Performance analysis of wind resource assessment programs in complex terrain

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Abstract.

In order to provide optimal sitting of wind turbines, a reliable estimate of the wind resource over a given area is required. This paper compared the performance of two models, WAsP and WindSim in predicting the power production of individual turbines. The prediction accuracy is determined as function of wind direction (terrain), turbine spacing and turbulence. Recommendations are made as to the reliability and suitability of these models for different situations.

Key words

Wind energy, resource assessment, WAsP, WindSim, complex terrain.

1. Introduction

Renewable energy sources are increasing being looked to in order to provide power with minimal environmental impact. The most commercially advanced of these at present is wind power.

One of the challenges to effective sitting of wind turbines is the ability to make reliable and accurate predictions of the wind power resource. This challenge becomes more difficult in areas of complex terrain where numerical modelling of the wind flow is non-trivial. There are a number of commercial wind resource assessment programs that have been developed in order to give estimates of site wind speed at potential wind farm sites, including such as WAsP and MS-Micro. It is generally accepted that such models produce reasonable results when the terrain is fairly flat with only gentle hills. However, if the wind farm is to be situated in mountainous terrain, which is quite common in countries like Spain, the results become less reliable.

There have been a number of studies describing the applicability of WAsP in various different types of terrain. However, there is increasing interest in applying more complete Navier Stokes models to flow in complex terrain, given that the required computing power is now more affordable and can produce results in a reasonable time-frame with an acceptable spatial resolution.

The purpose of this paper is to compare the accuracy with regard to wind resource assessment of the commonly used WAsP package with a relatively new wind resource assessment program, WindSim which uses a more complete Navier Stokes solver based on the PHOENICS code which should give more accurate results in complex terrain. We present the particular results at one wind farm site in Spain.

The intention of this paper is to provide some guidance as to the expected improvement in accuracy over the commonly used linear WAsP model by using the WindSim package as well as an indication of some of the limitations of the two models.

2. The wind resource evaluation methods

Perhaps the first serious software package that has been developed in order to assess wind resource was the WAsP program [1]. This is generally considered to be the reference wind resource program at the present time.

The program is based on similar boundary layer physics to the MS-Micro package using the 3D extension by Mason and Sykes of the original linear 2D equations by Jackson and Hunt for wind flow over low hills [2,3]. In addition, the WAsP model includes a roughness change and shelter model to cater for the effect of obstacles. The model employs a zooming polar coordinate grid for optimum resolution at the point of interest.

Recent research has been carried out using more complete Navier-Stokes solvers. One of the first commercial programs to use such a solver is the WindSim model developed by Vector AS [4]. This package uses the computational fluid dynamics (CFD) model PHOENICS as it core solver. Potentially, the program is capable of more accurate results over steep hills than the WAsP model.

3. Methodology

To study the limitations that the different software packages have in assessing the wind power production at a site, several wind farms situated in varying degrees of complex terrain have been studied. The models are used to predict the expected wind energy production at each wind turbine in the farms and this is compared with the actual production. This paper focuses on the accurate study of one wind farm located in a semi-mountainous terrain. In this case, the complexity is mainly due to important changes of elevation, and high steepness. Another parameter influent on the study of a site is roughness changes; in this case is relatively constant. Regarding to the European Wind Atlas [9], selected wind farm roughness is relatively constant (a value of 0,05 m for roughness length) is assigned at most of the parts of the model.

The Wind Farm consists of 33 Wind Turbines, with a hub height of 55m, variable speed and stall control, a nominal potential power of 750 KW, a maximum power of 900 KW which totalize 24,75 MW of installed capacity.

This analysis gives a general picture of how well the two models are able to predict the overall power production but does not necessarily indicate what are the principal sources of any error. Therefore, we present a breakdown of the power production errors as a function of:

- Wind direction probability
- Wind shear and distribution
- Turbine spacing
- Grid resolution in the case of the CFD model.

Some overall conclusions are then drawn as to the relative accuracy of the two models and what factors affect the degree of accuracy.

Both software allows the conversion of time history wind measurements (speed and direction). However, they do not integrate any temporal verification, considering data as annual complete cycles. Thus, it is necessary to analyse the wind data measured, clean them and select the study data series. Beside, one of the main characteristics of wind is its variability annual, diurnal and situational. That means that its mean velocity could change a lot from one year to another and consequently the wind potential of a determined site. In order to well evaluate an elected zone wind potential, it is necessary to get a large set of annually wind data [6]. This example only have available four years of measurements before the wind farm started to operate and one year of data from the operation meteorological mast.

4. Data analysis and discussion

In order to compare how different models or empirical calculus performs, it is sought to estimate the wind climate at meteorological mast position, over a reference period elected. In this case, a two complete annual cycles had been elected.

More accurately, to know values of wind speed and direction at wind turbines hub height, it is necessary to reduce approximations about wind profile and distribution in direction at maximum mast height. The data used to perform this comparison study has been filtered in order to assure their quality.

4.1 Wind frequency

An important parameter in wind distribution modelling is the repartition in function of wind direction, especially in a complex terrain, where important changes in velocity could be due to eventual speed-ups created by orography. The wind rose of Figure 1 shows the difference in wind frequency between both models compared to the statistical treatment of the meteorological mast using long term series data. The statistical analysis of the mast data was performed using wind speed measurements at two different heights (30 and 10m).

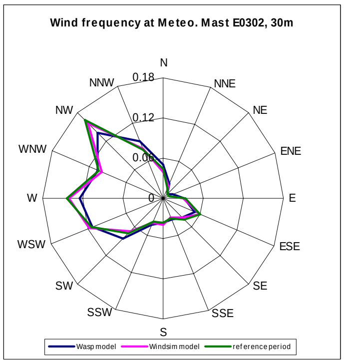

Figure 1: Wind Direction Frequencies by Binned Sectors Statistical, WAsP, Windsim Model.

It appears that WAsP has a tendency to over estimate the frequency of wind except in the most energetic sector. This is mainly due to a equal repartition to each direction sector of the zero wind speed data. Windsim tends to give results closer to measured model in almost all sectors.

Table 1: Wind frequency at different height, WasP and Windsim models..

Model	Height	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
WAsP	30	4.70%	2.20%	1.00%	1.50%	3.20%	5.50%	4.20%	3.60%	3.60%	4.00%	8.10%	11.00%	12.90%	11.30%	14.30%	8.80%
	40	5.00%	2.30%	1.00%	1.60%	3.20%	5.20%	4.00%	3.50%	3.70%	4.30%	8.60%	11.40%	12.50%	10.50%	13.90%	9.10%
	55	4.90%	2.20%	1.00%	1.60%	3.20%	5.40%	4.10%	3.50%	3.70%	4.10%	8.30%	11.20%	12.70%	10.90%	14.10%	8.90%
Windsim	30	4.30%	1.60%	0.90%	0.90%	3.30%	5.90%	4.20%	3.10%	3.50%	3.80%	7.20%	11.40%	14.20%	10.40%	17.00%	8.40%
	40	4.50%	1.70%	0.90%	0.90%	3.30%	5.80%	4.10%	3.00%	3.50%	4.10%	7.30%	11.20%	14.10%	10.40%	16.70%	8.40%
	55	4.70%	1.90%	1.00%	0.90%	3.20%	5.80%	4.10%	2.90%	3.60%	4.50%	7.30%	11.10%	13.90%	10.30%	16.40%	8.30%

We observed that at hub height (55m), the highest values of frequency, for both model, seem to slightly decrease. This is mainly due to a less sensitivity to the ground effects, speed-ups and deflection. However, the same differences between models appears: Windsim keeps giving an higher value of frequency for the most energetic sectors and lower for the less energetic sectors.

4.2 Vertical wind profile

A statistical analysis of the mast data was done using wind speed measurements at two different heights (30 and 10m). As the mast permits two level of measurements, it is possible to determine the alpha coefficient defined by the Power Law following equation, which is commonly used in most of the cases that require height extrapolation.

$$U(z) = Ur \times (z/z)\alpha \qquad \text{Equation(1)}$$

Where U and Ur represent wind speed at z and zr height, being z the top measure height and zr the low measure height.

The concurrent data from both measure heights are binned and classified in sectors according to the reference wind direction. Therefore, it is calculated a value of α for each of the sectors considered

The standard logarithmic velocity profile is used as a basis in WAsP wind profile calculus. However, this profile is modified to take into account the effects of non-neutral stability and up-wind roughness changes. [1] Observing WAsP representation of wind profile (fig 2), only sectors E, ESE WNW seem to present a reverse profile, which could correspond to a low value α, following the a power law interpretation.

These values are logic, considering the important speed-ups in that directions, due to an important elevation down-stream respect to the meteorological mast. Indeed, hills exert a profound influence on the flow, which is taken into account in the WAsP model of the vertical wind profile. We know that, the hill-upstream profile could be logarithmic but introducing a “knee” at the height of relative speed-up, as shown on the following representation.

The highest value of speed-up is found for sector WSW, which is also one of the more energetic sectors. That is why the reverse wind profile appears in a stronger form.

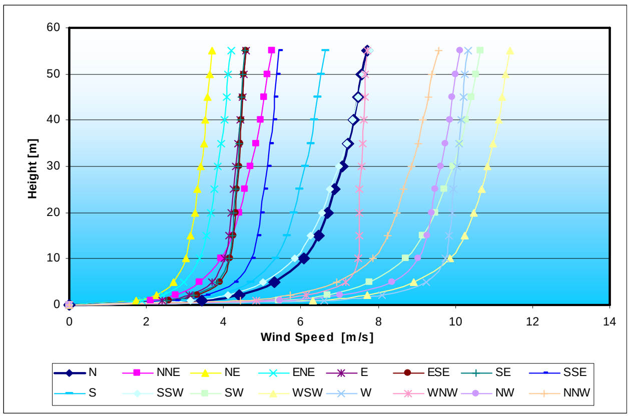

Figure 2. WAsP vertical wind profile, by direction binned sectors.

As a CFD model, Windsim wind profile do not come from a modification of logarithmic law. Figure 3 shows the vertical wind profile calculated by Windsim for each direction binned sector. It appears clearly that on the two wind shear graphs, in most of the direction sectors, WAsP over evaluate the wind velocity respect to Windsim. Windsim give a lower value of the mean wind speed, especially at hub height. Indeed, this over estimation that WAsP does, is mainly due to vertical wind profile applied, too close to the logarithmic law. The terrain of the selected wind farm present a high complexity more in terms of orography than roughness, parameter well taken into account in WAsP calculations. Consequently, a 3D Navier-Stokes model, in this case, gives results closer to reality. Table present comparison between WAsP and Windsim respect to statistical power law results.

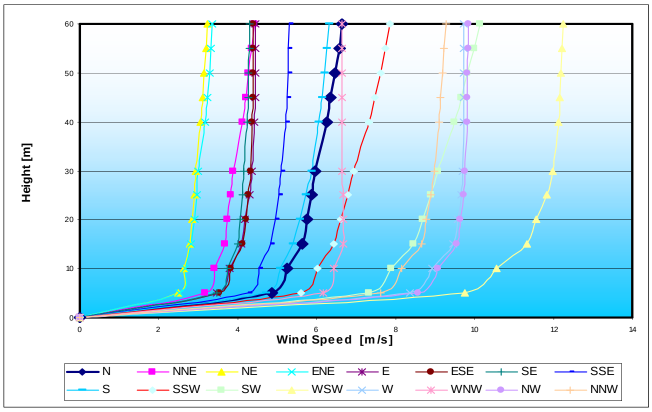

Figure 3. Windsim wind shear, by direction binned sectors

Table 1 presents the discrepancies between the extrapolation at several heights of this statistical calculus and the results given by the linear WAsP model and the CFD Windsim model:

Table 1: Discrepancies between Numerical and Calculated WasP/ Windsim wind shear.

		N	NNE	NE	ENE	E	ESE	SE	SSE
5 m	WAsP	13%	16%	42%	15%	-12%	-8%	4%	8%
	Windsim	3%	9%	31%	-1%	-17%	-17%	-6%	7%
10 m	WAsP	19%	22%	34%	23%	-6%	-2%	7%	8%
	Windsim	3%	6%	17%	-3%	-11%	-10%	-3%	4%
20 m	WAsP	20%	22%	21%	25%	-3%	0%	6%	3%
	Windsim	3%	3%	6%	-1%	-3%	-2%	1%	2%
30 m	WAsP	21%	22%	15%	27%	-1%	2%	5%	0%
	Windsim	2%	1%	0%	-1%	0%	0%	1%	0%
40 m	WAsP	21%	22%	11%	28%	1%	3%	5%	-1%
	Windsim	3%	2%	-4%	2%	1%	1%	1%	-2%
55 m	WAsP	22%	23%	7%	31%	4%	5%	6%	-3%
	Windsim	4%	2%	-7%	3%	1%	1%	0%	-5%
		S	SSW	SW	WSW	W	WNW	NW	NNW
5 m	WAsP	7%	-12%	-4%	-17%	9%	13%	-1%	2%
	Windsim	8%	-2%	-10%	-9%	-1%	-3%	1%	13%
10 m	WAsP	9%	-5%	3%	-12%	9%	16%	2%	5%
	Windsim	3%	-2%	-7%	-6%	0%	0%	2%	9%
20 m	WAsP	6%	-2%	7%	-10%	5%	15%	1%	3%
	Windsim	1%	-1%	-2%	-1%	1%	2%	3%	7%
30 m	WAsP	4%	0%	9%	-10%	3%	15%	0%	2%
	Windsim	0%	0%	0%	0%	-1%	1%	2%	3%
40 m	WAsP	3%	2%	11%	-9%	2%	16%	1%	1%
	Windsim	-2%	2%	3%	-1%	-3%	1%	0%	0%
55 m	WAsP	2%	4%	13%	-9%	1%	17%	1%	1%
	Windsim	-3%	4%	6%	-2%	-5%	0%	-2%	-3%

Important differences are found close to ground. These observations are mainly due to the lack of accuracy of power law at ground level.

For the most energetic sectors, we can see that WAsP present values of wind speed always superior to Windsim, except in sector WSW, which is the most powerful sector (9% inferior to the statistic power law value at hub height). At the same time, Windsim keeps being very close to the value calculated statistically (inferior in a 2% at hub height).

We can notice that generally, at measurement mast height of 30 m, Windsim values keep being very close to the statistical data (between –1% to 3%), keeping in mind that the statistical values at 30 m are real and not generated following power law.

Windsim seem to reproduce better the vertical wind profile than WAsP. However, both models tends to over estimate wind velocity at hub height, in comparison with the calculus who followed the power law.

As a CFD model, Windsim reproduce in a much better way all effects of orography and simple roughness who acts significantly on vertical wind profile.

Using WAsP to estimate wind speed at hub height will involve an over estimation of the power extractable. Respect to statistic data power law correlation, Windsim seem to underestimate the wind speed at hub height, but in a very reasonable margin.

4.3 Wind distribution (Weibull parameters)

In order to perform a suitable comparison between both numerical models of wind at the met mast, it is necessary to study both, shape and scale, Weibull parameters, in function of direction binned sectors. These are summarized in Tables 3 and 4.

Table 3: Calculated Weibull Shape Factor Measured, WAsP and Windsim model

Model	Height	N	NNE	NE	ENE	E	ESE	SE	SSE	S
Measured	30	1.68	2.16	1.88	1.91	2.03	2.21	1.92	2.26	2.34
WAsP	30	1.69	1.56	1.67	1.91	2.04	2.10	1.89	2.06	2.10
	40	1.77	1.64	1.76	2.01	2.15	2.21	1.98	2.14	2.20
	55	1.85	1.72	1.86	2.11	2.26	2.31	2.07	2.22	2.29
Windsim	30	1.74	2.32	2.12	2.24	2.02	2.06	1.78	2.28	2.31
	40	1.71	2.01	2.08	2.10	2.01	2.05	1.77	2.25	2.27
	55	1.70	1.82	2.05	2.03	2.00	2.05	1.77	2.23	2.28
Model	Height	SSW	SW	WSW	W	WNW	NW	NNW	MEAN VALUE	
Measured	30	2.37	2.39	2.14	1.77	1.83	2.33	2.00	**1.63**	
WAsP	30	2.10	1.95	2.02	1.88	1.72	2.51	2.17	**1.69**	
	40	2.21	1.98	2.06	1.92	1.79	2.64	2.29	**1.73**	
	55	2.31	2.02	2.11	1.98	1.85	2.77	2.42	**1.79**	
Windsim	30	2.25	2.31	2.14	1.97	1.76	2.64	2.28	**1.62**	
	40	2.19	2.25	2.14	1.96	1.76	2.63	2.29	**1.63**	
	55	2.15	2.20	2.13	1.96	1.76	2.63	2.29	**1.64**	

Table 4: Calculated Weibull Scale Factor Parameters Measured, WAsP And Windsim Model

Model	Height	N	NNE	NE	ENE	E	ESE	SE	SSE	S
Measured	30	6.54	4.37	3.34	3.43	4.93	4.88	4.66	5.79	6.64
WAsP	30	7.90	5.20	3.80	4.30	4.90	5.00	4.90	5.80	6.90
	40	8.30	5.50	4.00	4.50	5.00	5.00	5.00	5.90	7.20
	55	8.70	5.90	4.20	4.70	5.20	5.20	5.10	6.10	7.50
Windsim	30	6.85	4.54	3.48	3.57	4.92	4.84	4.60	5.81	6.66
	40	7.15	4.78	3.60	3.75	4.99	4.90	4.69	5.93	6.89
	55	7.47	5.01	3.75	3.90	5.03	4.91	4.74	6.02	7.13
Model	Height	SSW	SW	WSW	W	WNW	NW	NNW	MEAN VALUE	
Measured	30	7.85	10.25	13.56	10.97	7.39	10.83	9.84	**8.88**	
WAsP	30	7.90	11.20	12.20	11.30	8.50	10.90	10.00	**9.10**	
	40	8.30	11.60	12.50	11.50	8.60	11.10	10.40	**9.30**	
	55	8.80	12.00	12.90	11.60	8.70	11.40	10.80	**9.60**	
Windsim	30	7.80	10.20	13.52	11.32	7.40	11.22	10.41	**8.85**	
	40	8.20	10.65	13.67	11.35	7.42	11.26	10.53	**8.09**	
	55	8.68	11.19	13.81	11.35	7.41	11.30	10.68	**9.11**	

When comparing the measured and modelled Weibull C scale parameters, it seems like WAsP model has a tendency to slightly over predict the C parameter at 30m height. The same process is observed for the Windsim model but results keep being closer to statistics calculations of C parameter. WAsP gives an inferior value to the Windsim for mainly all most powerful sectors: WSW, W, NW and NNW.

Concerning the K shape factor, we can see on the previous fig 20 that Windsim is closer to the measured model than WAsP, at least in the mean sectors. We can notice that concerning sector NW, which present the highest frequency, both models over estimate the shape parameter, introducing a sharper peak in the distribution, thus indicating a lower wind speed variation than the measured data model. In this case the linear model give a better result.

The same tendency is observed at higher levels (40 m and 55m). In most of sectors, Windsim gives a lower value of scale factor and higher values of shape factor, which means that Windsim model accept a higher wind speed variation. This tendency increases for the less energetic sectors.

Finally, if we consider the global distribution of Weibull, not binned in function of sectors, we notice that Windsim model give a distribution very close to the one calculated from measured data: a positive discrepancy of 0,7% for K factor and negative of 0,4% for C factor. In comparison WAsP model give a discrepancy of +3,6% for K factor and + 3,4 % for C factor.

4.4 Production estimations and comparison

A first study was carried out, comparing results between a defined year total production and a long-term estimation. In that case, WAsP overestimate the production in a 21% whereas Windsim give an overestimation of 15%. Both models are far from the real output production obtained with a significant positive error. However, numerous parameters are not taken into account in the long term/defined year comparison, on both sides of the comparative analysis: wind flow model and also production data used.

Indeed, it is absolutely necessary to define several methods of correction of the different approximations done in this first comparison, with the purpose of refining our comparison between that two models.

Correction apply on meteorological and production year 2004 data: The numerical simulations were performed using meteorological data measured on site during the operation of the wind farm. Then the mast concerned is affected by the wake effect due to the rotation of each wind turbine rotor. A brief correlation using WAsP was performed to determine a correction factor to apply on the measured wind speed to obtain a correct data to enter as input of both software.

Just as it was necessary to correct the wind data entered as input at meteorological mast level, we need also to verify the quality of the output production data. In order to approximate losses not taken into account by the wind resource assessment programs (due to grid connections, grid cuts, indisponibility, etc…), it is common to introduce a corrective factor of 6 to 8 % of losses, which is applied on the annual production estimations. However, these values are too approximative to perform a correct comparison between the two models and the real production of the wind farm. Consequently , we need to applied a filtering process on the output production data. We will apply the Robust Data Filtering Method [7] on the data of each wind turbine of the selected Wind farm. However, it is necessary to see that this process tends to slightly overestimate the annual total production.

Final Results of the year 2004 Production comparison:

Table 5 shows that the overall results given by WAsP and Windsim model are relatively close to reality. WAsP seem to keep overestimating the total estimated annual production but in more reasonable form. Windsim is more close to the value expected (real filtered power production is a little over estimated).

Table 5. Year 2004 Power Production
Real filtered, WAsP, Windsim, Windsim Refined Models

Wind Turbine	Production power data filtered	Annual power dat production	WAsP 2004 Production	Windsim 2004 Production	Windsim 2004 nested Production	Wasp discrepancy	Windsim discrepancy	Windsim nested discrepancy
1	1476.94	1836.53	2039	2004.61	1910.74	11.0%	9.2%	4.0%
2	1417.81	1758.22	1917	1936.44	1822.77	9.0%	10.1%	3.7%
3	1396.25	1932.25	1903	1745.33	1687.45	-1.5%	-9.7%	-12.7%
4	1148.90	1690.97	1951	1810.27	1799.82	15.4%	7.1%	6.4%
5	1376.02	1695.16	2051	1725.14	1721.22	21.0%	1.8%	1.5%
6	1308.60	1982.87	2088	1852.48	2003.74	5.3%	-6.6%	1.1%
7	1540.07	1905.38	1980	1992.45	1914.42	3.9%	4.6%	0.5%
8	1658.57	2027.83	2093	2122.96	2031.08	3.2%	4.7%	0.2%
9	1656.23	2103.10	2107	1880.67	2127.11	0.2%	-10.6%	1.1%
10	1637.55	2029.85	2003	2069.93	2004.76	-1.3%	2.0%	-1.2%
11	1549.71	1928.61	2087	1918.36	1922.15	8.2%	-0.5%	-0.3%
12	1578.69	1948.29	1998	1857.77	1857.68	2.6%	-4.6%	-4.7%
13	1607.56	1989.48	2117	1675.61	1918.98	6.4%	-15.8%	-3.5%
14	1699.13	2094.57	2403	2152.26	2091.13	14.7%	2.8%	-0.2%
15	1918.58	2377.76	2450	2329.75	2223.05	3.0%	-2.0%	-6.5%
16	1953.50	2394.83	2281	2091.37	2235.55	-4.8%	-12.7%	-6.7%
17	1319.60	2047.17	2158	1770.93	2084.37	5.4%	-13.5%	1.8%
18	1169.54	1833.91	2068	1892.36	1855.65	12.8%	3.2%	1.2%
19	1597.59	2111.26	1750	1319.45	2025.44	-17.1%	-37.5%	-4.1%
20	1614.79	2232.10	2254	1977.67	1884.70	1.0%	-11.4%	-15.6%
21	1937.66	2396.82	2598	1954.27	2023.97	8.4%	-18.5%	-15.6%
22	1912.29	2431.24	2440	2317.23	2321.23	0.4%	-4.7%	-4.5%
23	1917.77	2429.46	2307	2214.41	2000.04	-5.0%	-8.9%	-17.7%
24	1869.99	2389.25	2487	2438.36	2276.27	4.1%	2.1%	-4.7%
25	1911.98	2445.63	2550	2504.23	2394.42	4.3%	2.4%	-2.1%
26	1914.72	2471.57	2539	2490.17	2454.12	2.7%	0.8%	-0.7%
27	1945.63	2450.10	2507	2415.99	2322.40	2.3%	-1.4%	-5.2%
28	1776.46	2305.06	2415	2380.68	2474.98	4.8%	3.3%	7.4%
29	1947.93	2457.12	2215	2168.44	2227.88	-9.9%	-11.7%	-9.3%
30	1955.13	2476.36	2455	2336.98	2451.51	-0.9%	-5.6%	-1.0%
31	1989.74	2511.42	2398	2496.90	2441.41	-4.5%	-0.6%	-2.8%
32	2023.15	2559.56	2456	2096.71	2456.06	-4.0%	-18.1%	-4.0%
33	1919.11	2440.09	2497	2573.67	2440.86	2.3%	5.5%	0.0%
WIND FARM	**55647.194**	**71683.82306**	**73562**	**68513.87**	**69406.96**	**2.6%**	**-4.4%**	**-3.2%**

As observed in the previous long-term - year 2004 comparison, WAsP give its best results for the Wind Turbines located close to the meteorological mast (Turbine 7 to 10), WAsP keeps predicting worse the wind turbines farther away from the meteorological mast. This problem might be caused by the fact that WAsP does not take into account recirculation processes, because of the linearization of Navier-Stokes equations simplifications, quite frequent in terrain with complex orography. The performance of WAsP is higher in sites with complex roughness and simple orography. On the contrary, Windsim seem to improve handling of the orography

Nevertheless. two nesting processes in Windsim were necessary to get a relatively good accuracy in reproducing wind comportment in the selected wind farm site.
The first model, including a very large scale (covering the four wind farm of the region) gave us very bad results, not summarized in. Table 5 summarize only the two finest model (wind farm scale model and wind farm parted in three). Refining the model, using nesting procedure, gives definitively more accuracy to the model. On the previous table, it is possible to see a real improvement of the Windsim estimation (global discrepancy decrease in a 1,4%). In spite of this, it is important to notice that results obtained close to the boundaries of the model need to be treated carefully. For example, the finest model of Windsim performed parts the wind farm in three. The turbine 23 is located very close to the limit on the third reduced map and consequently we observe a real increscent of discrepancy with the second nested model.

Finally, in the case of year 2004, the meteorological mast used as predictor in both simulations has a measurement height of 55m, which is equal to wind turbine hub height. That is one of the reason of WAsP increscent of performance. The extrapolation until turbine hub height is much more reduced (still present because of changes in altitude in function of terrain) than in the long term study case, where the reference mast has a measurement height of 30m. The errors due to the application of a logarithmic profile are significantly reduced

4. Conclusion

The paper discusses the relative accuracy of the two models indicating where a more complex Navier Stokes model can produce more accurate results in complex terrain and also details the limitation of this code and the simpler linearised WAsP code to give guidance on the conditions under which each code is likely to produce reliable results.

The comparison on the way that the WAsP and Windsim reproduce wind flow at the reference meteorological mast are logic. Indeed, in the case of sites presenting a simple roughness and a high steepness, the CFD model was expected to be closer to reality. WAsP applying the logarithmic law to define the wind shear profile, usually gives an overestimated value of wind speed at wind turbine hub height. The consequence of this error is an overestimation of the wind turbines production in the long term study.
In terms of real production, the CFD model Windsim keeps being closer to reality than a linear model such as WAsP, because its better way to reproduce wind flow in steep terrain (including recirculation process). However, it is necessary to keep in mind that Windsim commits several errors.
First of all, it does not offer any model of calculus of wake effect. Consequently, it is necessary to apply a calculated coefficient or export a resource grid file to another software (WAsP or WindPro) in order to take into account these losses which could be very important in some wind farm layouts.
Moreover, the grid resolution is an high factor of prediction accuracy in the case of the CFD model. It is obvious that a refined model usually generate a better model of the wind flow, without avoiding recirculation, but could introduce troubles at boundaries. It is important also, to keep in mind that several nesting processes increases calculation time and then the simulation cost.

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References

[1] A.J. Bowen and N.G Mortensen, *WAsP Prediction Errors Due to Site Orography"* , Riso National Laboratory, December 2004, pp 28-29, pp 34-35.
[2] RISO WAsP web site, . http://www.wasp.dk.

[3] VECTOR AS Windsim, http://www.windsim.com.
[4] P. Moreno, M. Romero and A. N. Gravdhal, "*Wind flow over Complex Terrain: Application of Linear and CFD Models*", METEOTEST, Bern, Switzerland; VECTOR AS, Tonsberg, Norway. 1998.
[5] Vestas Web site Windsim,http://www.vestas.com.
[6] AWS TrueWind, LLC "*Estimation of the Long-Term Average Wind Speed and Energy Production at the Proposed. East Mountain Wind Project Site*".
[7] P.S. Jackson, J.C.R. Hunt, Turbulent wind flow over a low hill, Quart. J. R. Met. Soc. 101 (1975) 929-955.
[8] P.J. Mason, R.I. Sykes, Flow over an isolated hill of moderate slope, Quart. J. R. Met. Soc. 105 (1979) 383-395.
[9] I. Troen and E.L. Petersen*, "European Wind Atlas"*, Riso National Laboratory, 1989. pp 389.
[10] R. Derickson, M. McDiarmid, B. Cochran and J.A. Peterka, "*Wind Energy Explained, Theory, Design and Application*",. ", WILEY, University of Massachusetts, 2002, pp. 50-78, pp 370-409.
[11] Instituto Nacional Meteorología , ttp://www.inm.es.
[12] B. Schaffner and A. N. Gravdhal, *"Wind modelling in Mountains: Intercomparison and Validation of Models*", ECOTECNIA, Barcelona, Spain; VECTOR AS, Tonsberg, Norway. 2003.

[13] A Llombart, C. Pueyo, J.M. Fandos, J.J. Guerrero, "*Robust Data Filtering in Wind Power Systems*" February 2006, European Wind Energy Conference & Exhibition, EWEC. 2006
[14] A. Llombart, S. J. Watson, D. Llombart and J.M. Fandos; *"Power Curve Characterization I: improving the bin method*" ICREPQ, 2005