

ENERGY

# Forecasting wind turbine icing

The value of icing forecasts on the day-head energy market trading

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10th Feb 2016

# DNV GL Short-Term Forecasting Summary



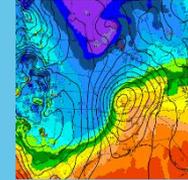
Wind, solar and power demand forecasts



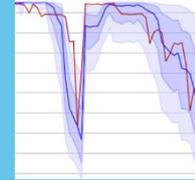
5 minutes to 15 days into the future



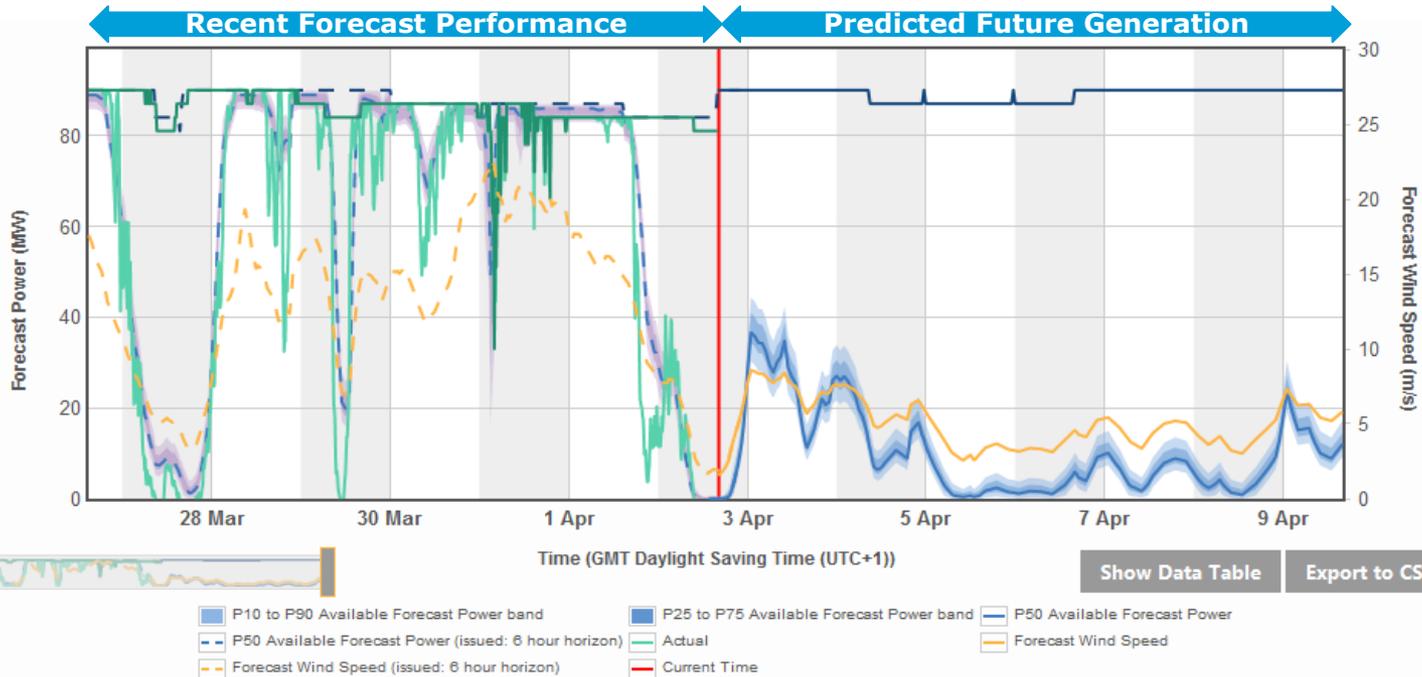
Global Experience > 50 GW capacity > 20 countries



Data from the World's best forecast models



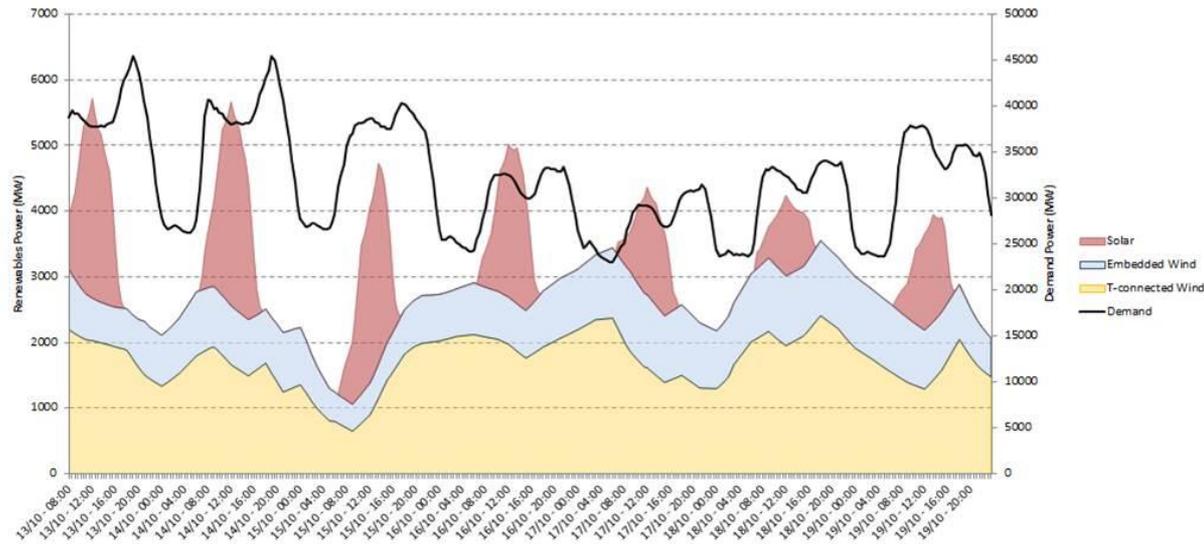
Accurate uncertainty data for risk evaluation



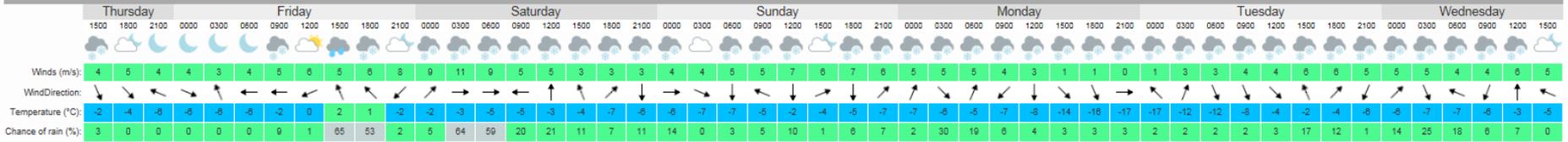
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# Forecasting – Reducing Risk

- Energy trading
- Optimised operations & maintenance
- Generation scheduling and grid operation

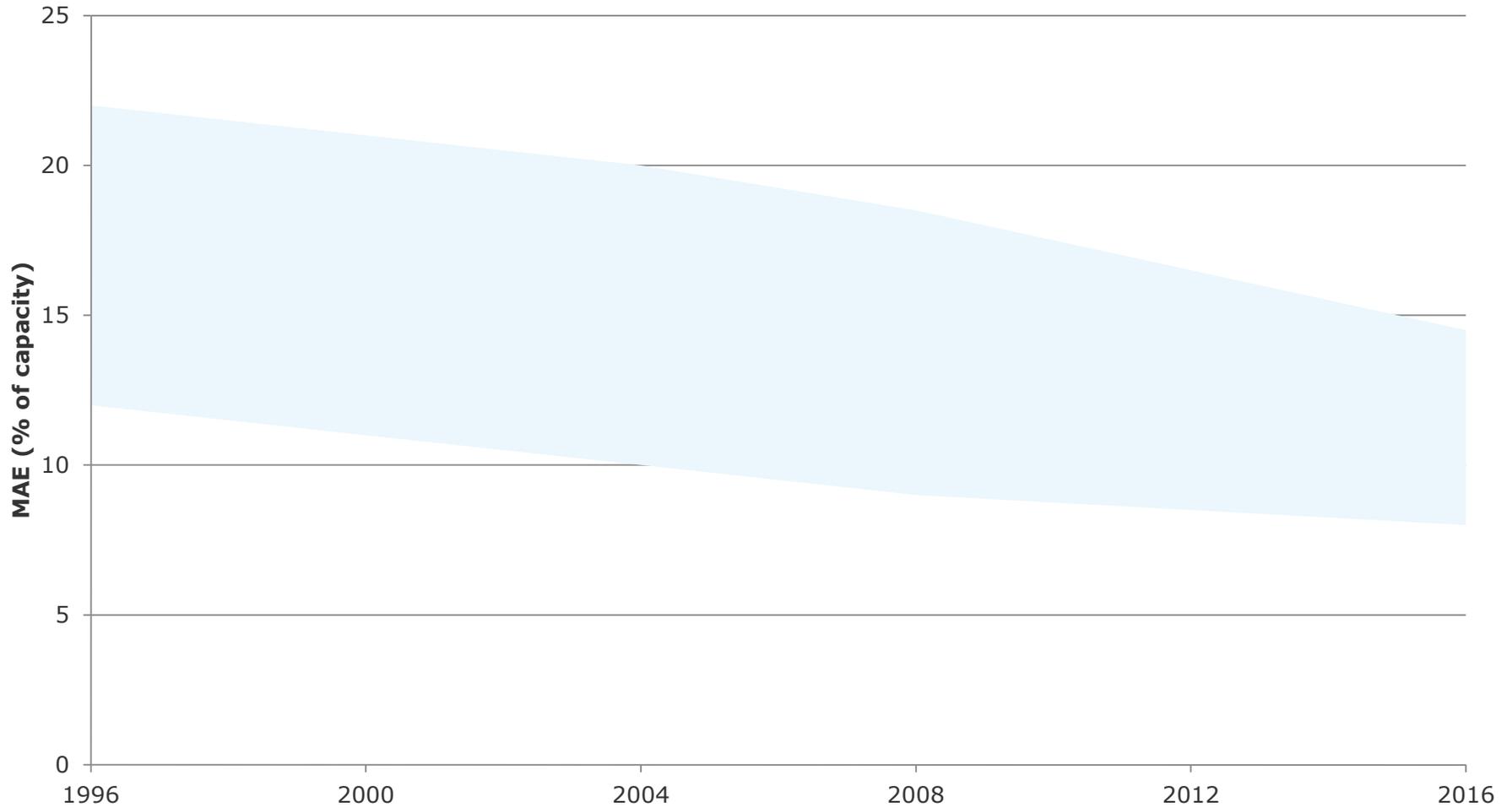


Are, Sweden



Private and confidential

# Wind Energy Forecasting Accuracy Through The Years



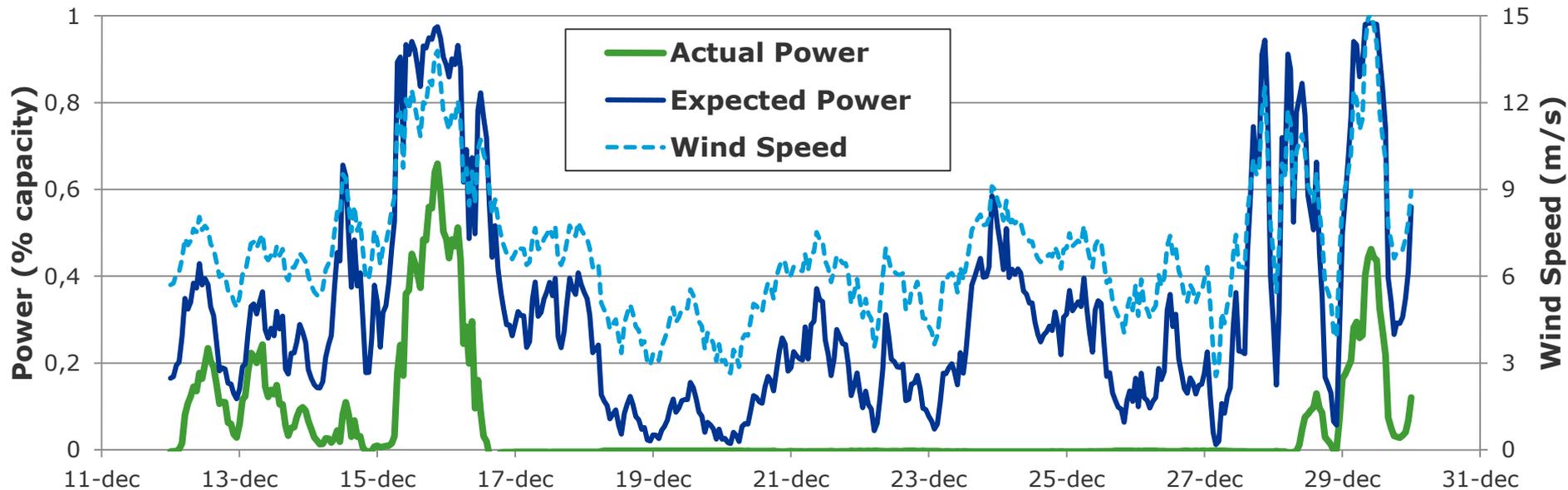
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## Challenge – Icing losses

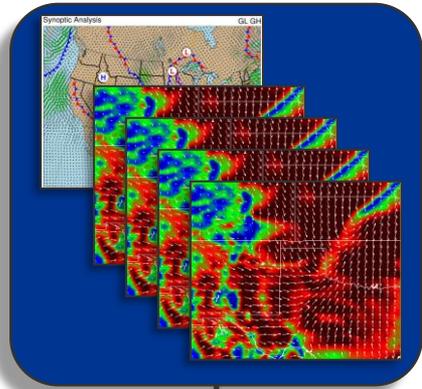
- Icing losses in Scandinavia are variable and can be highly significant
  - Annual energy production losses from  $\sim 0\%$  up to  $>10\%$
  - Monthly energy production losses from  $1\%$  up to  $>50\%$

*(Staffan Lindahl: Quantification of energy losses cause by blade icing using SCADA data, Winterwind 2014)*

- Individual icing events can lead to full loss of power

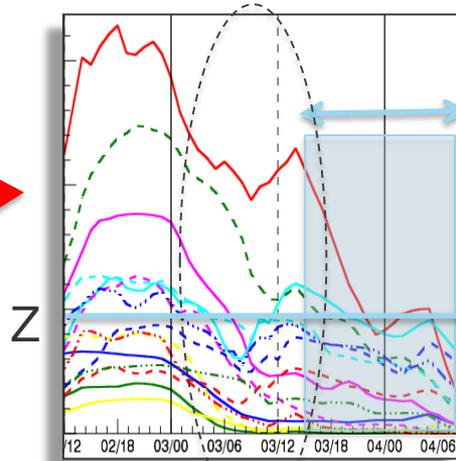


# Methods – icing model

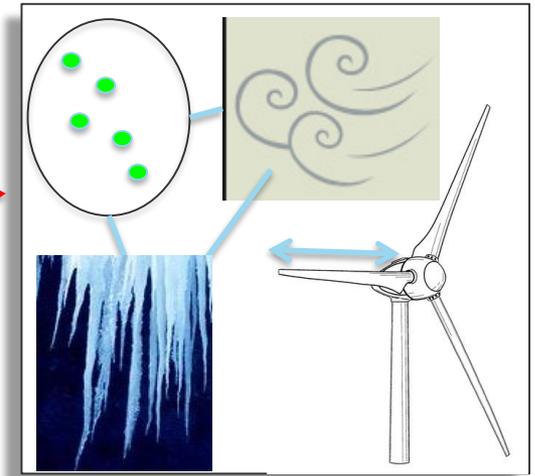


Wind Speed  
Wind Direction  
Temperature  
Pressure  
Relative Humidity

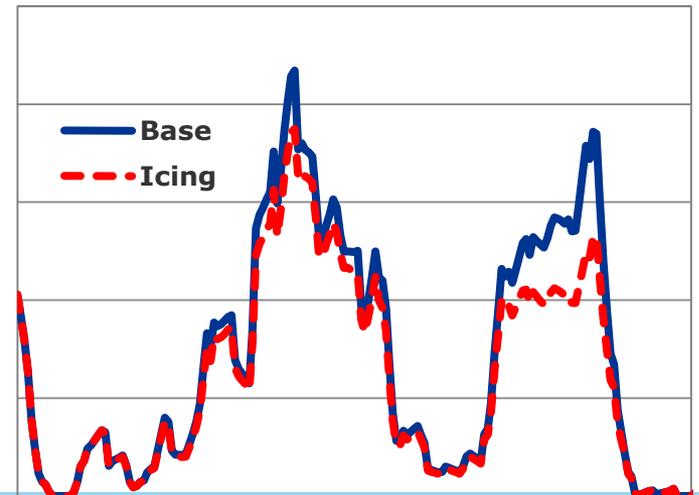
- Ensemble NWP predictions
- Predicted freezing/thawing time
- Ice accretion parameterization
- Power adjustment



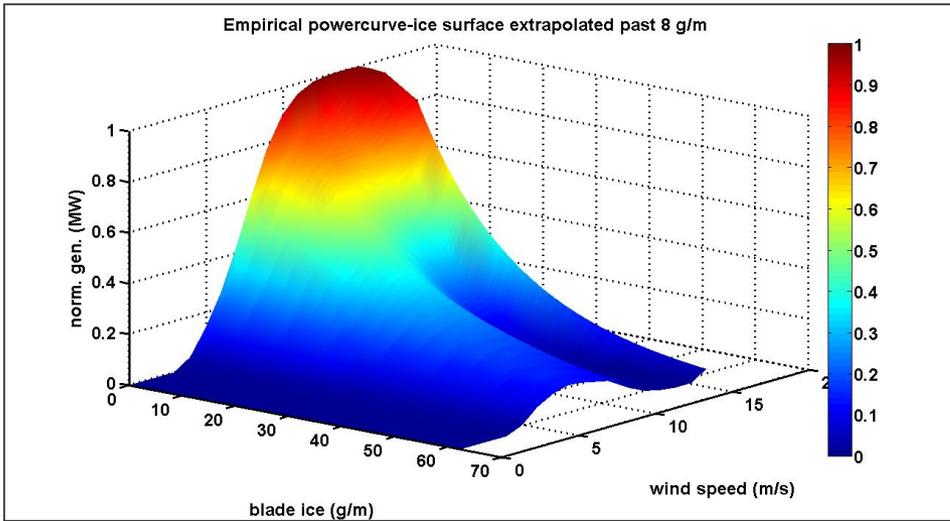
Ensemble Predictions



Adapted from Frohboese and Anders (2007)



# Methods – icing model power conversion



Borrowed from [http://www.tuuliatlas.fi/icingatlas/icingatlas\\_6.html](http://www.tuuliatlas.fi/icingatlas/icingatlas_6.html)

- Finnish Wind Energy Atlas  
Ljungberg & Niemelä Model
- Converts blade ice, wind speed to power degradation

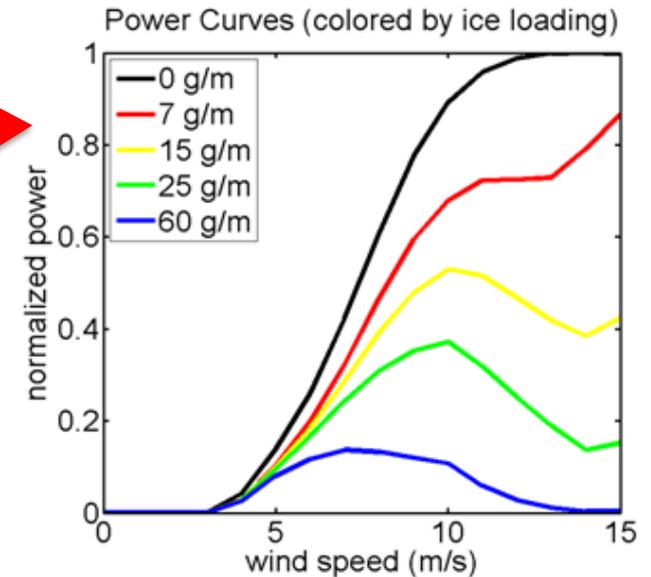
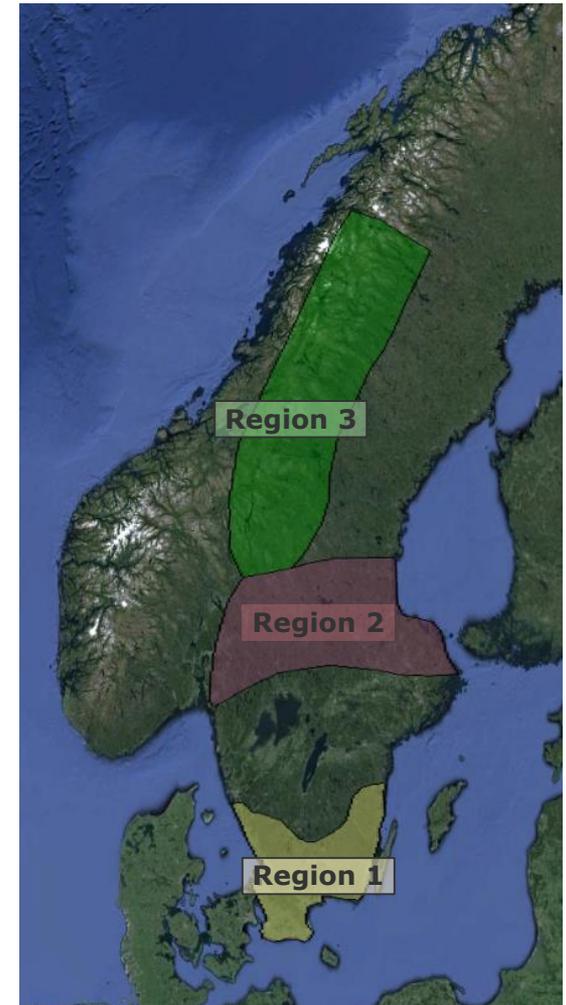


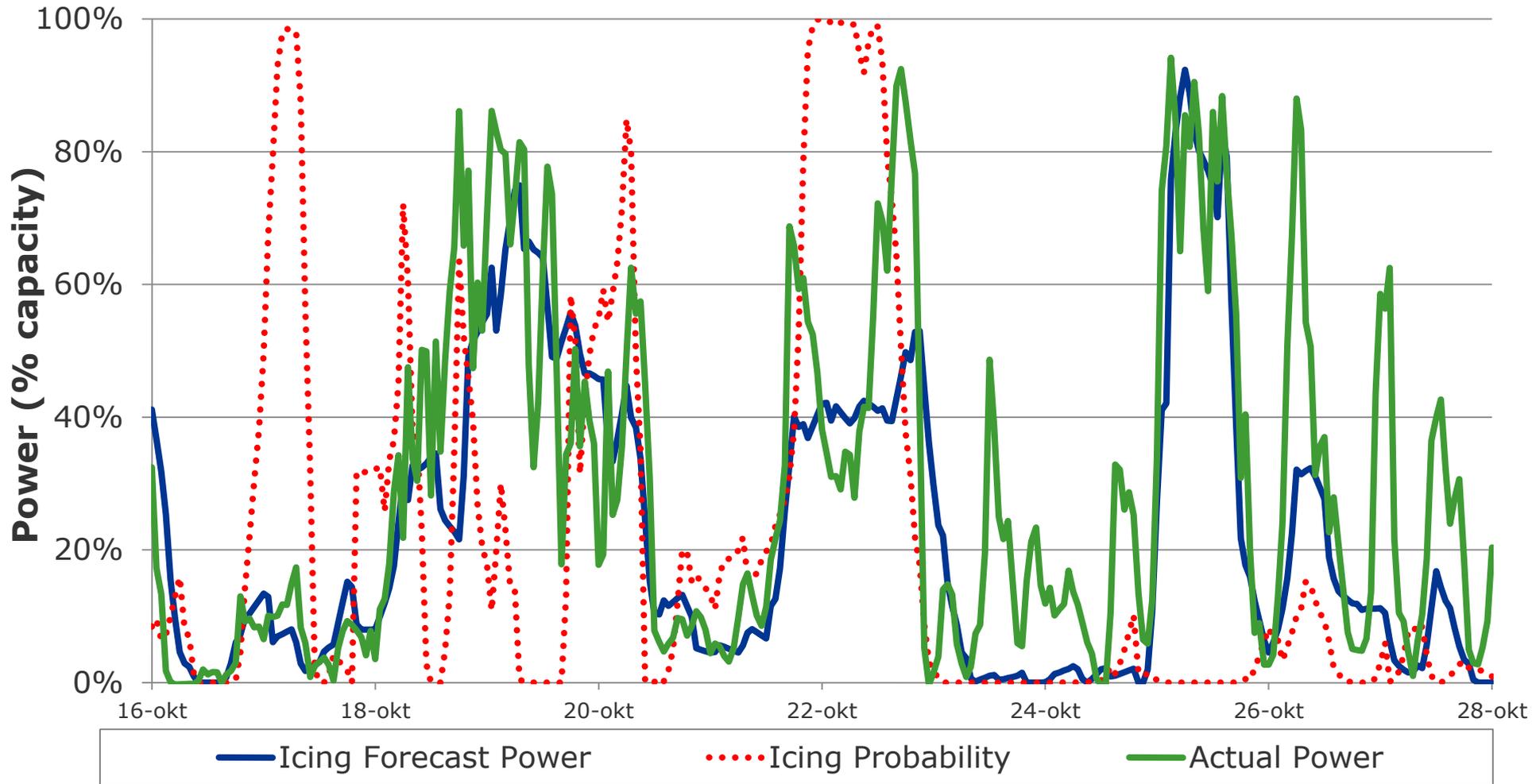
Figure 1: Adapted from Ljungberg, K. and S Niemelä (2011)

## Validation Data

- 3 wind farms, ~40 wind turbines
- Projects in Region 2 and Region 3, where there is sufficient icing to test model
- For each site:
  - ~1 year of data for model training
  - ~1 year of data for validation
- For all projects the turbines remain operational during blade icing periods

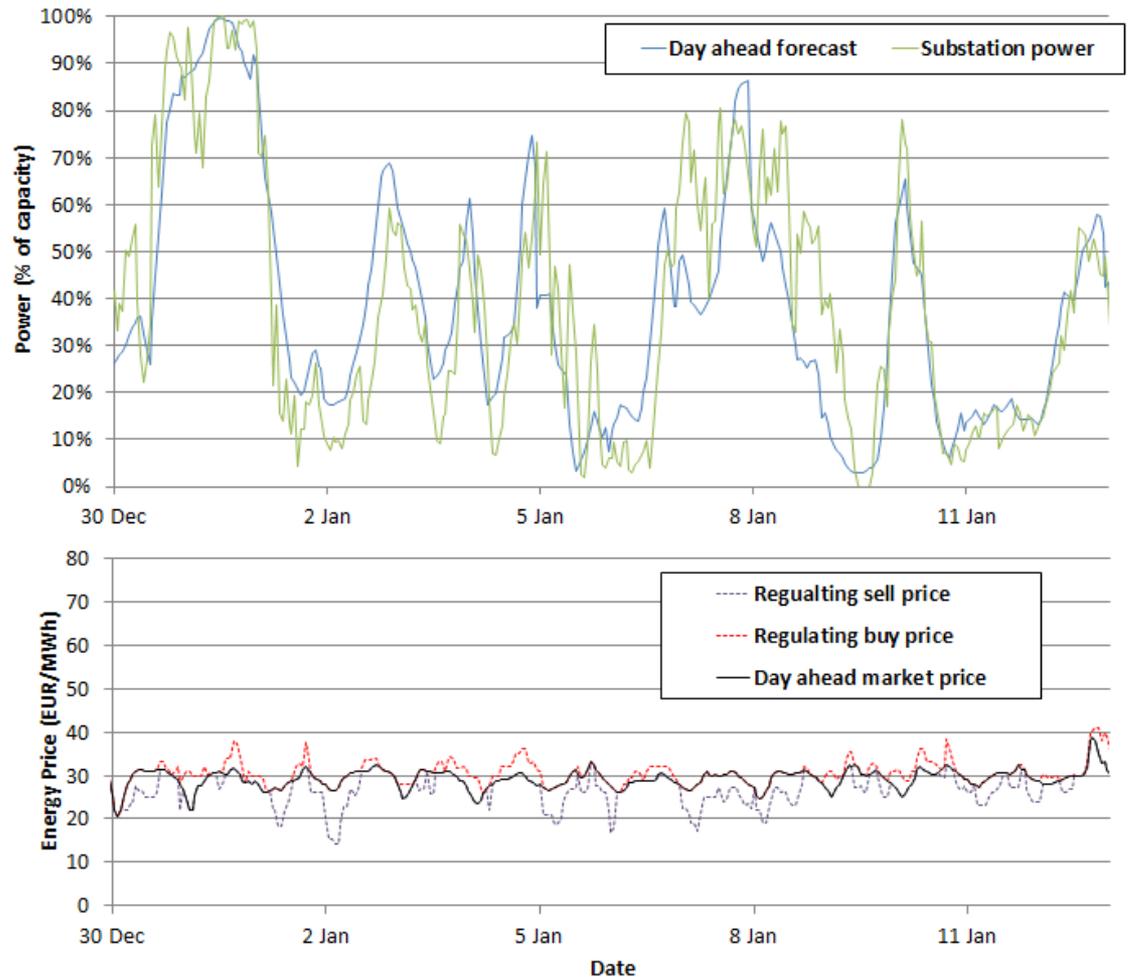


# Value to forecast users – an advanced warning system



# The Nordic/Baltic day-ahead market (Elspot)

- 12:00 CET daily trade
- Hour by hour order of the next day
- Scheduled energy sold at Elspot day-ahead price
- Shortfall bought at regulation buy price
- Excess sold at regulation sell price
- Intraday market also available



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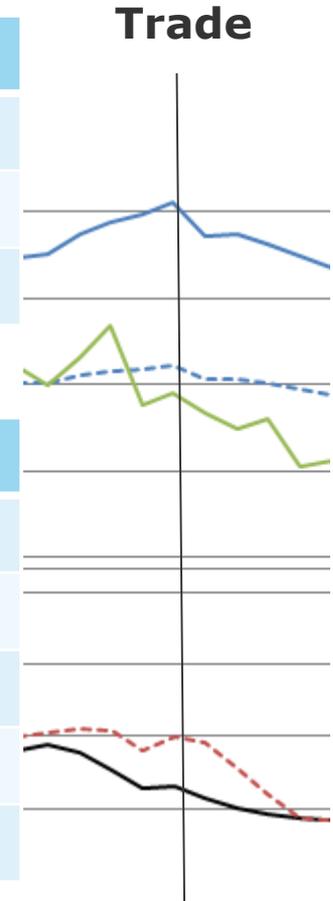
# Show me the money! – example trades

## Day Ahead Market

	Standard	Icing model
Forecast (MWh)	20	11
DAM (€/MWh)	33	33
DAM revenue (€)	660	363

## Regulation Market

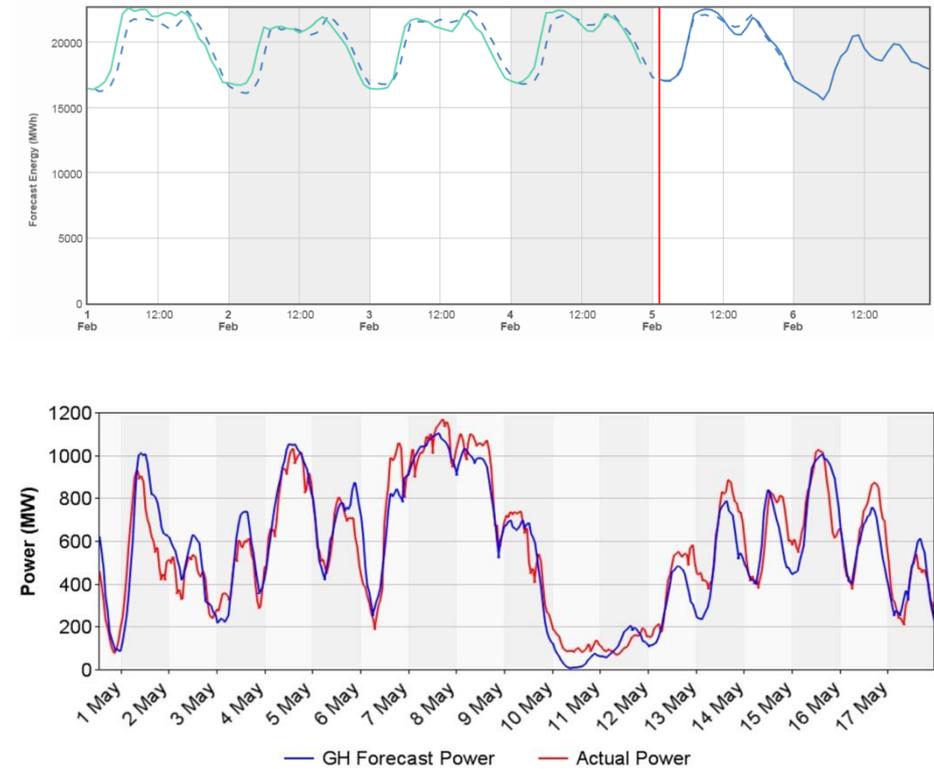
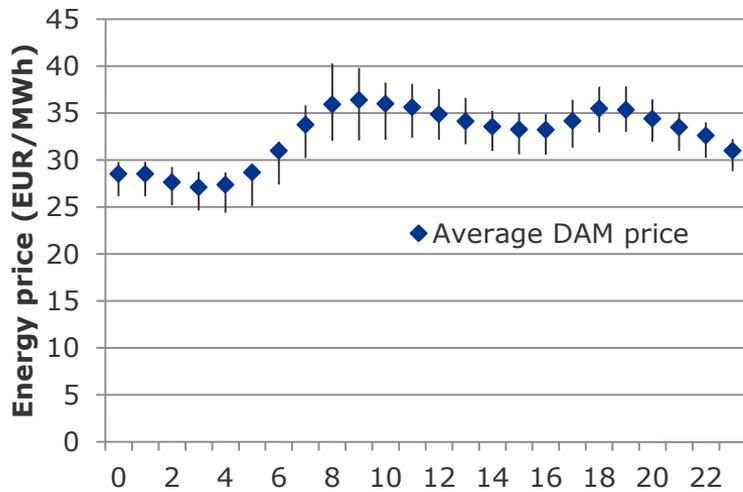
	Standard	Icing model
Actual (MWh)	9	9
Delta (MWh)	-11	-2
Buy (€/MWh)	40	40
Balancing (€)	-440	-80
Total (€)	220	283



**Icing forecast benefit ~1000 EUR/winter for 15MW wind farm**

# Conclusion

- Short-term forecasting minimises risk
- Detailed modelling can further improve advanced forecasts
- Further research on market fundamentals



# Thank you – I will be at stand no. 36

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**SAFER, SMARTER, GREENER**

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