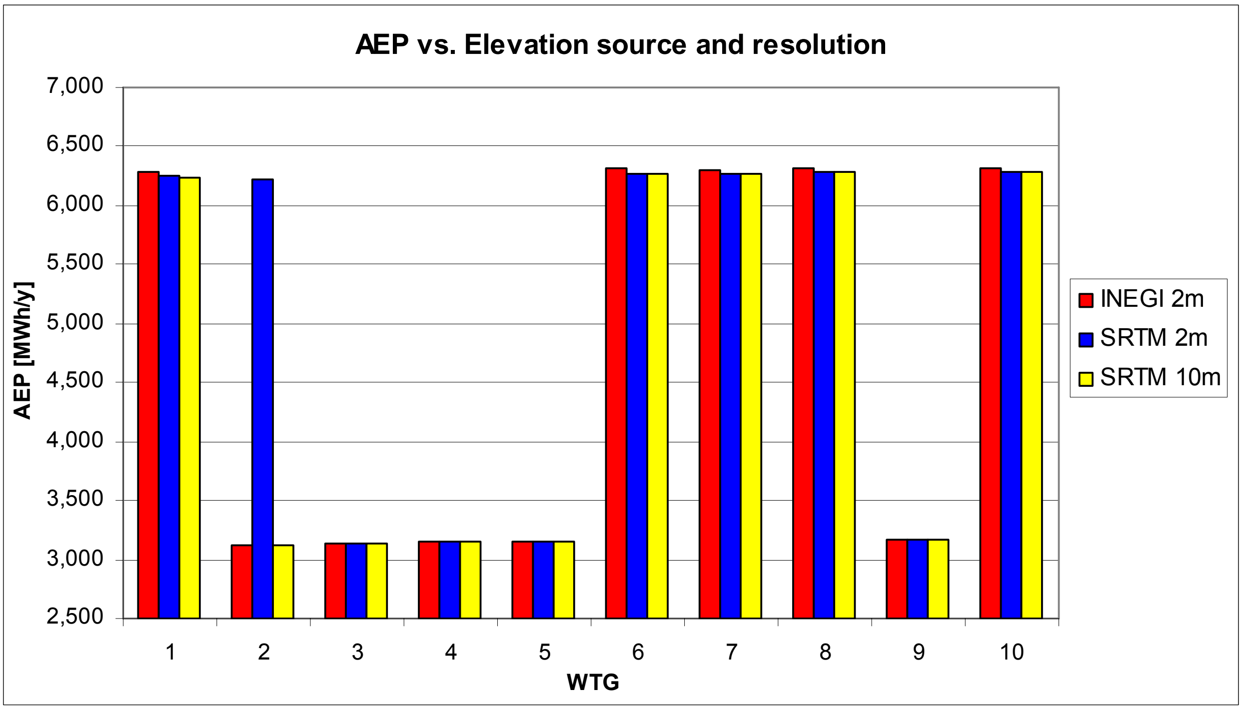


Figure 6.36 AEP vs. Elevation source and resolution

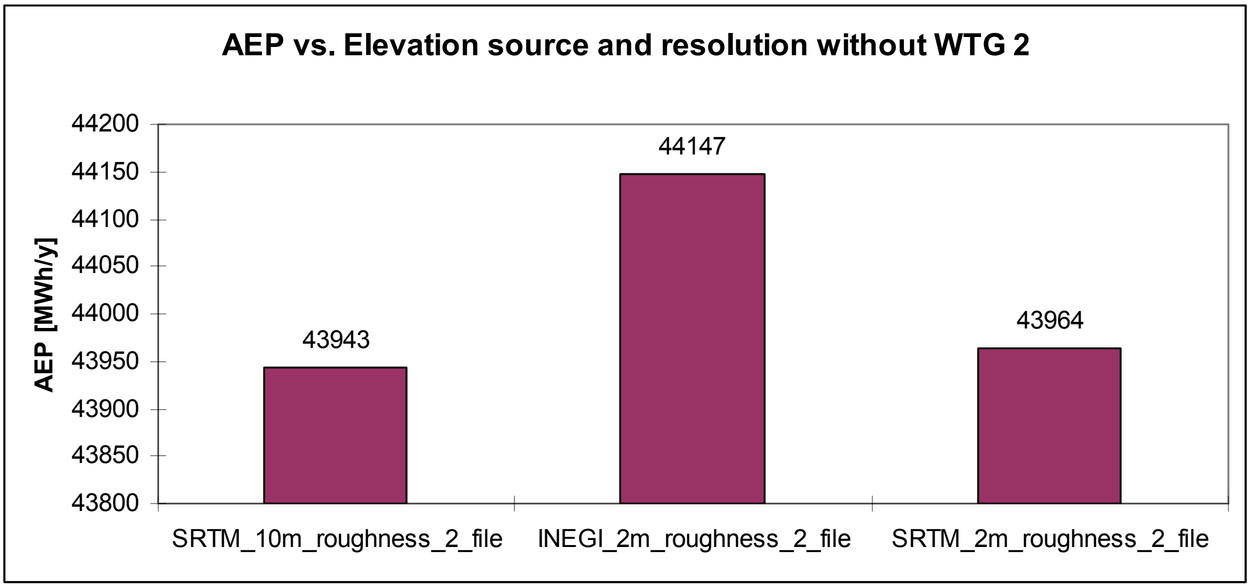


Figure 6.37 AEP vs. Elevation source and resolution without WTG 2

6.3.2.2 Influence of the Roughness resolution on the AEP

The second comparison will be done between the roughness with a resolution of 500m, 1 km and the roughness class 2 chosen for the whole area. The simulation has been made for the three cases, with the SRTM elevation map with a resolution of 2 m contour lines and the same wind atlas used for the past simulation. Looking at the chart with the AEP of each WTG, we can see that the simulations done with the 1km roughness resolution have the lowest results, with an AEP of 44918 MWh/y. With the 500m roughness resolution we have an AEP of 45701 MWh/y which is a little bit higher then the last one. The highest AEP of 50193 comes from the simulation with the roughness class 2 for the whole study area. Even if the AEP of WTG 2 exceed again by far away the results of the other simulations, the tendency shows a higher energy production by the scenario with roughness class 2, followed by roughness 500m and finally roughness 1km with the lowest values (see second chart).

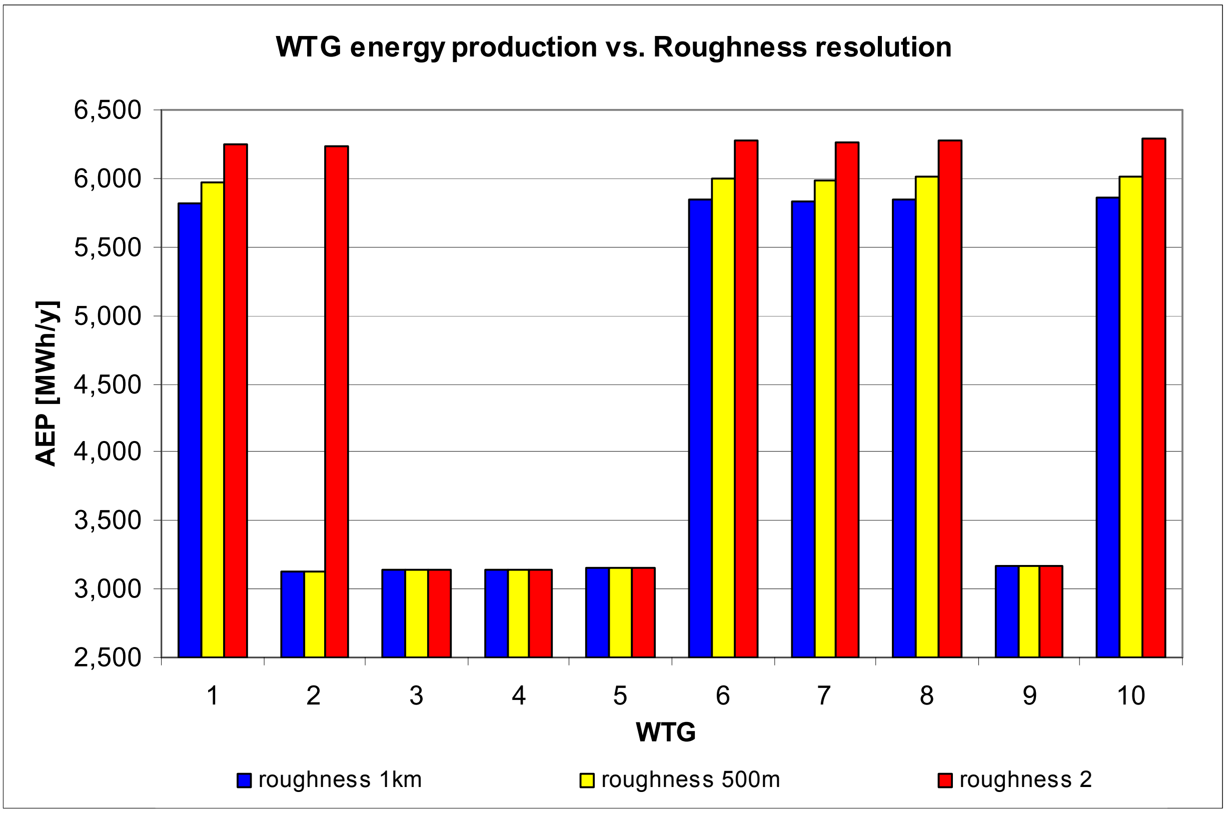


Figure 6.38 WTG AEP vs. Roughness resolution

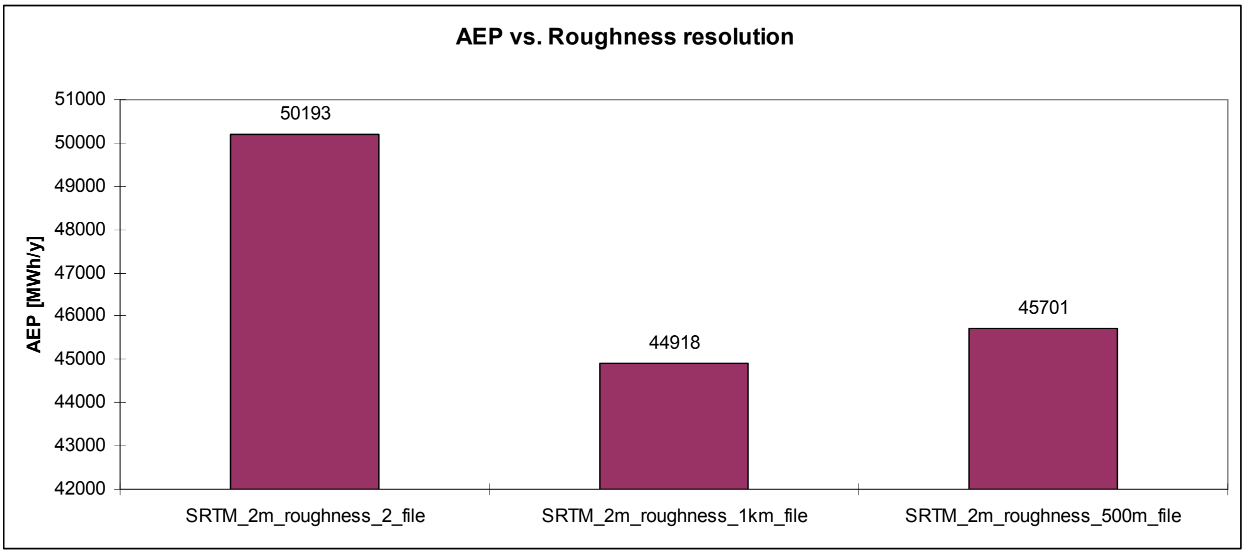


Figure 6.39 Wind farm AEP vs. Roughness resolution

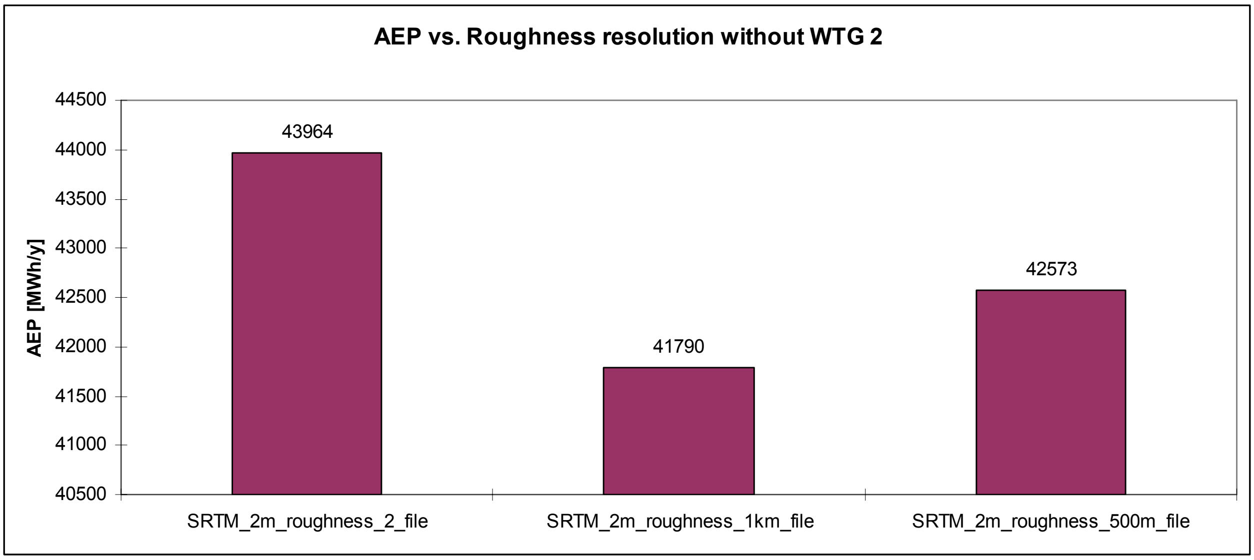


Figure 6.40 Wind farm AEP vs. Roughness resolution without WTG 2

6.3.2.3 Influence of the roughness source file on the AEP

Influence of the source file used in the simulation on the AEP

The elevation map used comes from SRTM with a resolution of 2m

The 2 roughness source: file and rose has been compared for the 2 different roughness resolutions of 500m and 1km. In the configurations for the calculation of the Wind park energy production, the user can choose in the wind site data configuration, 3 different type of roughness:

- Roughness rose
- Roughness file
- Roughness area

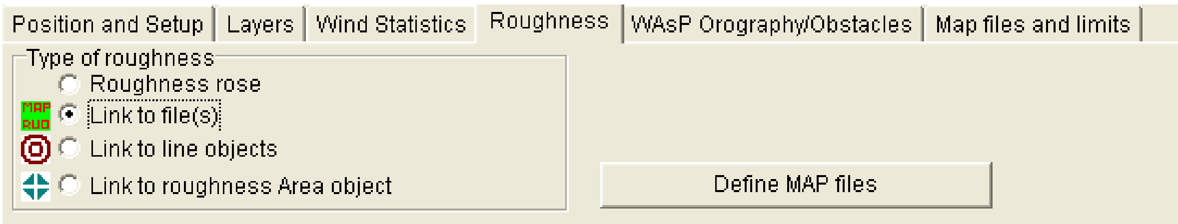


Figure 6.41 Configuration of the wind site [25]

By choosing the roughness rose or the roughness area, the results are equal. But there is a great difference when choosing the roughness rose or the roughness file as source file for the simulation, see chart below:

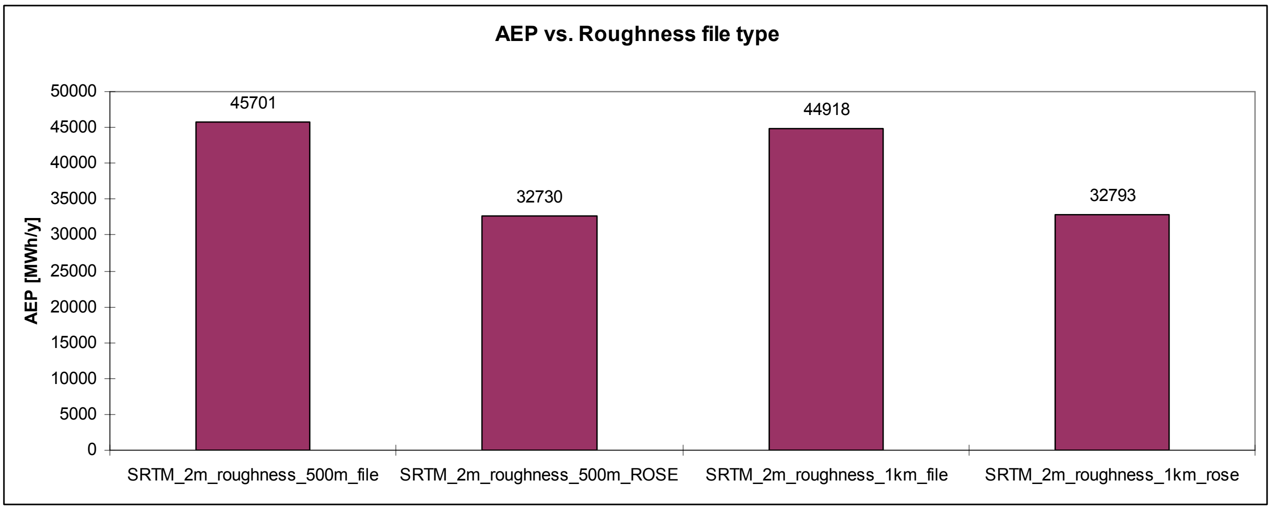


Figure 6.42 AEP vs. Roughness file type

The AEP is much higher by choosing the roughness file in comparison to the results from the roughness rose. We have a difference of about 36% to 39% for this wind site.

This shows us the importance of the way to configure the parameters for the simulation of the WF energy calculation.

6.3.3 Results of the elevation and roughness study in Francisco Villa

A general comparison with all simulated scenarios shows us how big are the gaps between the different parameters we have chosen. To prove these results it is important to compare the simulated results with the observed results from real data coming from an existing WF. This is the only way to validate these results.

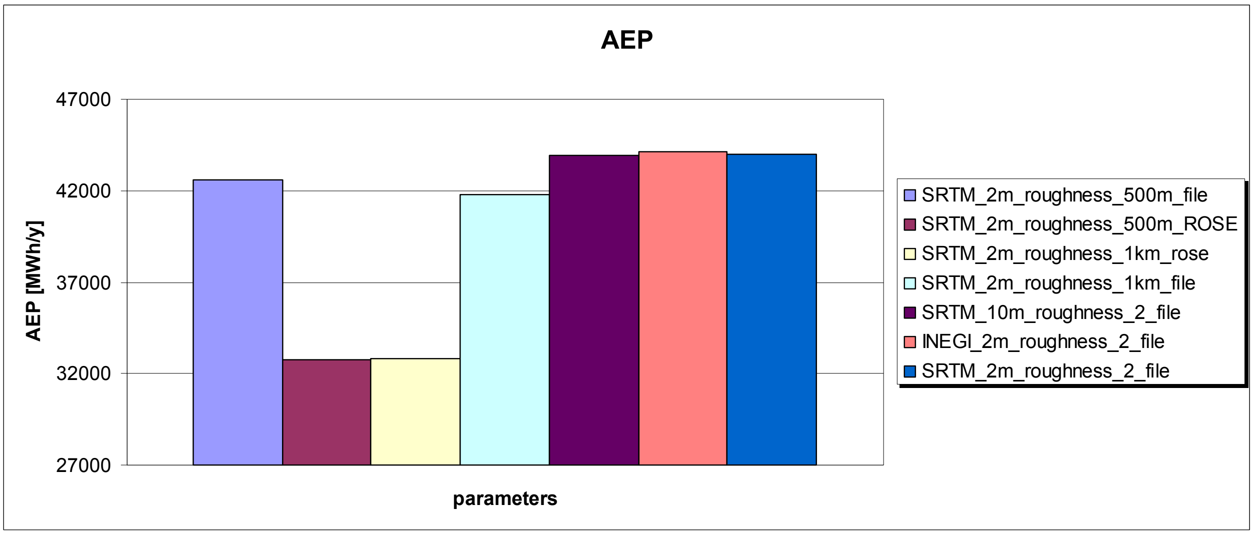


Figure 6.43 AEP vs. all parameters

6.4 San Luis Potosi – Mexico

6.4.1 Wind atlas of the Eastern Region of the State of SLP

In this study, the objective is to generate a wind atlas of the state of SLP using NARR meteorological data, SRTM contour lines with a resolution of curves for each 15m and a roughness class of 1,5.

The wind atlas has been created by dividing the state of SLP in 60km x 60km areas. The calculation is based on the meteorological data from the NARR satellites.

For every NARR wind data, a wind statistic has been created with the module STATGEN. The calculation of each resource grid was done by using all surrounding wind statistics to have more suitable results. For every resource grid calculation, the wind statistics situated in the grid area have been used and weighted together. In the following picture we can see the different power density resource grid generated at a height of 60m with a resolution of 2000m.

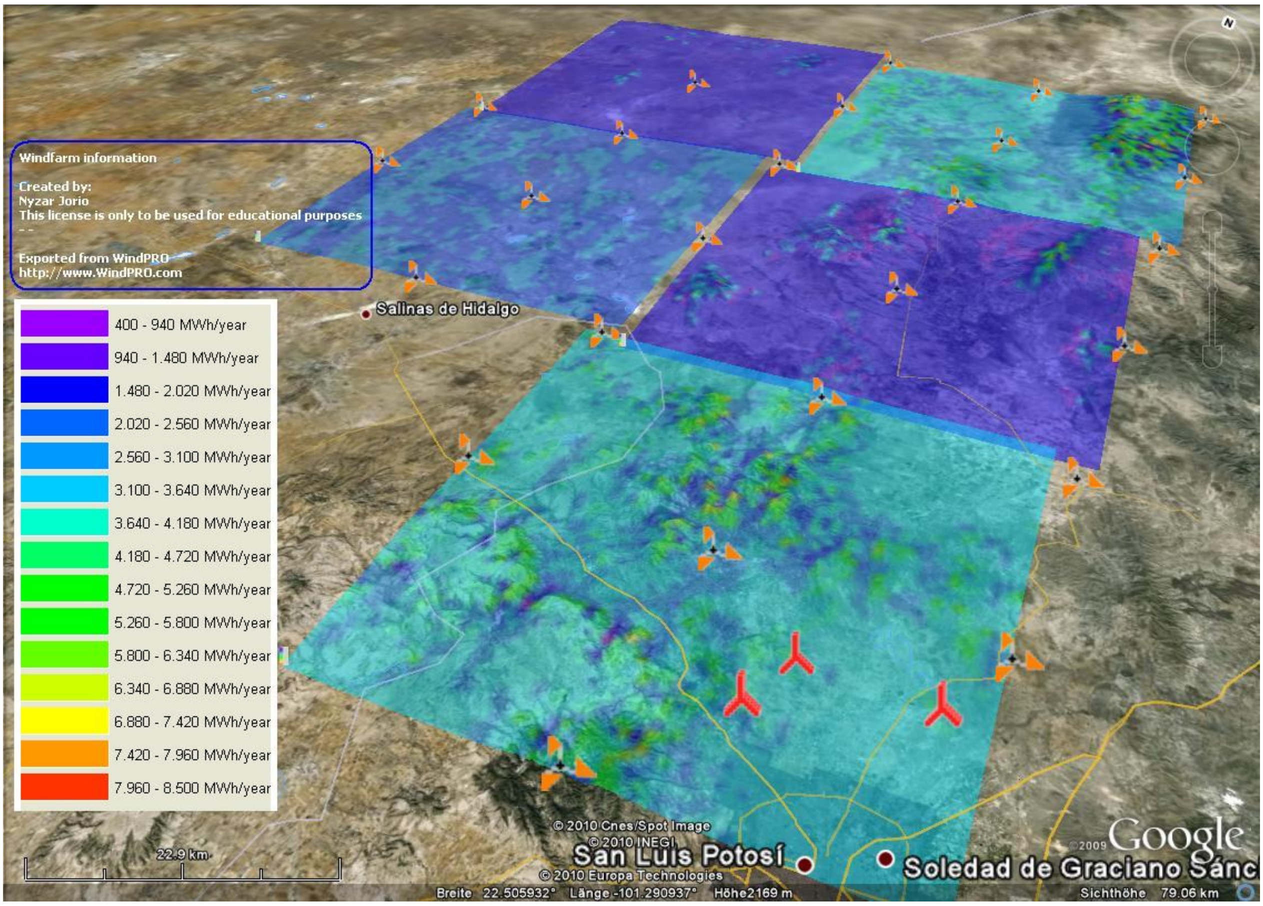


Figure 6.44 Wind energy potential of the state of SLP [25] [26]

According to the results of the wind atlas, the most interesting regions are the one in the north of the city of San Luis Potosi and in the north part, in the region of Matehuala and Real de 14. The power density would be in some parts around 3500 till 5000 MWh/y, by using a WTG of 60m hub height and 66m RD.

7 Conclusion and recommendations

This work shows us the performance of the software WindPRO and of course WAsP which is integrated in the energy yield calculations. Various studies have been done to see the performance of the resource assessment software, which shows how many possibilities exist to configure the various modules for the generation of wind statistics, wind atlas and AEP calculation.

The major tools and source of information used for the simulation are:

- The Meteo-Object, which analyses the measurement data and summarizes it in form of a Weibull distribution and frequency rose.
- The MCP module which makes a correlation between short term and long term measurements in order to have a better prediction of the local wind.
- With the Terrain data (elevation map, roughness and obstacles) and the correlated wind data, a wind statistic can be generated to be used afterwards in the creation of a wind Atlas with the ATLAS module.
- A resource grid can be generated with the Wind atlas of the region, in order to give an overview about the wind energy potential of the studied region and to find the best emplacement of the WTG
- Combined with the power curve of the WTG, the wake model and the Wind atlas, the annual energy yield can be calculated for each individual WTG and for the whole wind farm with the Park module.
- Finally the environmental impact modules, which give an overview about the noise, shadow and visibility impact on the surrounding region where the Wind farm will be installed.

To reduce the errors and uncertainties, it is important that the wind systems and orography are as close as possible to the reality. During the planning of a wind farm, the user needs current digital terrain maps of the region and has to visit the area of investigation which is part of the micrositing work.

7.1 Recommendations

For further studies in the field of this master thesis, it is recommended to validate the results and to see the accuracy of the wind assessment software. To achieve this, a comparison must be made between the simulation result and the real data coming from existing wind farms located in the same region. This was unfortunately not possible to do during the field work in Brazil and in Mexico, due to the secrecy and privacy of the companies operating the wind farms. Furthermore, it would be very interesting to work with Windsim, which is a CFD wind simulation software, and to compare the results with the software used during this work.

Finally, it would be very interesting to see the economical and energy policy aspect of wind farm development in Brazil and Mexico which are the countries with the highest installed wind energy capacity and also the highest wind energy potential in Latin America.

8 Timetable Work plan

<table>
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<tr><th colspan="8">Mexico</th><th colspan="6">Germany</th><th colspan="6">Brazil</th></tr>
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</table>

Table 8.1 Work plan

9 Appendix

9.1 Wind class turbine study

Key results of the 5 simulations with the 5 different GE1.5 wind turbines in Icapui

9.1.1 GE 1.5xle

Key results for height 60,0 m above ground level

Terrain UTM SAD69 Zone: 24

	East	North	Name of wind distribution	Type	Wind energy [kWh/m²]	Mean wind speed [m/s]	Equivalent roughness
C	688.374	9.473.426	icapui rose	ATLAS	2.980	7,9	0,9

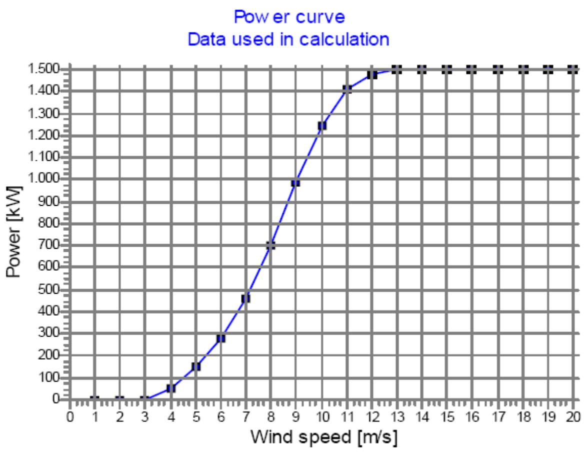
Calculated Annual Energy for Wind Farm

WTG combination	Result PARK [MWh/y]	GROSS (no loss) Free WTGs [MWh/y]	Park efficiency [%]	Specific results¤) Capacity factor [%]	Mean WTG result [MWh/y]	Full load hours [Hours/year]	Mean wind speed @hub height [m/s]
Wind farm	50.713,4	56.800,6	89,3	42,9	5.634,8	3.757	7,9

¤) Based on wake reduced results, but no other losses included

Calculated Annual Energy for each of 9 new WTGs with total 13,5 MW rated power

	Terrain	WTG type Valid	Manufact.	Type-generator	Power, rated [kW]	Rotor diameter [m]	Hub height [m]	Power curve Creator	Name	Annual Energy Result [MWh]	Park Efficiency [%]	Capacity factor [%]	Mean wind speed [m/s]
1	C	Yes	GE WIND ENERGY	GE 1.5 xle-1.500	1.500	82,5	58,7	EMD	Level 0 - Calculated - Standard operation - 2006	5.375,8	85,2	40,9	7,88
2	C	Yes	GE WIND ENERGY	GE 1.5 xle-1.500	1.500	82,5	58,7	EMD	Level 0 - Calculated - Standard operation - 2006	5.015,7	79,5	38,1	7,88
3	C	Yes	GE WIND ENERGY	GE 1.5 xle-1.500	1.500	82,5	58,7	EMD	Level 0 - Calculated - Standard operation - 2006	5.004,7	79,3	38,1	7,88
4	C	Yes	GE WIND ENERGY	GE 1.5 xle-1.500	1.500	82,5	58,7	EMD	Level 0 - Calculated - Standard operation - 2006	5.640,5	89,4	42,9	7,88
5	C	Yes	GE WIND ENERGY	GE 1.5 xle-1.500	1.500	82,5	58,7	EMD	Level 0 - Calculated - Standard operation - 2006	5.393,4	85,5	41,0	7,88
6	C	Yes	GE WIND ENERGY	GE 1.5 xle-1.500	1.500	82,5	58,7	EMD	Level 0 - Calculated - Standard operation - 2006	5.386,5	85,3	41,0	7,88
7	C	Yes	GE WIND ENERGY	GE 1.5 xle-1.500	1.500	82,5	58,7	EMD	Level 0 - Calculated - Standard operation - 2006	6.308,3	100,0	48,0	7,88
8	C	Yes	GE WIND ENERGY	GE 1.5 xle-1.500	1.500	82,5	58,7	EMD	Level 0 - Calculated - Standard operation - 2006	6.294,6	99,7	47,9	7,88
9	C	Yes	GE WIND ENERGY	GE 1.5 xle-1.500	1.500	82,5	58,7	EMD	Level 0 - Calculated - Standard operation - 2006	6.293,9	99,7	47,9	7,88



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	2,7	0,03	2,50- 3,50	1,7	1,7	0,0
4,0	55,4	0,28	3,50- 4,50	18,8	20,5	0,4
5,0	148,9	0,38	4,50- 5,50	87,9	108,4	2,0
6,0	278,8	0,41	5,50- 6,50	269,1	377,5	7,0
7,0	461,3	0,43	6,50- 7,50	613,9	991,4	18,4
8,0	702,9	0,44	7,50- 8,50	1.056,6	2.048,1	38,1
9,0	986,1	0,43	8,50- 9,50	1.317,6	3.365,6	62,6
10,0	1.241,6	0,40	9,50-10,50	1.126,9	4.492,6	83,6
11,0	1.407,4	0,34	10,50-11,50	625,9	5.118,5	95,2
12,0	1.477,9	0,27	11,50-12,50	212,4	5.330,9	99,2
13,0	1.497,6	0,22	12,50-13,50	40,7	5.371,6	99,9
14,0	1.500,0	0,18	13,50-14,50	4,0	5.375,6	100,0
15,0	1.500,0	0,14	14,50-15,50	0,2	5.375,8	100,0
16,0	1.500,0	0,12	15,50-16,50	0,0	5.375,8	100,0
17,0	1.500,0	0,10	16,50-17,50	0,0	5.375,8	100,0
18,0	1.500,0	0,08	17,50-18,50	0,0	5.375,8	100,0
19,0	1.500,0	0,07	18,50-19,50	0,0	5.375,8	100,0
20,0	1.500,0	0,06	19,50-20,50	0,0	5.375,8	100,0

9.1.2 GE 1.5s

Key results for height 60,0 m above ground level

Terrain UTM SAD69 Zone: 24

	East	North	Name of wind distribution	Type	Wind energy [kWh/m²]	Mean wind speed [m/s]	Equivalent roughness
C	688.374	9.473.426	icapui rose	ATLAS	2.980	7,9	0,9

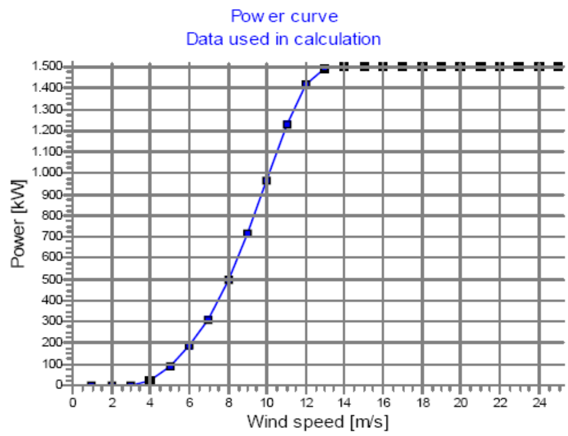
Calculated Annual Energy for Wind Farm

WTG combination	Result PARK [MWh/y]	GROSS (no loss) Free WTGs [MWh/y]	Park efficiency [%]	Specific results¤) Capacity factor [%]	Specific results¤) Mean WTG result [MWh/y]	Specific results¤) Full load hours [Hours/year]	Mean wind speed @hub height [m/s]
Wind farm	41.704,7	45.435,8	91,8	35,2	4.633,9	3.089	8,1

¤) Based on wake reduced results, but no other losses included

Calculated Annual Energy for each of 9 new WTGs with total 13,5 MW rated power

	Terrain	WTG type Valid	Manufact.	Type-generator	Power, rated [kW]	Rotor diameter [m]	Hub height [m]	Power curve Creator	Name	Annual Energy Result [MWh]	Park Efficiency [%]	Capacity factor [%]	Mean wind speed [m/s]
1	C	Yes	GE WIND ENERGY	GE 1.5s-1.500	1.500	70,5	64,7	EMD	DEWI 01/00 1.225 25.00 0.00	4.480,9	88,8	34,1	8,07
2	C	Yes	GE WIND ENERGY	GE 1.5s-1.500	1.500	70,5	64,7	EMD	DEWI 01/00 1.225 25.00 0.00	4.252,8	84,2	32,3	8,07
3	C	Yes	GE WIND ENERGY	GE 1.5s-1.500	1.500	70,5	64,7	EMD	DEWI 01/00 1.225 25.00 0.00	4.253,3	84,3	32,3	8,07
4	C	Yes	GE WIND ENERGY	GE 1.5s-1.500	1.500	70,5	64,7	EMD	DEWI 01/00 1.225 25.00 0.00	4.630,3	91,7	35,2	8,07
5	C	Yes	GE WIND ENERGY	GE 1.5s-1.500	1.500	70,5	64,7	EMD	DEWI 01/00 1.225 25.00 0.00	4.482,0	88,8	34,1	8,07
6	C	Yes	GE WIND ENERGY	GE 1.5s-1.500	1.500	70,5	64,7	EMD	DEWI 01/00 1.225 25.00 0.00	4.476,7	88,7	34,0	8,07
7	C	Yes	GE WIND ENERGY	GE 1.5s-1.500	1.500	70,5	64,7	EMD	DEWI 01/00 1.225 25.00 0.00	5.046,8	100,0	38,4	8,07
8	C	Yes	GE WIND ENERGY	GE 1.5s-1.500	1.500	70,5	64,7	EMD	DEWI 01/00 1.225 25.00 0.00	5.040,9	99,9	38,3	8,07
9	C	Yes	GE WIND ENERGY	GE 1.5s-1.500	1.500	70,5	64,7	EMD	DEWI 01/00 1.225 25.00 0.00	5.040,9	99,9	38,3	8,07



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	0,8	0,8	0,0
4,0	26,1	0,18	3,50- 4,50	9,9	10,7	0,2
5,0	87,5	0,31	4,50- 5,50	52,5	63,2	1,4
6,0	186,4	0,38	5,50- 6,50	173,1	236,2	5,3
7,0	310,7	0,40	6,50- 7,50	413,6	649,9	14,5
8,0	494,3	0,42	7,50- 8,50	755,6	1.405,4	31,4
9,0	714,5	0,43	8,50- 9,50	1.029,1	2.434,5	54,3
10,0	964,3	0,42	9,50-10,50	1.006,8	3.441,3	76,8
11,0	1.228,9	0,41	10,50-11,50	674,7	4.116,1	91,9
12,0	1.416,2	0,36	11,50-12,50	286,5	4.402,6	98,3
13,0	1.489,4	0,30	12,50-13,50	69,2	4.471,8	99,8
14,0	1.500,0	0,24	13,50-14,50	8,6	4.480,4	100,0
15,0	1.500,0	0,20	14,50-15,50	0,5	4.480,9	100,0
16,0	1.500,0	0,16	15,50-16,50	0,0	4.480,9	100,0
17,0	1.500,0	0,13	16,50-17,50	0,0	4.480,9	100,0
18,0	1.500,0	0,11	17,50-18,50	0,0	4.480,9	100,0
19,0	1.500,0	0,10	18,50-19,50	0,0	4.480,9	100,0
20,0	1.500,0	0,08	19,50-20,50	0,0	4.480,9	100,0
21,0	1.500,0	0,07	20,50-21,50	0,0	4.480,9	100,0
22,0	1.500,0	0,06	21,50-22,50	0,0	4.480,9	100,0
23,0	1.500,0	0,05	22,50-23,50	0,0	4.480,9	100,0
24,0	1.500,0	0,05	23,50-24,50	0,0	4.480,9	100,0
25,0	1.500,0	0,04	24,50-25,50	0,0	4.480,9	100,0

9.1.3 GE 1.5se

Key results for height 60,0 m above ground level

Terrain UTM SAD69 Zone: 24

	East	North	Name of wind distribution	Type	Wind energy [kWh/m²]	Mean wind speed [m/s]	Equivalent roughness
B	688.374	9.473.426	icapui rose	ATLAS	2.980	7,9	0,9

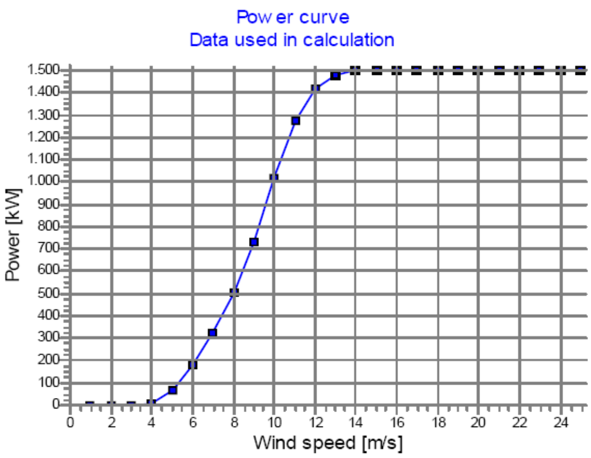
Calculated Annual Energy for Wind Farm

WTG combination	Result PARK [MWh/y]	GROSS (no loss) Free WTGs [MWh/y]	Park efficiency [%]	Specific results¤) Capacity factor [%]	Specific results¤) Mean WTG result [MWh/y]	Specific results¤) Full load hours [Hours/year]	Mean wind speed @hub height [m/s]
Wind farm	41.879,6	46.705,2	89,7	35,4	4.653,3	3.102	8,1

¤) Based on wake reduced results, but no other losses included

Calculated Annual Energy for each of 9 new WTGs with total 13,5 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]	Efficiency [%]	Capacity factor [%]	Mean wind speed [m/s]
1	B	Yes	GE WIND ENERGY	GE 1.5se-1.500	1.500	70,5	64,7	EMD	Level 0 - calculated - HH<64.7m - non-WZIII - 2005	4.465,7	86,1	34,0	8,07
2	B	Yes	GE WIND ENERGY	GE 1.5se-1.500	1.500	70,5	64,7	EMD	Level 0 - calculated - HH<64.7m - non-WZIII - 2005	4.164,7	80,3	31,7	8,07
3	B	Yes	GE WIND ENERGY	GE 1.5se-1.500	1.500	70,5	64,7	EMD	Level 0 - calculated - HH<64.7m - non-WZIII - 2005	4.171,2	80,4	31,7	8,07
4	B	Yes	GE WIND ENERGY	GE 1.5se-1.500	1.500	70,5	64,7	EMD	Level 0 - calculated - HH<64.7m - non-WZIII - 2005	4.641,4	89,4	35,3	8,07
5	B	Yes	GE WIND ENERGY	GE 1.5se-1.500	1.500	70,5	64,7	EMD	Level 0 - calculated - HH<64.7m - non-WZIII - 2005	4.447,7	85,7	33,8	8,07
6	B	Yes	GE WIND ENERGY	GE 1.5se-1.500	1.500	70,5	64,7	EMD	Level 0 - calculated - HH<64.7m - non-WZIII - 2005	4.441,4	85,6	33,8	8,07
7	B	Yes	GE WIND ENERGY	GE 1.5se-1.500	1.500	70,5	64,7	EMD	Level 0 - calculated - HH<64.7m - non-WZIII - 2005	5.187,5	100,0	39,5	8,07
8	B	Yes	GE WIND ENERGY	GE 1.5se-1.500	1.500	70,5	64,7	EMD	Level 0 - calculated - HH<64.7m - non-WZIII - 2005	5.179,9	99,8	39,4	8,07
9	B	Yes	GE WIND ENERGY	GE 1.5se-1.500	1.500	70,5	64,7	EMD	Level 0 - calculated - HH<64.7m - non-WZIII - 2005	5.180,0	99,8	39,4	8,07



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	9,5	0,07	3,50- 4,50	6,2	6,2	0,1
5,0	71,4	0,25	4,50- 5,50	44,8	50,9	1,1
6,0	182,0	0,37	5,50- 6,50	167,0	217,9	4,9
7,0	326,2	0,42	6,50- 7,50	413,3	631,3	14,1
8,0	502,9	0,43	7,50- 8,50	751,5	1.382,8	31,0
9,0	733,4	0,44	8,50- 9,50	1.028,6	2.411,4	54,0
10,0	1.015,0	0,45	9,50-10,50	1.018,5	3.429,9	76,8
11,0	1.270,1	0,42	10,50-11,50	679,1	4.108,9	92,0
12,0	1.419,2	0,36	11,50-12,50	281,3	4.390,3	98,3
13,0	1.480,5	0,30	12,50-13,50	66,6	4.456,9	99,8
14,0	1.497,4	0,24	13,50-14,50	8,3	4.465,2	100,0
15,0	1.500,0	0,20	14,50-15,50	0,5	4.465,7	100,0
16,0	1.500,0	0,16	15,50-16,50	0,0	4.465,7	100,0
17,0	1.500,0	0,13	16,50-17,50	0,0	4.465,7	100,0
18,0	1.500,0	0,11	17,50-18,50	0,0	4.465,7	100,0
19,0	1.500,0	0,10	18,50-19,50	0,0	4.465,7	100,0
20,0	1.500,0	0,08	19,50-20,50	0,0	4.465,7	100,0
21,0	1.500,0	0,07	20,50-21,50	0,0	4.465,7	100,0
22,0	1.500,0	0,06	21,50-22,50	0,0	4.465,7	100,0
23,0	1.500,0	0,05	22,50-23,50	0,0	4.465,7	100,0
24,0	1.500,0	0,05	23,50-24,50	0,0	4.465,7	100,0
25,0	1.500,0	0,04	24,50-25,50	0,0	4.465,7	100,0

9.1.4 GE 1.5sl

Key results for height 60,0 m above ground level

Terrain UTM SAD69 Zone: 24

	East	North	Name of wind distribution	Type	Wind energy [kWh/m²]	Mean wind speed [m/s]	Equivalent roughness
A	688.374	9.473.426	icapui rose	ATLAS	2.980	7,9	0,9

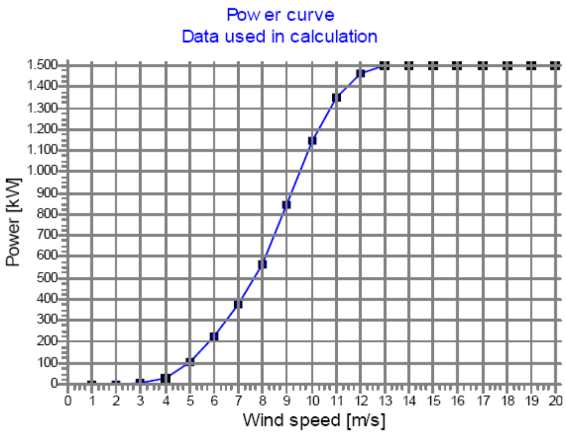
Calculated Annual Energy for Wind Farm

				Specific results¤)			
WTG combination	Result PARK [MWh/y]	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]
Wind farm	46.106,7	50.778,3	90,8	39,0	5.123,0	3.415	8,0

¤) Based on wake reduced results, but no other losses included

Calculated Annual Energy for each of 9 new WTGs with total 13,5 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]	Efficiency [%]	Capacity factor [%]	Mean wind speed [m/s]
1 A	Yes	GE WIND ENERGY	GE 1.5sl-1.500	1.500	77,0	61,4	EMD	Man. 01-2000	4.929,8	87,4	37,5	7,97
2 A	Yes	GE WIND ENERGY	GE 1.5sl-1.500	1.500	77,0	61,4	EMD	Man. 01-2000	4.648,7	82,4	35,4	7,97
3 A	Yes	GE WIND ENERGY	GE 1.5sl-1.500	1.500	77,0	61,4	EMD	Man. 01-2000	4.646,0	82,3	35,3	7,97
4 A	Yes	GE WIND ENERGY	GE 1.5sl-1.500	1.500	77,0	61,4	EMD	Man. 01-2000	5.120,0	90,7	38,9	7,97
5 A	Yes	GE WIND ENERGY	GE 1.5sl-1.500	1.500	77,0	61,4	EMD	Man. 01-2000	4.932,7	87,4	37,5	7,97
6 A	Yes	GE WIND ENERGY	GE 1.5sl-1.500	1.500	77,0	61,4	EMD	Man. 01-2000	4.927,4	87,3	37,5	7,97
7 A	Yes	GE WIND ENERGY	GE 1.5sl-1.500	1.500	77,0	61,4	EMD	Man. 01-2000	5.640,0	100,0	42,9	7,97
8 A	Yes	GE WIND ENERGY	GE 1.5sl-1.500	1.500	77,0	61,4	EMD	Man. 01-2000	5.631,1	99,8	42,8	7,97
9 A	Yes	GE WIND ENERGY	GE 1.5sl-1.500	1.500	77,0	61,4	EMD	Man. 01-2000	5.630,9	99,8	42,8	7,97



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	3,8	0,05	2,50- 3,50	1,3	1,3	0,0
4,0	32,9	0,19	3,50- 4,50	13,1	14,4	0,3
5,0	109,1	0,32	4,50- 5,50	66,7	81,1	1,6
6,0	222,9	0,38	5,50- 6,50	215,5	296,6	6,0
7,0	376,0	0,40	6,50- 7,50	499,7	796,2	16,2
8,0	567,6	0,41	7,50- 8,50	880,6	1.676,8	34,0
9,0	841,1	0,43	8,50- 9,50	1.172,0	2.848,8	57,8
10,0	1.142,3	0,42	9,50-10,50	1.100,0	3.948,9	80,1
11,0	1.347,7	0,37	10,50-11,50	671,7	4.620,6	93,7
12,0	1.465,6	0,31	11,50-12,50	249,9	4.870,5	98,8
13,0	1.500,0	0,25	12,50-13,50	53,2	4.923,7	99,9
14,0	1.500,0	0,20	13,50-14,50	5,8	4.929,5	100,0
15,0	1.500,0	0,16	14,50-15,50	0,3	4.929,8	100,0
16,0	1.500,0	0,13	15,50-16,50	0,0	4.929,8	100,0
17,0	1.500,0	0,11	16,50-17,50	0,0	4.929,8	100,0
18,0	1.500,0	0,09	17,50-18,50	0,0	4.929,8	100,0
19,0	1.500,0	0,08	18,50-19,50	0,0	4.929,8	100,0
20,0	1.500,0	0,07	19,50-20,50	0,0	4.929,8	100,0

9.1.5 GE 1.5sle

Key results for height 60,0 m above ground level

Terrain UTM SAD69 Zone: 24

	East	North	Name of wind distribution	Type	Wind energy [kWh/m²]	Mean wind speed [m/s]	Equivalent roughness
A	688.374	9.473.426	icapui rose	ATLAS	2.980	7,9	0,9

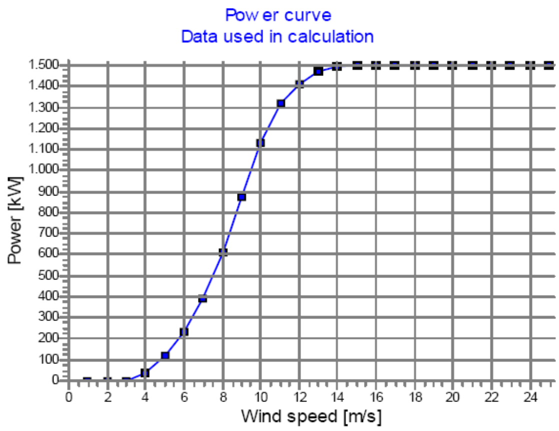
Calculated Annual Energy for Wind Farm

WTG combination	Result PARK [MWh/y]	GROSS (no loss) Free WTGs [MWh/y]	Park efficiency [%]	Specific results¤) Capacity factor [%]	Mean WTG result [MWh/y]	Full load hours [Hours/year]	Mean wind speed @hub height [m/s]
Wind farm	46.335,6	51.987,0	89,1	39,2	5.148,4	3.432	8,0

¤) Based on wake reduced results, but no other losses included

Calculated Annual Energy for each of 9 new WTGs with total 13,5 MW rated power

Terrain	WTG type Valid	Manufact.	Type-generator	Power, rated [kW]	Rotor diameter [m]	Hub height [m]	Power curve Creator	Name	Annual Energy Result [MWh]	Park Efficiency [%]	Capacity factor [%]	Mean wind speed [m/s]
1 A	Yes	GE WIND ENERGY	GE 1.5sle-1.500	1.500	77,0	61,4	EMD	Level 0 - Calculated - 10%<TI<15% - 2006	4.918,6	85,2	37,4	7,97
2 A	Yes	GE WIND ENERGY	GE 1.5sle-1.500	1.500	77,0	61,4	EMD	Level 0 - Calculated - 10%<TI<15% - 2006	4.574,9	79,2	34,8	7,97
3 A	Yes	GE WIND ENERGY	GE 1.5sle-1.500	1.500	77,0	61,4	EMD	Level 0 - Calculated - 10%<TI<15% - 2006	4.574,6	79,2	34,8	7,97
4 A	Yes	GE WIND ENERGY	GE 1.5sle-1.500	1.500	77,0	61,4	EMD	Level 0 - Calculated - 10%<TI<15% - 2006	5.144,5	89,1	39,1	7,97
5 A	Yes	GE WIND ENERGY	GE 1.5sle-1.500	1.500	77,0	61,4	EMD	Level 0 - Calculated - 10%<TI<15% - 2006	4.915,1	85,1	37,4	7,97
6 A	Yes	GE WIND ENERGY	GE 1.5sle-1.500	1.500	77,0	61,4	EMD	Level 0 - Calculated - 10%<TI<15% - 2006	4.908,5	85,0	37,3	7,97
7 A	Yes	GE WIND ENERGY	GE 1.5sle-1.500	1.500	77,0	61,4	EMD	Level 0 - Calculated - 10%<TI<15% - 2006	5.773,9	100,0	43,9	7,97
8 A	Yes	GE WIND ENERGY	GE 1.5sle-1.500	1.500	77,0	61,4	EMD	Level 0 - Calculated - 10%<TI<15% - 2006	5.762,9	99,8	43,8	7,97
9 A	Yes	GE WIND ENERGY	GE 1.5sle-1.500	1.500	77,0	61,4	EMD	Level 0 - Calculated - 10%<TI<15% - 2006	5.762,7	99,8	43,8	7,97



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	1,2	1,2	0,0
4,0	39,9	0,23	3,50- 4,50	14,0	15,2	0,3
5,0	122,9	0,36	4,50- 5,50	69,7	84,9	1,7
6,0	236,8	0,40	5,50- 6,50	219,6	304,5	6,2
7,0	394,7	0,42	6,50- 7,50	510,7	815,2	16,6
8,0	607,5	0,44	7,50- 8,50	908,6	1.723,9	35,0
9,0	878,1	0,44	8,50- 9,50	1.188,0	2.911,9	59,2
10,0	1.130,9	0,42	9,50-10,50	1.075,7	3.987,6	81,1
11,0	1.317,3	0,36	10,50-11,50	639,4	4.627,0	94,1
12,0	1.412,5	0,30	11,50-12,50	235,7	4.862,7	98,9
13,0	1.466,7	0,25	12,50-13,50	50,0	4.912,7	99,9
14,0	1.488,9	0,20	13,50-14,50	5,6	4.918,3	100,0
15,0	1.500,0	0,16	14,50-15,50	0,3	4.918,6	100,0
16,0	1.500,0	0,13	15,50-16,50	0,0	4.918,6	100,0
17,0	1.500,0	0,11	16,50-17,50	0,0	4.918,6	100,0
18,0	1.500,0	0,09	17,50-18,50	0,0	4.918,6	100,0
19,0	1.500,0	0,08	18,50-19,50	0,0	4.918,6	100,0
20,0	1.500,0	0,07	19,50-20,50	0,0	4.918,6	100,0
21,0	1.500,0	0,06	20,50-21,50	0,0	4.918,6	100,0
22,0	1.500,0	0,05	21,50-22,50	0,0	4.918,6	100,0
23,0	1.500,0	0,05	22,50-23,50	0,0	4.918,6	100,0
24,0	1.500,0	0,04	23,50-24,50	0,0	4.918,6	100,0
25,0	1.500,0	0,04	24,50-25,50	0,0	4.918,6	100,0

9.2 Elevation and roughness study

Key results for the simulation with different elevation and roughness sources in Tamaulipas

9.2.1 SRTM 2m resolution

Key results for height 60,0 m above ground level

Terrain UTM NAD83 Zone: 14

Terrain	East	North	Name of wind distribution	Height [m]	Type	Wind energy [kWh/m²]	Mean wind speed [m/s]	Equivalent roughness
A	592.180	2.767.380	Default Meteo data description	40,0	WEIBULL	2.375	6,5	
C	592.202	2.767.907	Site data 12 sectors; Radius: 20.000 m (2)	0,0	ATLAS	5.936	8,9	0,0

Calculated Annual Energy for Wind Farm

WTG combination	Result PARK [MWh/y]	GROSS (no loss) Free WTGs [MWh/y]	Park efficiency [%]	Specific results¤) Capacity factor [%]	Specific results¤) Mean WTG result [MWh/y]	Specific results¤) Full load hours [Hours/year]	Mean wind speed @hub height [m/s]
Wind farm	50.193,1	50.205,9	100,0	32,7	5.019,3	2.868	8,0

¤) Based on wake reduced results, but no other losses included

Calculated Annual Energy for each of 10 new WTGs with total 17,5 MW rated power

Terrain	WTG type Valid	WTG type Manufact.	WTG type Type-generator	WTG type Power, rated [kW]	WTG type Rotor diameter [m]	WTG type Hub height [m]	Power curve Creator	Power curve Name	Annual Energy Result [MWh]	Park Efficiency [%]	Capacity factor [%]	Mean wind speed [m/s]
1 C	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.247,1	100,0	40,7	8,89
2 C	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.228,5	100,0	40,6	8,89
3 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	3.137,7	100,0	20,5	6,54
4 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	3.147,3	100,0	20,5	6,54
5 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	3.156,3	100,0	20,6	6,54
6 C	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.272,6	100,0	40,9	8,89
7 C	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.266,5	100,0	40,8	8,89
8 C	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.283,3	100,0	41,0	8,89
9 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	3.167,0	100,0	20,6	6,54
10 C	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.286,6	100,0	41,0	8,89

9.2.2 INEGI 2m resolution

Key results for height 60,0 m above ground level

Terrain UTM NAD83 Zone: 14

Terrain	East	North	Name of wind distribution	Height [m]	Type	Wind energy [kWh/m²]	Mean wind speed [m/s]	Equivalent roughness
A	592.180	2.767.380	Default Meteo data description	40,0	WEIBULL	2.375	6,5	
C	592.242	2.767.930	Site data 12 sectors; Radius: 20.000 m (2)	0,0	ATLAS	5.989	8,9	0,0

Calculated Annual Energy for Wind Farm

WTG combination	Result PARK [MWh/y]	GROSS (no loss) Free WTGs [MWh/y]	Park efficiency [%]	Specific results¤) Capacity factor [%]	Specific results¤) Mean WTG result [MWh/y]	Specific results¤) Full load hours [Hours/year]	Mean wind speed @hub height [m/s]
Wind farm	47.274,8	47.287,2	100,0	30,8	4.727,5	2.701	7,7

¤) Based on wake reduced results, but no other losses included

Calculated Annual Energy for each of 10 new WTGs with total 17,5 MW rated power

Terrain	WTG type Valid	WTG type Manufact.	WTG type Type-generator	WTG type Power, rated [kW]	WTG type Rotor diameter [m]	WTG type Hub height [m]	Power curve Creator	Power curve Name	Annual Energy Result [MWh]	Park Efficiency [%]	Capacity factor [%]	Mean wind speed [m/s]
1 C	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.283,6	100,0	41,0	8,92
2 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	3.127,5	100,0	20,4	6,54
3 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	3.137,7	100,0	20,5	6,54
4 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	3.147,3	100,0	20,5	6,54
5 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	3.156,3	100,0	20,6	6,54
6 C	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.309,1	100,0	41,1	8,92
7 C	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.303,0	100,0	41,1	8,92
8 C	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.319,9	100,0	41,2	8,92
9 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	3.167,0	100,0	20,6	6,54
10 C	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.323,2	100,0	41,2	8,92

9.2.3 SRTM 10m resolution

Key results for height 60,0 m above ground level

Terrain UTM NAD83 Zone: 14

	East	North	Name of wind distribution	Height [m]	Type	Wind energy [kWh/m²]	Mean wind speed [m/s]	Equivalent roughness
A	592.180	2.767.380	Default Meteo data description	40,0	WEIBULL	2.375	6,5	
B	592.242	2.767.930	fransisco villa_SRTM_10m_roughness_2	0,0	ATLAS	5.929	8,9	0,0

Calculated Annual Energy for Wind Farm

WTG combination	Result PARK [MWh/y]	GROSS (no loss) Free WTGs [MWh/y]	Park efficiency [%]	Specific results¤) Capacity factor [%]	Mean WTG result [MWh/y]	Full load hours [Hours/year]	Mean wind speed @hub height [m/s]
Wind farm	47.070,4	47.082,8	100,0	30,7	4.707,0	2.690	7,7

¤) Based on wake reduced results, but no other losses included

Calculated Annual Energy for each of 10 new WTGs with total 17,5 MW rated power

	Terrain	WTG type Valid	Manufact.	Type-generator	Power, rated [kW]	Rotor diameter [m]	Hub height [m]	Power curve Creator	Name	Annual Energy Result [MWh]	Park Efficiency [%]	Capacity factor [%]	Mean wind speed [m/s]
1	B	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.241,7	100,0	40,7	8,89
2	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	3.127,4	100,0	20,4	6,54
3	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	3.137,7	100,0	20,5	6,54
4	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	3.144,1	100,0	20,5	6,54
5	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	3.154,3	100,0	20,6	6,54
6	B	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.269,4	100,0	40,9	8,89
7	B	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.262,8	100,0	40,8	8,89
8	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	3.167,4	100,0	20,6	6,54
9	B	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.285,4	100,0	41,0	8,89
10	B	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.280,2	100,0	40,9	8,89

9.2.4 SRTM 2m resolution and roughness class 2 file

Key results for height 60,0 m above ground level

Terrain UTM NAD83 Zone: 14

	East	North	Name of wind distribution	Height [m]	Type	Wind energy [kWh/m²]	Mean wind speed [m/s]	Equivalent roughness
A	592.180	2.767.380	Default Meteo data description	40,0	WEIBULL	2.375	6,5	
C	592.202	2.767.907	Site data 12 sectors; Radius: 20.000 m (2)	0,0	ATLAS	5.936	8,9	0,0

Calculated Annual Energy for Wind Farm

WTG combination	Result PARK [MWh/y]	GROSS (no loss) Free WTGs [MWh/y]	Park efficiency [%]	Specific results¤) Capacity factor [%]	Mean WTG result [MWh/y]	Full load hours [Hours/year]	Mean wind speed @hub height [m/s]
Wind farm	50.193,1	50.205,9	100,0	32,7	5.019,3	2.868	8,0

¤) Based on wake reduced results, but no other losses included

Calculated Annual Energy for each of 10 new WTGs with total 17,5 MW rated power

	Terrain	WTG type Valid	Manufact.	Type-generator	Power, rated [kW]	Rotor diameter [m]	Hub height [m]	Power curve Creator	Name	Annual Energy Result [MWh]	Park Efficiency [%]	Capacity factor [%]	Mean wind speed [m/s]
1	C	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.247,1	100,0	40,7	8,89
2	C	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.228,5	100,0	40,6	8,89
3	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	3.137,7	100,0	20,5	6,54
4	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	3.147,3	100,0	20,5	6,54
5	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	3.156,3	100,0	20,6	6,54
6	C	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.272,6	100,0	40,9	8,89
7	C	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.266,5	100,0	40,8	8,89
8	C	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.283,3	100,0	41,0	8,89
9	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	3.167,0	100,0	20,6	6,54
10	C	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.286,6	100,0	41,0	8,89

9.2.5 SRTM 2m resolution and roughness resolution 1km file

Key results for height 60,0 m above ground level

Terrain UTM NAD83 Zone: 14

	East	North	Name of wind distribution	Height [m]	Type	Wind energy [kWh/m²]	Mean wind speed [m/s]	Equivalent roughness
A	592.180	2.767.380	Default Meteo data description	40,0	WEIBULL	2.375	6,5	
C	592.242	2.767.930	fransisco villa_SRTM_2m_roughness_1km	0,0	ATLAS	5.307	8,6	0,0

Calculated Annual Energy for Wind Farm

WTG combination	Result PARK [MWh/y]	GROSS (no loss) Free WTGs [MWh/y]	Park efficiency [%]	Specific results¤) Capacity factor [%]	Mean WTG result [MWh/y]	Full load hours [Hours/year]	Mean wind speed @hub height [m/s]
Wind farm	44.918,4	44.930,6	100,0	29,3	4.491,8	2.567	7,5

¤) Based on wake reduced results, but no other losses included

Calculated Annual Energy for each of 10 new WTGs with total 17,5 MW rated power

Terrain	Valid	WTG type Manufact.	Type-generator	Power, rated [kW]	Rotor diameter [m]	Hub height [m]	Power curve Creator	Name	Annual Energy Result [MWh]	Park Efficiency [%]	Capacity factor [%]	Mean wind speed [m/s]
1 C	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.812,1	100,0	37,9	8,56
2 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	3.127,8	100,0	20,4	6,54
3 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	3.137,2	100,0	20,5	6,54
4 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	3.144,7	100,0	20,5	6,54
5 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	3.154,5	100,0	20,6	6,54
6 C	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.838,3	100,0	38,1	8,56
7 C	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.831,8	100,0	38,0	8,56
8 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	3.166,6	100,0	20,6	6,54
9 C	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.854,9	100,0	38,2	8,56
10 C	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.850,5	100,0	38,1	8,56

9.2.6 SRTM 2m resolution and roughness resolution 500m file

Key results for height 60,0 m above ground level

Terrain UTM NAD83 Zone: 14

	East	North	Name of wind distribution	Height [m]	Type	Wind energy [kWh/m²]	Mean wind speed [m/s]	Equivalent roughness
A	592.180	2.767.380	Default Meteo data description	40,0	WEIBULL	2.375	6,5	
C	592.242	2.767.930	fransisco villa_SRTM_2m_roughness_500m	0,0	ATLAS	5.522	8,7	0,0

Calculated Annual Energy for Wind Farm

WTG combination	Result PARK [MWh/y]	GROSS (no loss) Free WTGs [MWh/y]	Park efficiency [%]	Specific results¤) Capacity factor [%]	Mean WTG result [MWh/y]	Full load hours [Hours/year]	Mean wind speed @hub height [m/s]
Wind farm	45.701,7	45.714,1	100,0	29,8	4.570,2	2.612	7,6

¤) Based on wake reduced results, but no other losses included

Calculated Annual Energy for each of 10 new WTGs with total 17,5 MW rated power

Terrain	Valid	WTG type Manufact.	Type-generator	Power, rated [kW]	Rotor diameter [m]	Hub height [m]	Power curve Creator	Name	Annual Energy Result [MWh]	Park Efficiency [%]	Capacity factor [%]	Mean wind speed [m/s]
1 C	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.968,6	100,0	38,9	8,68
2 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	3.127,8	100,0	20,4	6,54
3 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	3.137,2	100,0	20,5	6,54
4 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	3.144,7	100,0	20,5	6,54
5 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	3.154,5	100,0	20,6	6,54
6 C	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.995,0	100,0	39,1	8,68
7 C	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.988,4	100,0	39,0	8,68
8 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	3.166,6	100,0	20,6	6,54
9 C	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.011,7	100,0	39,2	8,68
10 C	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.007,3	100,0	39,2	8,68

9.2.7 SRTM 2m resolution and roughness rose resolution 1km

Key results for height 60,0 m above ground level

Terrain UTM NAD83 Zone: 14

	East	North	Name of wind distribution	Height	Type	Wind energy	Mean wind speed	Equivalent roughness
				[m]		[kWh/m²]	[m/s]	
A	592.180	2.767.380	Default Meteo data description	40,0	WEIBULL	2.375	6,5	
C	592.242	2.767.930	fransisco villa_SRTM_2m_roughness_1km_rose	0,0	ATLAS	2.618	6,7	1,7

Calculated Annual Energy for Wind Farm

WTG combination	Result PARK	GROSS (no loss) Free WTGs	Park efficiency	Specific results¤) Capacity factor	Mean WTG result	Full load hours	Mean wind speed @hub height
	[MWh/y]	[MWh/y]	[%]	[%]	[MWh/y]	[Hours/year]	[m/s]
Wind farm	32.793,3	32.803,2	100,0	21,4	3.279,3	1.874	6,6

¤) Based on wake reduced results, but no other losses included

Calculated Annual Energy for each of 10 new WTGs with total 17,5 MW rated power

	WTG type						Power curve		Annual Energy	Park		
Terrain	Valid	Manufact.	Type-generator	Power, rated	Rotor diameter	Hub height	Creator	Name	Result	Efficiency	Capacity factor	Mean wind speed
				[kW]	[m]	[m]			[MWh]	[%]	[%]	[m/s]
1 C	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	3.393,1	99,9	22,1	6,72
2 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	3.127,8	100,0	20,4	6,54
3 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	3.137,2	100,0	20,5	6,54
4 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	3.144,7	100,0	20,5	6,54
5 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	3.154,5	100,0	20,6	6,54
6 C	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	3.413,4	100,0	22,3	6,72
7 C	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	3.408,5	100,0	22,2	6,72
8 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	3.166,6	100,0	20,6	6,54
9 C	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	3.425,4	100,0	22,3	6,72
10 C	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	3.422,1	100,0	22,3	6,72

SRTM 2m resolution and roughness rose resolution 500m

Key results for height 60,0 m above ground level

Terrain UTM NAD83 Zone: 14

	East	North	Name of wind distribution	Height	Type	Wind energy	Mean wind speed	Equivalent roughness
				[m]		[kWh/m²]	[m/s]	
A	592.180	2.767.380	Default Meteo data description	40,0	WEIBULL	2.375	6,5	
C	592.242	2.767.930	fransisco villa_SRTM_2m_roughness_500m_ROSE	0,0	ATLAS	2.608	6,7	1,7

Calculated Annual Energy for Wind Farm

WTG combination	Result PARK	GROSS (no loss) Free WTGs	Park efficiency	Specific results¤) Capacity factor	Mean WTG result	Full load hours	Mean wind speed @hub height
	[MWh/y]	[MWh/y]	[%]	[%]	[MWh/y]	[Hours/year]	[m/s]
Wind farm	32.730,0	32.739,8	100,0	21,3	3.273,0	1.870	6,6

¤) Based on wake reduced results, but no other losses included

Calculated Annual Energy for each of 10 new WTGs with total 17,5 MW rated power

	WTG type						Power curve		Annual Energy	Park		
Terrain	Valid	Manufact.	Type-generator	Power, rated	Rotor diameter	Hub height	Creator	Name	Result	Efficiency	Capacity factor	Mean wind speed
				[kW]	[m]	[m]			[MWh]	[%]	[%]	[m/s]
1 C	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	3.380,6	99,9	22,0	6,71
2 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	3.127,8	100,0	20,4	6,54
3 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	3.137,2	100,0	20,5	6,54
4 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	3.144,7	100,0	20,5	6,54
5 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	3.154,5	100,0	20,6	6,54
6 C	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	3.400,7	100,0	22,2	6,71
7 C	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	3.395,9	100,0	22,1	6,71
8 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	3.166,6	100,0	20,6	6,54
9 C	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	3.412,6	100,0	22,2	6,71
10 C	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	3.409,4	100,0	22,2	6,71

9.3 LA VENTA, WTG separation study

Key results of the simulation with different turbine spacing

9.3.1 3x6 RD

Calculated Annual Energy for Wind Farm

WTG combination	Result PARK [MWh/y]	GROSS (no loss) Free WTGs [MWh/y]	Specific results¤) Park efficiency [%]	Capacity factor [%]	Mean WTG result [MWh/y]	Full load hours [Hours/year]	Mean wind speed @hub height [m/s]
Wind farm	85.749,3	92.676,1	92,5	37,3	5.716,6	3.267	9,0

¤) Based on wake reduced results, but no other losses included

Calculated Annual Energy for each of 15 new WTGs with total 26,3 MW rated power

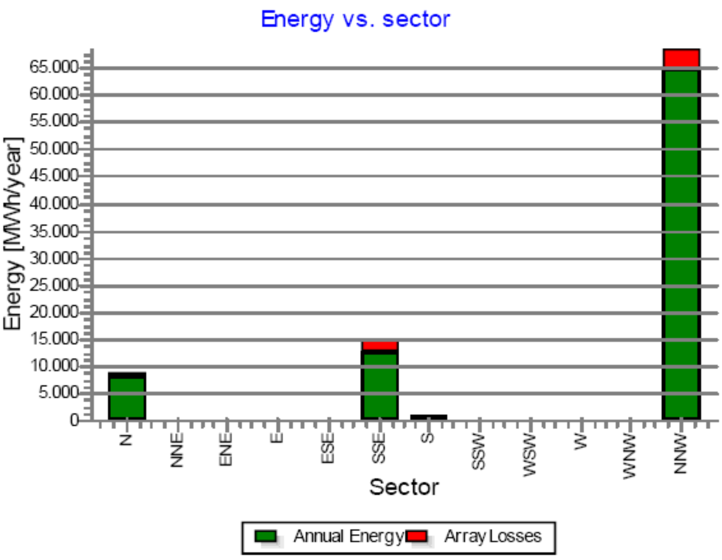
Terrain	WTG type Valid	Manufact.	Type-generator	Power, rated [kW]	Rotor diameter [m]	Hub height [m]	Power curve Creator	Name	Annual Energy Result [MWh]	Park Efficiency [%]	Capacity factor [%]	Mean wind speed [m/s]
1 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.932,2	96,0	38,7	8,99
2 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.890,7	95,3	38,4	8,99
3 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.885,7	95,3	38,4	8,99
4 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.885,4	95,3	38,4	8,99
5 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.905,4	95,6	38,5	8,99
6 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.591,3	90,5	36,4	8,99
7 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.575,5	90,2	36,3	8,99
8 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.571,4	90,2	36,3	8,99
9 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.599,3	90,6	36,5	8,99
10 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.668,2	91,7	36,9	8,99
11 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.621,6	91,0	36,6	8,99
12 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.600,1	90,6	36,5	8,99
13 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.605,2	90,7	36,5	8,99
14 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.648,7	91,4	36,8	8,99
15 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.768,5	93,4	37,6	8,99

PARK - Production Analysis

Calculation: la venta**WTG:** All new WTGs, Air density 1,170 kg/m³

Directional Analysis

Sector		0 N	1 NNE	2 ENE	3 E	4 ESE	5 SSE	6 S	7 SSW	8 WSW	9 W	10 WNW	11 NNW	Total
Roughness based energy	[MWh]	8.722,4	0,8	0,0	0,0	25,4	14.804,3	602,3	0,1	0,0	0,0	1,8	68.519,0	92.676,1
-Decrease due to array losses	[MWh]	734,4	0,2	0,0	0,0	6,5	2.308,4	96,9	0,0	0,0	0,0	0,6	3.779,9	6.926,8
Resulting energy	**[MWh]**	**7.987,9**	**0,7**	**0,0**	**0,0**	**18,9**	**12.495,9**	**505,4**	**0,1**	**0,0**	**0,0**	**1,2**	**64.739,1**	**85.749,3**
Specific energy	[kWh/m²]													1.671
Specific energy	[kWh/kW]													3.267
Decrease due to array losses	[%]	8,4	18,3	78,8	22,1	25,5	15,6	16,1	18,7	78,8	22,1	31,3	5,5	7,5
Utilization	[%]	25,2	3,2	0,0	0,3	13,9	32,3	31,7	1,7	0,0	0,1	6,1	17,5	19,4
Operational	[Hours/year]	851	94	58	75	213	2.412	320	37	24	27	71	3.358	7.541
Full Load Equivalent	[Hours/year]	304	0	0	0	1	476	19	0	0	0	0	2.466	3.267



9.3.2 4x8 RD

Calculated Annual Energy for Wind Farm

WTG combination	Result PARK [MWh/y]	GROSS (no loss) Free WTGs [MWh/y]	Park efficiency [%]	Specific results¤ Capacity factor [%]	Mean WTG result [MWh/y]	Full load hours [Hours/year]	Mean wind speed @hub height [m/s]
Wind farm	87.786,4	92.676,2	94,7	38,2	5.852,4	3.344	9,0

¤) Based on wake reduced results, but no other losses included

Calculated Annual Energy for each of 15 new WTGs with total 26,3 MW rated power

	Terrain	WTG type Valid	Manufact.	Type-generator	Power, rated [kW]	Rotor diameter [m]	Hub height [m]	Power curve Creator	Name	Annual Energy Result [MWh]	Park Efficiency [%]	Capacity factor [%]	Mean wind speed [m/s]
1	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.003,4	97,2	39,1	8,99
2	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.965,2	96,5	38,9	8,99
3	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.962,0	96,5	38,9	8,99
4	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.961,3	96,5	38,9	8,99
5	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.976,2	96,7	39,0	8,99
6	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.788,7	93,7	37,7	8,99
7	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.769,2	93,4	37,6	8,99
8	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.775,7	93,5	37,7	8,99
9	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.803,0	93,9	37,8	8,99
10	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.896,8	95,4	38,4	8,99
11	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.767,3	93,3	37,6	8,99
12	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.760,9	93,2	37,6	8,99
13	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.758,3	93,2	37,5	8,99
14	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.776,2	93,5	37,7	8,99
15	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.822,2	94,2	38,0	8,99

PARK - Production Analysis

Calculation: la venta**WTG:** All new WTGs, Air density 1,170 kg/m³

Directional Analysis

Sector		0 N	1 NNE	2 ENE	3 E	4 ESE	5 SSE	6 S	7 SSW	8 WSW	9 W	10 WNW	11 NNW	Total
Roughness based energy	[MWh]	8.722,4	0,8	0,0	0,0	25,4	14.804,3	602,3	0,1	0,0	0,0	1,8	68.519,1	92.676,2
-Decrease due to array losses	[MWh]	518,4	0,1	0,0	0,0	4,7	1.652,1	70,2	0,0	0,0	0,0	0,4	2.644,0	4.889,8
Resulting energy	**[MWh]**	**8.203,9**	**0,8**	**0,0**	**0,0**	**20,8**	**13.152,2**	**532,1**	**0,1**	**0,0**	**0,0**	**1,4**	**65.875,1**	**87.786,4**
Specific energy	[kWh/m²]													1.711
Specific energy	[kWh/kW]													3.344
Decrease due to array losses	[%]	5,9	10,3	69,7	12,1	18,3	11,2	11,7	10,5	69,7	12,1	22,2	3,9	5,3
Utilization	[%]	25,9	3,6	0,0	0,3	15,3	34,0	33,4	1,9	0,0	0,1	6,9	17,8	19,9
Operational	[Hours/year]	851	94	58	75	213	2.412	320	37	24	27	71	3.358	7.541
Full Load Equivalent	[Hours/year]	313	0	0	0	1	501	20	0	0	0	0	2.510	3.344

9.3.3 5x10 RD

Calculated Annual Energy for Wind Farm

WTG combination	Result PARK [MWh/y]	GROSS (no loss) Free WTGs [MWh/y]	Park efficiency [%]	Specific results¤ Capacity factor [%]	Mean WTG result [MWh/y]	Full load hours [Hours/year]	Mean wind speed @hub height [m/s]
Wind farm	89.117,4	92.676,0	96,2	38,7	5.941,2	3.395	9,0

¤) Based on wake reduced results, but no other losses included

Calculated Annual Energy for each of 15 new WTGs with total 26,3 MW rated power

	Terrain	WTG type Valid	Manufact.	Type-generator	Power, rated [kW]	Rotor diameter [m]	Hub height [m]	Power curve Creator	Name	Annual Energy Result [MWh]	Park Efficiency [%]	Capacity factor [%]	Mean wind speed [m/s]
1	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.045,5	97,8	39,4	8,99
2	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.016,3	97,4	39,2	8,99
3	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.014,3	97,3	39,2	8,99
4	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.013,5	97,3	39,2	8,99
5	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.034,8	97,7	39,3	8,99
6	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.900,1	95,5	38,5	8,99
7	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.870,2	95,0	38,3	8,99
8	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.876,7	95,1	38,3	8,99
9	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.893,9	95,4	38,4	8,99
10	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.964,6	96,5	38,9	8,99
11	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.890,9	95,3	38,4	8,99
12	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.886,5	95,3	38,4	8,99
13	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.884,9	95,2	38,4	8,99
14	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.897,0	95,4	38,4	8,99
15	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.928,3	96,0	38,6	8,99

PARK - Production Analysis

Calculation: la venta**WTG:** All new WTGs, Air density 1,170 kg/m³

Directional Analysis

Sector		0 N	1 NNE	2 ENE	3 E	4 ESE	5 SSE	6 S	7 SSW	8 WSW	9 W	10 WNW	11 NNW	Total
Roughness based energy	[MWh]	8.722,3	0,8	0,0	0,0	25,4	14.804,3	602,3	0,1	0,0	0,0	1,8	68.519,0	92.676,0
-Decrease due to array losses	[MWh]	368,0	0,1	0,0	0,0	3,5	1.224,2	50,6	0,0	0,0	0,0	0,3	1.912,0	3.558,7
Resulting energy	**[MWh]**	**8.354,3**	**0,8**	**0,0**	**0,0**	**21,9**	**13.580,1**	**551,7**	**0,1**	**0,0**	**0,0**	**1,5**	**66.606,9**	**89.117,3**
Specific energy	[kWh/m²]													1.737
Specific energy	[kWh/kW]													3.395
Decrease due to array losses	[%]	4,2	7,4	59,3	7,6	13,7	8,3	8,4	7,6	59,3	7,6	16,5	2,8	3,8
Utilization	[%]	26,4	3,7	0,0	0,3	16,1	35,1	34,6	2,0	0,0	0,1	7,4	18,0	20,2
Operational	[Hours/year]	851	94	58	75	213	2.412	320	37	24	27	71	3.358	7.541
Full Load Equivalent	[Hours/year]	318	0	0	0	1	517	21	0	0	0	0	2.537	3.395

9.3.4 6x12 RD

Calculated Annual Energy for Wind Farm

WTG combination	Result PARK [MWh/y]	GROSS (no loss) Free WTGs [MWh/y]	Park efficiency [%]	Specific results¤) Capacity factor [%]	Mean WTG result [MWh/y]	Full load hours [Hours/year]	Mean wind speed @hub height [m/s]
Wind farm	89.888,1	92.676,1	97,0	39,1	5.992,5	3.424	9,0

¤) Based on wake reduced results, but no other losses included

Calculated Annual Energy for each of 15 new WTGs with total 26,3 MW rated power

	Terrain	WTG type Valid	Manufact.	Type-generator	Power, rated [kW]	Rotor diameter [m]	Hub height [m]	Power curve Creator	Name	Annual Energy Result [MWh]	Park Efficiency [%]	Capacity factor [%]	Mean wind speed [m/s]
1	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.073,5	98,3	39,6	8,99
2	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.047,9	97,9	39,4	8,99
3	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.046,4	97,9	39,4	8,99
4	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.045,8	97,9	39,4	8,99
5	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.062,6	98,1	39,5	8,99
6	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.959,8	96,5	38,9	8,99
7	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.936,7	96,1	38,7	8,99
8	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.941,9	96,2	38,7	8,99
9	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.954,8	96,4	38,8	8,99
10	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.014,3	97,3	39,2	8,99
11	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.955,9	96,4	38,8	8,99
12	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.952,5	96,3	38,8	8,99
13	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.951,2	96,3	38,8	8,99
14	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.960,2	96,5	38,9	8,99
15	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.984,5	96,9	39,0	8,99

PARK - Production Analysis

Calculation: la venta**WTG:** All new WTGs, Air density 1,170 kg/m³

Directional Analysis

Sector		0 N	1 NNE	2 ENE	3 E	4 ESE	5 SSE	6 S	7 SSW	8 WSW	9 W	10 WNW	11 NNW	Total
Roughness based energy	[MWh]	8.722,4	0,8	0,0	0,0	25,4	14.804,3	602,3	0,1	0,0	0,0	1,8	68.519,0	92.676,1
-Decrease due to array losses	[MWh]	284,4	0,1	0,0	0,0	2,7	969,9	39,6	0,0	0,0	0,0	0,2	1.491,2	2.788,0
Resulting energy	**[MWh]**	**8.437,9**	**0,8**	**0,0**	**0,0**	**22,7**	**13.834,4**	**562,7**	**0,1**	**0,0**	**0,0**	**1,5**	**67.027,8**	**89.888,1**
Specific energy	[kWh/m²]													1.752
Specific energy	[kWh/kW]													3.424
Decrease due to array losses	[%]	3,3	6,3	50,8	6,5	10,5	6,6	6,6	6,4	50,8	6,5	12,6	2,2	3,0
Utilization	[%]	26,7	3,7	0,0	0,3	16,7	35,8	35,3	2,0	0,0	0,1	7,7	18,1	20,3
Operational	[Hours/year]	851	94	58	75	213	2.412	320	37	24	27	71	3.358	7.541
Full Load Equivalent	[Hours/year]	321	0	0	0	1	527	21	0	0	0	0	2.553	3.424

9.4 La Venta: Wake model Study

Key results for the simulations with different wake models

9.4.1 N.O. Jensen (RISØ/EMD)

Calculated Annual Energy for Wind Farm

WTG combination	Result PARK [MWh/y]	GROSS (no loss) Free WTGs [MWh/y]	Park efficiency [%]	Specific results¤) Capacity factor [%]	Mean WTG result [MWh/y]	Full load hours [Hours/year]	Mean wind speed @hub height [m/s]
Wind farm	89.117,4	92.676,0	96,2	38,7	5.941,2	3.395	9,0

¤) Based on wake reduced results, but no other losses included

Calculated Annual Energy for each of 15 new WTGs with total 26,3 MW rated power

Terrain	WTG type Valid	Manufact.	Type-generator	Power, rated [kW]	Rotor diameter [m]	Hub height [m]	Power curve Creator	Name	Annual Energy Result [MWh]	Park Efficiency [%]	Capacity factor [%]	Mean wind speed [m/s]
1 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.045,5	97,8	39,4	8,99
2 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.016,3	97,4	39,2	8,99
3 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.014,3	97,3	39,2	8,99
4 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.013,5	97,3	39,2	8,99
5 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.034,8	97,7	39,3	8,99
6 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.900,1	95,5	38,5	8,99
7 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.870,2	95,0	38,3	8,99
8 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.876,7	95,1	38,3	8,99
9 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.893,9	95,4	38,4	8,99
10 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.964,6	96,5	38,9	8,99
11 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.890,9	95,3	38,4	8,99
12 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.886,5	95,3	38,4	8,99
13 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.884,9	95,2	38,4	8,99
14 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.897,0	95,4	38,4	8,99
15 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.928,3	96,0	38,6	8,99

PARK - Production Analysis

Calculation: la venta**WTG:** All new WTGs, Air density 1,170 kg/m³

Directional Analysis

Sector		0 N	1 NNE	2 ENE	3 E	4 ESE	5 SSE	6 S	7 SSW	8 WSW	9 W	10 WNW	11 NNW	Total
Roughness based energy	[MWh]	8.722,3	0,8	0,0	0,0	25,4	14.804,3	602,3	0,1	0,0	0,0	1,8	68.519,0	92.676,0
-Decrease due to array losses	[MWh]	368,0	0,1	0,0	0,0	3,5	1.224,2	50,6	0,0	0,0	0,0	0,3	1.912,0	3.558,7
Resulting energy	**[MWh]**	**8.354,3**	**0,8**	**0,0**	**0,0**	**21,9**	**13.580,1**	**551,7**	**0,1**	**0,0**	**0,0**	**1,5**	**66.606,9**	**89.117,3**
Specific energy	[kWh/m²]													1.737
Specific energy	[kWh/kW]													3.395
Decrease due to array losses	[%]	4,2	7,4	59,3	7,6	13,7	8,3	8,4	7,6	59,3	7,6	16,5	2,8	3,8
Utilization	[%]	26,4	3,7	0,0	0,3	16,1	35,1	34,6	2,0	0,0	0,1	7,4	18,0	20,2
Operational	[Hours/year]	851	94	58	75	213	2.412	320	37	24	27	71	3.358	7.541
Full Load Equivalent	[Hours/year]	318	0	0	0	1	517	21	0	0	0	0	2.537	3.395

9.4.2 Eddy Viscosity Model (J.F. Ainslie) : 1986

Calculated Annual Energy for Wind Farm

WTG combination	Result PARK [MWh/y]	GROSS (no loss) Free WTGs [MWh/y]	Park efficiency [%]	Specific results¤) Capacity factor [%]	Specific results¤) Mean WTG result [MWh/y]	Specific results¤) Full load hours [Hours/year]	Mean wind speed @hub height [m/s]
Wind farm	90.304,6	92.676,1	97,4	39,2	6.020,3	3.440	9,0

¤) Based on wake reduced results, but no other losses included

Calculated Annual Energy for each of 15 new WTGs with total 26,3 MW rated power

	Terrain	WTG type Valid	Manufact.	Type-generator	Power, rated [kW]	Rotor diameter [m]	Hub height [m]	Power curve Creator	Name	Annual Energy Result [MWh]	Park Efficiency [%]	Capacity factor [%]	Mean wind speed [m/s]
1	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.093,0	98,6	39,7	8,99
2	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.066,8	98,2	39,5	8,99
3	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.065,0	98,2	39,5	8,99
4	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.064,2	98,2	39,5	8,99
5	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.076,2	98,3	39,6	8,99
6	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.979,8	96,8	39,0	8,99
7	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.964,9	96,5	38,9	8,99
8	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.971,1	96,6	38,9	8,99
9	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.982,5	96,8	39,0	8,99
10	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.037,9	97,7	39,4	8,99
11	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.996,2	97,1	39,1	8,99
12	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.993,3	97,0	39,1	8,99
13	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.992,0	97,0	39,1	8,99
14	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.001,1	97,1	39,1	8,99
15	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.020,7	97,4	39,2	8,99

PARK - Production Analysis

Calculation: LA venta with diff wake nodel**WTG:** All new WTGs, Air density 1,170 kg/m³

Directional Analysis

Sector		0 N	1 NNE	2 ENE	3 E	4 ESE	5 SSE	6 S	7 SSW	8 WSW	9 W	10 WNW	11 NNW	Total
Roughness based energy	[MWh]	8.722,4	0,8	0,0	0,0	25,4	14.804,3	602,3	0,1	0,0	0,0	1,8	68.519,0	92.676,0
-Decrease due to array losses	[MWh]	236,4	0,0	0,0	0,0	2,2	811,1	34,5	0,0	0,0	0,0	0,2	1.287,1	2.371,4
Resulting energy	**[MWh]**	**8.486,0**	**0,8**	**0,0**	**0,0**	**23,2**	**13.993,2**	**567,8**	**0,1**	**0,0**	**0,0**	**1,6**	**67.231,9**	**90.304,6**
Specific energy	[kWh/m²]													1.760
Specific energy	[kWh/kW]													3.440
Decrease due to array losses	[%]	2,7	5,7	36,7	6,5	8,8	5,5	5,7	5,9	35,0	7,0	9,2	1,9	2,6
Utilization	[%]	26,8	3,7	0,0	0,3	17,1	36,2	35,6	2,0	0,0	0,1	8,0	18,2	20,4
Operational	[Hours/year]	851	94	58	75	213	2.412	320	37	24	27	71	3.358	7.541
Full Load Equivalent	[Hours/year]	323	0	0	0	1	533	22	0	0	0	0	2.561	3.440

9.4.3 EWTS II (G.C.Larsen) : 1999

Calculated Annual Energy for Wind Farm

WTG combination	Result PARK [MWh/y]	GROSS (no loss) Free WTGs [MWh/y]	Park efficiency [%]	Specific results¤) Capacity factor [%]	Specific results¤) Mean WTG result [MWh/y]	Specific results¤) Full load hours [Hours/year]	Mean wind speed @hub height [m/s]
Wind farm	90.470,6	92.676,1	97,6	39,3	6.031,4	3.446	9,0

¤) Based on wake reduced results, but no other losses included

Calculated Annual Energy for each of 15 new WTGs with total 26,3 MW rated power

	Terrain	WTG type Valid	Manufact.	Type-generator	Power, rated [kW]	Rotor diameter [m]	Hub height [m]	Power curve Creator	Name	Annual Energy Result [MWh]	Park Efficiency [%]	Capacity factor [%]	Mean wind speed [m/s]
1	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.098,9	98,7	39,8	8,99
2	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.088,9	98,6	39,7	8,99
3	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.086,7	98,5	39,7	8,99
4	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.086,6	98,5	39,7	8,99
5	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.089,5	98,6	39,7	8,99
6	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.008,1	97,2	39,2	8,99
7	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.004,5	97,2	39,1	8,99
8	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.006,4	97,2	39,2	8,99
9	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.015,2	97,4	39,2	8,99
10	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.043,6	97,8	39,4	8,99
11	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.988,3	96,9	39,0	8,99
12	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.982,2	96,8	39,0	8,99
13	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.981,4	96,8	39,0	8,99
14	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.985,6	96,9	39,0	8,99
15	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.004,8	97,2	39,1	8,99

PARK - Production Analysis

Calculation: LA venta with diff wake nodel**WTG:** All new WTGs, Air density 1,170 kg/m³

Directional Analysis

Sector		0 N	1 NNE	2 ENE	3 E	4 ESE	5 SSE	6 S	7 SSW	8 WSW	9 W	10 WNW	11 NNW	Total
Roughness based energy	[MWh]	8.722,4	0,8	0,0	0,0	25,4	14.804,3	602,3	0,1	0,0	0,0	1,8	68.519,0	92.676,0
-Decrease due to array losses	[MWh]	164,8	0,1	0,0	0,0	2,7	765,0	28,8	0,0	0,0	0,0	0,1	1.243,9	2.205,5
Resulting energy	**[MWh]**	**8.557,5**	**0,8**	**0,0**	**0,0**	**22,7**	**14.039,3**	**573,5**	**0,1**	**0,0**	**0,0**	**1,6**	**67.275,1**	**90.470,6**
Specific energy	[kWh/m²]													1.763
Specific energy	[kWh/kW]													3.446
Decrease due to array losses	[%]	1,9	7,7	69,0	9,7	10,7	5,2	4,8	7,9	67,5	9,4	8,5	1,8	2,4
Utilization	[%]	27,0	3,7	0,0	0,3	16,7	36,3	36,0	2,0	0,0	0,1	8,1	18,2	20,5
Operational	[Hours/year]	851	94	58	75	213	2.412	320	37	24	27	71	3.358	7.541
Full Load Equivalent	[Hours/year]	326	0	0	0	1	535	22	0	0	0	0	2.563	3.446

9.4.4 EWTS II (G.C.Larsen): 2008

Calculated Annual Energy for Wind Farm

WTG combination	Result PARK [MWh/y]	GROSS (no loss) Free WTGs [MWh/y]	Park efficiency [%]	Specific results¤) Capacity factor [%]	Mean WTG result [MWh/y]	Full load hours [Hours/year]	Mean wind speed @hub height [m/s]
Wind farm	90.470,6	92.676,1	97,6	39,3	6.031,4	3.446	9,0

¤) Based on wake reduced results, but no other losses included

Calculated Annual Energy for each of 15 new WTGs with total 26,3 MW rated power

	Terrain	WTG type Valid	Manufact.	Type-generator	Power, rated [kW]	Rotor diameter [m]	Hub height [m]	Power curve Creator	Name	Annual Energy Result [MWh]	Park Efficiency [%]	Capacity factor [%]	Mean wind speed [m/s]
1	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.098,9	98,7	39,8	8,99
2	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.088,9	98,6	39,7	8,99
3	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.086,7	98,5	39,7	8,99
4	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.086,6	98,5	39,7	8,99
5	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.089,5	98,6	39,7	8,99
6	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.008,1	97,2	39,2	8,99
7	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.004,5	97,2	39,1	8,99
8	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.006,4	97,2	39,2	8,99
9	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.015,2	97,4	39,2	8,99
10	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.043,6	97,8	39,4	8,99
11	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.988,3	96,9	39,0	8,99
12	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.982,2	96,8	39,0	8,99
13	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.981,4	96,8	39,0	8,99
14	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.985,6	96,9	39,0	8,99
15	A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.004,8	97,2	39,1	8,99

PARK - Production Analysis

Calculation: LA venta with diff wake nodel**WTG:** All new WTGs, Air density 1,170 kg/m³

Directional Analysis

Sector		0 N	1 NNE	2 ENE	3 E	4 ESE	5 SSE	6 S	7 SSW	8 WSW	9 W	10 WNW	11 NNW	Total
Roughness based energy	[MWh]	8.722,4	0,8	0,0	0,0	25,4	14.804,3	602,3	0,1	0,0	0,0	1,8	68.519,0	92.676,0
-Decrease due to array losses	[MWh]	164,8	0,1	0,0	0,0	2,7	765,0	28,8	0,0	0,0	0,0	0,1	1.243,9	2.205,5
Resulting energy	**[MWh]**	**8.557,5**	**0,8**	**0,0**	**0,0**	**22,7**	**14.039,3**	**573,5**	**0,1**	**0,0**	**0,0**	**1,6**	**67.275,1**	**90.470,6**
Specific energy	[kWh/m²]													1.763
Specific energy	[kWh/kW]													3.446
Decrease due to array losses	[%]	1,9	7,7	69,0	9,7	10,7	5,2	4,8	7,9	67,5	9,4	8,5	1,8	2,4
Utilization	[%]	27,0	3,7	0,0	0,3	16,7	36,3	36,0	2,0	0,0	0,1	8,1	18,2	20,5
Operational	[Hours/year]	851	94	58	75	213	2.412	320	37	24	27	71	3.358	7.541
Full Load Equivalent	[Hours/year]	326	0	0	0	1	535	22	0	0	0	0	2.563	3.446

9.4.5 N.O. Jensen (EMD) : 2005

Calculated Annual Energy for Wind Farm

WTG combination	Result PARK [MWh/y]	GROSS (no loss) Free WTGs [MWh/y]	Park efficiency [%]	Specific results¤) Capacity factor [%]	Mean WTG result [MWh/y]	Full load hours [Hours/year]	Mean wind speed @hub height [m/s]
Wind farm	88.800,1	92.676,1	95,8	38,6	5.920,0	3.383	9,0

¤) Based on wake reduced results, but no other losses included

Calculated Annual Energy for each of 15 new WTGs with total 26,3 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]	Efficiency [%]	Capacity factor [%]	Mean wind speed [m/s]
1 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.044,1	97,8	39,4	8,99
2 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.009,6	97,3	39,2	8,99
3 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.007,2	97,2	39,2	8,99
4 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.006,4	97,2	39,2	8,99
5 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	6.023,9	97,5	39,3	8,99
6 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.869,2	95,0	38,3	8,99
7 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.848,2	94,7	38,1	8,99
8 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.860,2	94,9	38,2	8,99
9 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.883,7	95,2	38,4	8,99
10 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.967,7	96,6	38,9	8,99
11 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.845,2	94,6	38,1	8,99
12 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.840,1	94,5	38,1	8,99
13 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.838,0	94,5	38,1	8,99
14 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.857,2	94,8	38,2	8,99
15 A	Yes	VESTAS	V66-1.750	1.750	66,0	60,0	EMD	Level 0 - calculated -106.2dB(A) - 04-2001	5.899,5	95,5	38,5	8,99

PARK - Production Analysis

Calculation: LA venta with diff wake nodel**WTG:** All new WTGs, Air density 1,170 kg/m³

Directional Analysis

Sector		0 N	1 NNE	2 ENE	3 E	4 ESE	5 SSE	6 S	7 SSW	8 WSW	9 W	10 WNW	11 NNW	Total
Roughness based energy	[MWh]	8.722,4	0,8	0,0	0,0	25,4	14.804,3	602,3	0,1	0,0	0,0	1,8	68.519,0	92.676,0
-Decrease due to array losses	[MWh]	502,2	0,1	0,0	0,0	4,4	1.321,3	57,6	0,0	0,0	0,0	0,3	1.990,0	3.875,9
Resulting energy	**[MWh]**	**8.220,1**	**0,8**	**0,0**	**0,0**	**21,1**	**13.482,9**	**544,7**	**0,1**	**0,0**	**0,0**	**1,4**	**66.528,9**	**88.800,1**
Specific energy	[kWh/m²]													1.730
Specific energy	[kWh/kW]													3.383
Decrease due to array losses	[%]	5,8	10,0	54,0	11,1	17,1	8,9	9,6	10,2	54,0	11,1	18,2	2,9	4,2
Utilization	[%]	26,0	3,6	0,0	0,3	15,5	34,8	34,2	1,9	0,0	0,1	7,2	18,0	20,1
Operational	[Hours/year]	851	94	58	75	213	2.412	320	37	24	27	71	3.358	7.541
Full Load Equivalent	[Hours/year]	313	0	0	0	1	514	21	0	0	0	0	2.534	3.383

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