
**SIRAGRUNNEN**, NORWAY
**200 MW WIND FARM**

3 – 8 MW turbines

EMD International A/S
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# MICRO SITING & ENERGY YIELD


**Illustration of 8 MW layout with Google Earth.**

## *Assignment*

| | | |
|---|---|---|
| Client: | EMD: | *Rev.1 april 25, 2008*<br>*Rev.2 August 12, 2008*<br>*Rev.3 januar 16, 2009* |
| Siragrunnen AS | Project Manager:<br>(Signature) | Per Nielsen, EMD-DK |
| | Checked by:<br>(Signature) | Mads V Sørensen, EMD-DK |
| Att: Harald Dirdal | Document: | C:\Users\per.EMD\Documents\WindPRO Data\PROJECTS\Norge\Siragrunnen\Rapporter\Siragrunnen_energycalc_micrositing_rev3.doc |

Content of report:



**Appendices:**

| | | |
|---|---|---|
| Appendix | A | Microsoft Word - EMD-Siragrunnen_report-1-Wind-evaluation.pdf |



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## *Micro siting and estimation of energy production for the project:*

SIRAGRUNNEN, NORWAY

## *Summary*

Revision 1 fixes the wind farm size to 200 MW.
Revision 2 includes fishing restrictions and the guaranteed offshore power curve from Repower.
Revision 3 increase the utilized water depths from 35 to 45m and only 200 MW layouts.
Only the rev.3 is shown in details in this report. In the summary also the results from previous versions is shown.

13 different wind farm layouts has been designed, with following results and remarks on restrictions:

| WTG type | WTG | Number | Windfarm | Calc.Gross |
|---|---|---|---|---|
| | MW | | MW | GWh/y |
| V90-3.000 | 3 | 61 | 183 | 577,1 |
| SWT-3.6-107-3.600 | 3,6 | 44 | 158,4 | 590,5 |
| Repower #) | 5 | 33 | 165 | 659,4 |
| DUMMY | 8 | 23 | 184 | 781,9 |

All 7 x 8 RD spacing, 35 m max water depth

| WTG type | WTG | Number | Windfarm | Calc.Gross |
|---|---|---|---|---|
| | MW | 0 | MW | GWh/y |
| V90-3.000 | 3 | 67 | 201 | 655,9 |
| Repower #) | 5 | 40 | 200 | 780,2 |
| DUMMY | 8 | 25 | 200 | 826,9 |

# Based on temporary power curve from Repower
Rev.1 All based on 200 MW, 35 m max water depth

| WTG type | WTG | Number | Windfarm | Calc.Gross |
|---|---|---|---|---|
| | MW | 0 | MW | GWh/y |
| V90-3.000 | 3 | 67 | 201 | 646,1 |
| Repower | 5 | 40 | 200 | 714,8 |
| DUMMY | 8 | 25 | 200 | 795,4 |

Rev. 2 All 200 MW with fishing restrictions, 35 m max water depth

| WTG type | WTG | Number | Windfarm | **Calc.Gross** | |
|---|---|---|---|---|---|
| | MW | 0 | MW | **GWh/y** | Change |
| V90-3.000 | 3 | 67 | 201 | **657,8** | 1,8% |
| Repower | 5 | 40 | 200 | **720,0** | 0,7% |
| Repower Opti | 5 | 40 | 200 | **728,4** | 1,8% |
| DUMMY #) | 8 | 25 | 200 | **805,9** | 1,3% |

Rev.3 All 200 MW with fishing restrictions and increased water depth to 45m. The increase relative to previous calculation is given in rightmost column.



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As seen in the table, expanding to 45m depth adds up to 1.8%. In chapter 6.4 the water depth graph show that only few turbines are outside the old 35 m depth restriction.

Losses due to grid, availability etc. round 8-10% must be expected, these are not subtracted in figures above.

The calculations hold large uncertainties due to the wind data basis. Local measurements are recommended.

In the calculation following up and down sides shall be mentioned:

No buildings around Lista Fyr mast is included in the "terrain cleaning" of wind data, an upside rough estimated to; 0 – 5%.
Long term correction is not performed, based on NCAR 30 year data this holds an upside of round 2%
PARK model is run with inclusion of increased roughness inside wind farm area – this might be a slightly conservative approach, an upside of 2 – 4%.
WindSim analyses indicate less wind relative to WAsP modeling; this holds a down side round 2.5 %.

So there are included slightly more upsides than downsides making the calculations slightly conservative, although we are here talking few percentages, where the uncertainties due to large extrapolations as well horizontally as vertically combined with lack of knowledge on the quality of the wind data from Lista fyr and the possible not found Mesoskala effects, is much larger.



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# 1. Site, project and purpose description.

The site is located in southeast part of Norway, starting round 2 km from coastline. The area with water depths below 35 m is round 25 km$^2$.

The purpose of this report is to describe the performed micro siting based on turbines from 3-8 MW. The goal is to establish a wind farm up to 200 MW. Additionally energy production is estimates based on wind data from the nearby Lista Fyr. The winddata cleaning and establishment of a wind statistics is described in separate report “EMD-Siragrunnen_report-1-Wind-evaluation”. Further WindSim CFD simulations is performed to investigate possible meso scale effects changing the wind climate from the Lista Fyr position to Siragrunnen.

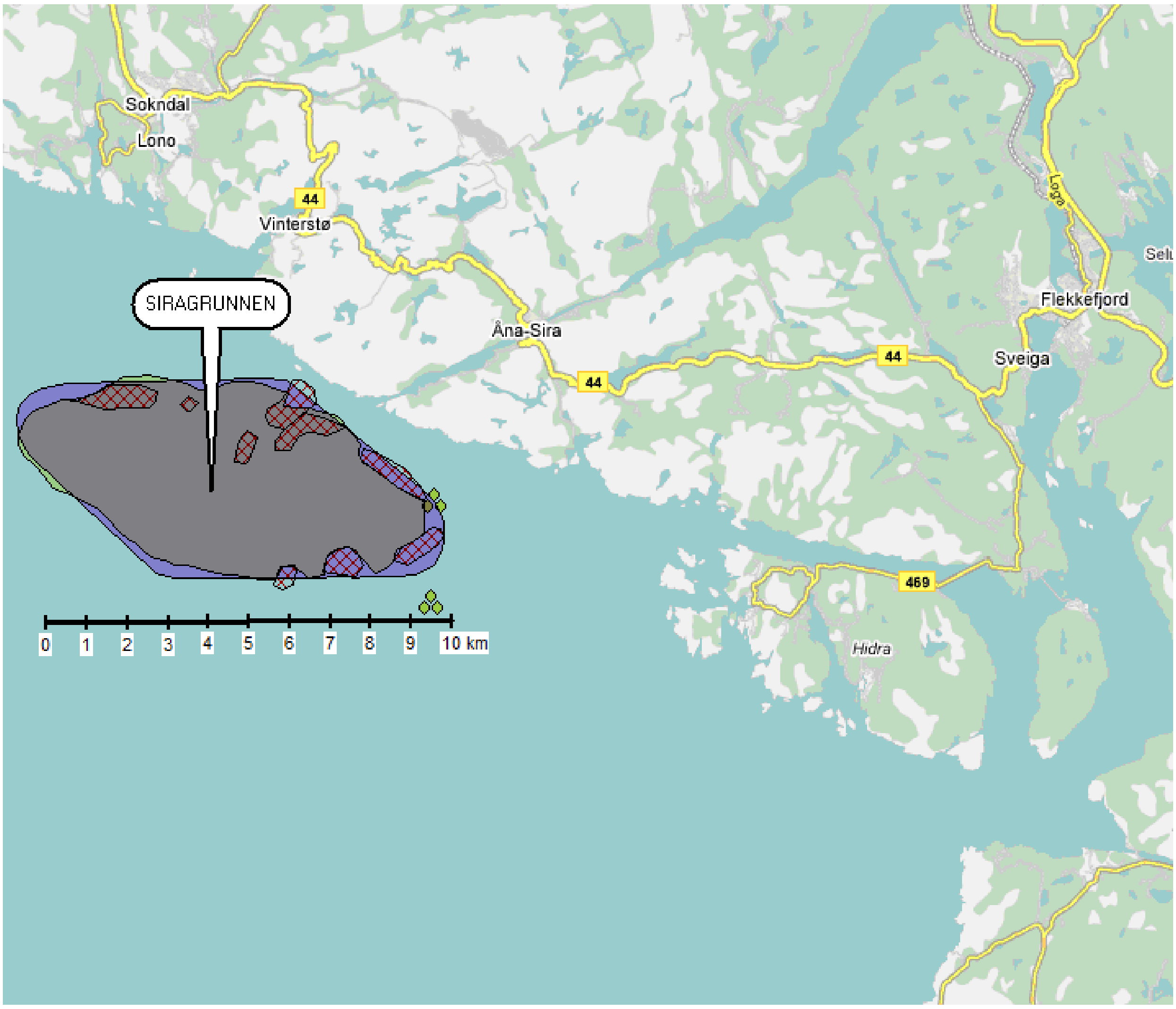


**Figure 1 Map of the site, where the area with water depths below 45 m is shown in yellow – with blue the “base” plan area, red x hatched the fishing restrictions.**



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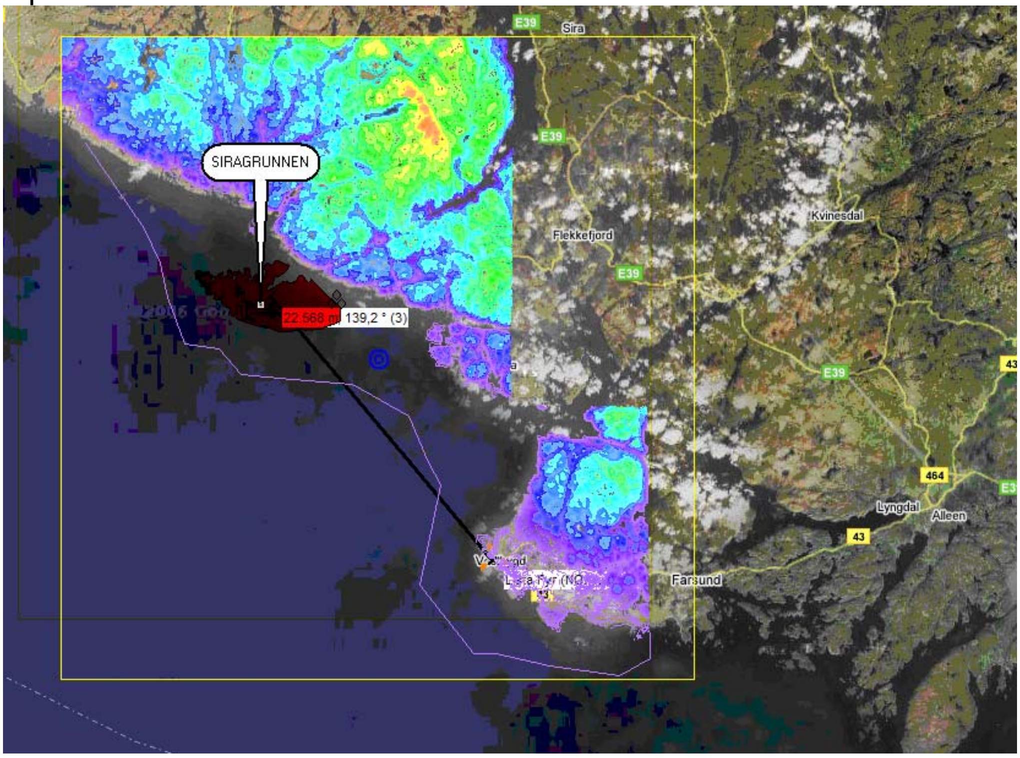
## 2. Available data for the task

The report *"EMD-Siragrunnen_report-1-Wind-evaluation"* describes the wind data established as a wind statistic (WAsP format).
From Halvor Mohn digital water depth measurements as xyz files with round 5 m equidistance is delivered for the site.
Maps from Internet
Digital height contour data, SRTM from Internet

**Wind turbine types**
Following wind turbine types has been used for the layout variants:
Vestas 3 MW, 90m rotordiameter, 80m hub height
Repower 5 MW, 126 m rotor diameter, 90 m hub height
DUMMY 8 MW, 150 m rotor diameter, 125 m hub height (EMD construction)

## 3. Terrain description

**Height contours**
EMD has created the digital elevation model (DEM) based on NASA SRTM data, which is grid-based with a spacing of 90 m. Contours are interpolated between grid points using WindPRO with an equidistance of 5 m. The data has been checked versus background maps and adjusted around the Lista Fyr position, where the details are very important. For Siragrunnen the accuracy of the elevation data is of less importance due to distance from site to shore.




**Figur 1 Lista Fyr is seen 22 km sw of the site in a very flat region. The elevation data used is seen, going up to round 550 m at highest point (red), round 15 km NE of the site.**



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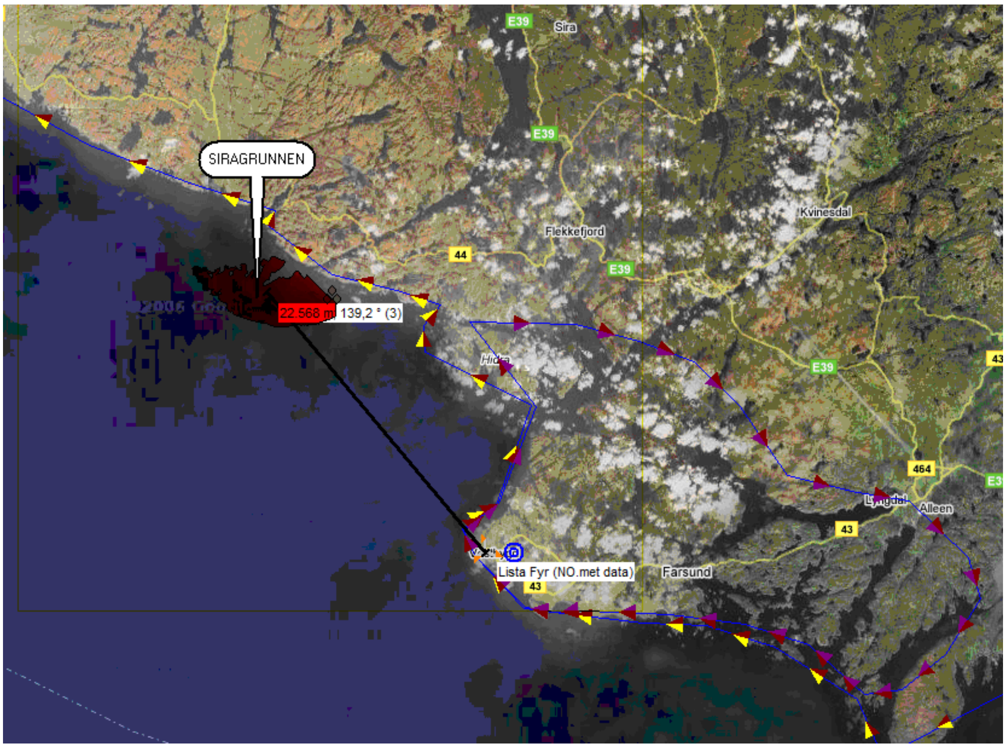
## Roughness data

EMD has created relative simple roughness description based on satellite images and photos around Lista fyr. The roughness of the landscape determines how much the surrounding terrain will drag the wind profile, thereby slowing the wind down. The area has been classified in a radius exceeding 20.000 m from each turbine/mast.




**Figur 2 Roughness description. Onshore roughness class 1.5 is assumed apart from the near surroundings of Lista Fyr, where photos indicate less roughness, here set to class 1. Offshore class 0 is used.**

**No local obstacles have been considered. For the Lista Fyr location some houses near the measurement mast might gear up the wind statistic, but this is “kept” as an upside.**



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## *4. Long term wind expectations*

A critical issue is which wind conditions can be expected over the approximate next 20 years where the turbines are expected to be in operation. Experiences from Northern Europe tell that this is not easy to predict. In Denmark and Germany the 10 years between 1985 and 1995 had an energy level around 10% above the average and later between 1996-2006 around 10% below the average. So using only 8 years of reference (Lista Fyr data from 2000-2007 is used) can lead to quite wrong conclusions. Therefore analyses based on NCAR 30 year data have been used to evaluate the 8 year period. This indicates that the period used might have round 2% less energy content than the 30 y period. But the data is not geared based on this meaning this is kept as an upside.

## *5. Micro siting – layout of wind farm*

A critical issue is the spacing of the turbines. There are more issues to consider:
To utilize the site best require low spacing
To reduce cable cost and transport cost (during installation and maintenance) require low spacing
To reduce array losses require high spacing
To reduce wake added turbulence on neighbor turbines require high spacing

The last one might based on most recent "best practice" be one of the most important. For a relative small offshore site like this, the array loss considerations might not be that critical, while at larger offshore wind farms, this might a more important factor.

Our judgment from interviews with manufactures and participation in several offshore project designs, tell us that 8 RD (Rotor Diameters) in main wind direction and 7 RD in opposite direction for a site with wind direction variations and size like this will be most suitable.

We will use a "regular pattern" layout, mainly due to visual aspects.

Both "main design criteria" can be revised – especially this might become relevant during the public opinion phase, where many new issues like fishing, sailing, communication lines etc. might call for a revised layout.

We go for 200 MW in all 3 variants, spacing the turbines as much as possible, but still keeping the layout in a straight geometric layout.



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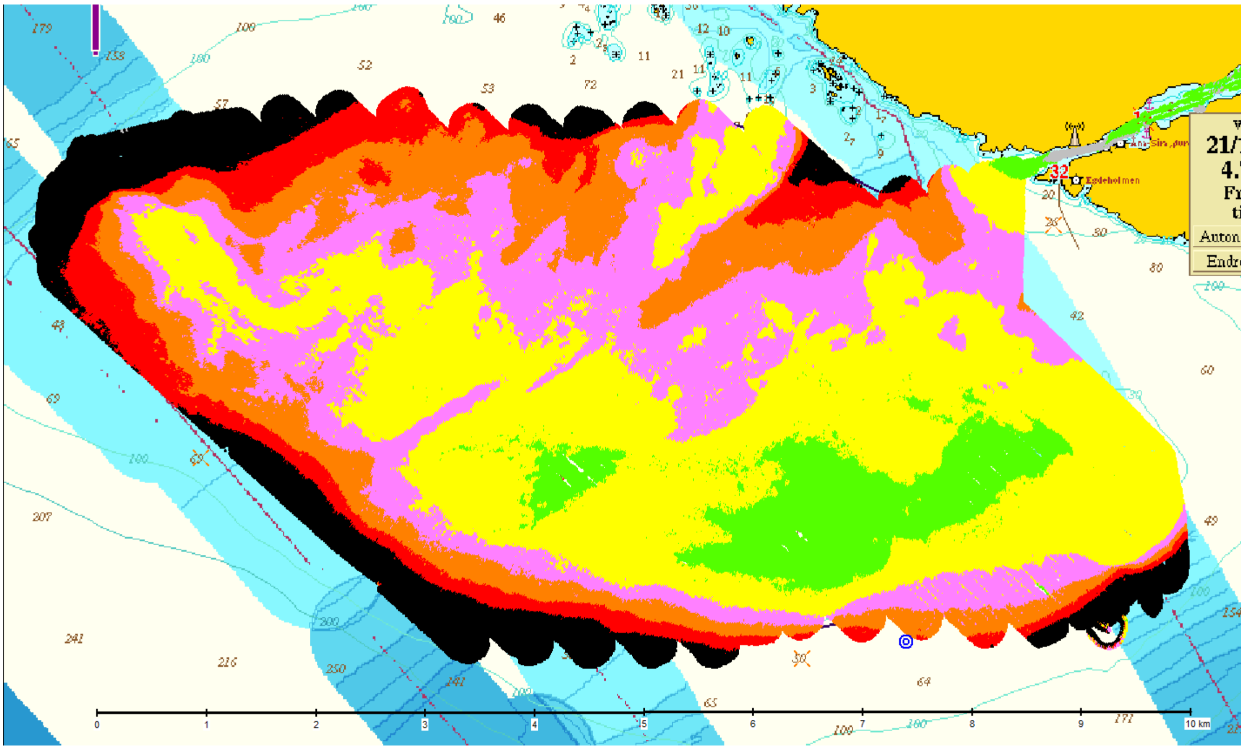
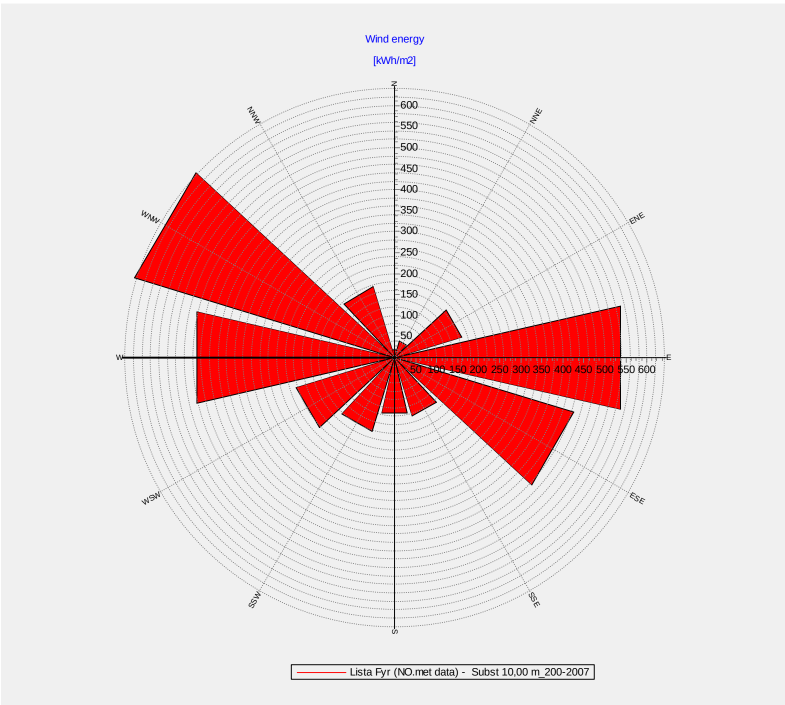


| Start | End | Color 1 |
|---|---|---|
| -45 | -40 | |
| -40 | -35 | |
| -35 | -30 | |
| -30 | -20 | |
| -20 | -10 | |
| -10 | 0 | |

**Figur 3 The water depth maps. See color scale ->**




**Figur 4 Energy distribution rose.**



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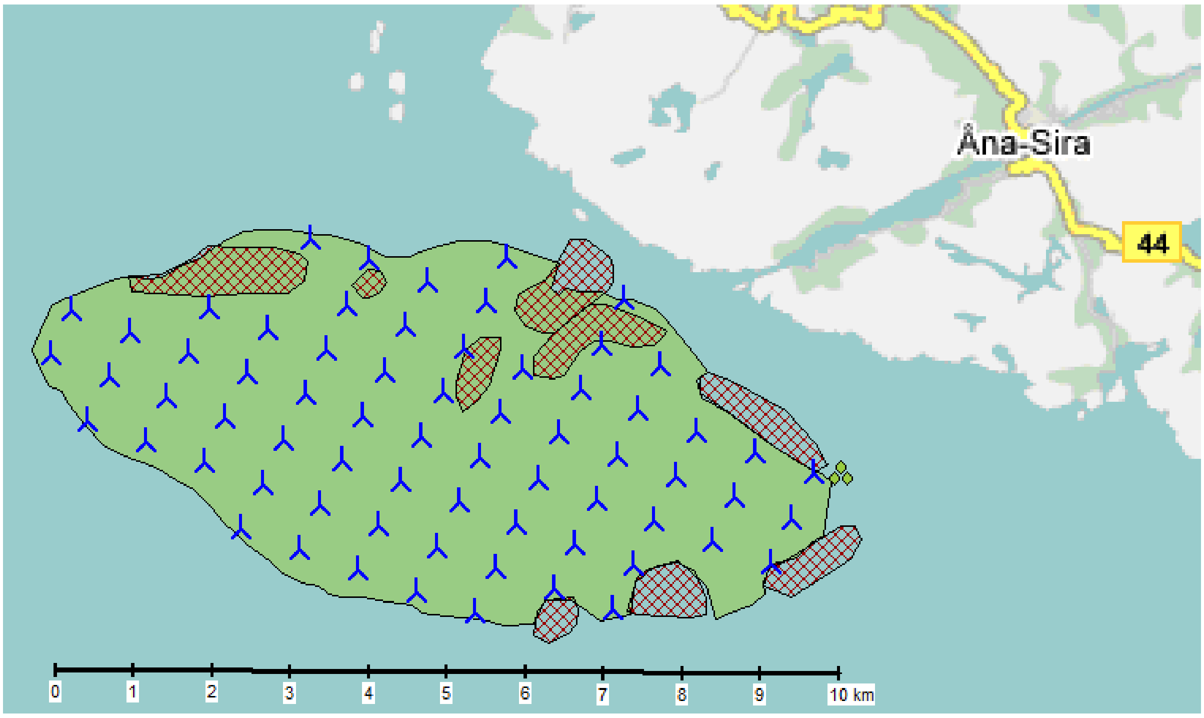
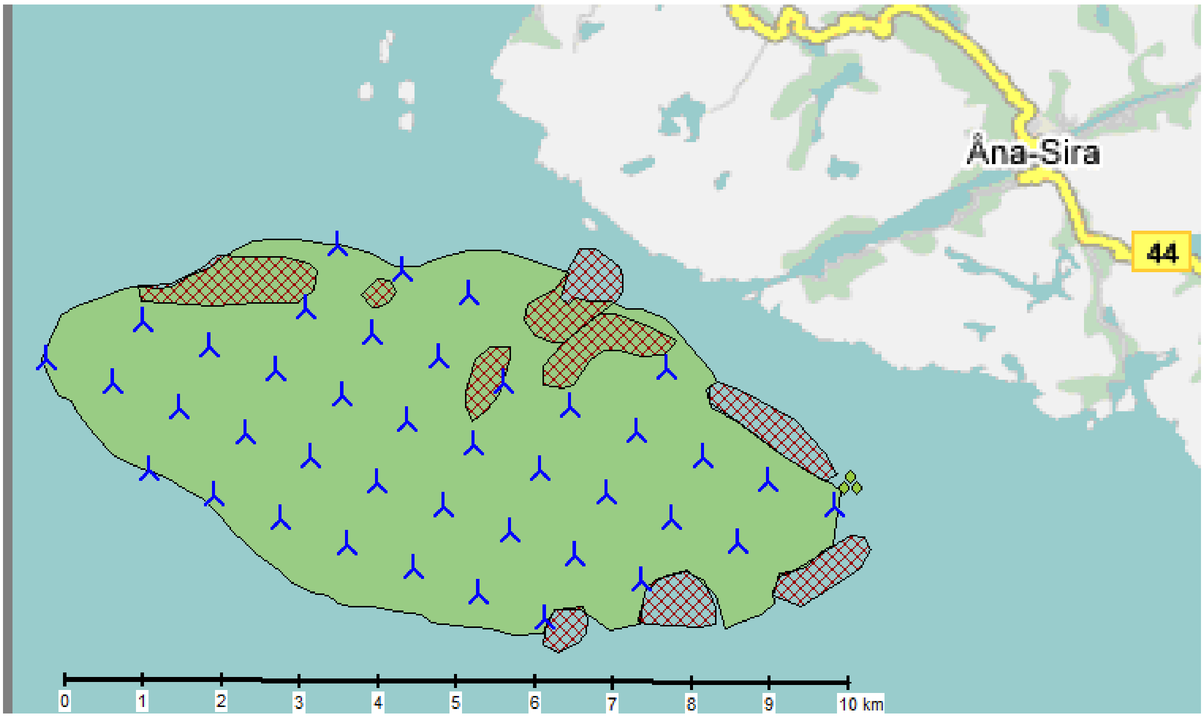
The most wind will be along the longest site. If there are more than 5 rows perpendicular to main wind direction, an increased roughness inside the wind farm area are considered needed to compensate for weakness in the array los model (PARK model). There will be added an area with roughness class 1 in this case.

## 200 MW layouts including fishing restrictions and up to 45 m depth




**Figur 5 67 x 3 MW = 201 MW including fishing restrictions.**




**Figur 6 40 x 5 MW = 200 MW including fishing restrictions.**



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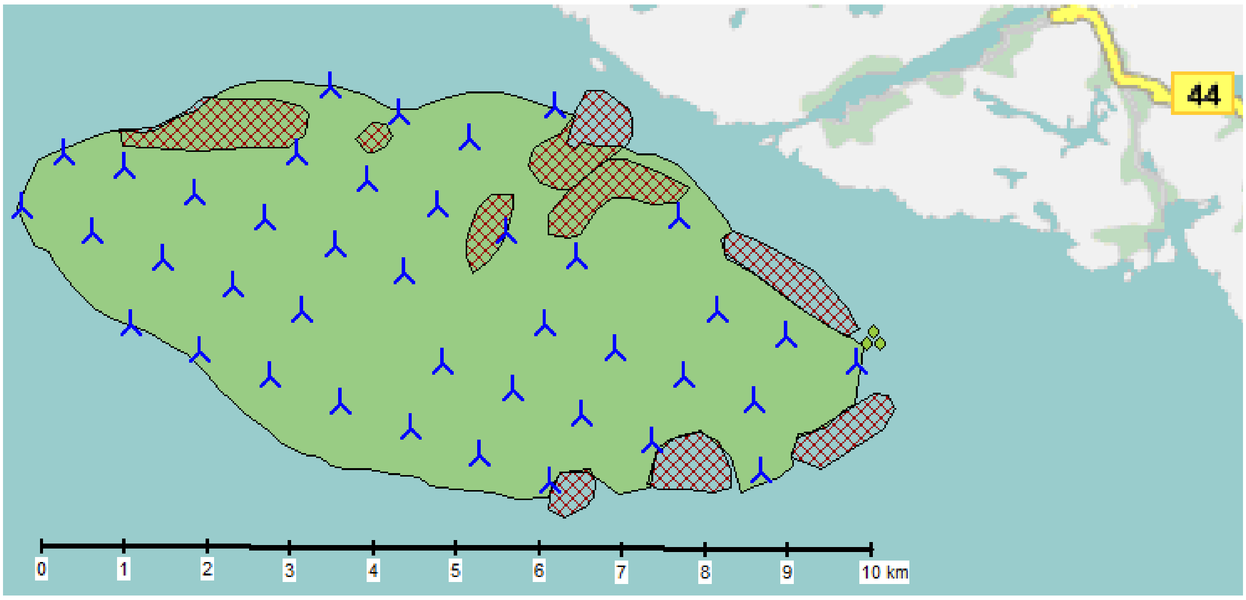
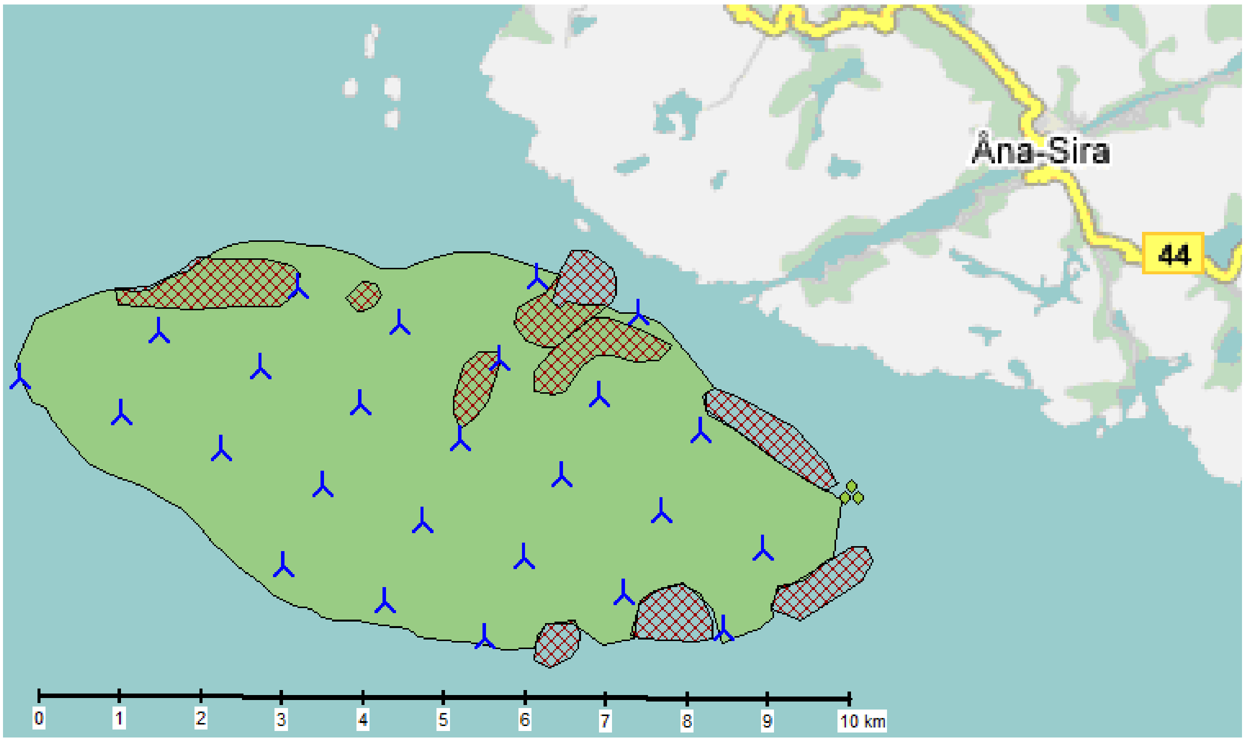



**Figur 7 40 x 5 MW = 200 MW including fishing restrictions – optimized by moving "poorest" WTGs to other parts where straight geometry only are slightly violated.**




**Figur 8 25 x 8 MW = 200 MW including fishing restrictions**



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## 6. Energy calculations

The method for energy calculation is the Wind Atlas method, using the WAsP model to transform the wind data measured at Lista Fyr, 10 m a.g.l. to the turbine positions at hub height.

Transforming wind data as well at a some distance (22 km) horizontal in a rather complex region, with possible wind climate differences as vertical from 10 m to round 100 m, is of cause some uncertain. Additionally the quality of the Lista Fyr measurements might not comply with "wind energy calculation standards".

Therefore the uncertainties must be considered "very high", probably in the region round 20-25%.

### 6.1 Model setup and adjustments

As mentioned previous, an internal roughness class 1 has been added inside the wind farm area. This might be a conservative approach, while this seems not to be needed for Horns Rev, but at other offshore locations, like Nysted, it seems to be needed. And for sure at the model test case with the best data, Zafarana in Egypt (desert location) it is needed.

The Wake decay constant is set to 0.04, normal for offshore calculations.

Airdensity used is 1.27 kg/m3, based on standard pressure and 3°C as annual average.

### 6.2 Results

In the tables below the key values for each layout is seen.

| WTG type | WTG | Number | Windfarm | Hub height | Rotor-sea | Tot height | Rotor | Area/wtg | Area all | Row | In-row |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | MW | | MW | | m | m | m | m^2 | m^2 | RD | RD |
| V90-3.000 | 3 | 67 | 201 | 80 | 35 | 125 | 90 | 6.362 | 426.236 | 8,8 | 7,0 |
| Repower | 5 | 40 | 200 | 90 | 27 | 153 | 126 | 12.469 | 498.759 | 7,1 | 7,0 |
| Repower Opti | 5 | 40 | 200 | 90 | 27 | 153 | 126 | 12.469 | 498.759 | 7,1 | 7,0 |
| DUMMY #) | 8 | 25 | 200 | 125 | 50 | 200 | 150 | 17.671 | 441.786 | 8,8 | 7,3 |

| WTG type | WTG | Number | Windfarm | **Calc.Gross** | Efficiency * | Wind speed | Full load | Cap.factor | kWh/m^2 | HP-value | Increase |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | MW | 0 | MW | **GWh/y** | % | m/s | | | | | |
| V90-3.000 | 3 | 67 | 201 | **657,8** | 89,3 | 8,5 | 3.273 | 0,37 | 1.543 | 98,0 | 1,8% |
| Repower | 5 | 40 | 200 | **720,0** | 89,1 | 8,6 | 3.600 | 0,41 | 1.444 | 99,0 | 0,7% |
| Repower Opti | 5 | 40 | 200 | **728,4** | 90,0 | 8,6 | 3.642 | 0,42 | 1.460 | 99,0 | 1,8% |
| DUMMY #) | 8 | 25 | 200 | **805,9** | 94,8 | 9,2 | 4.030 | 0,46 | 1.824 | 98,0 | 1,3% |

*) The values for efficiency is the "raw wake losses" – the added wake losses due to increased roughness is not included in the figures in the table above. The reduction due to this is round 4%.



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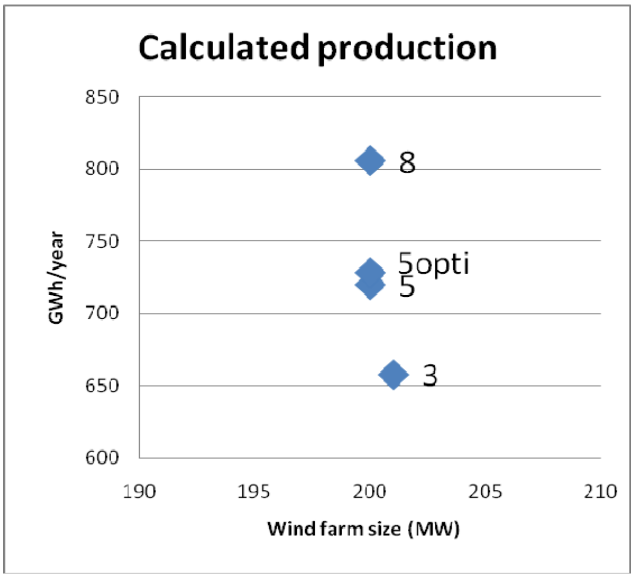
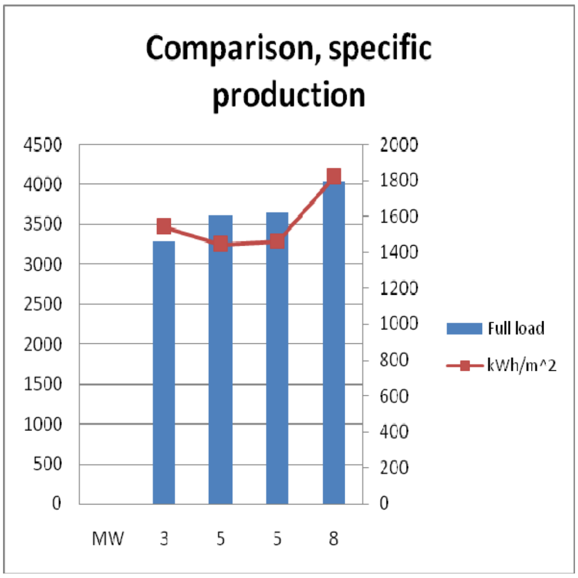
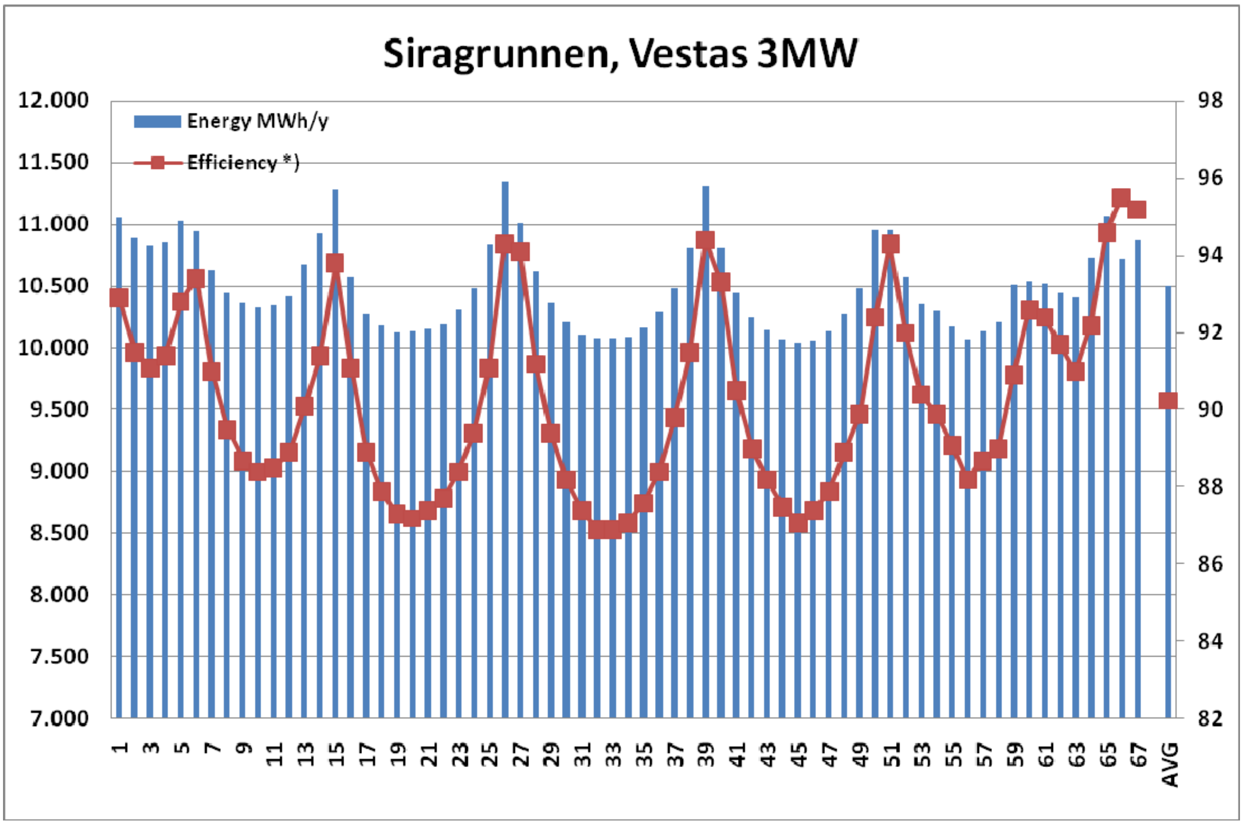



The larger turbine, the higher production, for the 5 MW it is due to larger rotor, for the 8MW due to larger hub height. But also the wake losses are different.

## 6.3 Graphic presentations for individual turbines



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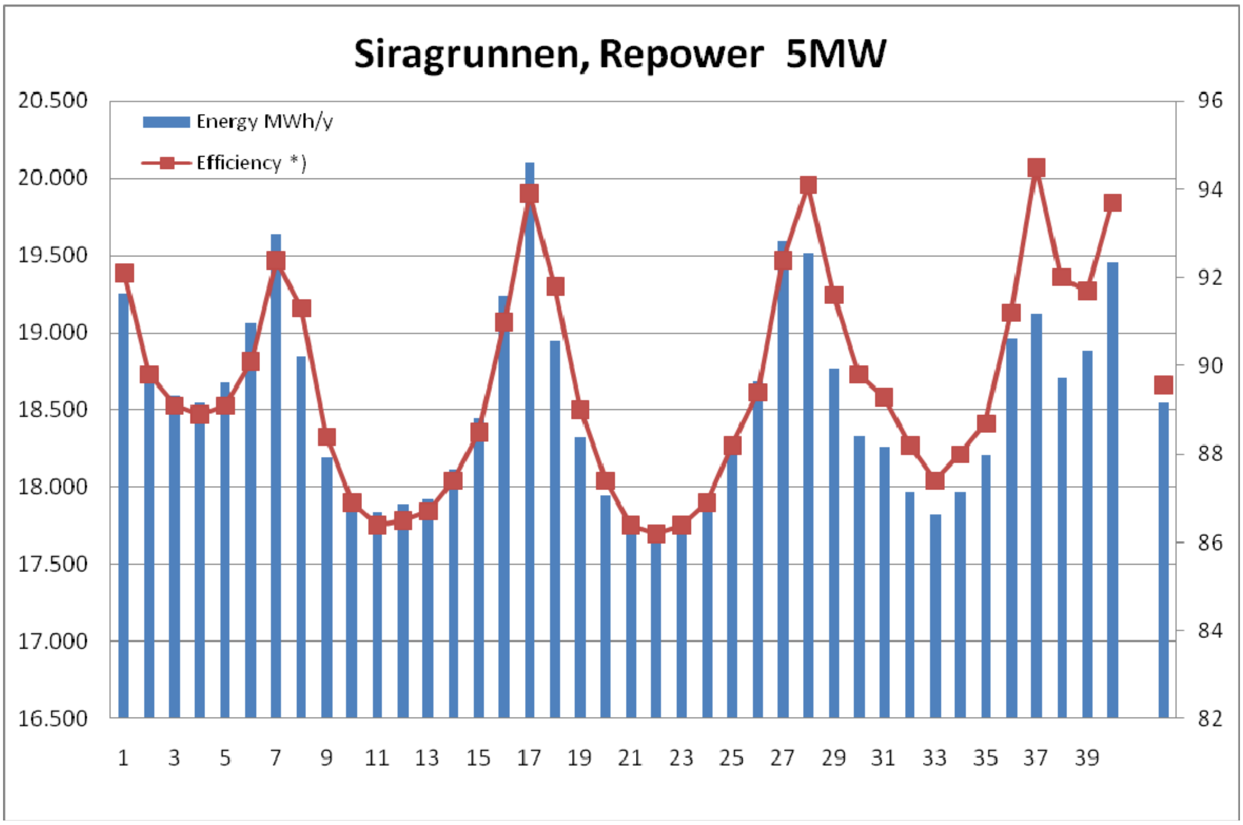


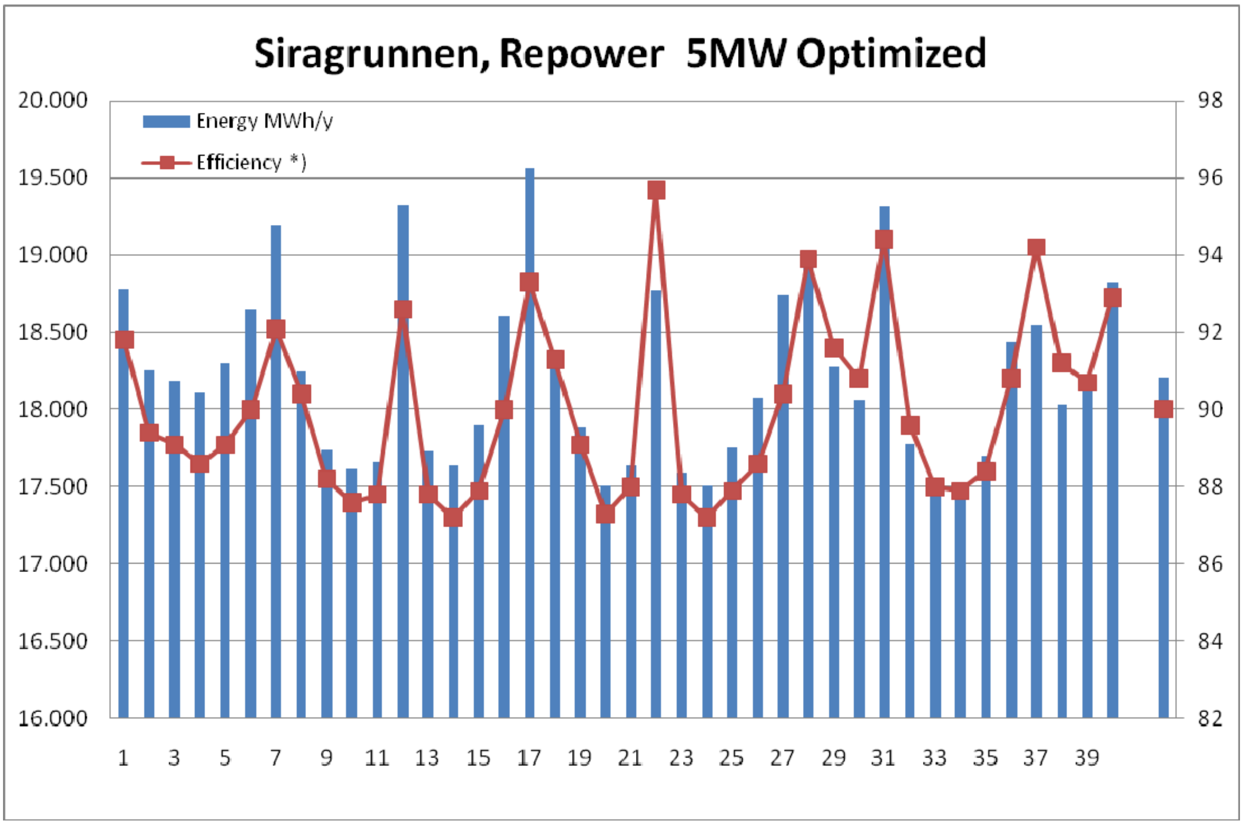




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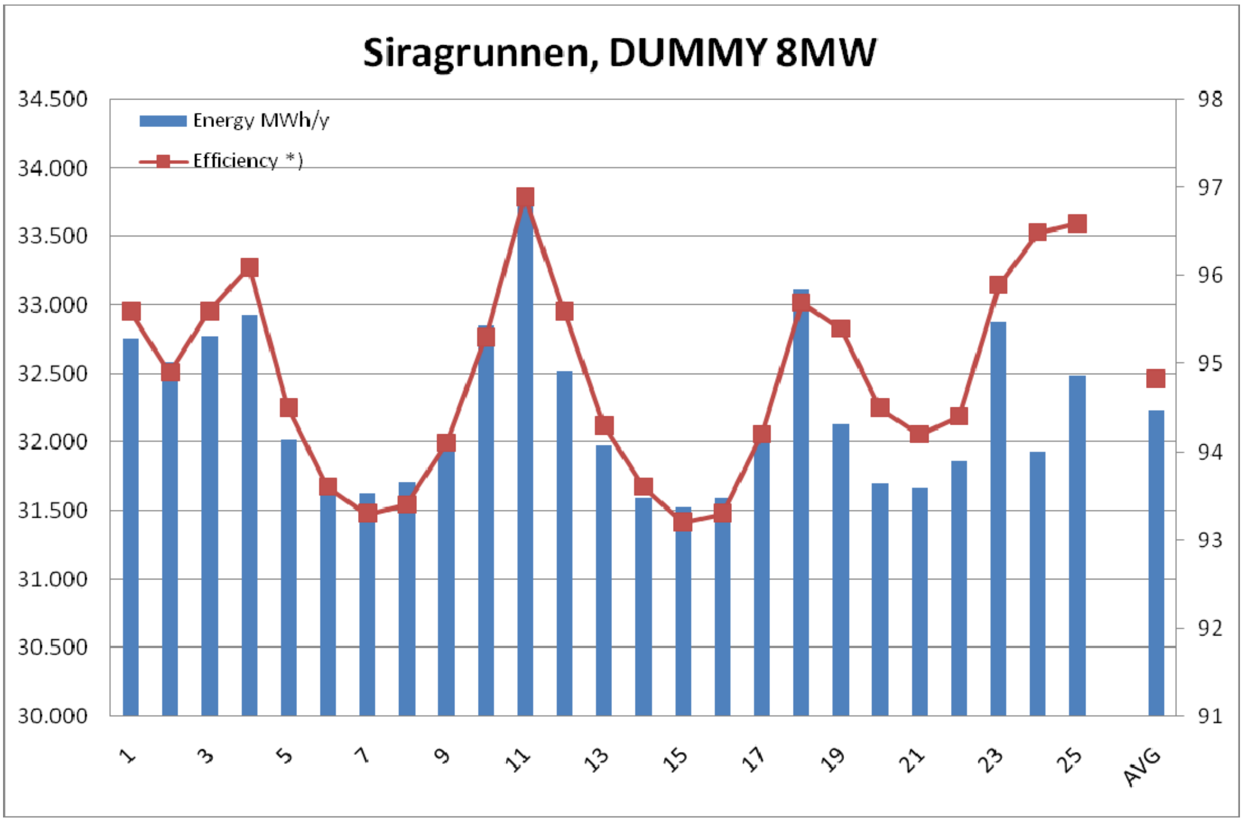
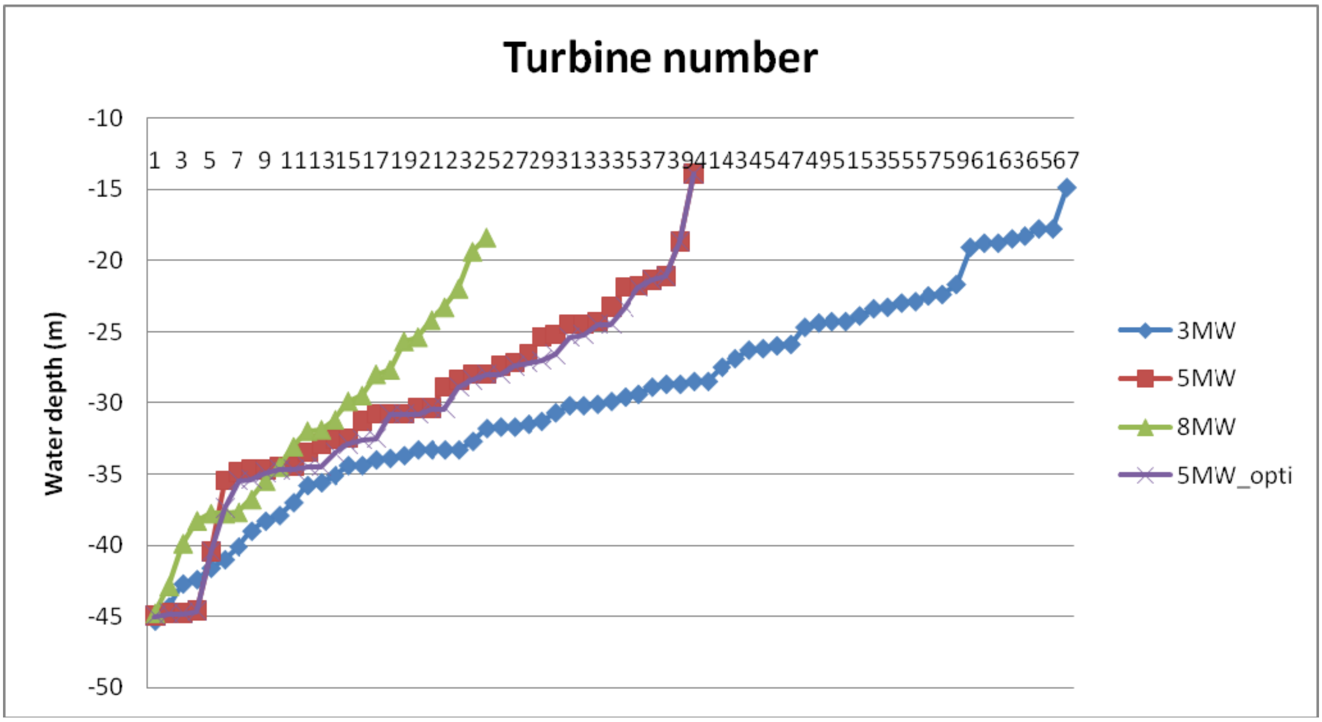



*) The values for efficiency is the “raw wake losses” – the added wake losses due to increased roughness is not included in these figures.

## 6.4 Water depths




**Figur 9 The water depths for turbines sorted by water depth.**



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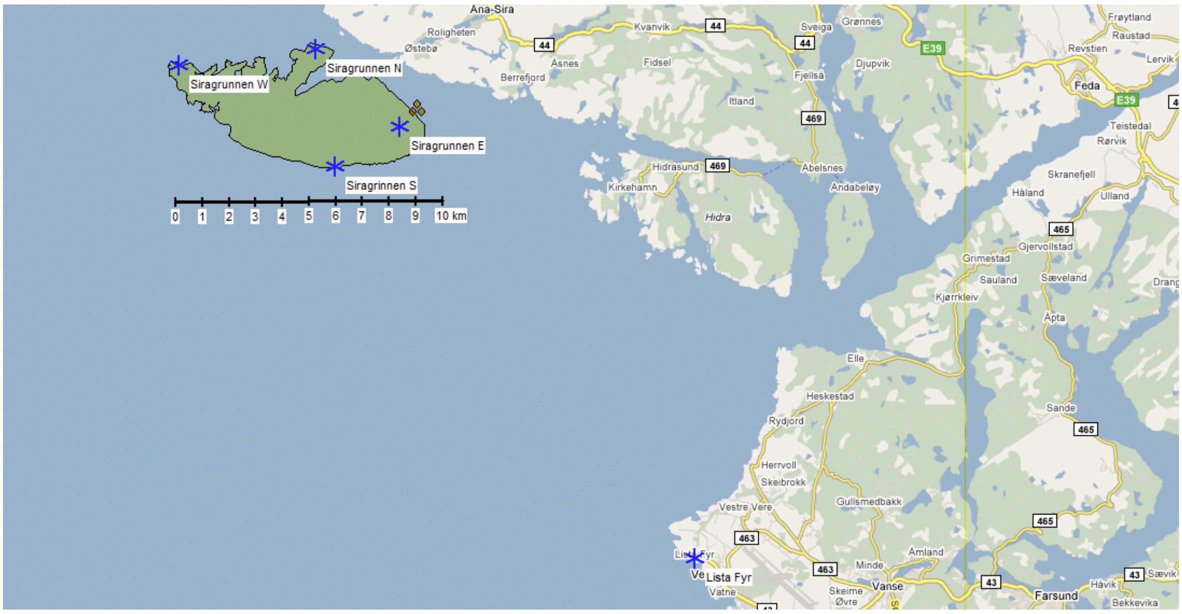
# *7. WindSim calculations*

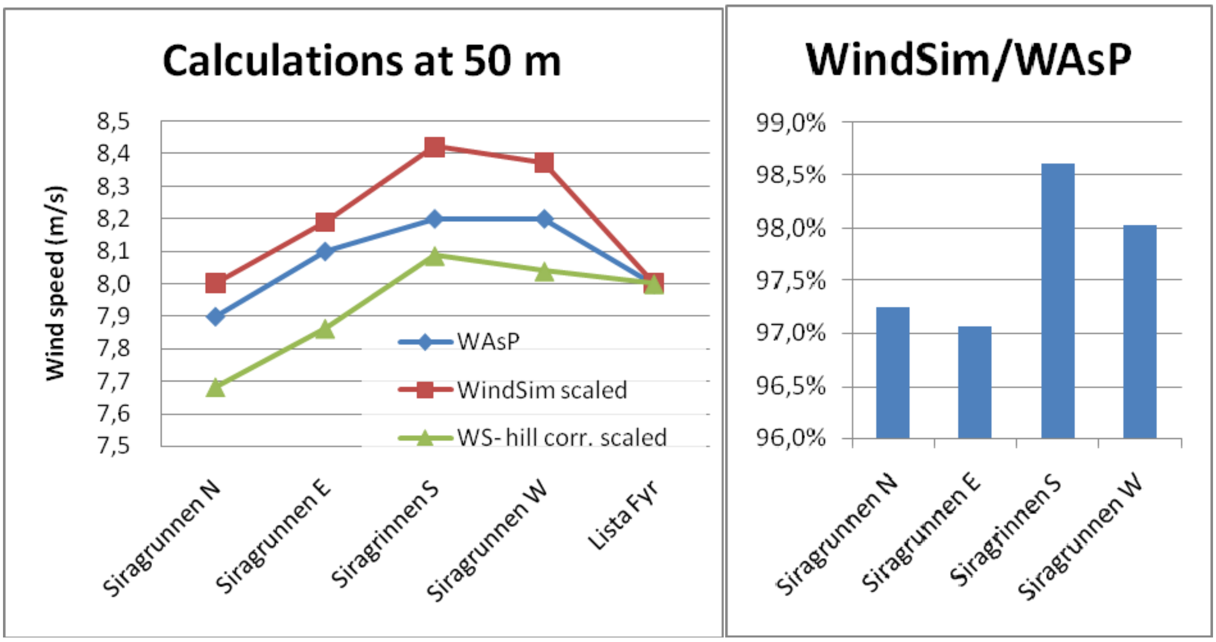
In order to check if there seem to be meso scale effects from the mountains near the site that might change the wind climate from the reference site (Lista) to the site (Siragrunnen), WindSim CFD calculations is performed.

Especially it is of interest to evaluate if there seem to be reductions in wind speeds due to the mountain at the site relative to the reference site. Therefore wind speeds at 4 points at the site are calculated with the WindSim model which is compared to the WAsP calculations.




**Figur 10 The 4 calculation points at the site and the Lista Fyr site.**

Due to the large area that must be included in the calculation, the details around Lista Fyr cannot be included in the calculations. The grid size needed for handling such large area is simply too coarse to include local details as the small hill at Lista Fyr. Therefore some interpretation is needed to conclude from the results.




**Figur 11 Calculation results for WAsP and WindSim at 50 m height, where the WindSim results are scaled to match the WAsP results at Lista Fyr.**

The red graph show how WindSim calculates slightly higher wind speeds at Siragrunnen relative to WAsP, all relative to Lista Fyr.

But while Lista Fyr is located at a small hill, and this hill not is included sufficient accurate in the WindSim model due to the resolution, WindSim will under predict the Lista Fyr site, and therefore relative over predict the Siragrunnen calculation points. This we try to compensate with the green line, where the WAsP calculated hill increase at Lista Fyr is used as correction factor for the WindSim results at Siragrunnen. The conclusion is that WindSim calculates round 3% less wind speed at the part of the site near the coastline, and round 2% less at the part of the site at highest distance to the coastline. All in all a “down side” of round 2.5%. We choose due to the small change not to correct the WAsP calculations based on this, but keep it as a down side.

A more detailed report regarding the WindSim analyses will be added as a separate document.

## *8. Notes on losses and uncertainty*

The calculation result includes array losses and other model adjustments, but not the expected losses which must be subtracted. The two major loss components are grid losses and availability losses. They will typically sum up to round 8%.

The uncertainty (can be + or -) is as mentioned high mainly due to the weak wind data basis, where as well the Lista Fyr data as the WasP extrapolations holds large uncertainties.

The loss and uncertainty components are not detailled evaluated here.



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