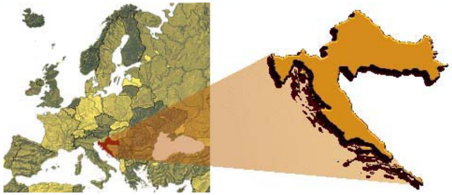
Ice & Rocks III

Conference on Wind Energy in Complex Terrain



OPERATIONAL EXPERIENCE: WF RAVNE ON ISLAND OF PAG

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Zadar, Croatia, 5-6 May 2010

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- Dedicated and motivated personnel
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Pružanje znanstvenih i stručnih usluga iz područja energetike

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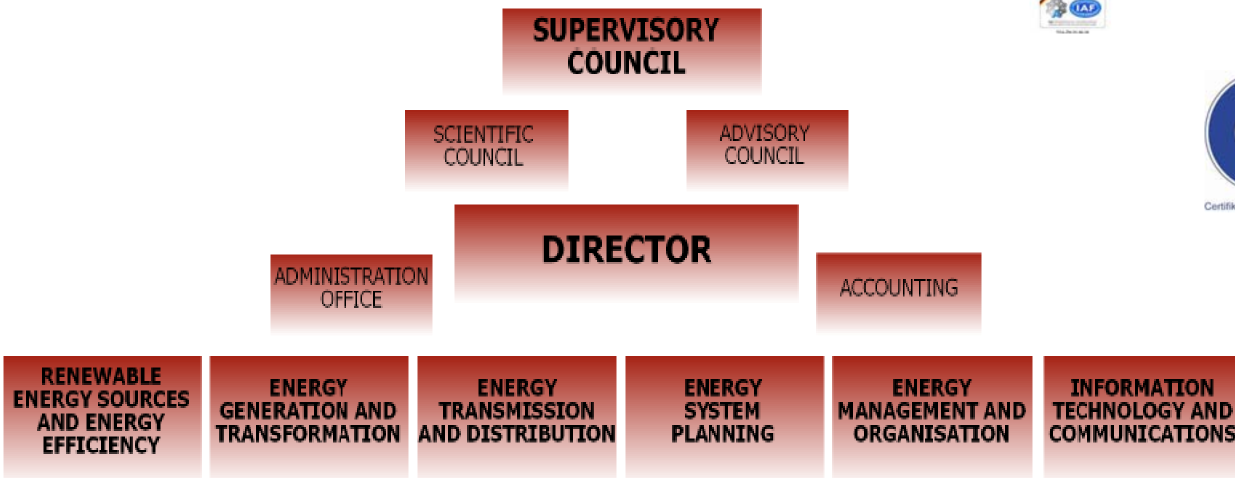
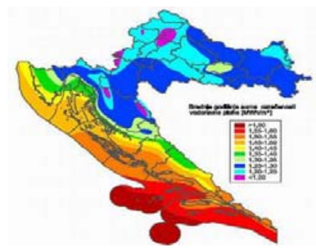


Department for renewable energy and energy efficiency

- Covers all RES technologies, 15 employees
- Wind:
  - Studies for the purpose of issuing permits
  - Wind measurements
  - Wind resource assessment and energy yield calculation (wind studies)
  - Preliminary environmental and spatial impact assessment
  - Grid connection studies
  - Feasibility studies
  - Legal, technical and economic consultancy to public authorities and private sector






Content

1. WF Ravne site description
2. General overview: energy production
3. Power curve
4. Cut-off regulation
5. Availability
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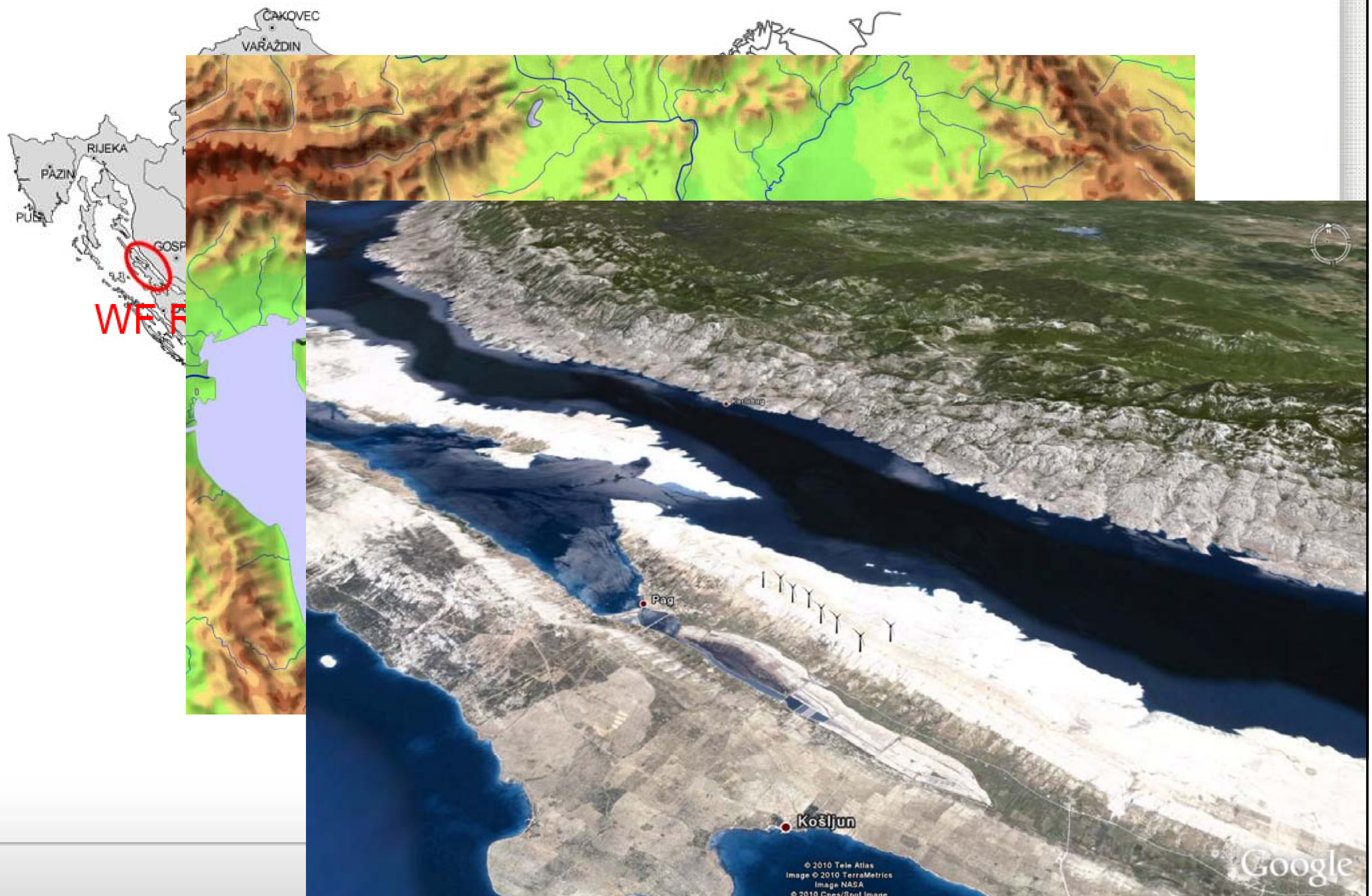
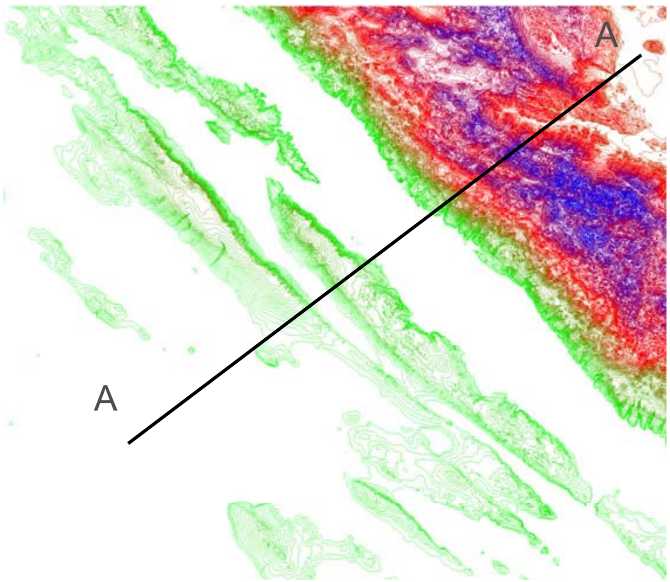
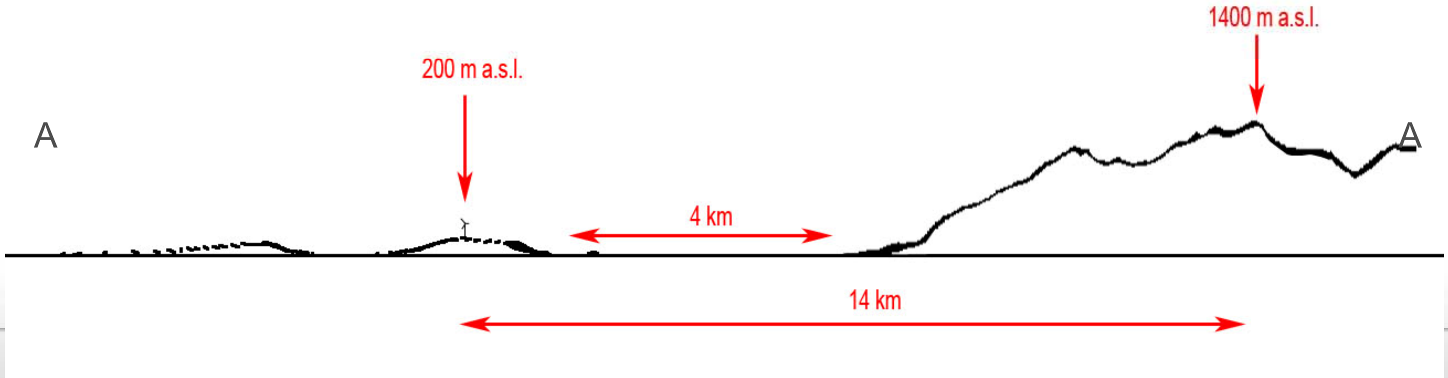
WF Ravne site description (1)



WF Ravne Site description (2)

- Height variation of the terrain: 0-1620 m a.s.l. (within 20 km radius)
- The site is separated from the Velebit mountain by sea channel
- Closest mountain peaks up to 1400 m a.s.l.
- Steep slopes – intensive flow separation
- Several parallel passes at sea level
- The surrounding orography can be classified as very complex

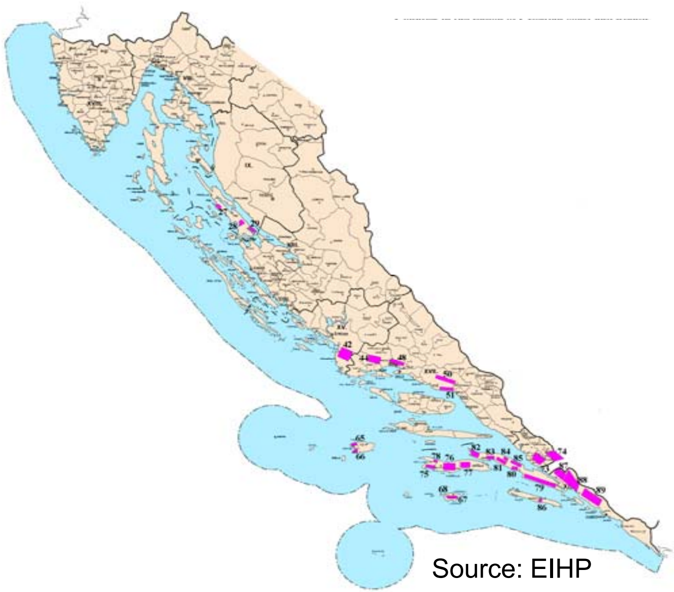


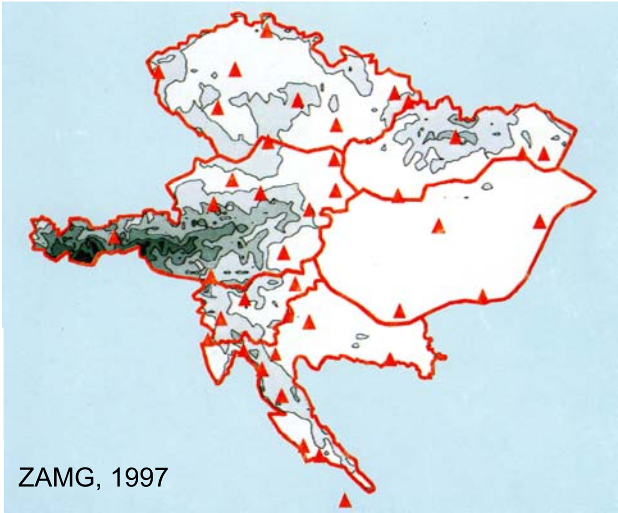


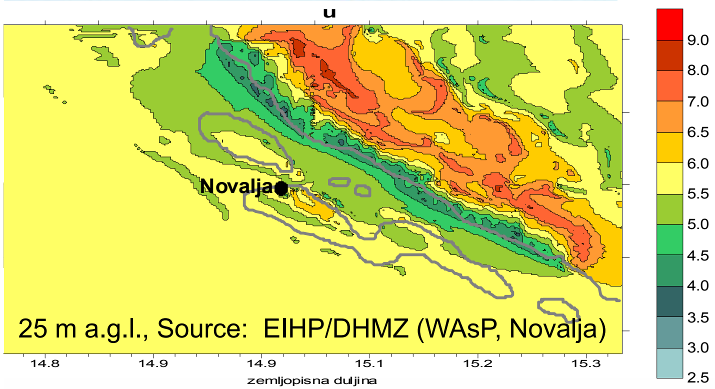
WF Ravne – Site images

Reginal wind resource

- Early estimates od the wind resource – 1996-1998

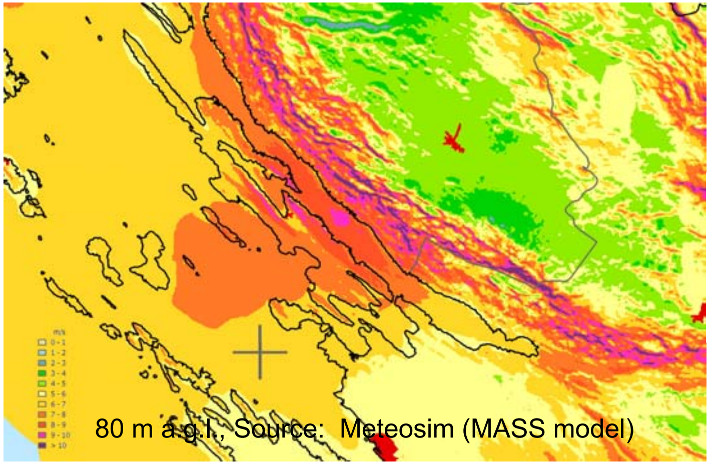


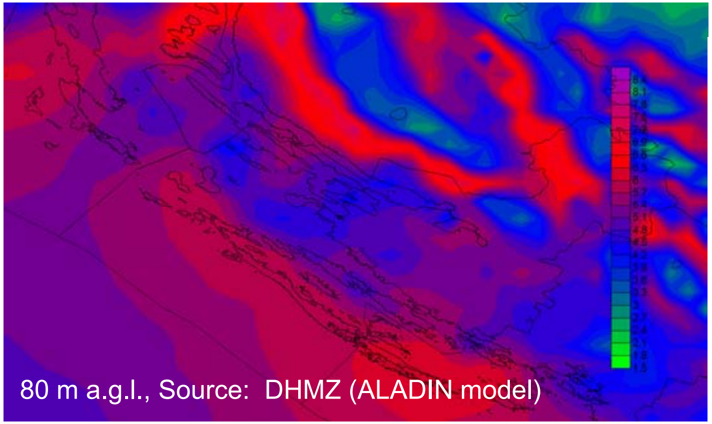




WF Ravne site (3)

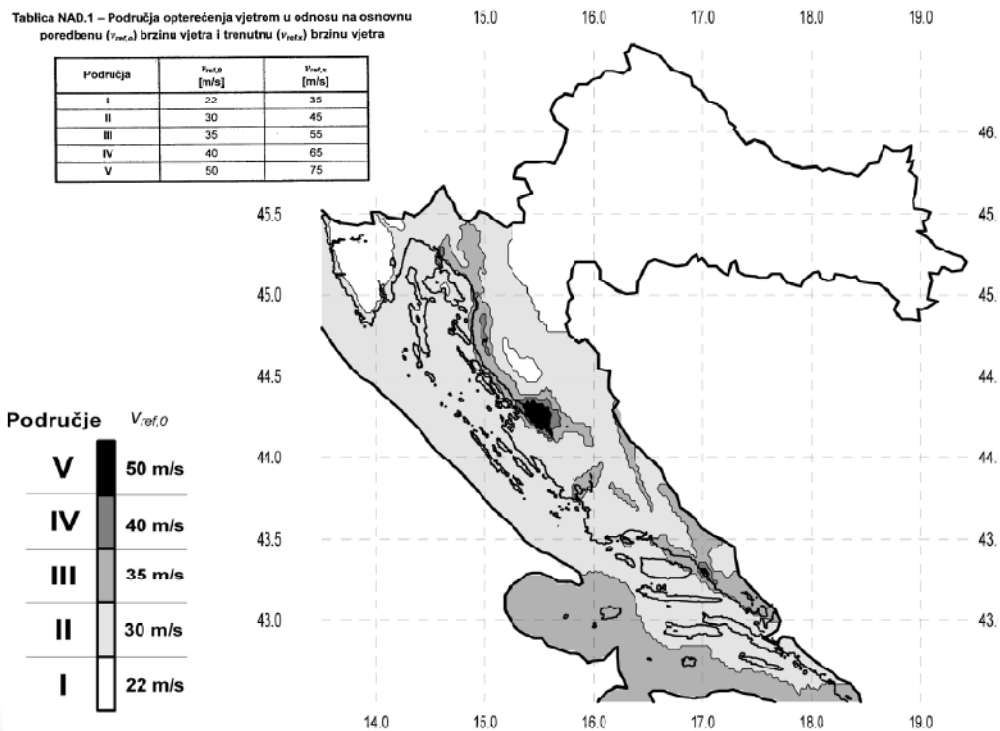
- At the beginning of wind farm development (1999) no regional wind maps were available
- In the meantime several wind maps are prepared by use of different mesoscale models
- Wind maps suggest large uncertainty around the wind resource on the site
- On-site average wind speed: 6-9 m/s 80 m a.g.l.





WF Ravne – site with extreme wind conditions

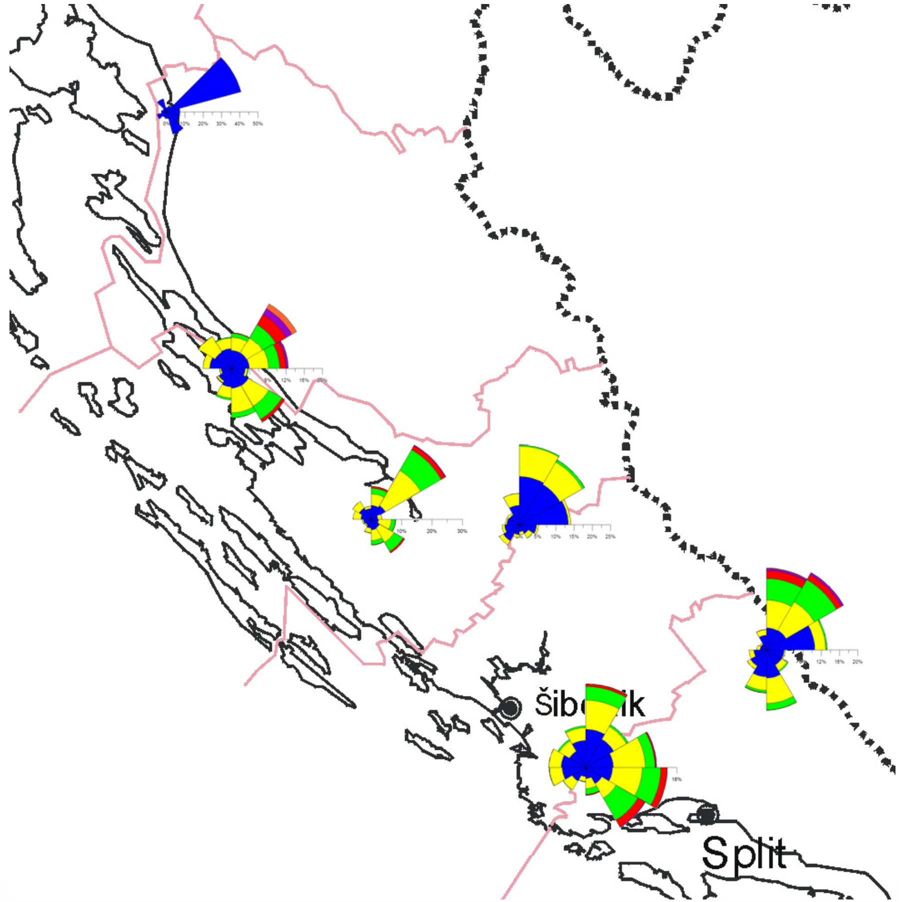
- Traditionally known area of extreme wind
- Croatian National application document for windload (Eurocode)


Tablica NAD.1 – Područja opterećenja vjetrom u odnosu na osnovnu poredbenu ($v_{ref,0}$) brzinu vjetra i trenutnu ($v_{ref,x}$) brzinu vjetra

Područja	$v_{ref,0}$ [m/s]	$v_{ref,x}$ [m/s]
I	22	35
II	30	45
III	35	55
IV	40	65
V	50	75

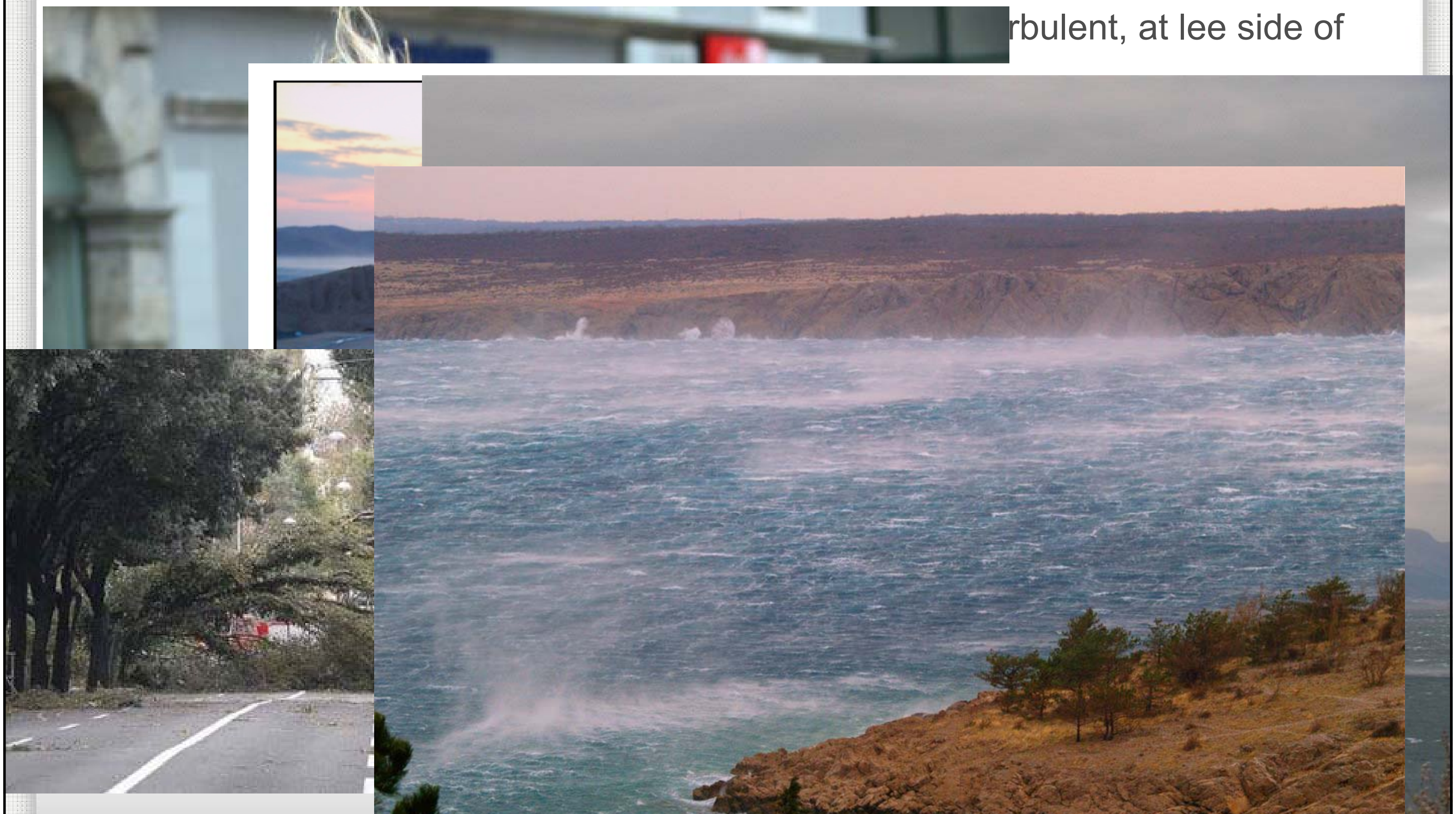
East Adriatic Cost and Hinterland - Wind roses

- Three main wind directions:
  - N-NE (Bora)
  - SE (Jugo-Sirocco)
  - NW

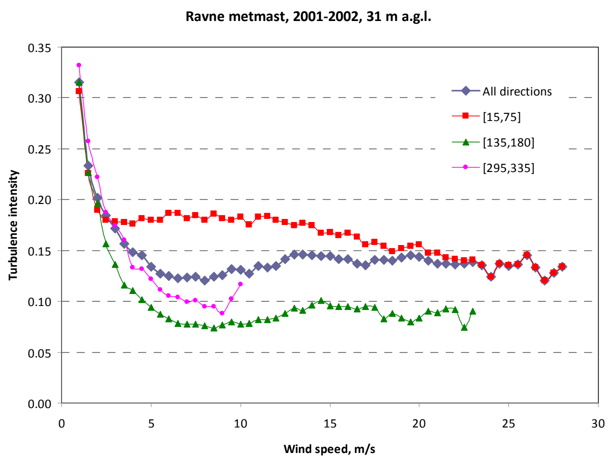


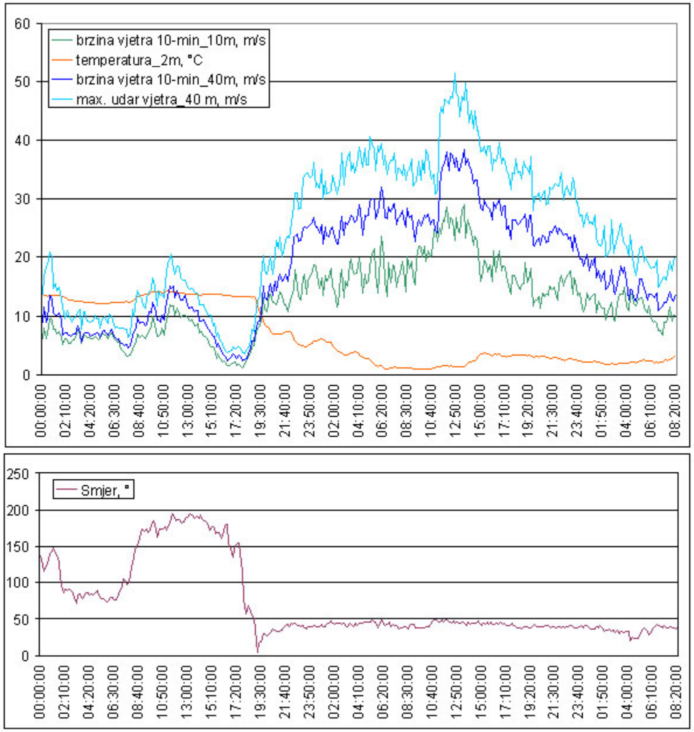
Bora

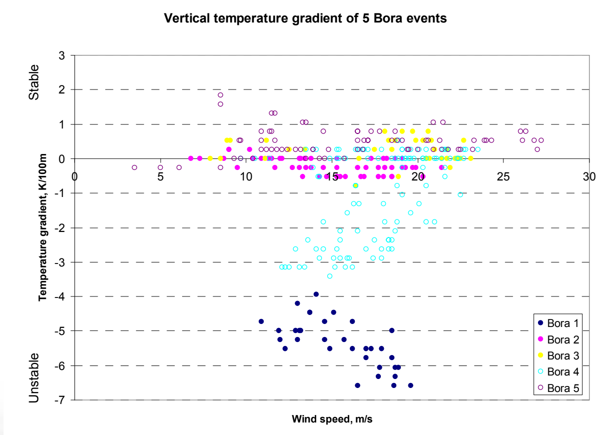
- Bora is local wind that frequently occurs in the costal area of Croatia
- NNE-ENE direction
- rbulent, at lee side of



Bora


Ravne metmast, 2001-2002, 31 m a.g.l.
Turbulence intensity
Wind speed, m/s
All directions
[15,75]
[135,180]
[295,335]

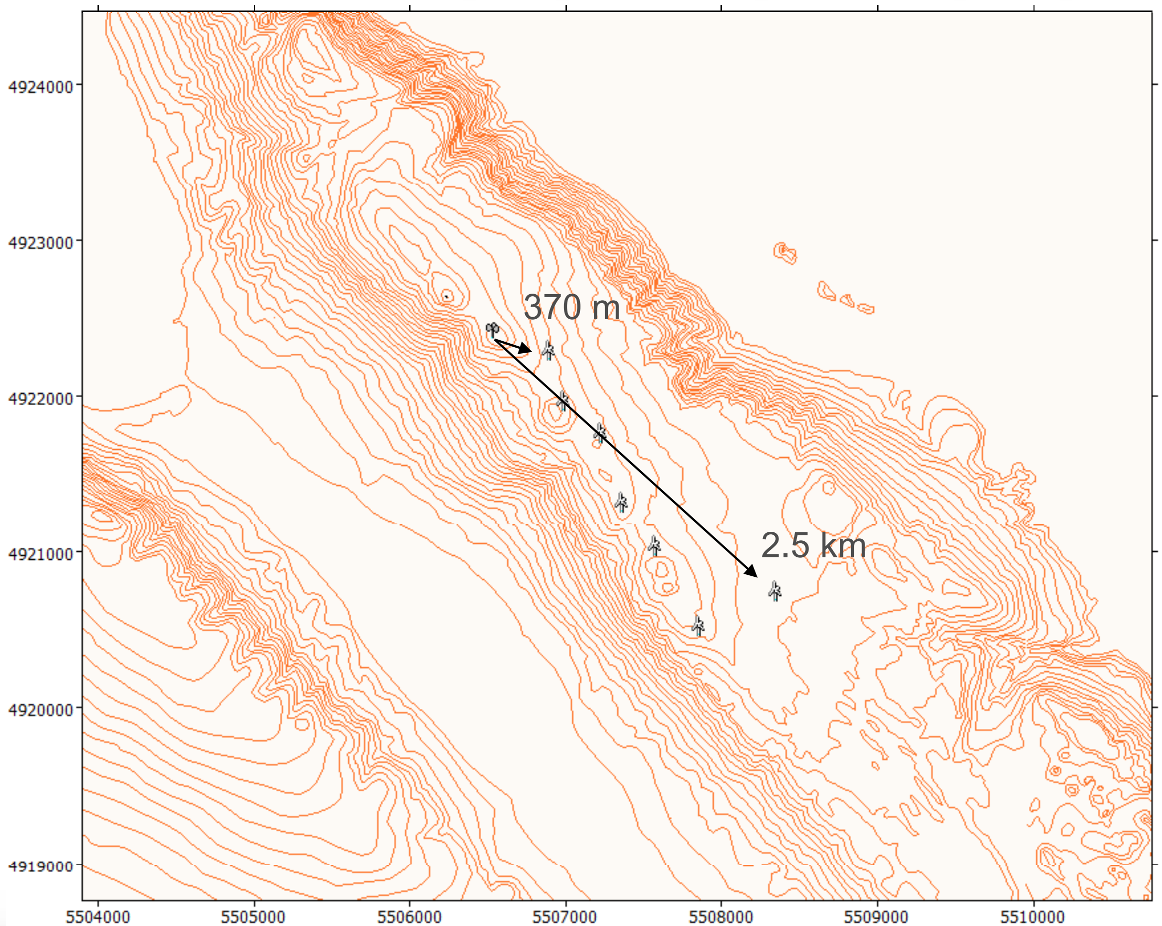

brzina vjetra 10-min_10m, m/s
temperatura_2m, °C
brzina vjetra 10-min_40m, m/s
max. udar vjetra_40 m, m/s
Smjer, °


Vertical temperature gradient of 5 Bora events
Stable
Unstable
Temperature gradient, K/100m
Wind speed, m/s
Bora 1
Bora 2
Bora 3
Bora 4
Bora 5

WF Ravne – Project development

- Start of project development 1999, construction and test run 2004, commissioning 2005
- High quality wind measurement during 2001-2002
- 31 m tall mast, two levels of measurements
- Pioneering project for Croatia: permitting, EIA, PPA, land use issue.... time consuming process
- Planed size of the wind farm: 6 MW (limit set by HEP at that time)
- Realised project:
  - total power 5.95 MW
  - 7 x Vestas V52 850 kW OptiSpeed wind turbine
  - variable speed operation 14.58-26.24 rpm
  - rated speed 15 m/s
  - hub height 49 m

WF Ravne - Layout



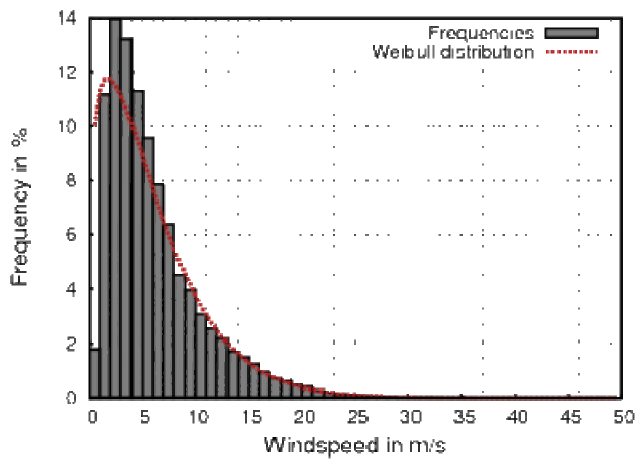
WF Ravne – Operational Experience

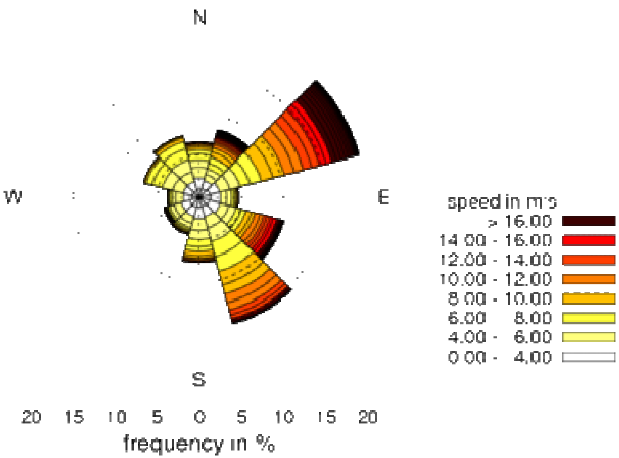
- Indicators:
  - Production
  - Power curve
  - Special effects – high wind hysteresis
  - Availability

- Data available:
  - Vestas WEA on-line recordings (internal monitoring system for WF owners)
    - automatic recording of about 50 parameters, including nacelle wind speed, power, production, total operating hours, etc.
    - row data (10 min) and aggregated (hourly, daily, monthly, yearly)
    - inconsistency of data, need of selection (filtering)
  - AWP measurements from 31 m mast (2001-2002; 2005-2006)
    - very low availability of wind direction during 2005-2006

WF Ravne – Estimated production (1)

- Several energy yield estimates resulting in 11.0-15.0 GWh/a (European Wind Atlas Method), difference in long-term correlation, WT type, hub height, etc.
- Analysis before and after construction with old (WAsP) and new tools (CFD-WindSim)
- Long-term wind climate (49 m a.g.l.):
  - Average wind speed: 6.6 m/s
  - Predominant winds: Bora and Jugo





WF Ravne – Estimated production (2)

- Net yield (based on 2001-2002 measured wind data):

	WAsP (31-m mast data 2001-2002)	WindSim (31-m mast data 2001-2002)
Total gross AEP, GWh	13.5	14.0
Total net AEP (-wake), GWh	13.2	13.7
Total net AEP – systematic effects (9.6%), GWh (FLH)	12.0	12.4

Unavailability of the wind farm, %	3.0
Unavailability of the electric grid, %	0.5
Electric losses and own consumption, %	1.5
Dispatching of the wind turbine and special operation strategies, %	0.1
Regular maintenance, %	0.5
Blade degradation, %	0.5
Hysteresis effect, %	3.0
Losses induced by inclined flows and turbulence, %	0.5
TOTAL, %	9.6

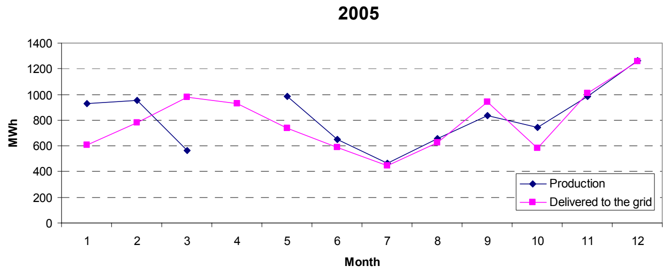
WF Ravne – Actual production

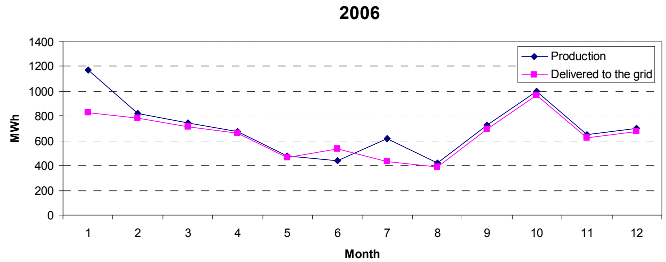
- WF Ravne internal recordings measured at generator terminals
- Delivery to the grid measured at connection point (10 kV transformer in Pag)
- Net production – own consumption included

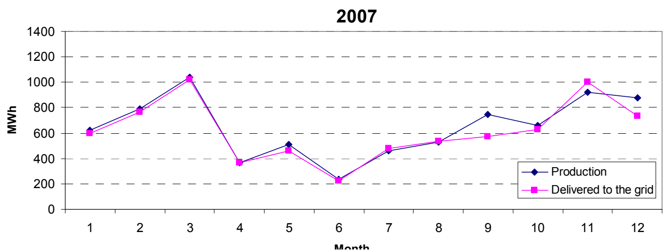
	Internal recordings, GWh	Delivered to the grid, GWh	Losses, %
2005	9.03*	9.49	
2006	8.44	7.75	
2007	7.76	7.39	4.84
2008	8.95	8.65	3.30
2009	9.70	9.41	2.97
Average	8.78	8.54	3.70 (2007-2009)

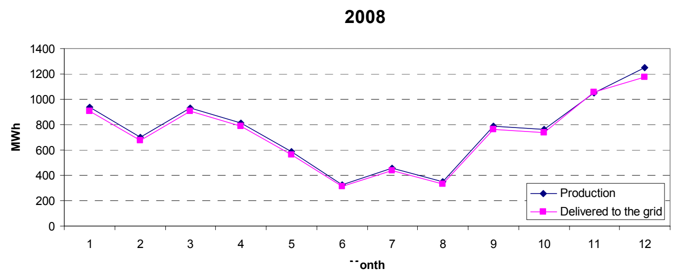
- Missing data for April 2005
- Difference is related to the electrical losses in cables and transformers
- 5-year average does not reflect climatological average

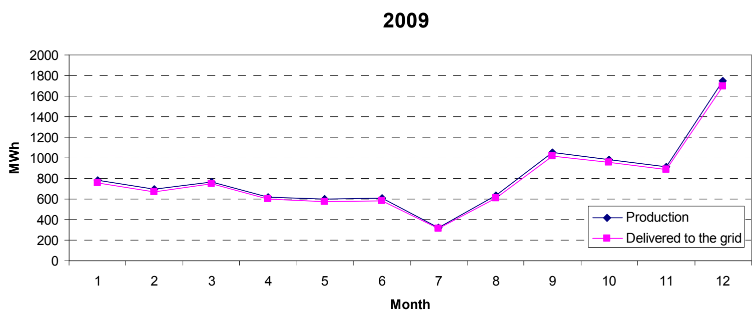
WF Ravne – Monthly production





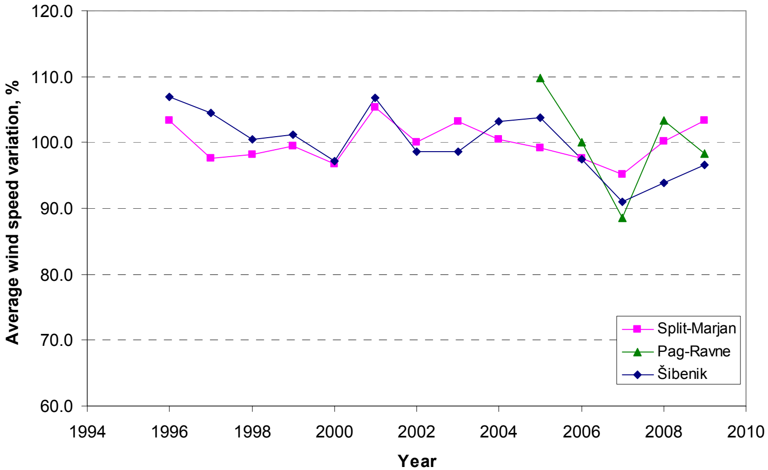


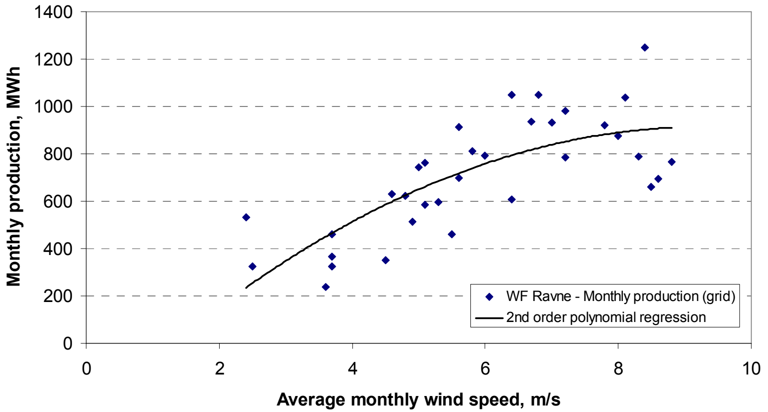




WF Ravne – Long-term production estimate from operational data (1)

- By extending the averaging period from 1 year to 5 years the average wind speed will vary much less
- Based on 15-year data from coastal meteorological stations the uncertainty of 5-year average wind speed is 2% with maximum variation of 4% (Šibenik)
- Scaling factor can be obtained from regression analysis, assuming:
  - average long-term wind speed of 6.6 m/s
  - unchanged operational practices





WF Ravne – Long-term production estimate from operational data (2)

- Different levels of production:

Estimated LT production, GWh	12.4
Actual production 2005-2009, GWh	8.5
Actual production scaled to the long-term, GWh	9.7

21.7% difference

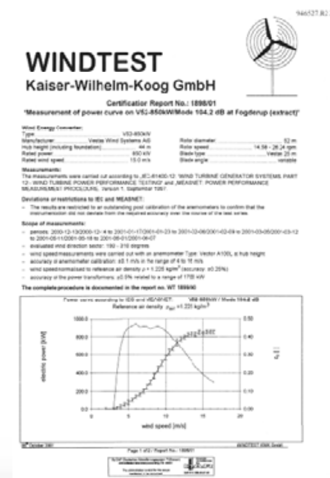
- After long-term adjustment still 21.7% discrepancy
  - Overprediction?
    - Flow models, wind measurement bias, ...
  - Underperformance?
    - Specific and/or systematic effects that discount energy production more then assumed......

WF Ravne – Power curve

- Power curves are measured under some test site wind conditions
- Wind farm site conditions can differ from test site wind conditions
  - Influence on power curve - actual performance can differ from site to site
  - Difficult to validate, site calibration according to IEC 61400-12-1 or nacelle anemometer calibration needed (not performed at Ravne site)
- The available database on wind farm performance contains records with errors
  - Filtering needed to take into account only “healthy”, proven, data
  - The main problem - nacelle anemometer data for wind speed
- All results of power curve analysis only of indicative value

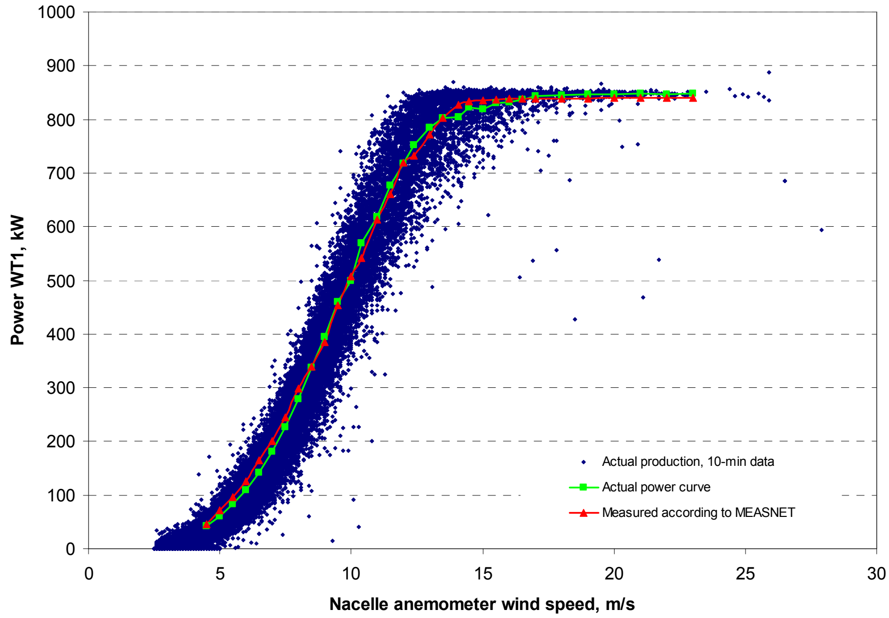
V52-105 kW, 104.2 dB(A)

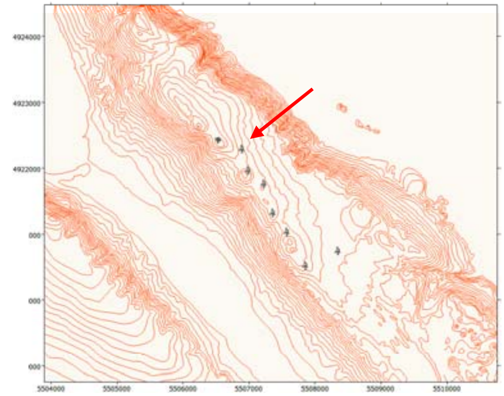
V10 [m/s]	1.225	1.060	1.090	1.120	1.150	1.180	1.210	1.240	1.270
4	25.5	20.4	21.3	22.3	23.2	24.1	25.1	26.0	27.0
5	67.4	56.6	58.6	60.5	62.5	64.5	66.4	68.4	70.4
6	125	106	109	113	116	119	123	126	130
7	203	173	179	184	189	195	200	206	211
8	304	260	268	276	284	292	300	308	317
9	425	365	376	387	398	409	420	431	441
10	554	480	494	507	521	534	547	561	572
11	671	595	610	624	637	651	665	679	688
12	759	696	709	720	731	742	753	765	770
13	811	770	780	787	794	800	807	814	817
14	836	815	820	824	827	831	834	838	839
15	846	837	839	841	842	843	845	846	847
16	849	846	847	847	848	848	849	849	849
17	850	849	849	849	849	850	850	850	850
18-->25	850	850	850	850	850	850	850	850	850



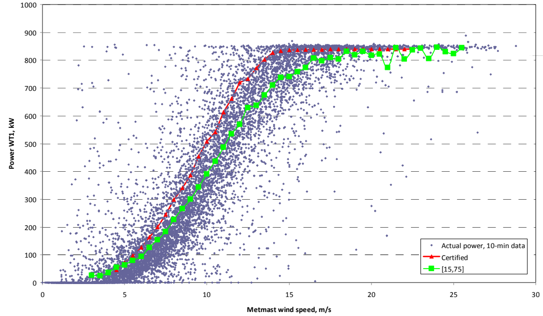
WF Ravne – Power curve (1)

- Northest wind turbine, WT1
- Nine months of correct data (2005-2006)



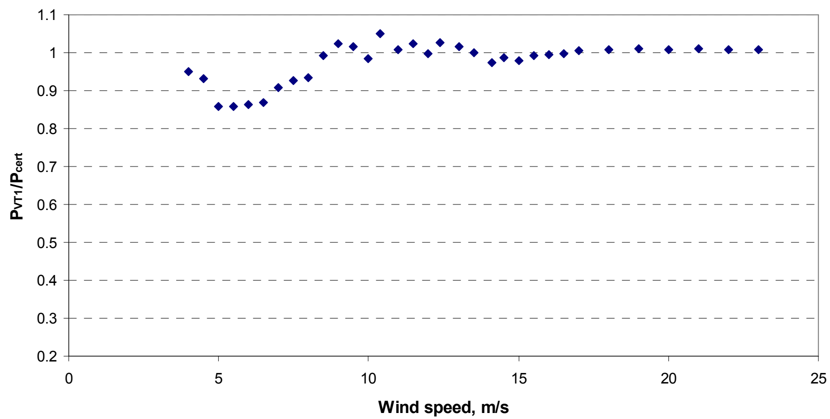


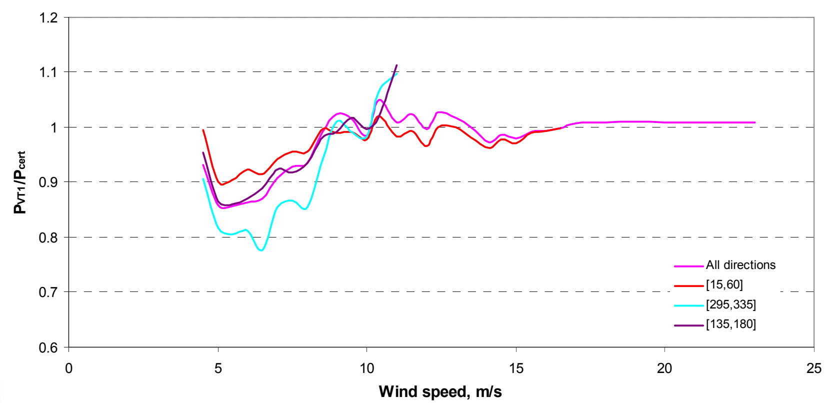
- Attempt with metmast data for sector [15,75]



WF Ravne – Power curve (2)

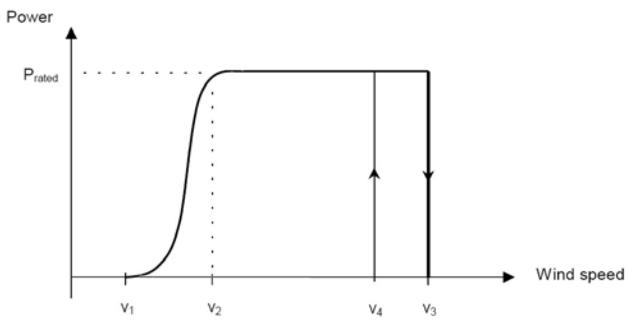
- Nacelle anemometer under strong influence of the WT1
- No firm conclusions on power curve behaviour at Ravne site due to lack of high quality data
- The influence of turbulence can be seen, and is in line with expectations

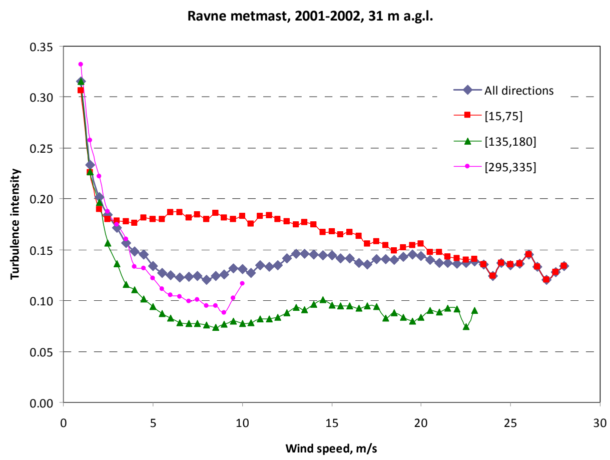




WF Ravne – Effect of cut-off regulation (1)

- Standard regulation approach: at v_3 wind turbine cuts-off, at v_4 restart
- Different cut-off wind speed criteria, f.e.:
  - 10 or 5-min ws: 25 m/s
  - 20-sec gust: 28 m/s
  - 3-sec gust: 30 m/s
  - restart wind speed (10-min): 18 m/s
- Standard cut-off regulation approach lead to high wind hysteresis energy losses at sites with high turbulence
- Wind turbines with standard approach (like Vestas V52) rarely operate up to 25 m/s (design cut-off wind speed)
- The effect is very dependant on the turbulence and how control parameters of the wind turbine are set



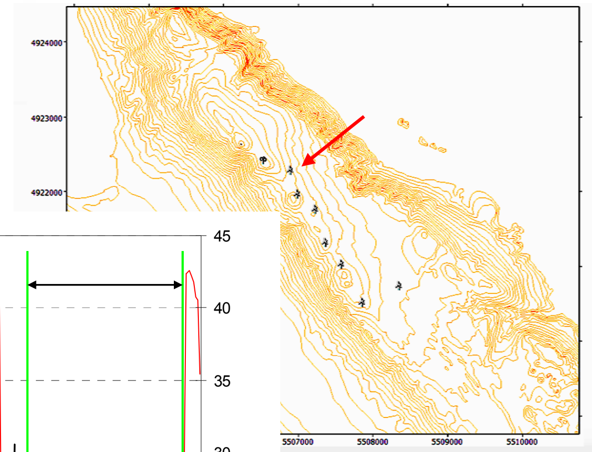


WF Ravne – Effect of cut-off regulation (2)

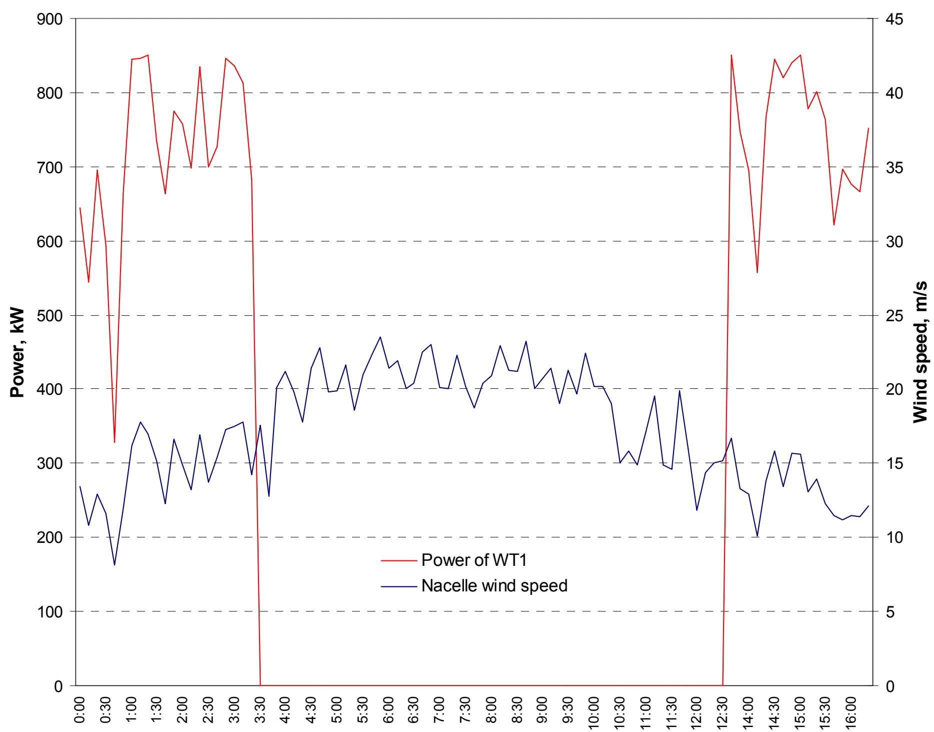
- Real life problems
  - Detection of hysteresis events depends on definition of hysteresis effect
  - Other reasons for cut-off can be mixed with wind speed cut-off criteria
  - High resolution data (3-s data) and detailed error log needed, but rarely available

- Analysis done for WT1 of WF Ravne
- Criteria:
  - No indication in the error log of specific reasons for cut-off
  - Nacelle wind speeds over 16 m/s
  - Restart wind speed (10-min): 18 m/s
  - Short intervals not considered

WF Ravne – Example (1)



WF Ravne – Example (2)



WF Ravne – Statistics of down-time events at WT1

- Energy production avoided due to cut-off regulation at Bora dominated site of WF Ravne seems to be underestimated in resource assessment studies
- The cut-off regulation and hysteresis effect have no effect on WT availability – WT is in RUN status!
- If WT stops for other reasons then cut-off regulation, actual energy loss is lower
- Reasonable assumption: 6-10% energy loss
- Improvement possible with different cut-off regulation strategy or other measures

Wind speed bin, m/s	Number of occurrences	Average duration in 10-min intervals
17	2	30
18	3	52
19	4	38
20	3	17
21	4	41
22	11	6
23	10	14
24	14	6
25	28	9.1
26	0	0
Total	79	14.3

Total production in 2006, WT1, MWh	1394
Energy not produced, MWh	157
Energy not produced, %	11.3

WF Ravne – Bora warning system

- Measure to improve the performance of the WF Ravne implemented by Vestas in 2008, still in test and training phase
- New 31-m met mast installed at the mainland, some 5 km in Bora upwind direction
- The data from the mast are part of WF control system
- The value and time duration of control parameters was several times changed in order to find optimum
- The result was not yet quantified, but qualitative effects are:
  - down time due to high wind increased
  - the rate of failures decreased
  - positive overall effect

WF Ravne – Technical availability

- Different definitions possible, one most commonly used by the manufacturers:

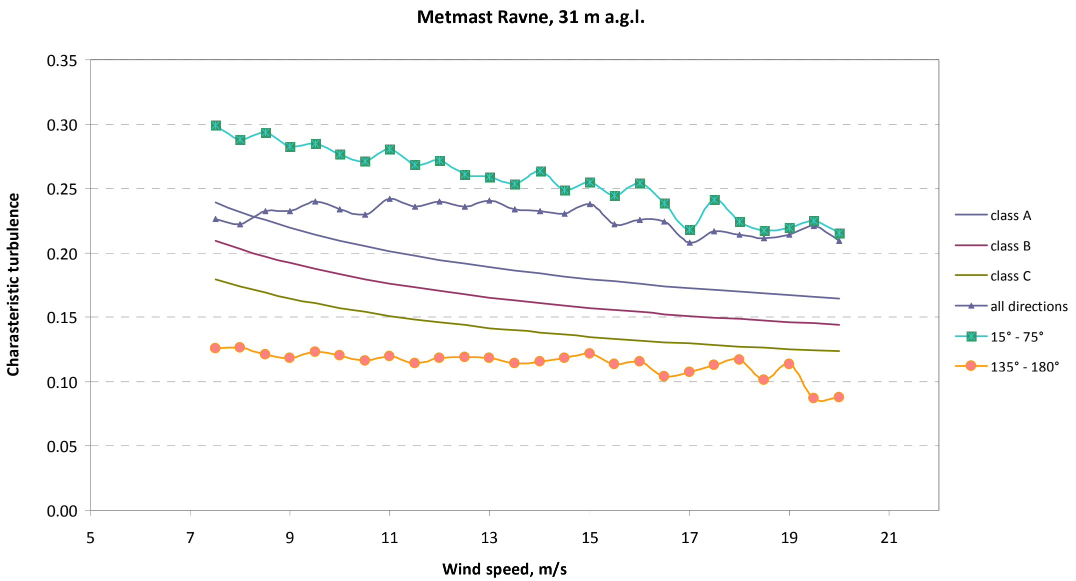
$$\text{Technical availability} = \frac{\text{Time that the turbine was in operation (RUN status)}}{\text{Total time - planned service - external events}}$$

- In case of WF Ravne planned service per WT: 92 hours/a
- External events: network failure, dispatching of the wind farm, etc...

	2006	4.2007-3.2008	4.2008-3.2009	4.2009-3.2010	Average (2007-2010)
WT1	*90.4*	81.8	89.8	84.7	85.4
WT2	*94.4*	90.3	92.9	80.7	87.8
WT3	*93.2*	90.5	89.5	89.5	89.9
WT4	*25.0*	81.2	58.1	86.4	75.6
WT5	*94.0*	72.9	71.3	89.3	78.2
WT6	*93.6*	88.6	90.9	94.3	91.3
WT7	*53.3*	81.7	77.1	70.4	76.4
Average	*79.2*	84.1	81.5	85.1	**84.0**

WF Ravne – Availability and WT class

- Low availability come from high frequency of equipment failures
- WT class at Ravne site: 1A
- Due to Bora, site conditions regarding turbulence exceed limits for class A
- High turbulence real challenge for wind turbines



CONCLUSIONS

- The wind resource assessment by use of “classical” approach might end in overestimating production – WF Ravne example
- Weak steps (at least):
  - long-term correlation
  - local effects associated with characteristics of Bora
- WF Ravne experience:
  - 5-year average of 1600 FLH – lower then expected for the available wind resource
  - power curve performance not easy to verify – further investigation needed
  - hysteresis effect and related loss of energy very much present at Ravne site.
  - technical availability much lover then in other projects
- The most important measure to improve the performance up to now: Bora warning system (in test phase)
- Bora warning system resulted in:
  - increased down-time due to high wind, but
  - less equipment failure
  - overall increase of production – positive financial effect

THANKS!