

Norwegian University
of Life Sciences

Estimation of Production Losses due to Icing on Wind Turbines at Kvitfjell Wind Farm

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Tønsberg, June 5, 2019

Agenda

- Scope of the thesis and approach
- Ice physics
- Site description
- Data processing
- Energy simulation
- Results
- Conclusion



The scope of the master thesis

“Estimate potential production losses due to ice accretion on wind turbine blades at the pre-operational wind farm Kvitfjell in Norway.”

How to approach?

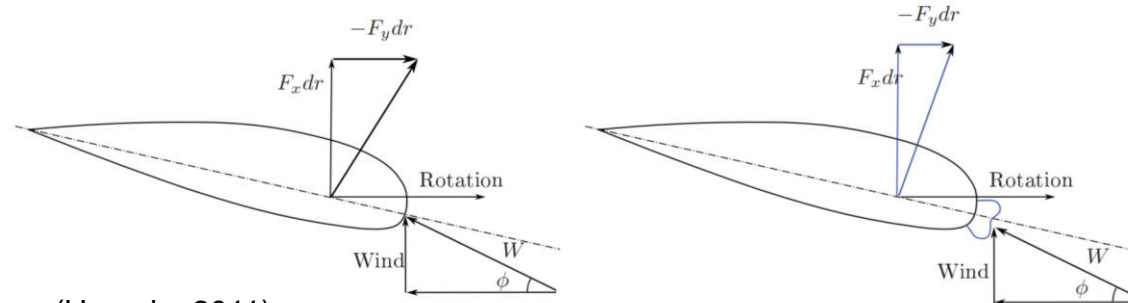
- Time historical met mast data
- Computational Fluid Dynamics
- Three scenarios



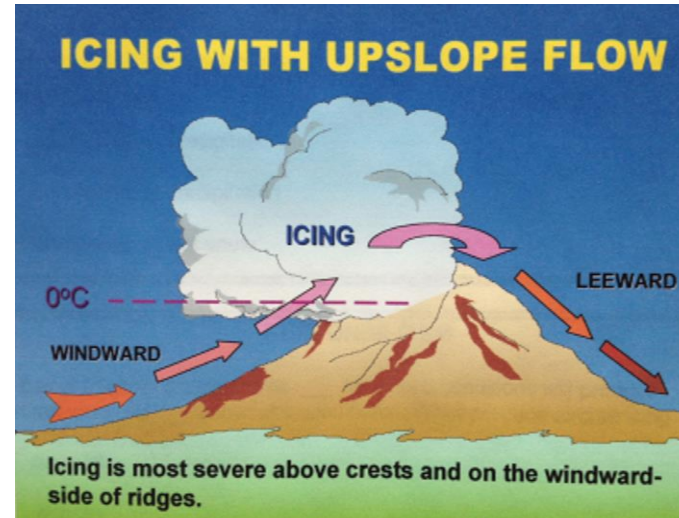
(Ronsten, 2008)

Ice physics

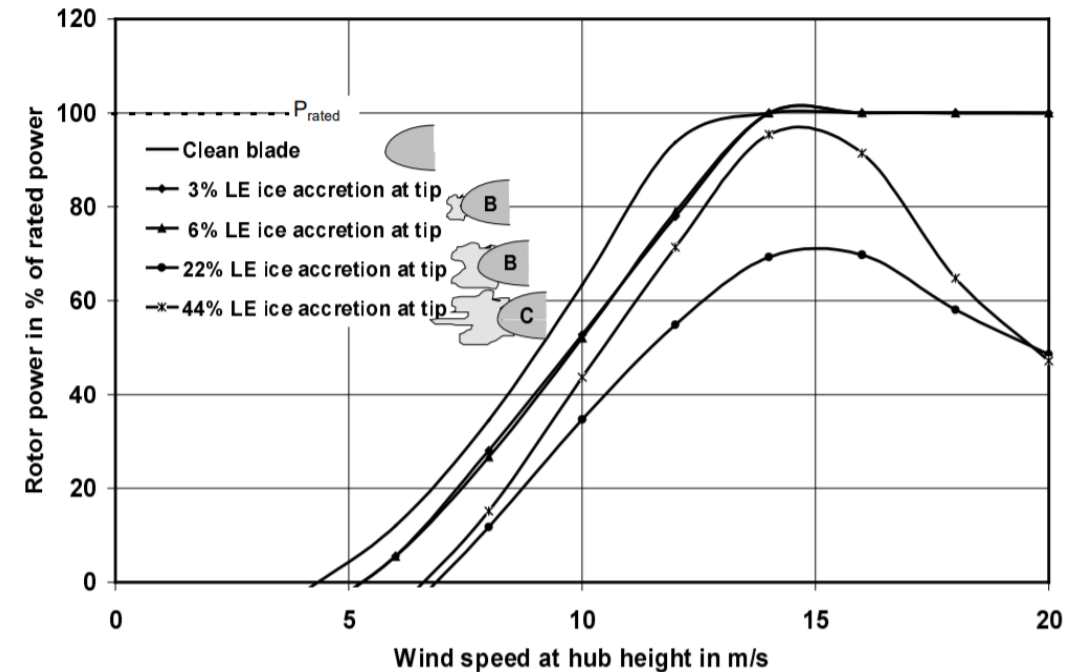
- Aerodynamic performance
- Type of ice and shape
- Incloud icing
 - Orographic lifting
- Removal of ice
 - Shedding



(Homola, 2011)



(National Weather Service)

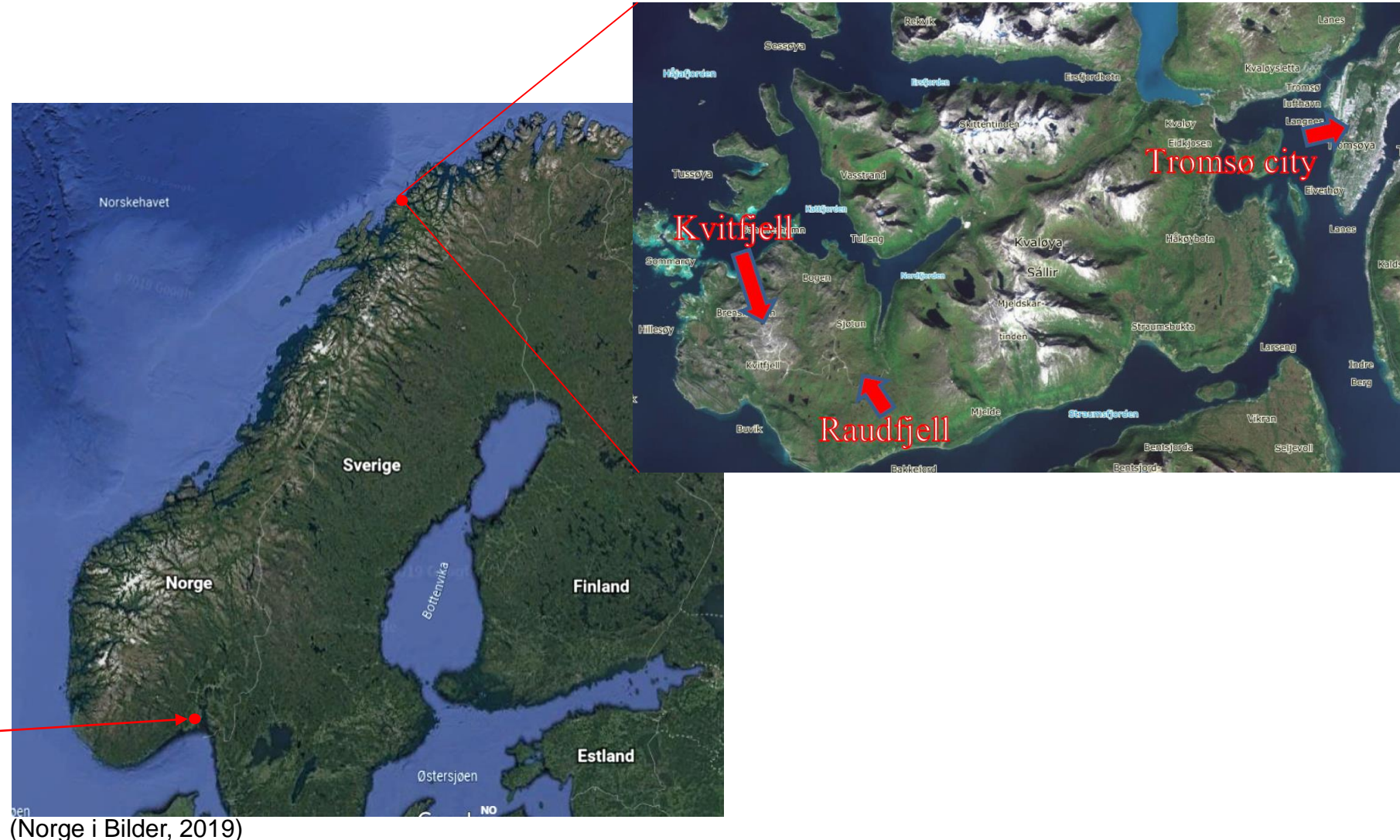


Calculated power curve for a pitch controlled fictitious turbine with different type of ice accretion (Seifert & Richert, 1998).

Site description

- Two mountains
Raudfjell and Kvittfjell
300-550 m above sea level
- Mild arctic climate
- 281,4 GW
- 67 turbines 4,2MW
Siemens

We are here



(Norge i Bilder, 2019)

Data processing- Identification of ice events

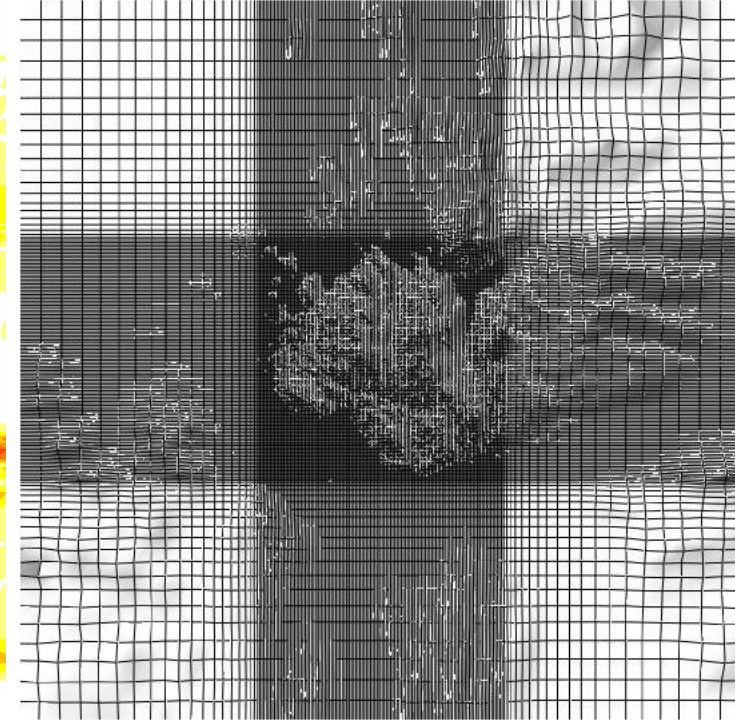
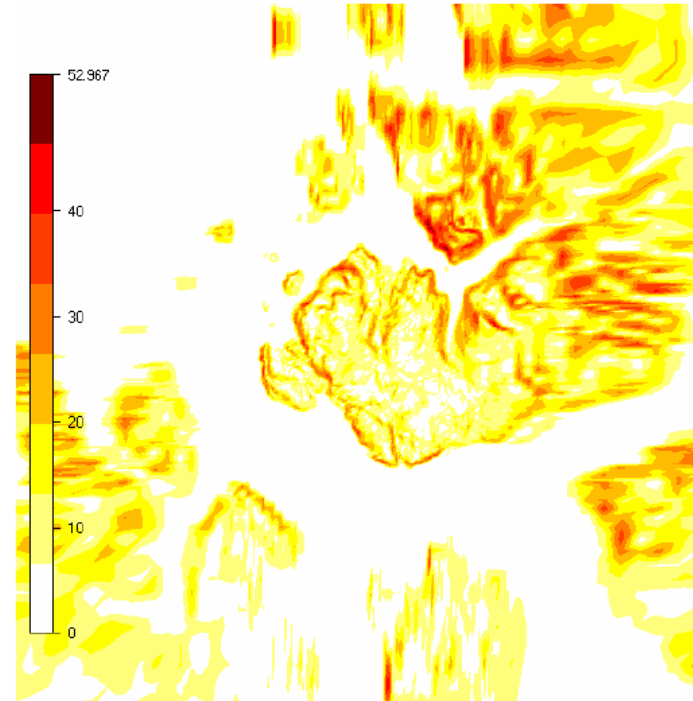
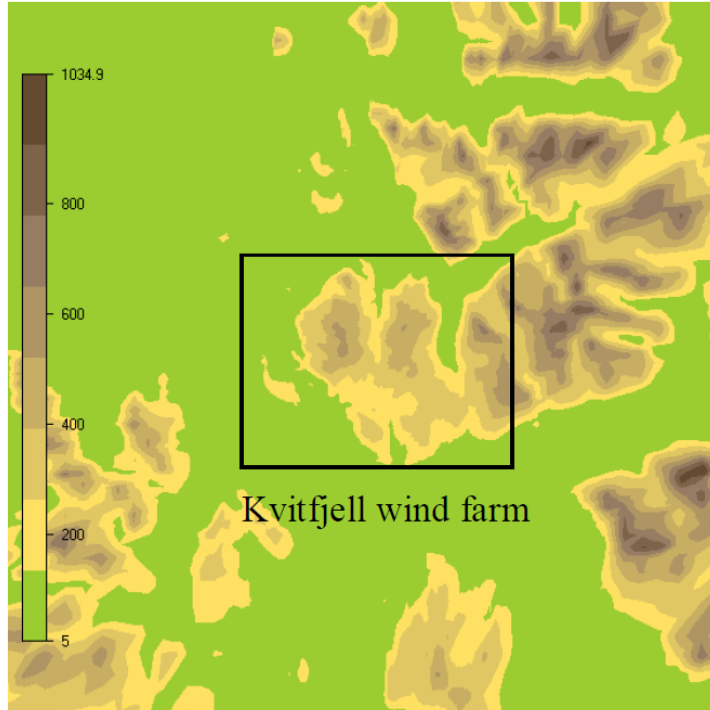
- Parameters
 - Temperature
 - RH
 - Heated and non-heated anemometers
 - Ice monitor indicator
- Evaluation of actual icing
- Accretion/percistance/ablation

Sensor	Criteria
Temperature [°C]	$T < 3$
Relative humidity [%]	$RH > 95$
Ice monitor [g]	$M > 200$
Anemometer [m/s]	$V_{\text{Thesis}} < 0,2$ for more than three consecutive time steps and $V_{\text{Vaisala}} > V_{\text{Thesis}}$

Data processing- Datasets

Dataset	Description
Normal	Complete time history with wind speed and direction from heated anemometers and wind vane.
No ice	Time history where ice events are excluded.
Ice	Time history of only ice events with heated sensors.

Energy simulation- WindSim modell



- Considerable inclination around the peninsula

	x	y	z	total
Grid spacing, min - max [m]	113.0 - 1220.3	113.0 - 1220.3	Variable	-
Number of cells	158	158	20	499280

.	1	2	3	4	5	6	7	8	9	10
z-dist. max [m]	14.7	51.2	101.7	166.1	244.5	336.8	443.1	563.4	697.7	845.9
z-dist. min [m]	19.4	67.5	133.9	218.8	322.1	443.8	583.8	742.3	919.2	1114.5

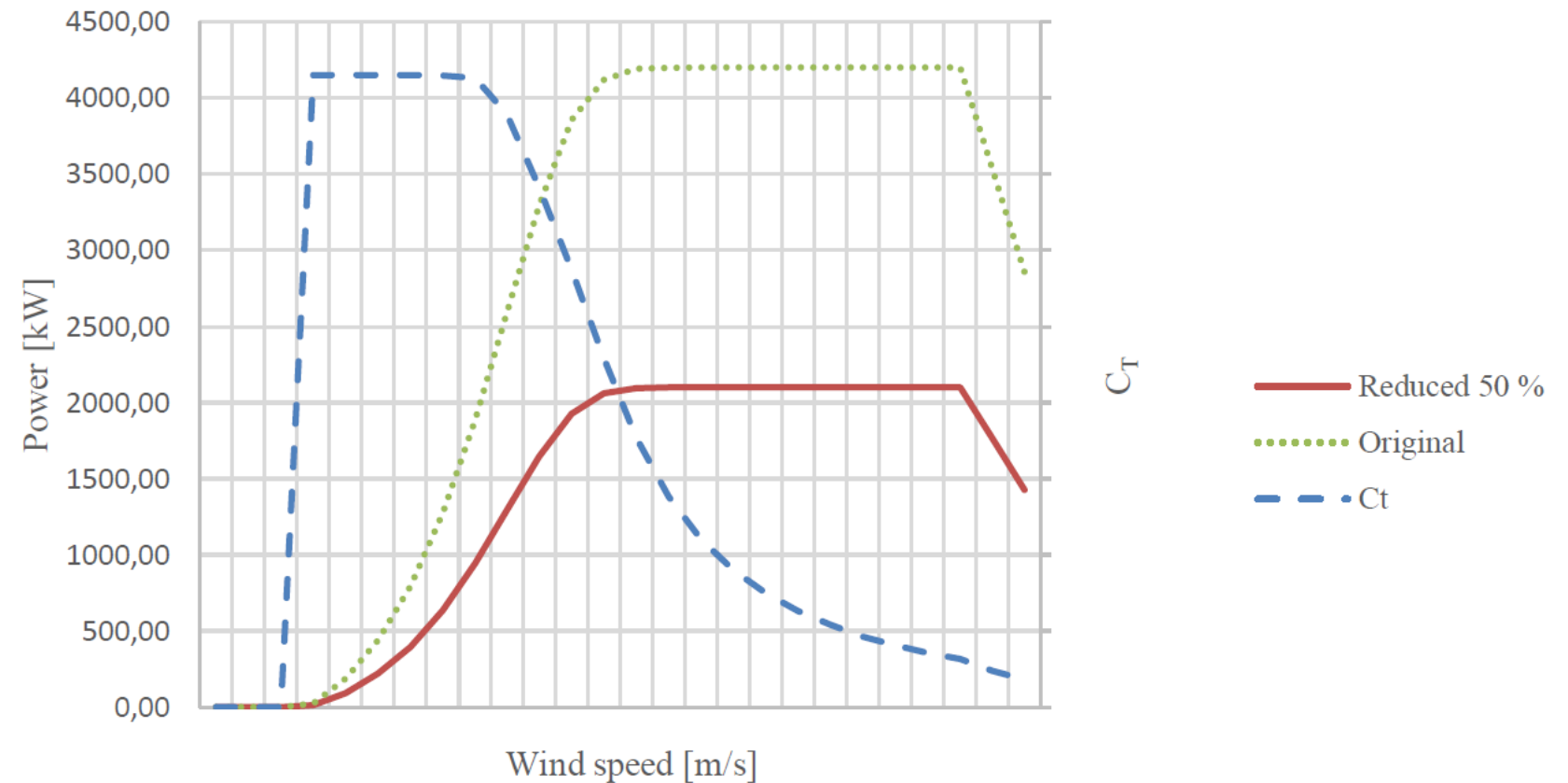
Energy simulation- Scenario description

Scenario	Description
Full production/Reference	No compensation for icing
Reduced production 1	Medium ice scenario. All turbines have their original power curve switched out with a reduced one. Assuming same ice intensity through the wind farm.
Reduced production 2	Worst case scenario. All turbines have their original power curve switched out with the worst-case scenario curve.

Energy simulation- WindSim modell power curve

- Assumed homogeneous icing on the site
- Based on OWI
 - Uncertainties
- Worst case scenario power curve = 0 due to complete stop

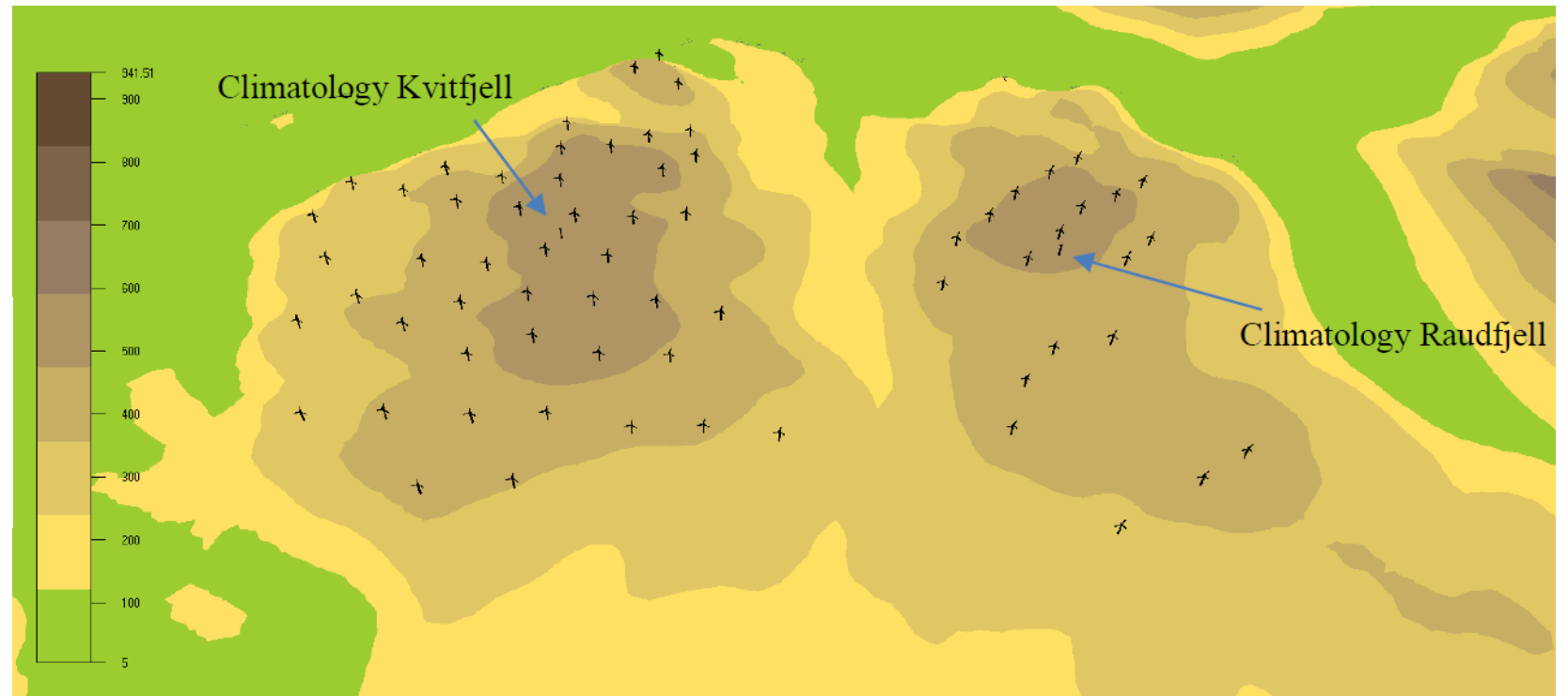
Original- and 50 % reduced power curve with thrust coefficient



Energy simulation- WindSim modell objects

- Unwanted influence

Layout #	Objects
L1	Kvitfjell and Raudfjell
L2	Kvitfjell
L3	Raudfjell



Energy simulation- WindSim modell layout

- Total production in the scenarios
 - L1
 - L2+L3

Scenario	Layout #	Power curve	Description
Full production	L1	Original	No compensation for ice
Reduced production 1	L2	50 %	Medium ice scenario. All turbines have their original power curve substituted with the 50 % power curve in ice events. Assuming same ice intensity through the wind farm.
	L3	50 %	
Reduced production 2	L2	Complete stop	Worst case scenario. All turbines have their original power curve switched out with the worst-case scenario curve.
	L3	Complete stop	

Energy simulation- Summary of approach

Scenario	Layout #	Dataset	Power curve	Description
Full production	L1	Kvitfjell normal, Raudfjell normal	Original	No compensation for ice
Reduced production 1	L2	Kvitfjell no ice	Original	Medium ice scenario. All turbines have their original power curve substituted with the 50 % power curve in ice events. Assuming same ice intensity through the wind farm.
		Kvitfjell ice	50 %	
	L3	Raudfjell no ice	Original	
		Raudfjell ice	50 %	
Reduced production 2	L2	Kvitfjell no ice	Original	Worst case scenario. All turbines have their original power curve switched out with the worst-case scenario curve.
		Kvitfjell ice	Complete stop	
	L3	Raudfjell no ice	Original	
		Raudfjell ice	Complete stop	

Results- Data processing

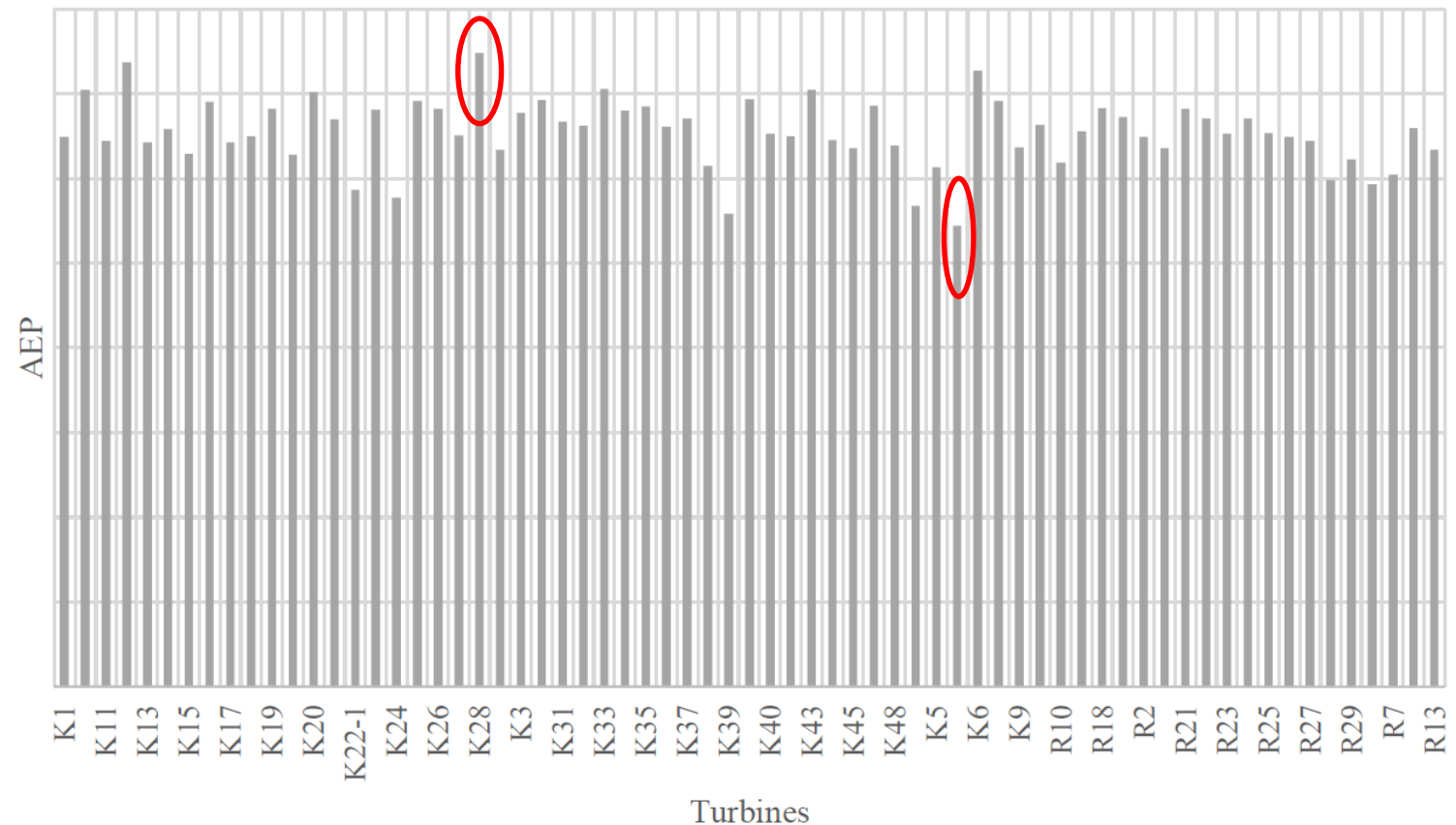
- Invalid datapoints
- Identified 38 ice events
 - 26 at Kvitfjell
 - 12 at Raudfjell
- Total hours of instrumental icing.
 - 19% Kvitfjell and 6% Raudfjell (17.07.2017.01.2015)

IEA Ice classification			
IEA Ice class	Meteorological icing	Instrumental icing	Icing loss
	% of year	% of year	% of gross annual production
5	>10	>20	>20
4	5-10	10-30	10-25
3	3-5	6-15	3-12
2	0,5-3	1-9	0,5-5
1	0-0,5	<1,5	0-0,5

Results- CFD simulation

- 27% difference in performance between K28 and K50
- CFD contributes to a more accurate model

Gross AEP for Kvitfjell and Raudfjell



Results- CFD simulation

Scenario	Layout #	Dataset	Power curve	Total gross energy production %
Full production/Reference	L1	Kvitfjell normal	Original	100,00
		Raudfjell normal	Original	100,00
Reduced production 1	L2	Kvitfjell no ice	Original	90,21
		Kvitfjell ice	50 %	4,89
	L3	Raudfjell no ice	Original	91,19
		Raudfjell ice	50 %	4,40
Reduced production 2	L2	Kvitfjell no ice	Original	90,21
		Kvitfjell ice	Complete stop	0,00
	L3	Raudfjell no ice	Original	91,19
		Raudfjell ice	Complete stop	0,00

Results- CFD simulation

- Kvitfjell 0,98 % higher production losses than Raudfjell
 - Inclination -> Orographic lifting

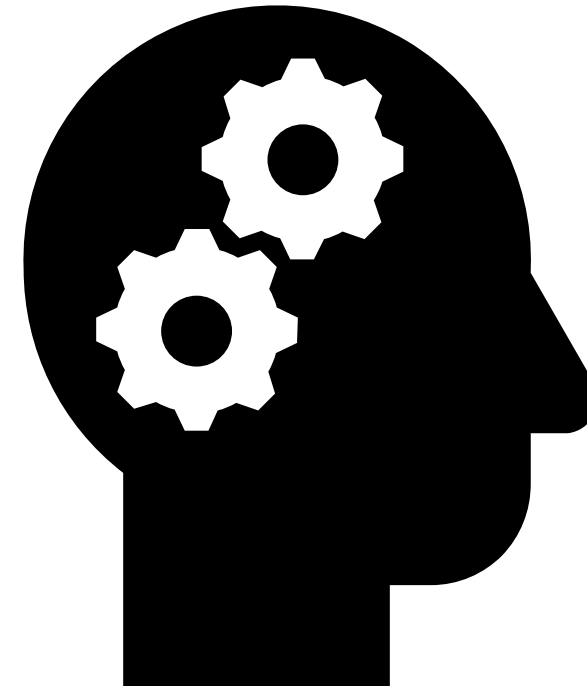
Total gross energy production %		
Kvitfjell	Reduced production 1	Reduced production 2
Production with ice	95,10	90,21
Losses due to ice	4,90	9,79

Total gross energy production %		
Raudfjell	Reduced production 1	Reduced production 2
Production with ice	95,59	91,19
Losses due to ice	4,41	8,81

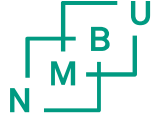
Total gross energy production %		
Total	Reduced production 1	Reduced production 2
Normal production	100,00	100,00
Production with ice	95,25	90,50
Losses due to ice	4,75	9,50

Conclusion

- Potential a more accurate approach
- Worst case scenario 9,50 % losses
- Most likely 4,75 % losses
- Uncertainties
 - Annual variation in atmospheric icing
 - Ice modelling is complex
 - Gradual reduced power curve
 - Homogeneous icing



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Thank you

