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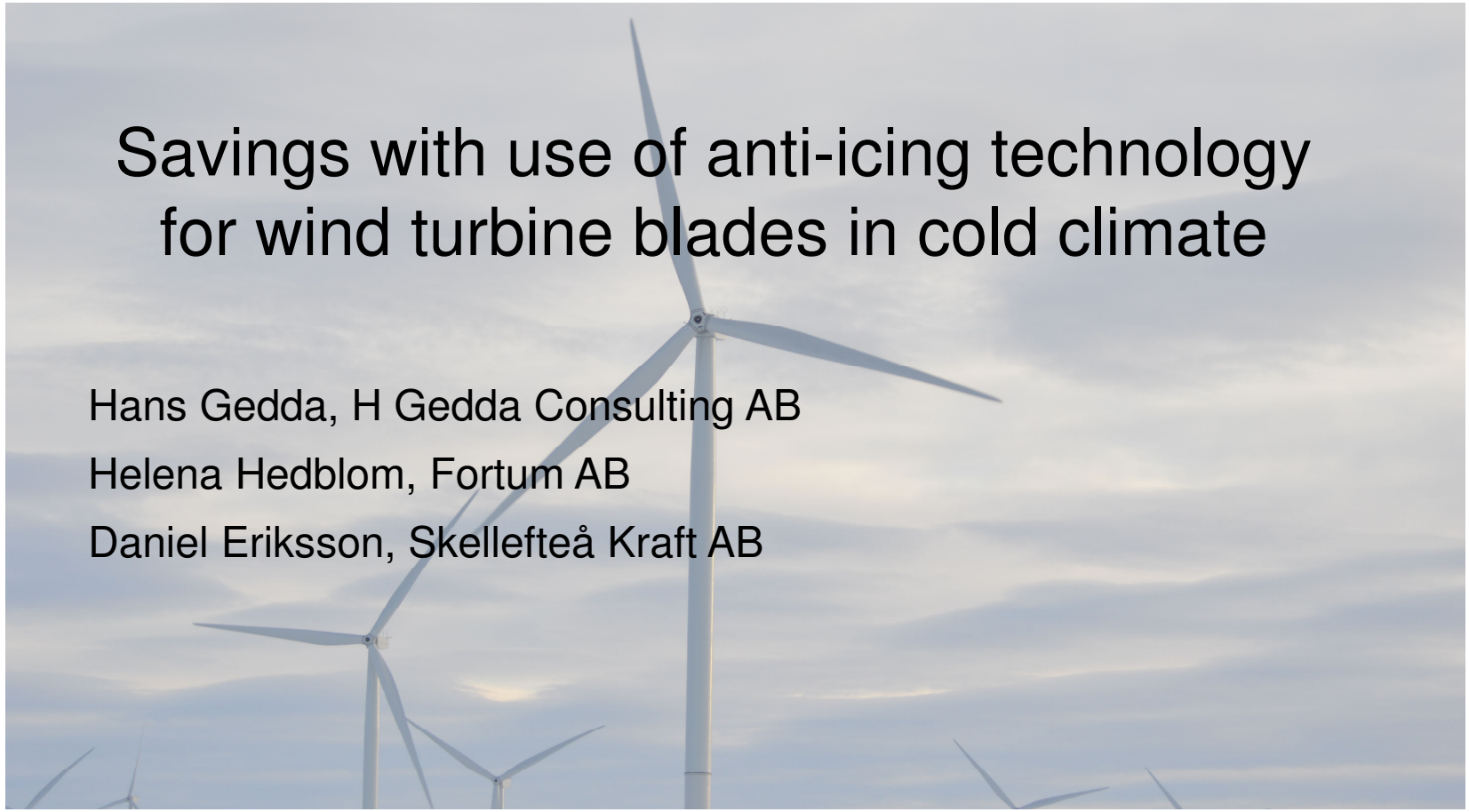

Savings with use of anti-icing technology for wind turbine blades in cold climate

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Agenda

- Presentation of Blaiken Vind AB
- Presentation of the Mawic project
- Results and observations
  - Uljabuouda
  - Jokkmokksliden/Storliden
  - Noise
- Other observations
- Conclusions

BlaikenVind AB

Between 2010 and 2016, Skellefteå Kraft and Fortum will under the joint company name of BlaikenVind AB, build one of Europe's largest wind farms in the area of Blaiken in northern Sweden.

The initiative follows Swedish and international targets in renewable energy and the vision of better energy options for climate-clever companies and people. Planning started in 2005 and together, our aim is now to contribute to a sustainable Sweden.

BlaikenVind AB runs the MAWIC project (self-funded)
Measurements Analysis Wind Power for Icy Climates.

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MAWIC - Objective

Increased knowledge and experience of maintenance on turbines equipped with anti-icing system for improvement and optimization of control algorithms with focus on lowest possible life cycle costs.

MAWIC

Measurements and analysis from three sites.

– Uljabuouda commissioned 2010, 10 WTG

– Jokkmokksliden/Storliden 18 WTG (15 with AIS) commissioned 2011.

Blaiken wind farm include totally 90 turbines where 30 turbines erected 2012.

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MAWIC

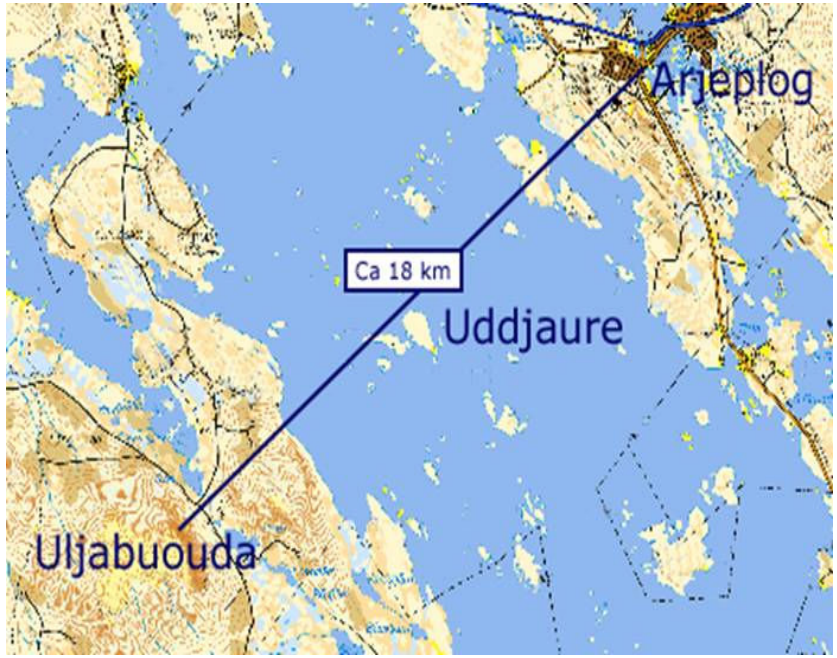
Measurement period

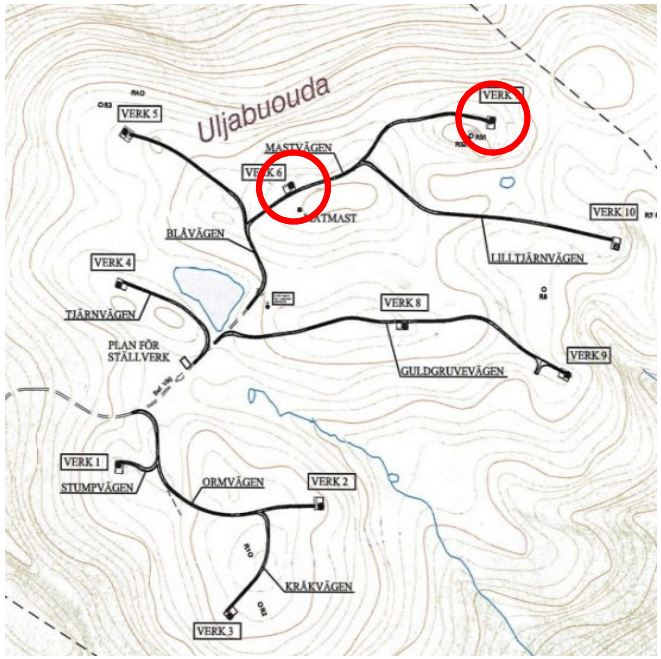
01-11-2011 to 31-03-2012 and
01-11-2012 to 31-03-2013

Continuously measurement and analysis of

- Wind Speed, direction
- Air pressure, Humidity and temperature
- Ice load
- Energy production and consumption in the ant-icing system. The study sites Uljabuouda, and Jokkmokksliden are recorded. (Blaiken is excluded in this presentation commissioned late 2012)

Uljabuouda





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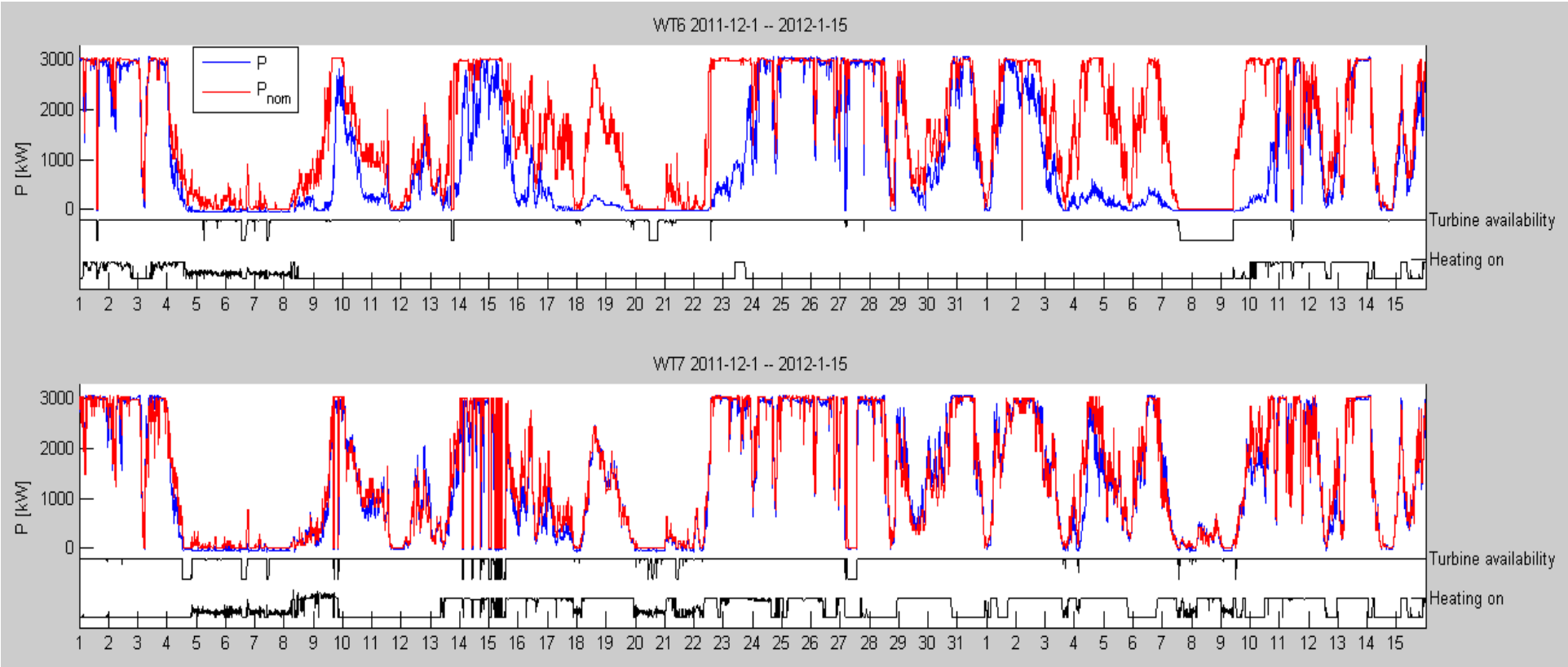
Results and observations at Uljabuouda

WTG 6 - 10 are the turbines included in this study, with focus on WTG 6 and 7.

The anti-icing system at WTG 6 has been disabled deliberately for longer periods for a direct comparison of the power production against the other turbines with enabled anti-icing system.

Uljabuouda 2011-12-01- 2012-01-15
Turbine 6, 7



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Identified icing events [h]
Nov 2011-Mar 2012
and Nov-Dec 2012 at Uljabuouda

Total number of hours that the blades were covered with ice before the ice melts or sublimates.

Icing event	Duration [h] 2011-2012	Duration [h] Nov-Dec 2012
Nov	30	380
Dec	520	744
Jan	612	
Feb	144	
Mar	55	
Totally	1 361	

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Potential savings at Uljabuouda with a anti-icing system

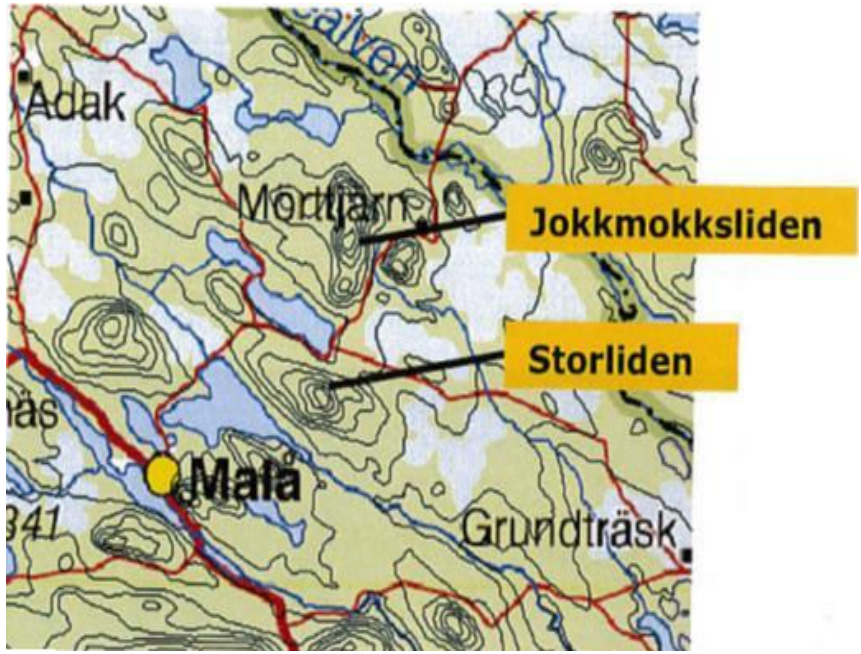
Assumption

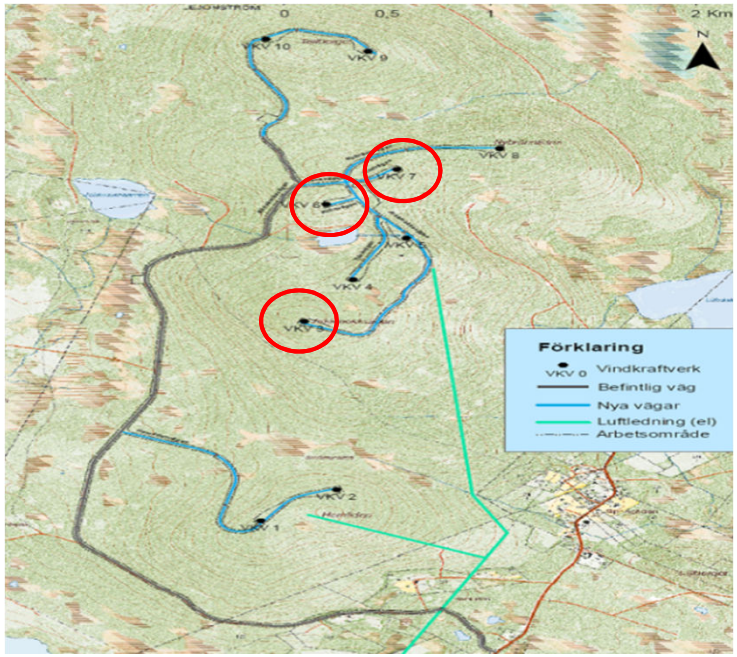
- 100% availability for both turbine and anti-icing system.
- Valid only for this evaluation period.
- Savings are expressed in SEK/EUR using daily spot price at Nord Pool and assuming a certificate price of 180 SEK/MWh ~ 20EUR/MWh
- The intervals cover the different turbine positions in the wind farm

Ice related production losses

	[MWh]	[tSEK]	[tEUR]
Anti-icing	80-130	45 -70	5,0-7,7
No anti-icing	950-1300	500-725	55,5-80,5

Jokkmokksliden/Storliden





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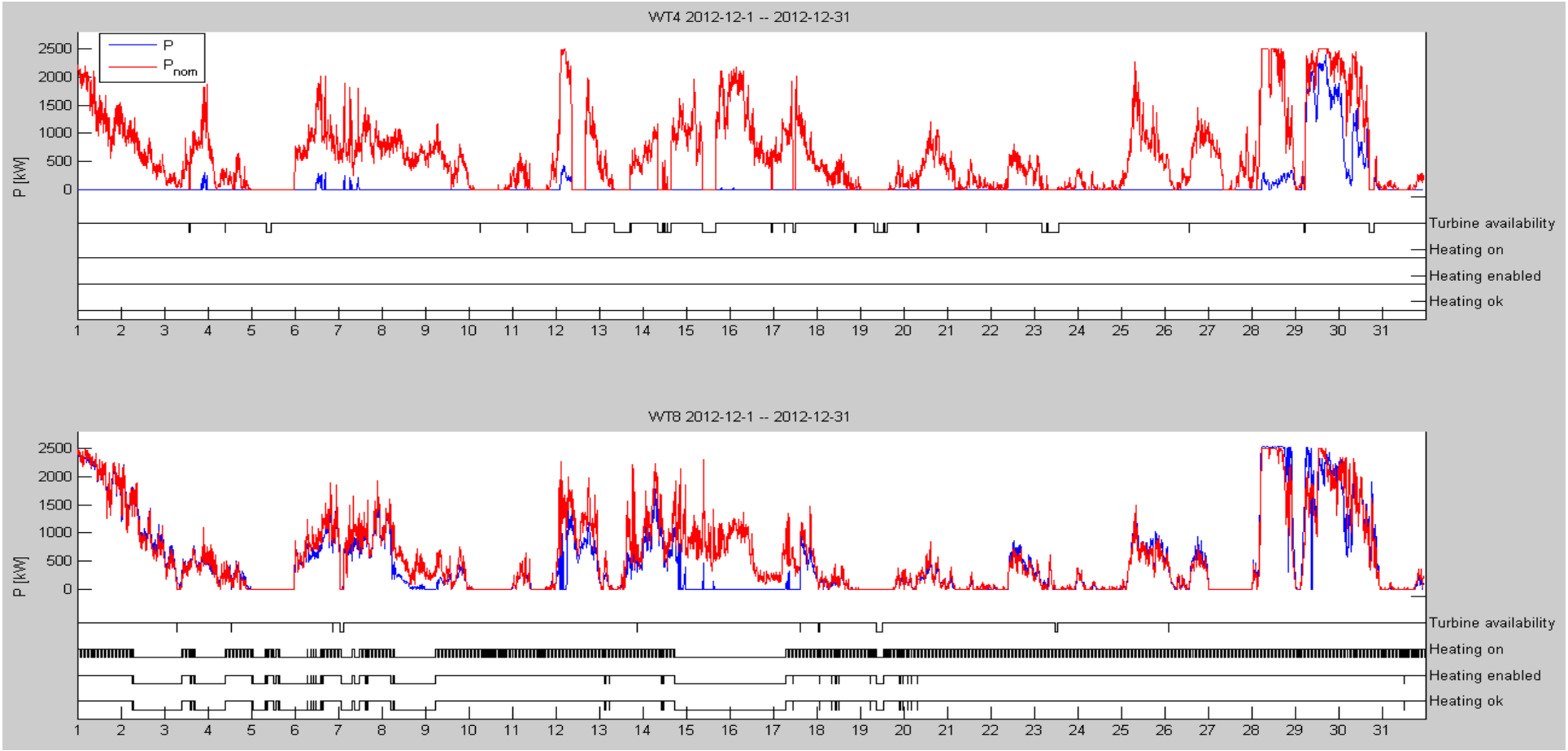
Jokkmokksliden 2012-12-01 2012-12-31
Turbine 4, 8



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Identified icing events [h]
Nov 2011-Mar 2012 and
Nov-Dec 2012 at Jokkmokksliden/Storliden

Total number of hours that the blades were covered with ice before the ice melts or sublimates.

Icing event	Duration [h] 2011-2012	Duration [h] 2012 Nov-dec
Nov	54	150
Dec	533	670
Jan	593	
Feb	132	
Mar	0	
Totally	1312	

Potential savings at Storliden/Jokkmokksliden with a ant-icing system

Assumption

- 100% availability for both turbine and anti-icing system.
- Valid only for this evaluation period.
- Savings are expressed in SEK/EUR, using daily spot price at Nord Pool and assuming a certificate price of 180 SEK/MWh ~ 20 EUR/MWh
- The intervals cover the different turbine positions in the wind farm

Ice related production losses

	[MWh]	[tSEK]	[tEUR]
Anti-icing	60-75	35-45	3,8-5,0
No anti-icing	700-900	375-475	41,6-52,7

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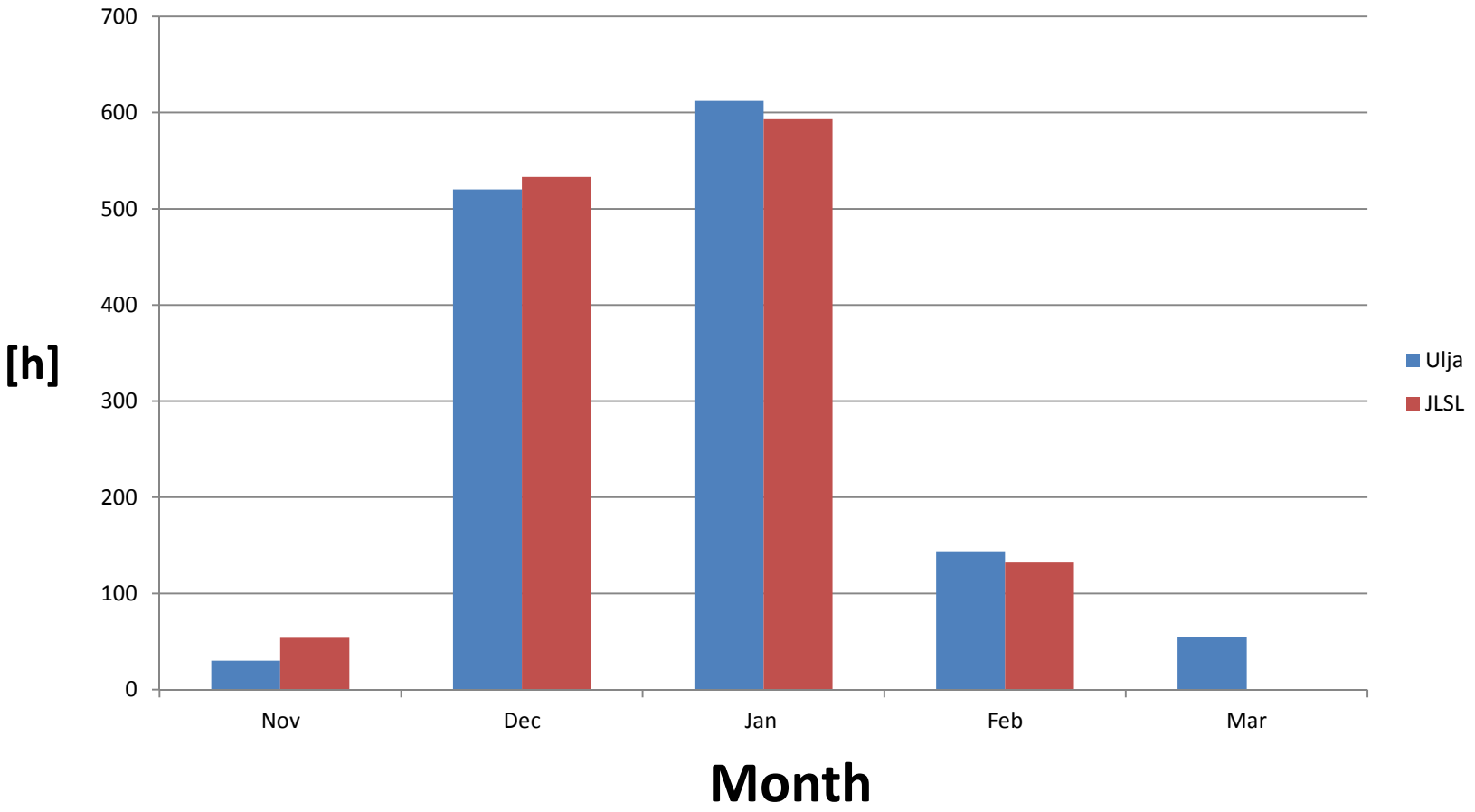
Energy Consumption from the anti-icing system is estimated to 1-1,5 % of the production at Jokkmokksliden and 2-2,5% for Uljabuouda in this investigation for a month with severe icing.

Icing [h] Nov- Mar 2011-2012



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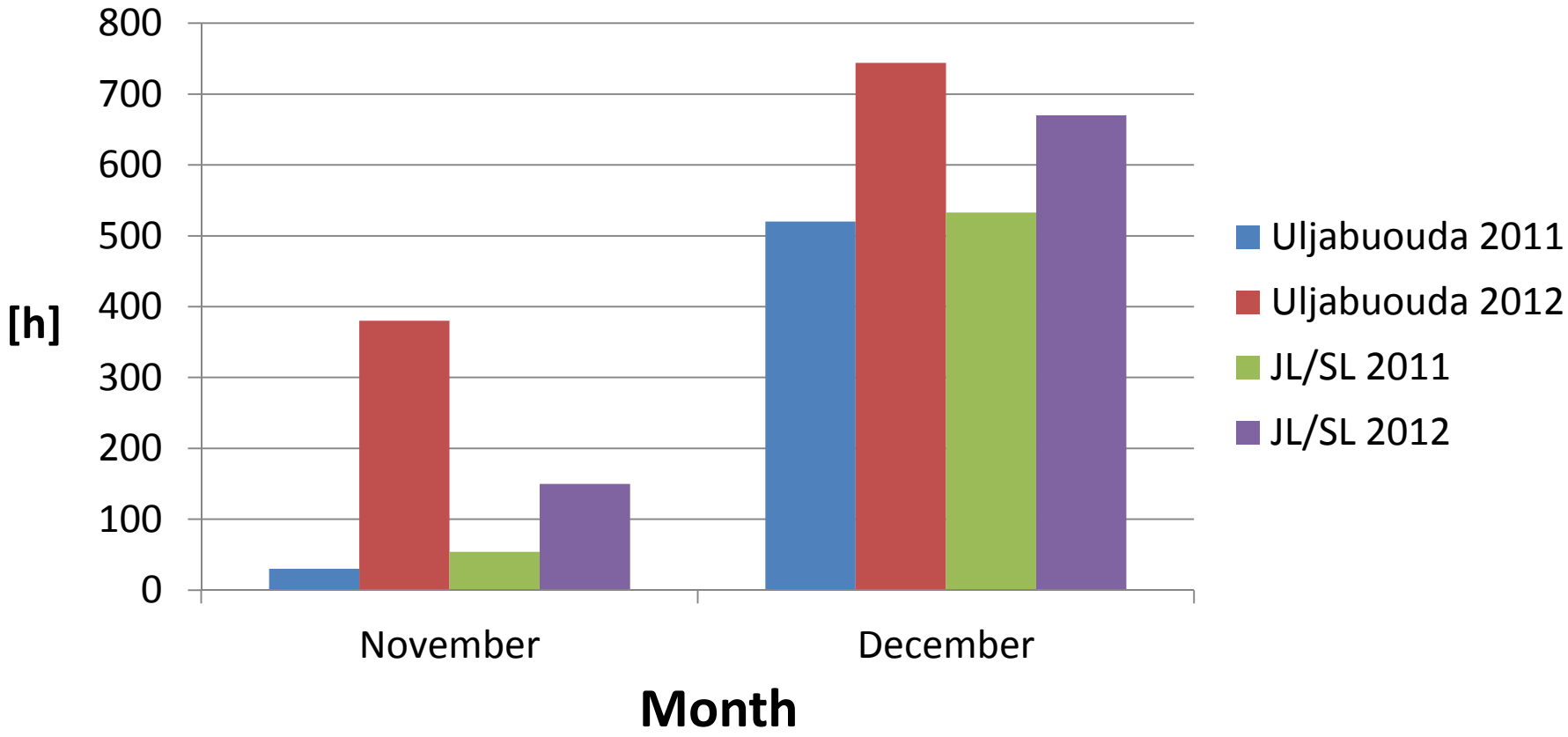
Icing [h] Nov- Dec 2011 and 2012 at Uljabuouda and Jokkmokksliden/Storliden



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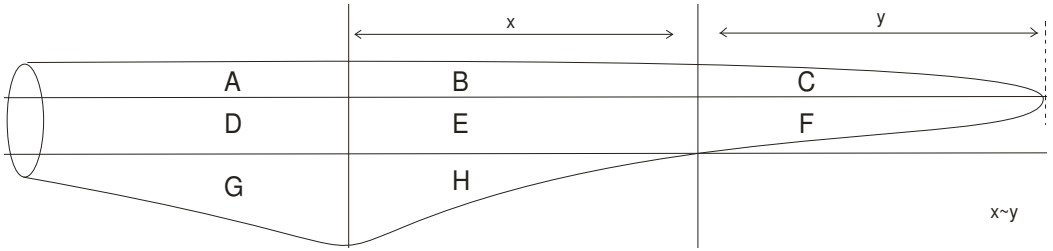
Noise

Manual observations of rotor blade icing and noise level for WT4-7 at Jokkmokksliden were made daily at 9:00, 13:00 and 17:00 between December 2010 to April 2011.

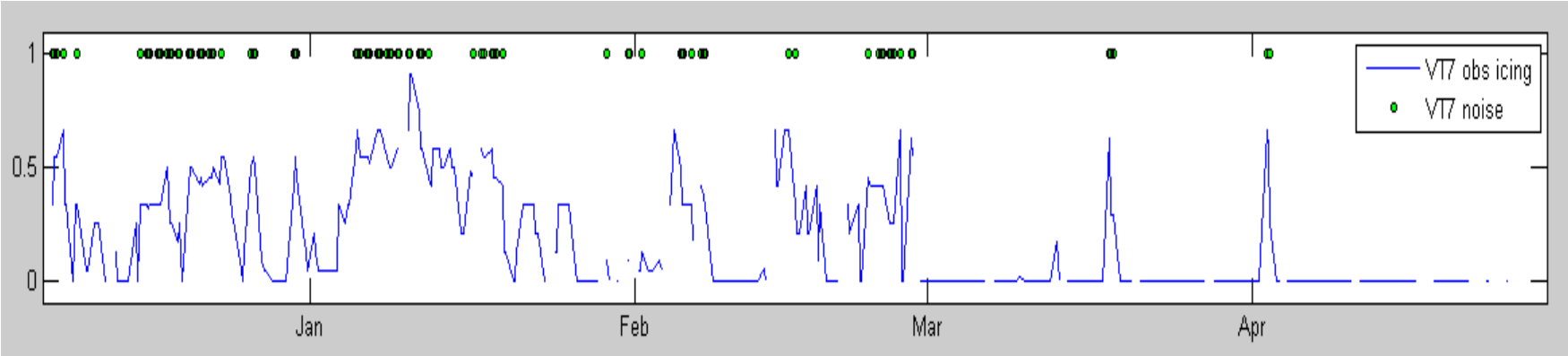
Each rotor blade was divided into 8 sections.

The degree of icing on each part was assessed using a scale 0-3, where 0 means no icing and 3 heavy icing.



Noise

In figure below the normalized sum of icing levels on all parts of the three blades of WT7 is plotted together with green dots representing unusually high noise levels. The discontinuities are due to low visibility. A clear connection between icing and excessive noise can be found.



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December 19, 2012

Comparison of a turbine with AIS system and reference turbine without AIS at Jokkmokksliden

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Other interesting observations 2011-2012

- Mean temperature is 1.6ºC lower for Blaiken and Uljabuouda compared to Jokkmokksliden
- The main icing events have been observed at all sites with a short delay between them.
- Duration of icing periods can differ slightly between the sites.
- A significant reduction of production losses are expected with use of anti-icing system.

Conclusions (2011-2012)

Some icing events have been observed when the AIS has been inactive.

Some periods without icing have been observed when the AIS has been active.

The conclusion is that there is room for improvement of the control algorithms.

A clear connection between icing and excessive noise can be found.

Savings with use of properly working AIS system is approximately 1 000 [MWh]/turbine for Uljabuouda and 800 [MWh] for Jokkmokksliden/Storliden respectively

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