Wind energy utilization at Hiiumaa, Estonia;
Wind Atlas, Wind resource map, wind energy workshop and proposals for ongoing work

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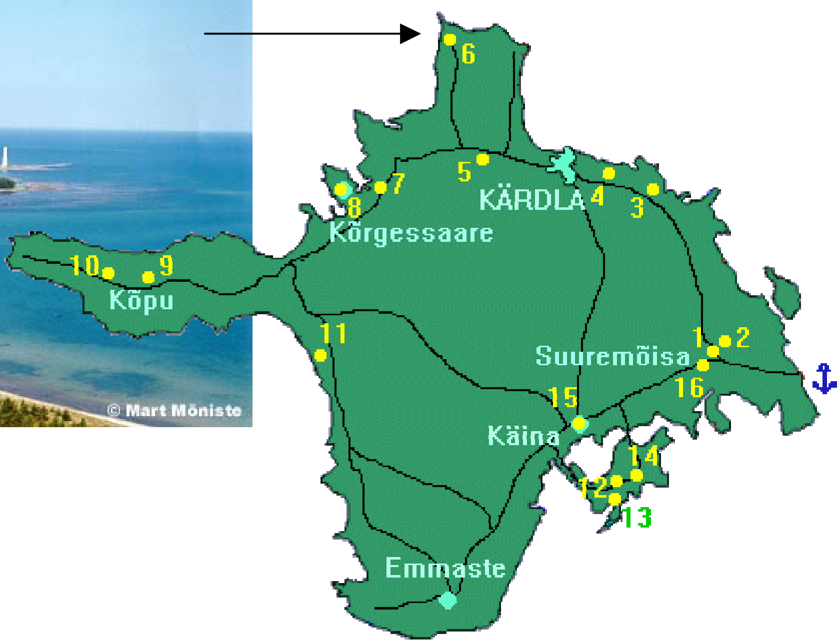
Period: Genvind, Danish WTG manufacturer, initiated the project in 1993. Due to the bankruptcy of Genvind the project were stopped, but "reopened" in 2000 due to a contract between Carl Bro Consulting group and the Danish Ministry of Energy- and environment.

Abstract: This report describes the development of a Wind Atlas for Hiiumaa, based on meteorological measurements at Kootsaara in 10 and 18 m a.g.l. The wind data has been analysed and cleaned for local terrain conditions based on the Wind Atlas Method (WAsP), RISØ. The resulting data files (the Wind Atlas) can be downloaded for use from WindPRO. There are relative high uncertainties primary due to the short period with available data and problems with the wind direction logger. A wind resource map is established for the whole Island Hiiumaa and a workshop held in October 2001 is described. Finally some proposals on ongoing work are given.



Content:

1 Introduction

1.1 Background

This Project is a subproject to the efforts by DEPA to finalise activities implemented during 1993-94. The project "Potential Of Wind Power In The Baltic States" included a wind turbine and a wind atlas for Latvia and Estonia. During the project execution Genvind was main contractor and EMD were subcontractor. Due to bankruptcy of Genvind, only the wind turbines were partly completed. However, the wind atlases were never completed to a point made operational for planners and investors.

A wind atlas is a set of wind data files describing the overall wind conditions for the region. These could be used for model calculation of expected wind energy output any place in the region. The wind atlas method is based on the wind atlas calculation model, developed by RISØ.

For Estonia, one set of 10-year data from Hiiumaa, Kärdlu, was delivered.

In Estonia and Latvia a UNDP project for creation of wind atlases is ongoing. This project includes wind measurements to create new and better wind data for preparation of a wind atlas. The UNDP project does have nearly the same objective as the EMD wind atlas project from 1993.

In Estonia activities are progressing. In Latvia the activities has been more or less stalled as The Meteorological Office in Latvia claim that data has been delivered (to EMD) and no wind atlas returned. Consequently, data has not been made available.

As the activities are ongoing in Estonia, this project will contribute to the planning steps following completion of a wind atlas for Hiiumaa. A major contribution is to demonstrate creation of a wind resource map based on a wind atlas for the island Hiiumaa and a workshop on that issue arranged. The workshop will also be open for participation of Latvians with interest in wind energy.

A resource map is a visualisation of the wind atlas (the .LIB files) and inclusion of the terrain to locate the resources of an area. The map is used for planning purposes and for identification of sites for investors.

1.2 Objectives

The overall objective of the Wind Baltic II project is described in common TOR.

The specific objectives of this part is:

a) Prepare a wind resource map showing the wind energy potential for Hiiumaa. Responsible: Energy and Environmental Data
b) Training courses in use of wind atlas and wind resource map for planning. Responsible: Energy and Environmental Data

1.3 Outputs

The outputs from this part of the project are:

A report, describing methodology, data, and results (including evaluation of data from existing wind turbines). A part of the report is a disc with the data ready for use as .LIB files. The report and data will additionally be accessible at the Internet at http://www.emd.dk/, to where links from others can be established.

2 Wind Atlas for Hiiumaa

2.1 Methodology

To prepare a Wind Atlas – or as we prefer to name it, a set of wind statistics (or regional wind climates or .LIB files) – the Wind Atlas method is used. This is comprehensive described in the book "European Wind Atlas", which can be ordered by RISØ at http://www.windatlas.dk/

Basically the figure 2 on next page from European Wind Atlas, RISØ, describes what it is all about.

Based on measured wind data (speed and direction), the data are cleaned with respect to the local terrain conditions around the measure mast:

- Sheltering obstacles
- The roughness of the terrain
- The orography (the height contours of the landscape)

Then a regional wind climate is calculated, which consist of a table with Weibull A and k parameters for:

- Each of the Roughness Classes 0, 1, 2, 3 (4 in total)
- Each of the heights 10, 25, 50, 100, 200m agl (5 in total)
- Each of the directions N, NNE, ENE, E, ..., NNW (12 in total)

This gives a total of 4x5x12 = 240 Wind Speed Distributions.

A wind distribution is described by the Weibull A and k parameters, where A = approximately 1.126 x W_{mean} and k is the shape factor – examples are given in figure 1 below.

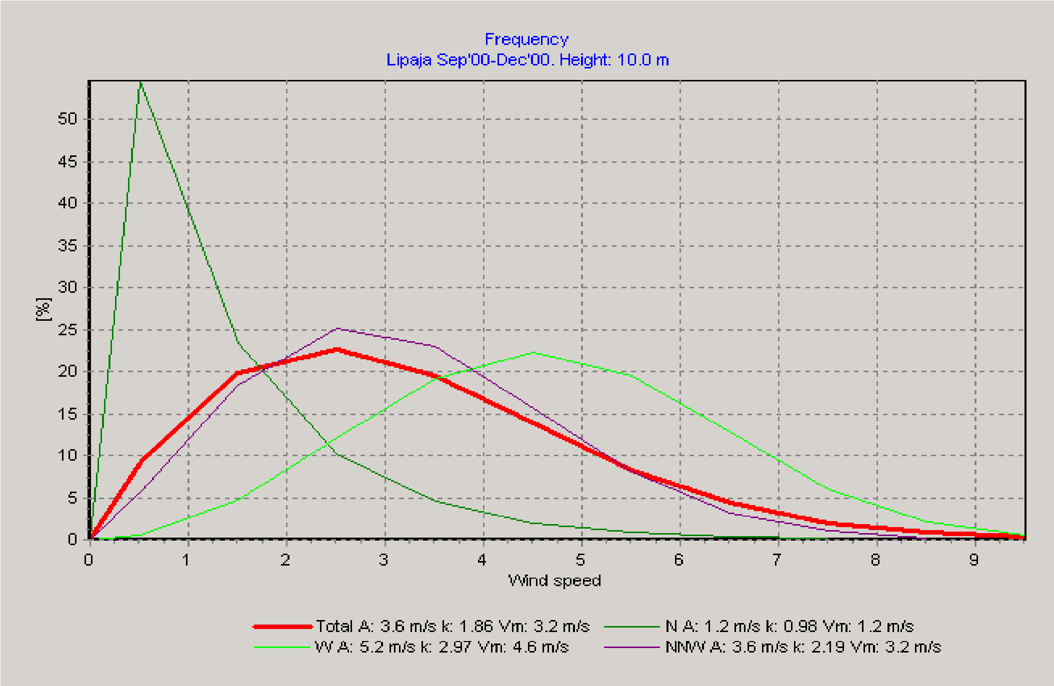


Figure 1 The Weibull function describes the typically seen wind distributions with just 2 parameters, A and k. Here 4 examples of combinations are shown – high k value means more concentrated wind within a small wind speed interval – the A is proportional with mean wind speed.

With these Wind speed distributions, any site in the region which has the same regional wind climate (normally within 50 – 100 km radius, when the terrain is not to complex), can be calculated by transforming the data backwards through the same models **at the specific site**, typically WTG site, correcting for:

- Sheltering obstacles
- The roughness of the terrain
- The orography

The most critical aspect of the wind atlases is their quality, which may vary significant. An error margin of 50% in the estimated energy production is easily generated simply due to the fact that a Wind Atlas of poor quality was used. It is therefore important to crosscheck the applied Wind Atlas with other “neighbouring” Wind Atlases, and preferably make test calculations for existing WTG’s in the region, which have been operating for some years.

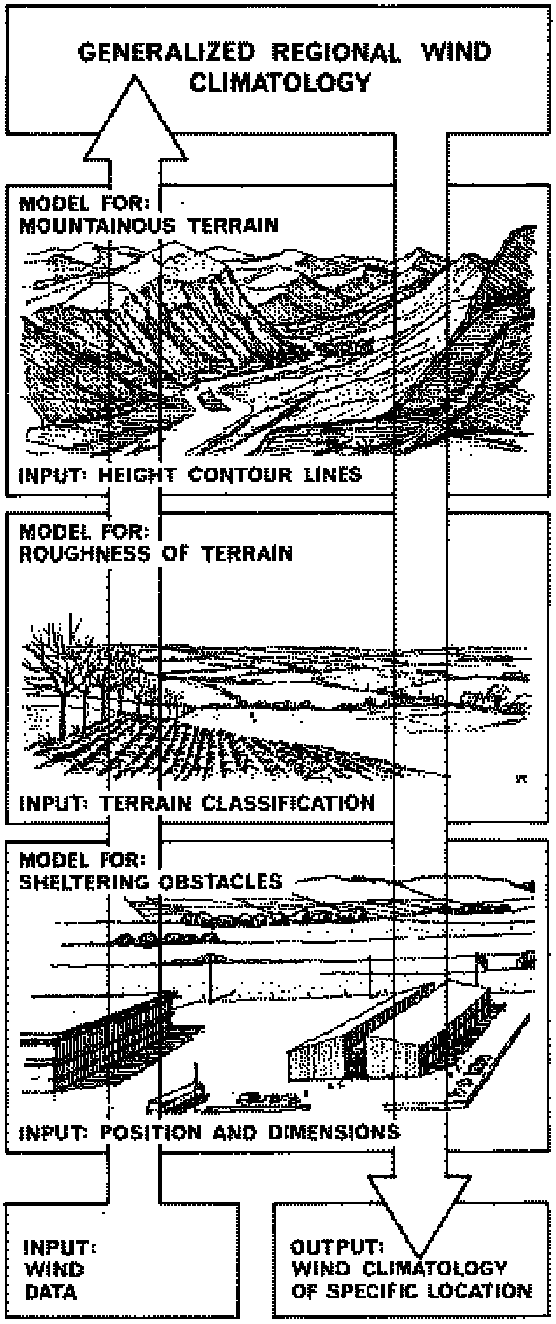


Figure 2 The principle in the Wind Atlas method

2.2 Software tools used.

The "basic" software – the "calculation engine" for performing the calculations is the WAsP software tool from RISØ, Denmark.

In this project, the WAsP tool is only used as calculation engine – all data handling, administration and report printing is done with the WindPRO software tool from EMD, Aalborg (www.emd.dk).

One of the strong facilities in WindPRO is the background map handling, which make the terrain classification easier and more reliable due to the geographic/graphic overview.

2.3 Data

First part of establishing a Wind Atlas is collecting the needed data. These are:

1. Maps and coordinate system used for the maps
2. Wind data/measurements and position of the meteorological mast

The data must be supplemented with a terrain description, which requires:

3. Height contours (Orography)
4. Roughness classification
5. Local obstacles

Before calculation of a Wind Atlas it is important to long term correct the wind data, while these in this case only are measured in a shorter period (8 months):

6. Long term correction of wind data

Then finally the wind statistic can be generated

7. Generation of wind statistic

The 7 steps will be described in the following:

The following data was available to EMD for Hiiumaa:

2.3.1 Maps and coordinate system used for the maps

Background map1: 50.000 covering the whole island and 1:350.000 covering the island and the surrounding land and sea in a radius of app. 30 km from Hiiumaa.

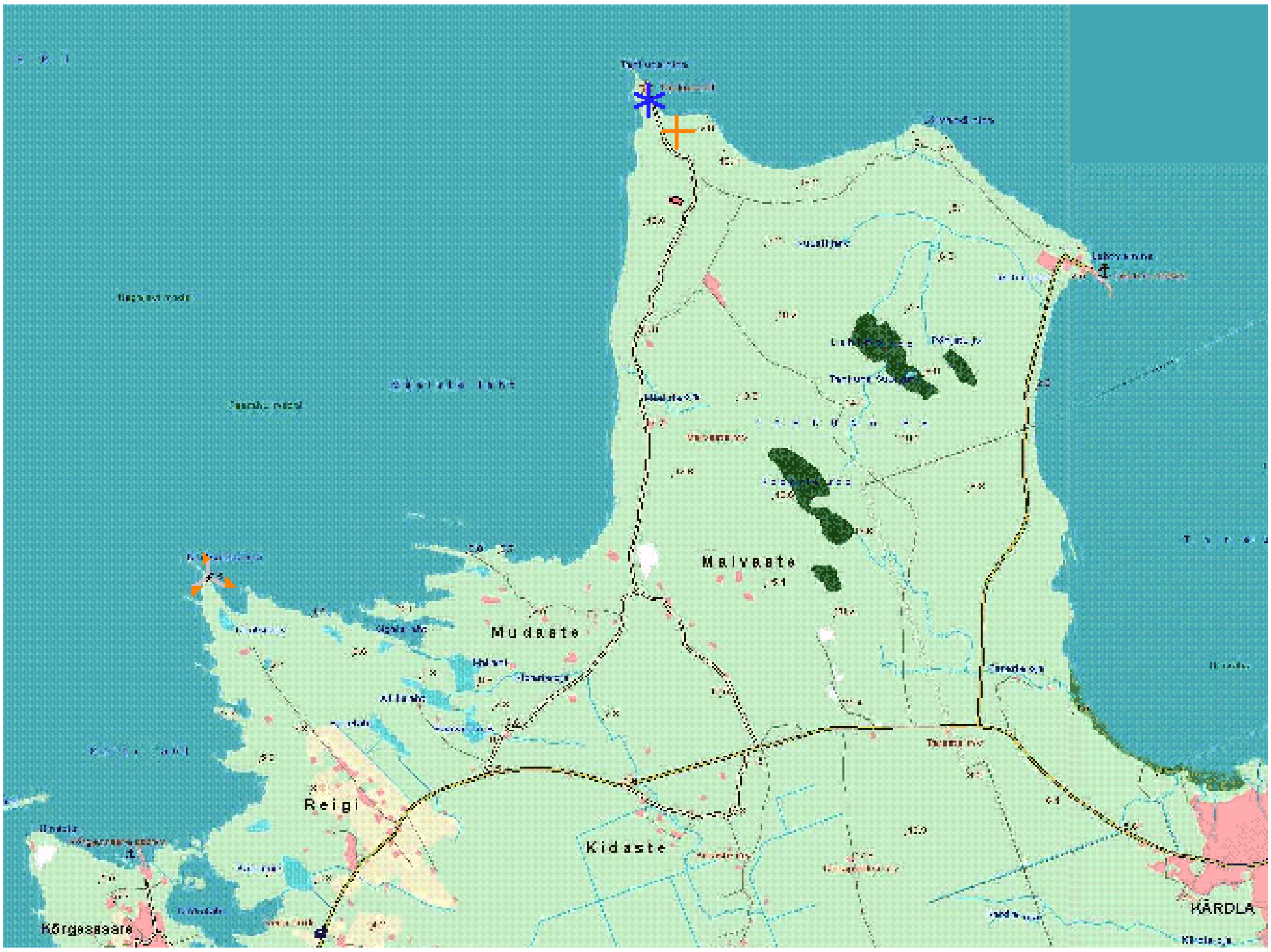
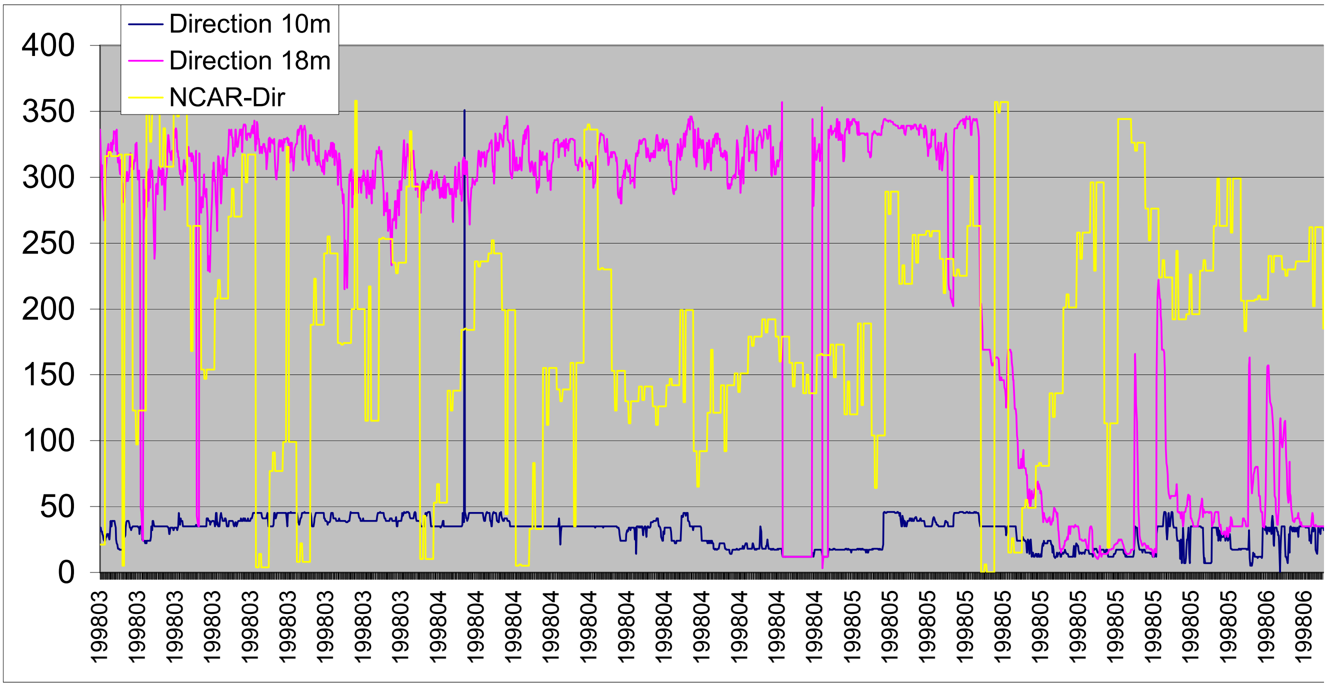


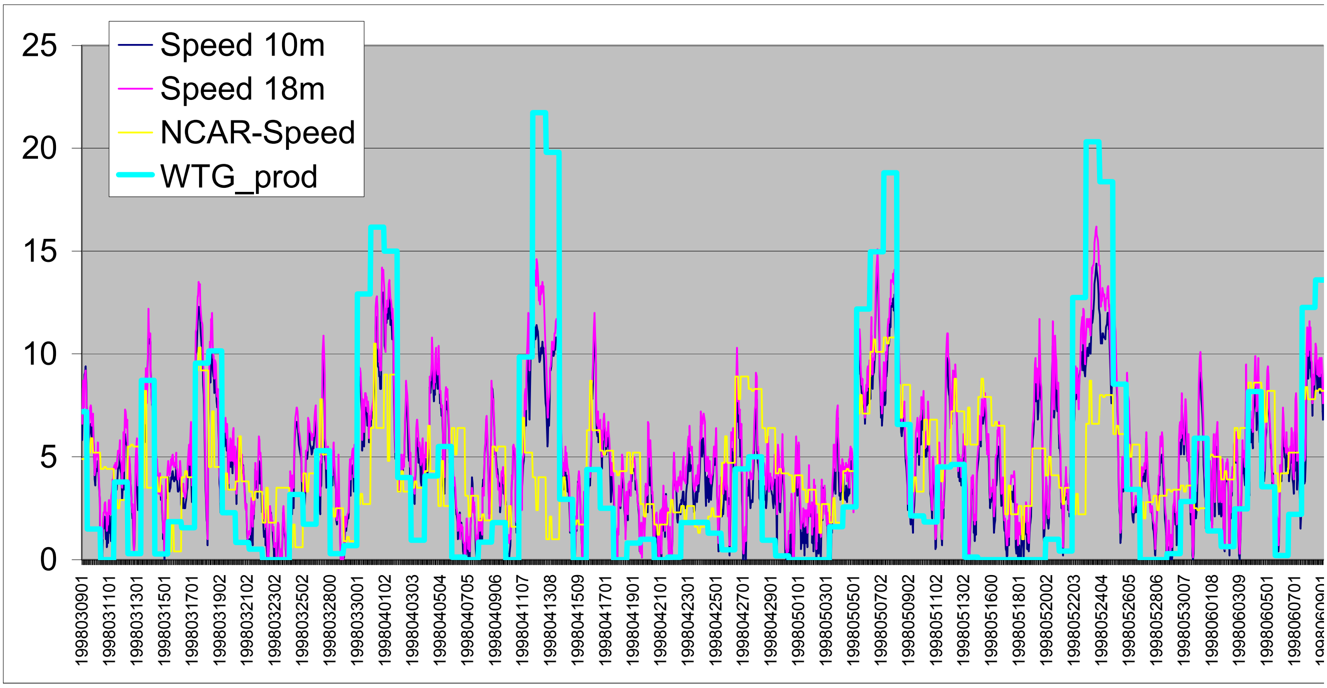
Figure 3 Map showing the WTG position (North) and the measure mast at the north-western peninsula Kootsaara nina.

2.3.2 Wind data/measurements and position of the meteorological mast

Wind data was available for 8 month, measured in 10 m and 18 m a.g.l. (9/3-98 – 8/11-98) but due to defect wind vanes the wind direction data had to be replaced with general data from a dataset called NCAR, see below.



Comparing the wind directions show very bad correlation. It seem that the wind direction sensors at the Met mast does not work. Even though the NCAR data direction normally not should be used to a detailed purpose as generating wind statistics, this is recommended in this case, while nothing better is available.



The wind speeds look much better. The two measure heights follow each other very well, and compare also well to NCAR. Finally they also compare well to the WTG production.

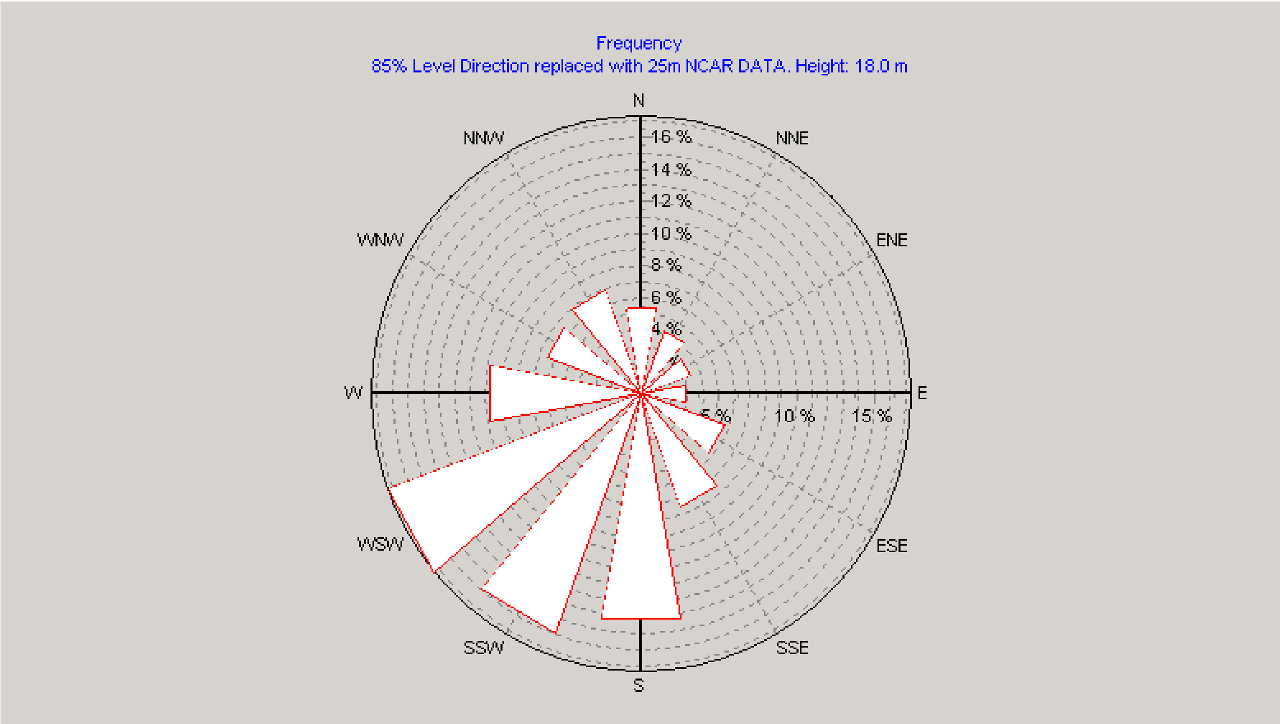


Figure 4 The direction distribution of the measured wind data could not be given by the local measured data and therefore a substitution with NCAR direction were performed. This of cause increases the uncertainty.

NCAR is geotropically wind data simulated with a large climate model, based on a very large number of measurements. The NCAR data are available (for free) at the Internet with 6-hour values, back from 1948 and updated monthly. EMD has developed routines to extract the data and calculate these down to a specific height above ground level at a specific roughness length.

2.3.3 Orography

Height contours (Orography) was delivered to EMD as a DXF-file (Drawing Exchange Format), but without any information on the elevation of the height contour lines. This was reconstructed by EMD. See map with orography in next section.

2.3.4 Roughness

Roughness classification of the island was performed by EMD based on the 1:50,000 maps, but also photos from the Internet of the island and our visit at the island in October 2001 have been used.

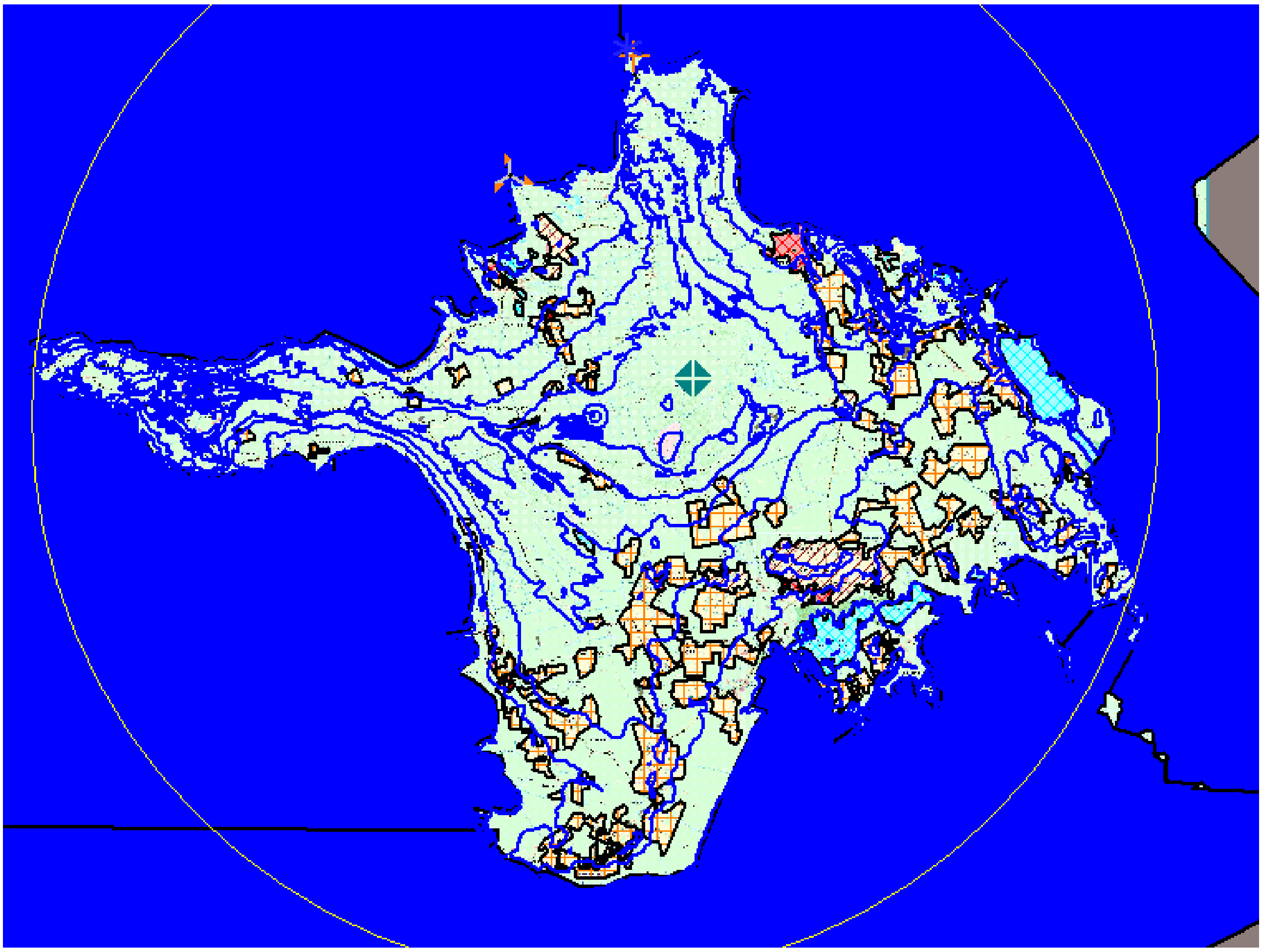


Figure 5 Map showing the height contour lines and the digitised roughness areas. Most of the island is covered with forest - only the orange-hatched regions are more open regions (RCL 1,2), where the forest is given RCL 2,8 and the Water RCL 0. Highest point is 65m and is found at the western peninsula.

2.3.5 Local obstacles

No local obstacles around the meteorological mast were included. It was not possible because of the bad quality of the background map and because EMD has not performed a site inspection around the meteorological mast. In the calculation of the wind resource map, local obstacles normally are not included. These have to be taken into account at the detailed planning of a WTG project. Especially at a site as this (Hiiumaa), heavily covered with forest, local obstacles can be deciding on local wind conditions. If a WTG project is placed inside a forest region, it can be necessarily to simply calculate with a lover hub height, responding to the height of the forest (displacement height, often recommended to 2/3 of obstacle height, but at dense obstacles op to the obstacle height.

2.3.6 Long term correction of wind data – use of data from existing WTG

Before establishment of a wind statistic, the wind data has to be long term corrected. We use wind index and the existing WTGs production data to perform this.

An existing WTG is in general very good wind data measurement equipment. The table below show the WTG production corrected to long-term production with different wind index.

Production on WTG Tahkuna(kWh) and wind index				
Year_month	kWh/month_ GV150	NCAR57_22 Windindex	NE-windindex_DK	NCAR60_22 Windindex
Sum	988,980	3,535	3,385	3,595
Avg	329,660	98	94	100
WCP		**335,709**	**350,599**	**330,091**

Some availability losses must be expected. To check the wind data we need availability corrected production data. If we use the lowest WCP (330 MWh) and assume availability of 97%, the long term and availability corrected production will be 330/0.97 = 340 MWh. Even if there has been no availability loss, the 340 MWh seems reasonable as a mean value of the different WCP's.

When we look at the parallel time series, see below, we believe most at the NCAR indexes. These seem to give rather good dynamic behaviour compared to WTG production. The advantage with NCAR data is that we have them for more than 30 years.

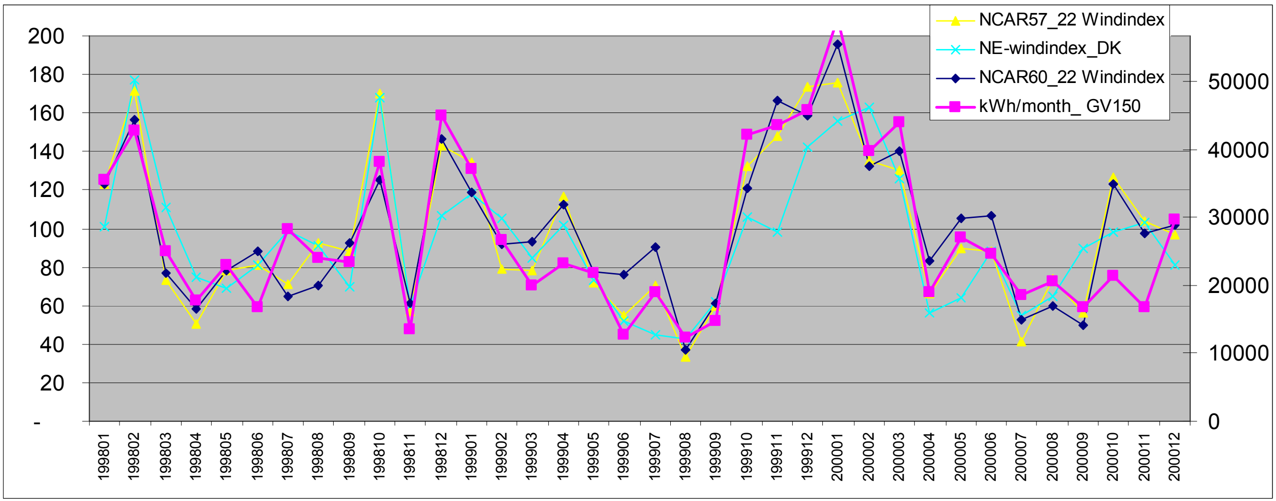


Figure 6 Wind index compared with monthly energy production for the 150 kW WTG at Hiiumaa.

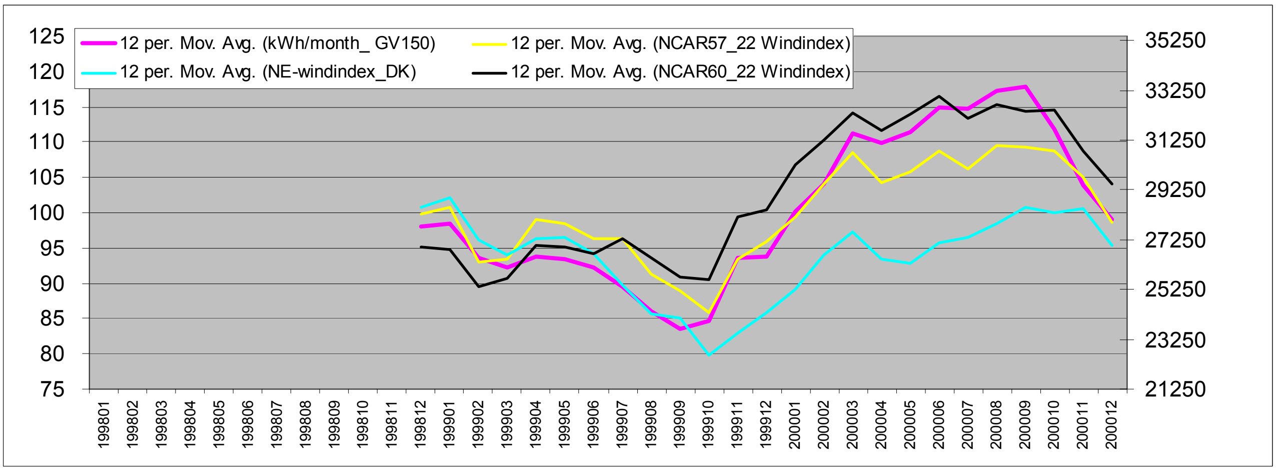


Figure 7 As previous graph, but 12-month mean values. For both graphs above, the right axis are adjusted so that 340 MWh/12 = 28,3 MWh corresponds to a wind index of 100%.

The visual inspection of the dynamic behaviour of the WTG production compared to NCAR wind index gives a good reason to use this for long term correcting the measure period.

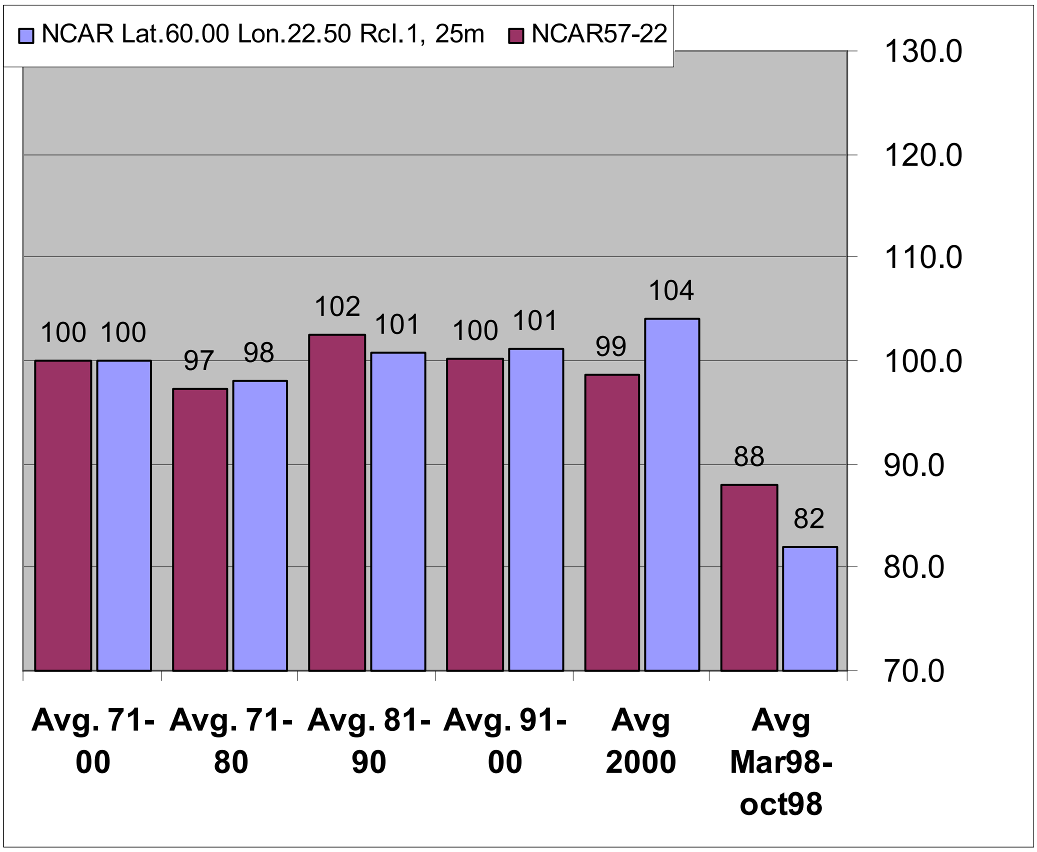


Figure 8 The NCAR index for the two nearest NCAR points to Hiiumaa. For March98 – Oct98 the indexes are 82 – 88 %.

For the period of special interest, the March-98 – Oct.98, where we have measured wind data, the two indexes say 88 and 82. – So an energy level of 85% would be the "average", but a more the more conservative value 87% is chosen. This means that calculating based on the measured wind data should give around 87% in calculation of the long term expected. For this we compensate by giving the wind statistic we generate based on the 8-month measurements a “regional correction factor” of 1,15 (= 1/0.87). This means that at any calculation where this wind statistic is used, 1,15 automatically will be multiplied on the calculated energy yield. Note: This is a special WindPRO feature that will not work using the data from WAsP direct or other software tools.

2.4 Generating a wind statistics/ Wind Atlas Data

Analyzed wind data are now converted into a wind statistic (wind atlas of the regional wind climate). As previously described a wind statistic are the wind observations cleaned with respect to site-specific conditions (terrain roughness, hills and local obstacles) resulting in a neutral set of data usable for a local region.

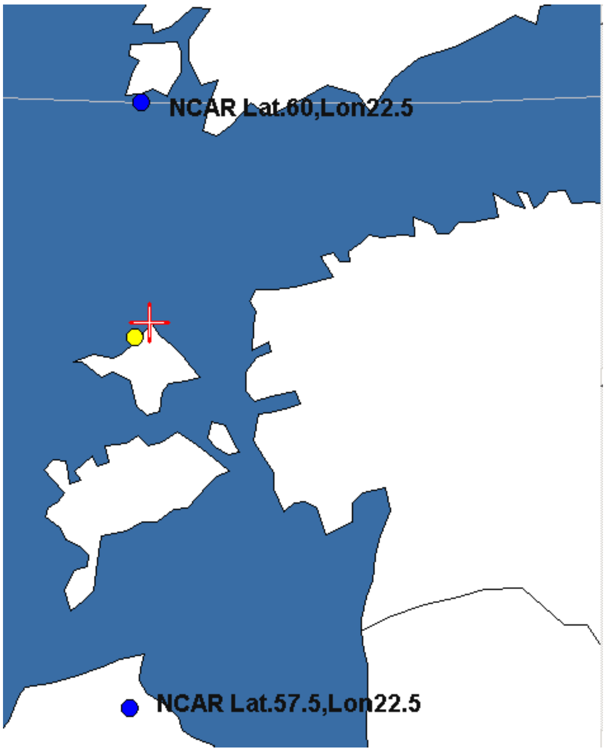


Figure 9 The 2 nearest NCAR data points 101 km north of site and 177 km south of site.

Country	Source	Name	Distance	Energy	WTG...
Lat.60	NCAR	NCAR data 6h-850hPa upper air data - ...	101.5	85.5	90.3
Lat.57.5	NCAR	NCAR data 6h-850hPa upper air data - ...	177.0	93.0	96.2
	[redacted]				
Estonia	USER	18,0 m Hiiumaa_Tuula_Direction replac...	9.2	80.0	77.4

Figure 10 The WTG energy level for the NCAR data points are in mean 93%. The local generated wind statistic has 77.4% - with correction factor 1.15 it is 89%. So there are quite well agreement for this location – often the NCAR data over predicts 5 – 15% in the northern regions.

2.5 Control and verification of the generated wind statistic

WAsP interface - Main Result

Calculation: 150 kW WTG at Tahkuna

Name WAsP Calc Tahkuna
Site Coordinates Local East: 418,915 North: 6,550,965
Air density 1.270 kg/m3

Calculation is based on "WAsP Calc Tahkuna", using WAsP (WASP5XL 16-12-1998 13:40) to convert the wind statistics and the terrain classifcation to a site specific wind speed distribution.
Using the selected power curve, the expected annual energy production is calculated.

Wind statistics EE 18,0 m Hiiumaa_Tuula_long termcorrected
Regional Correction Factor 1.15
Based on NCAR-data and existing WTG production indicates 80-88 % of nergy level in measure period, 87% is choosen - this gives 1,15 in correction factor.

Scale 1:25,000

Site Data

Terrain classification

Roughness classification (Roughness class)

Sector	Roughness at WTG	Distance to 1. change [m]	Roughness after 1. change	Distance to 2. change [m]	Roughness after 2. change	Distance to 3. change [m]	Roughness after 3. change	D 4 [m]	R 4	D 5 [m]	R 5
0 N	2.8	244	0.0								
1 NNE	2.7	209	0.0								
2 ENE	2.8	170	0.0								
3 E	2.8	171	0.0								
4 ESE	2.8	204	0.6	681	2.8	1,425	1.0	2,300	2.8	6,713	0.0
5 SSE	2.8	9,469	2.0	12,444	2.9	15,252	2.3	27,633	1.1		
6 S	2.8	575	2.0	975	2.5	6,711	2.7	26,007	1.8		
7 SSW	2.6	182	0.0	8,853	1.0	20,753	0.7	21,868	2.4	25,384	0.0
8 WSW	2.7	120	0.0								
9 W	2.8	111	0.0								
10 WNW	2.7	119	0.0								
11 NNW	2.6	180	0.0								

Calculation Results

Key results for height 50.0 m above ground level
Wind energy: 4,063 kWh/m2; Mean wind speed: 7.1 m/s; Mean roughness: 0.6
Key results for height 40.0 m above ground level
Wind energy: 3,735 kWh/m2; Mean wind speed: 6.9 m/s; Mean roughness: 0.6

Calculated Annual Energy

WTG type						Power curve		Annual Energy		
Valid	Manufact.	Type	Power [kW]	Diam. [m]	Height [m]	Creator	Name	Result [MWh]	Result-10% [MWh]	Mean wind speed [m/s]
No	VIND-SYSSEL		150	21.8	30.0	EMD	Tripod Jerlsev 86 1.225 25.00 0.60	339.5	306	6.5

Figure 11 The WindPRO print out of the calculated energy yield show 339.5 MWh - very close to the expected actual long-term production of 340 MWh/year. There are of cause still uncertainties, mainly the description of the local obstacles, but also the power curve is uncertain. Full documentation of the calculation is enclosed in appendix E.

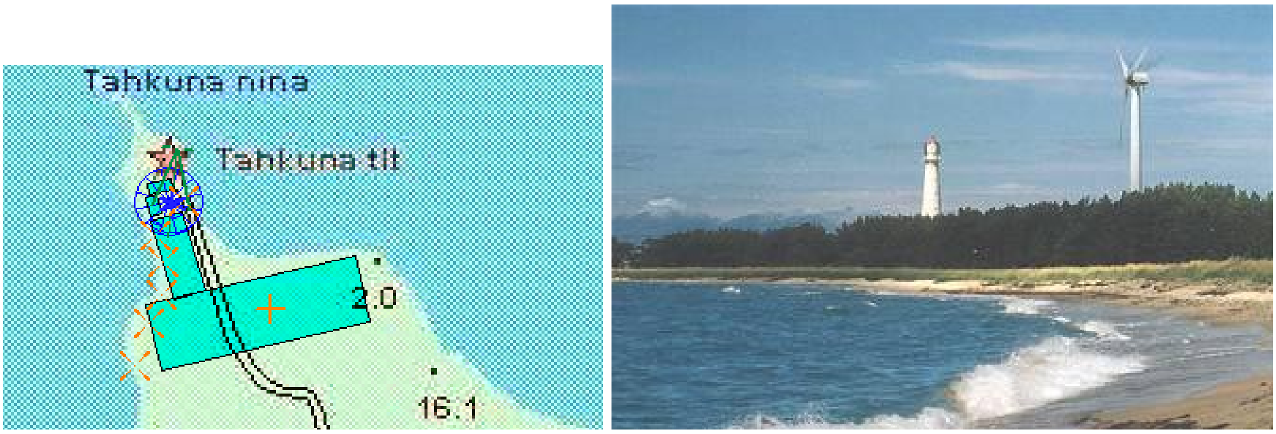


Figure 12 To the left are shown how the local obstacles are marked. To the right a photo taken from south west (source: Homepage of the Hiiumaa WTG: http://www.riik.ee/bka/hiiumaa/projektid/tahkuna/index.html)

The local obstacles around the WTG are difficult to describe precisely due to the limitation in the calculation model (only handling rectangular obstacle elements).

Figure 13 Photomontage, where the 150 kW WTG is rendered on top of a photo taken from the lighthouse. (Originally photo from Genvind, 1992)

Figure 14 A few more air-photos from Hiiumaa home page.

3 Wind resource map of Hiiumaa

A Wind Resource Map is a useful tool, which has many purposes, for example in Wind Energy Planning, where the search for good Wind Energy areas is a part of the process.

For Hiiumaa a wind resource map is calculated with a resolution of 250 m based on digitised height contour lines, roughness lines and the generated wind statistic based on local measurements described in previous text. WAsP is used as calculation engine.

Note that local obstacles not are included in a wind resource map calculation. This means that when using the map, one has to be very carefully in regions close to forest or inside forest, where the wind resource can decrease dramatically relative to what can be seen on the map. On Hiiumaa, which are relative flat and covered with forest, it is of very high importance to site eventually WTGs close to the coastline. The best spots seem to be at Kalana regarding the wind resource, but combined with grid accessibility, the south tip at Emmaste will probably be best suited for WTGs.

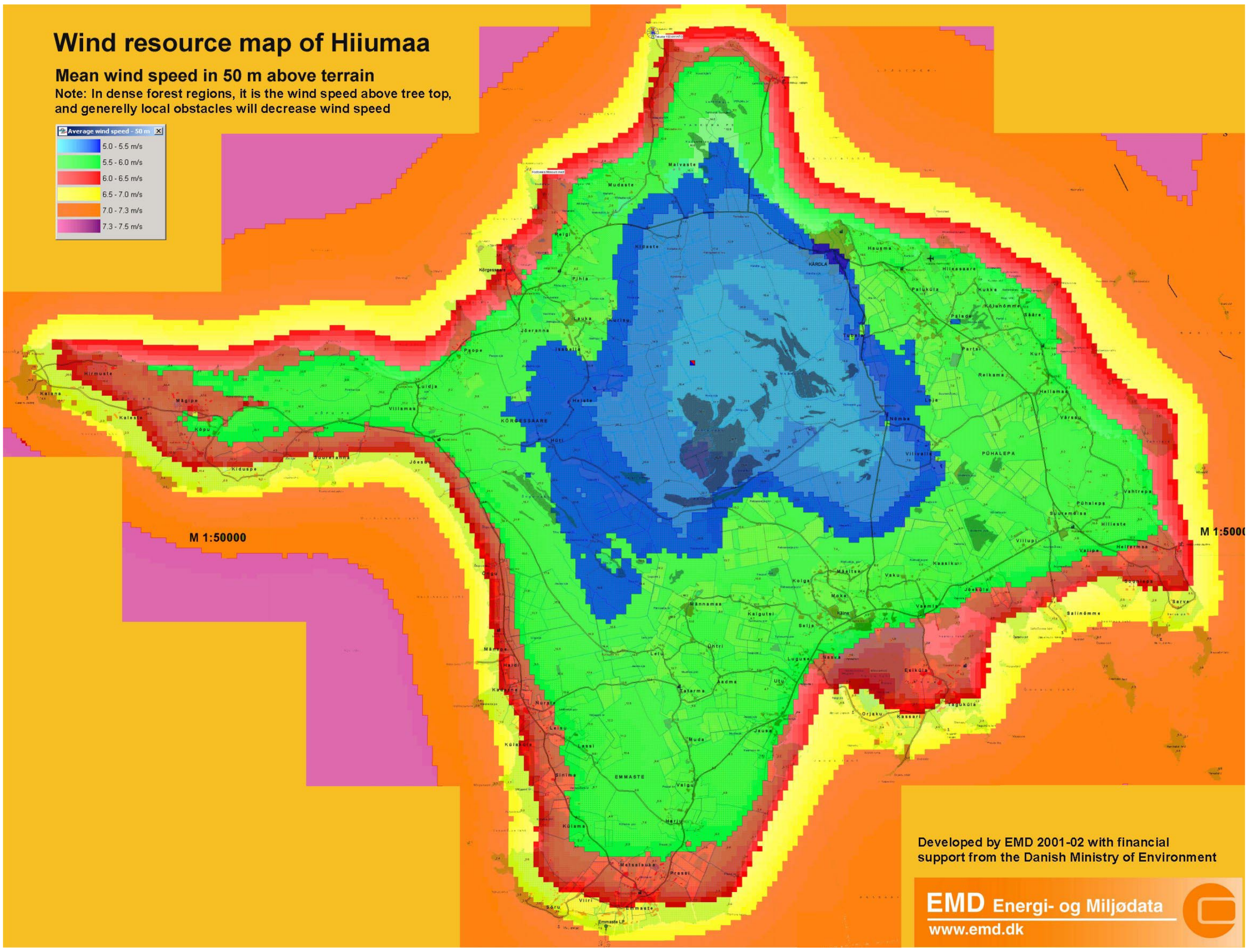


Figure 15 The wind resource map can be down loaded in a high-resolution version on www.emd.dk (menu "Documentation").

4 Wind energy workshop in Kärdla, Hiiumaa

4.1 Objectives of the workshop

The objectives of the workshop were the following:

1. Give the participants a general introduction to the theory behind Wind Turbine Generators (WTG's)
2. Transfer some of the Danish experiences e.g. concerning economy, ownership, planning, policy and legal frames.
3. Give the participants a thorough introduction to the environmental impacts of WTG's and how to calculate or illustrate those effects.
4. Give the participants a thorough introduction to analysis of wind data, establishing a wind statistics and calculating the energy production of proposed wind parks.
5. Train the participants in such calculations with practical exercises on PC's
6. Making the practical exercise more realistic by visiting the places for which exercises and calculations were performed.
7. Introducing the Latvian Wind Atlas.

A detailed workshop programme, participant list and course certificate is enclosed in appendix.

4.2 Evaluation of the workshop

Our evaluation of the workshop is the following:

1. The participants from Estonia and Latvia represented a good variety of institutions:
   - Government offices
   - Utility companies
   - NGO organisations
   - Private companies
   - Universities

2. There was a very strong interest for the workshop and the number of participants was far above average.
3. The participants were in general very keen learners and went through the practical exercises with great enthusiasm.
4. Several of the participants expressed a strong interest in a follow-up course focused on going in detail with the Danish approval process (e.g. in collaboration with a Danish county) and the economy aspect of WTG project (what is needed to make a project economical feasible).

4.3 Photos from the workshop

5 Proposals on on-going work at Hiiumaa

With Ruben Post, manager of the Center at Hiiumaa, where the workshop was held, we discussed the possibilities for further wind turbine development at Hiiumaa. This resulted in the below recommendations.

5.1 Background.

There are several proposals on permission request for WTG projects at the local authorities and the for grid connection permission at the utility. Many seem very little seriously.

There has been no planning process and is lack of experiences/capacity on treating the requests at the local authorities.

What should be done?

5.2 Proposal:

1. There should be given a set of requests to the Proposers, which on the one hand not include so complicated and expensive investigations, that the "real" local initiatives will be kept out, but on the other hand request so much information, that the "non serious" proposals can be taken out. E.g. information of exact site, WTG size, position and names of nearest neighbours (for noise and flicker evaluation), photo of site from different angles etc. should be included. And most important a good map showing all relevant positions (Proposed WTGs and neighbours).

2. All the proposals shall be treated together in one "common evaluation" for each region, so that partly the visual considerations, partly the grid situation can be seen together.

3. The local benefits and thereby local acceptance should be described in order to encourage a development where the local society get an advantage – and best representation in local ownership, so not only a "one time benefit" but a continuously benefit from the operating WTGs are placed locally. But also local labour in connection with establishment and operation of the WTGs should be mentioned as an important factor in evaluation of the project alternatives.

4. The expected financing conditions and the expected cash flow of the proposed project should be described based on at least 2 scenarios on price paid per kWh, which could be 2 scenarios, given by the Utility or Government.

The evaluation of the proposals could be supported from Denmark, where all projects could be "lined up" in very comparable form, combined with planning know how transfer to Estonian planners. The final output of the work should be a presentation of a priority list to the local politicians for final decision. Grid connection capabilities shall be considered, so that a “plan A” based on existing grid connection capability can be started, and a “plan B”, based on extended grid connection or local storage systems or combinations can be researched.