TOWARDS IMPROVING WIND ENERGY IN COLD CLIMATE:
HOW TO QUANTIFY THE USE OF ALTERNATIVE OPERATIONAL STRATEGIES

UNIVERSITÉ LAVAL

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Winterwind
INTERNATIONAL WIND ENERGY CONFERENCE
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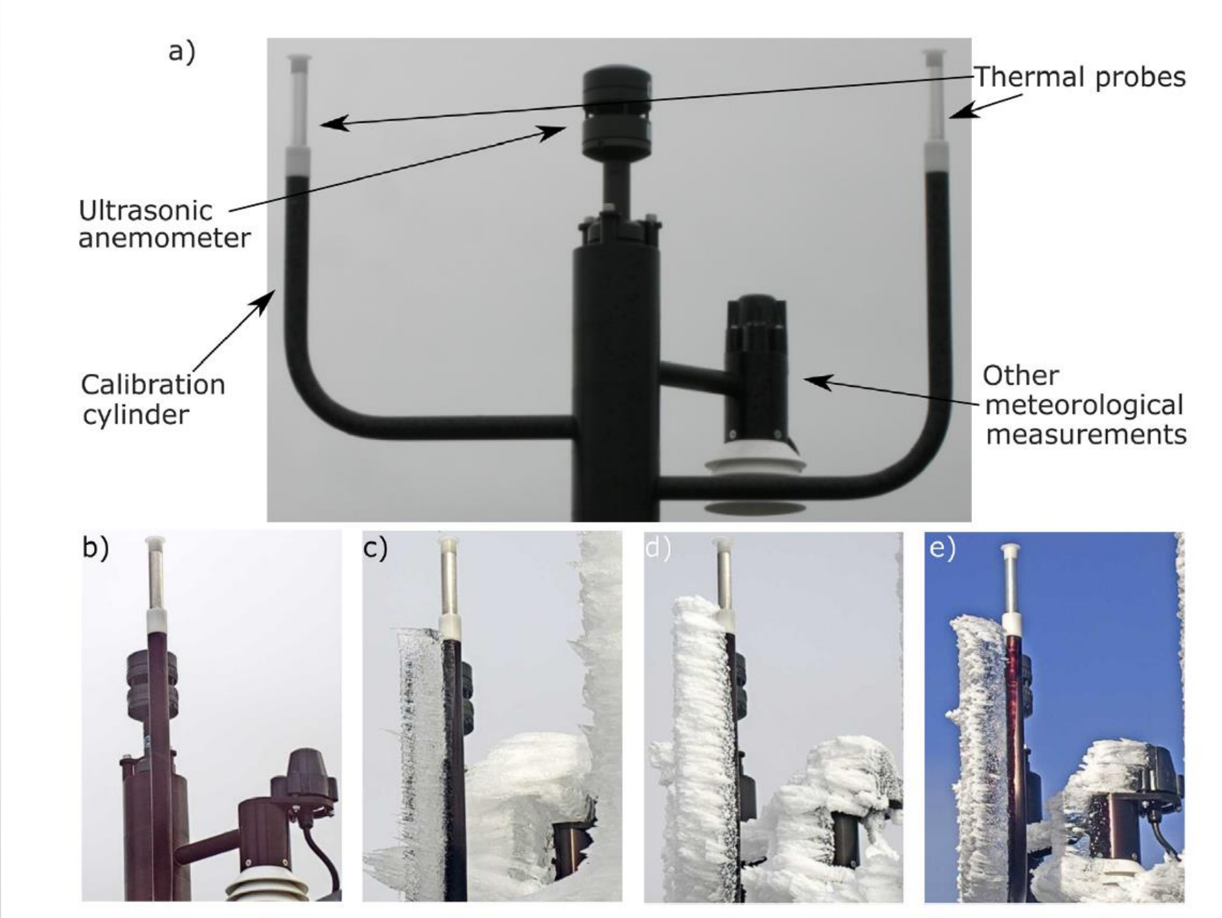
MY RESEARCH INTERESTS



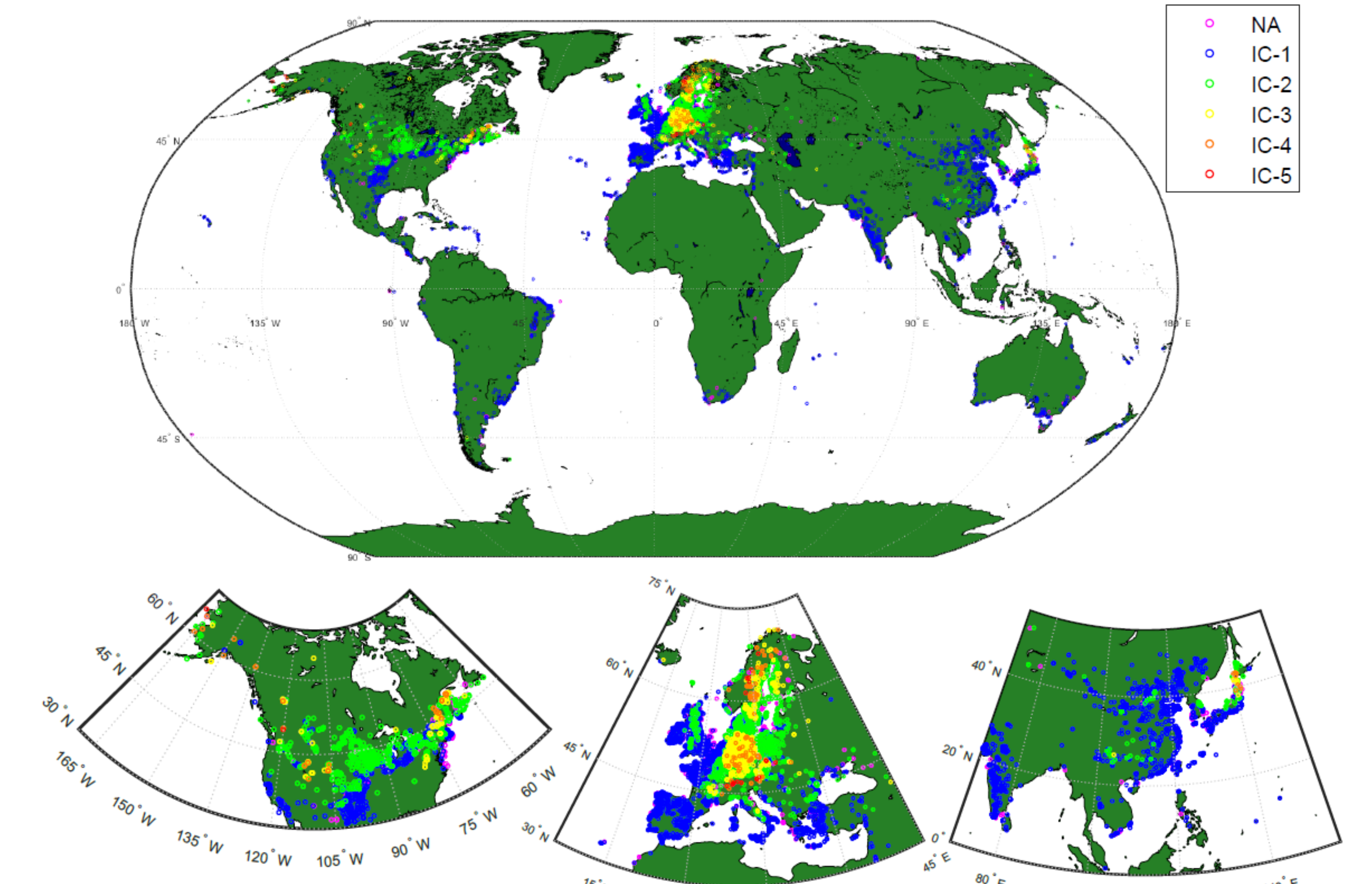
Roberge *et al.* (2019) *Field analysis, modeling and characterization of wind turbine hot air ice protection systems*. Cold Regions Science and Technology 163 (2019) 19-26

MY RESEARCH INTERESTS

New spin-off company launched in November 2020

www.icetek.ca

THE WIND ENERGY MARKET 2019-2020



data taken from: windpower.net and VTT icing study

- Total installed capacity: 506 GW
- Onshore: 481 GW (95%)
- 95 GW/481 GW without valid GPS coordinates (assumed ice class 1)
- Cold climate (IEA ice class 2 or higher): 131 GW (between 27% and 34%)

IC >= 2		
	Nb. of turbines	Installed capacity
Canada	5 065	9 850 MW
Europe	40 385	75 044 MW
N. USA	21 498	37 573 MW

IEA Ice class	Met. icing (% of year)	Inst. icing (% of year)	Prod. loss (% of AEP)
1	0-0.5	<1.5	0-0.5
2	0.5-3	1-9	0.5-5
3	3-5	6-15	3-12
4	5-10	10-30	10-25
5	>10	>20	>20

THE ICING PROBLEM!

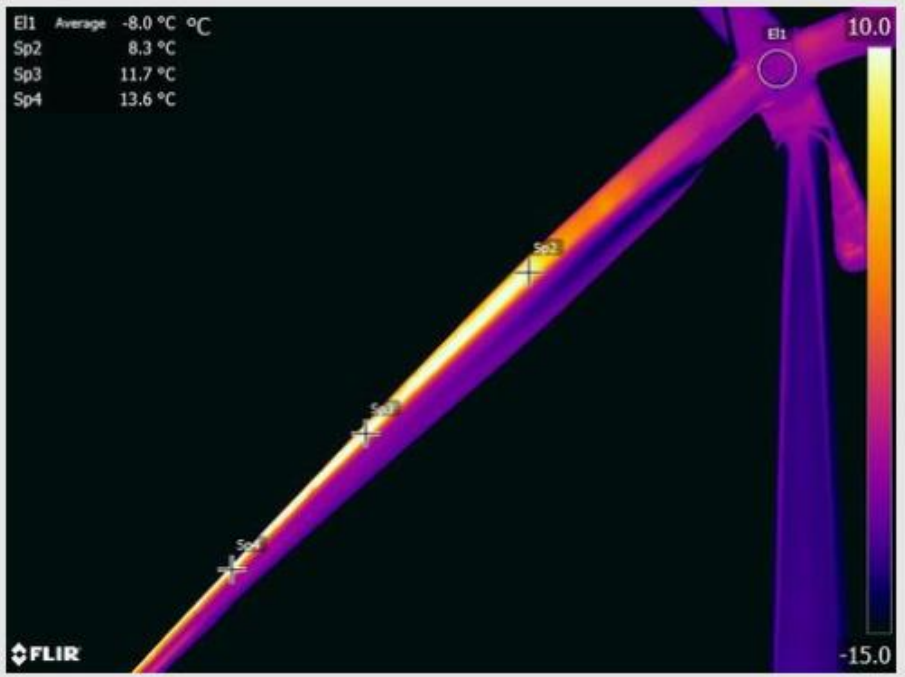
source: InnovWeek ENGIE

- Production losses;
- Excessive turbine loads;
- Health/safety issues.

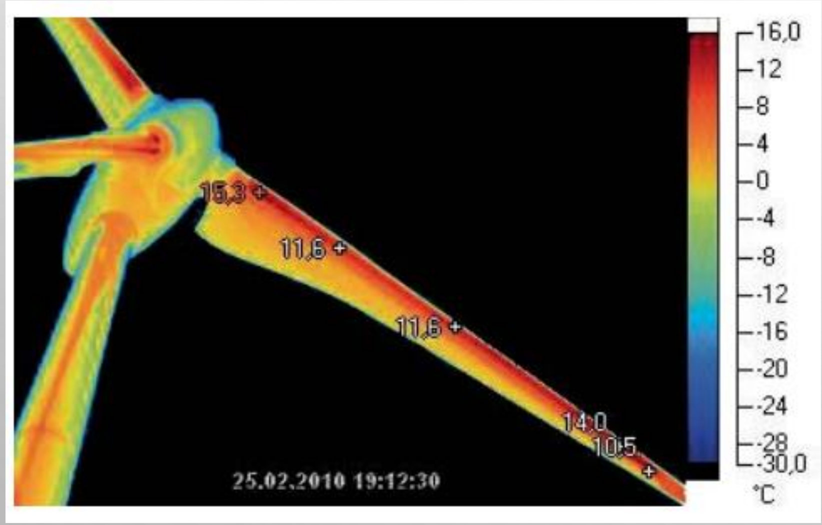
Bégin-Drolet *et al.* (2018) *The importance of accurate detection for turbine ice prevention systems*. Winterwind international conference 2018

WHAT IS AN ALTERNATIVE OPERATIONAL STRATEGY?

- Ice Protection Systems (IPS);
- Rubber boots;
- Expulsive de-icing;
- Icephobic coatings;
- Operation with ice;
- Retrofit hardware;
- …



Source: borealiswind.com/how-it-works

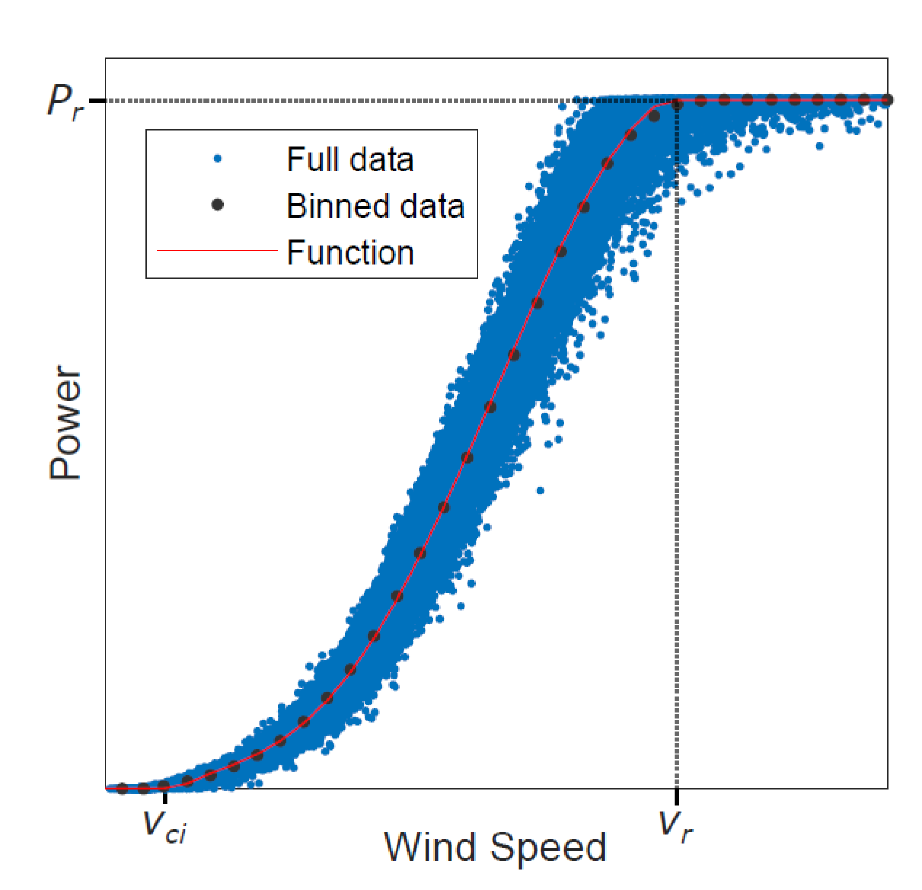


Source: https://www.enercon.de/fileadmin/Redakteur/Medien-Portal/windblatt/pdf/en/wb_01-2011_en.pdf

Source: wicetec.com/technology

HOW TO ASSESS ALTERNATIVE OPERATIONAL STRATEGIES?

1st step: good modelling of turbine expected behaviour;



Roberge *et al.* (2021), under review

$$P(v) = \begin{cases} 0 & \text{if } v < v_{ci} \\ P_5(v) & \text{if } v_{ci} < v < v_r \\ P_r & \text{if } v_r < v \end{cases}$$

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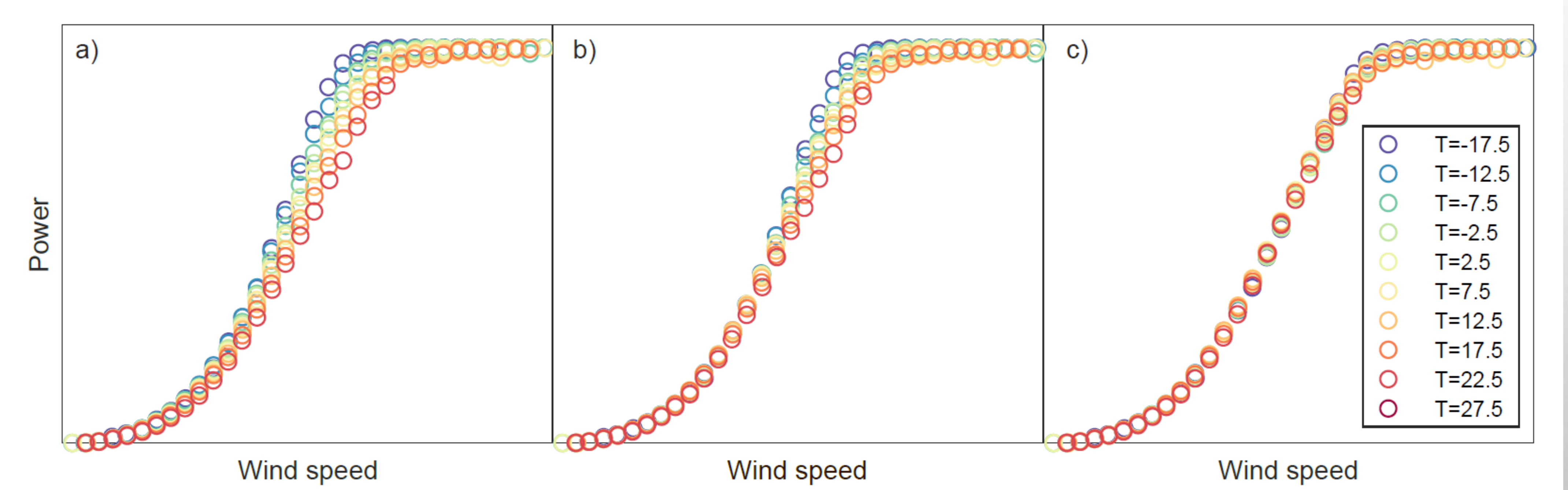


Example data set presenting the binned data divided in wind speed and temperature (in °C) ranges in a situation where the wind speed is :

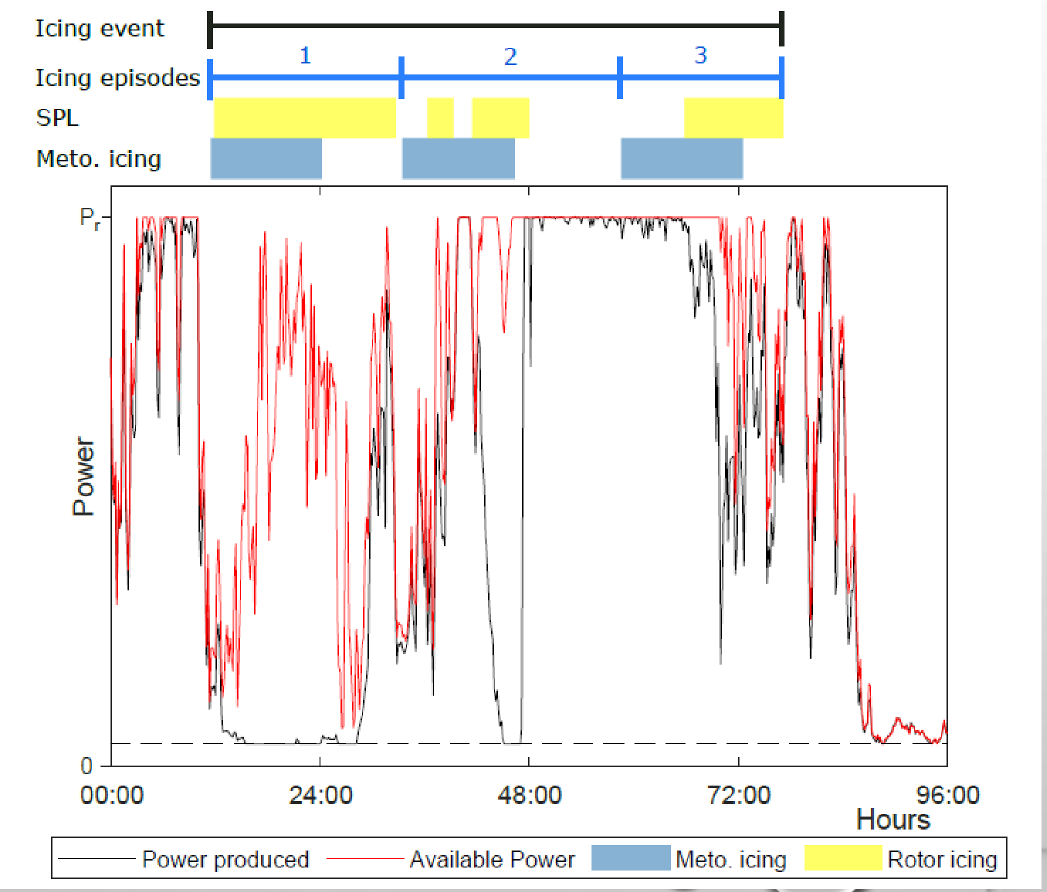
a) not corrected with temperature
b) Corrected using traditional approach
c) Corrected using new approach

Roberge *et al.* (2021), under review

HOW TO ASSESS ALTERNATIVE OPERATIONAL STRATEGIES?

1st step: good modelling of turbine expected behaviour;

2nd step: ability to identify/classify events;



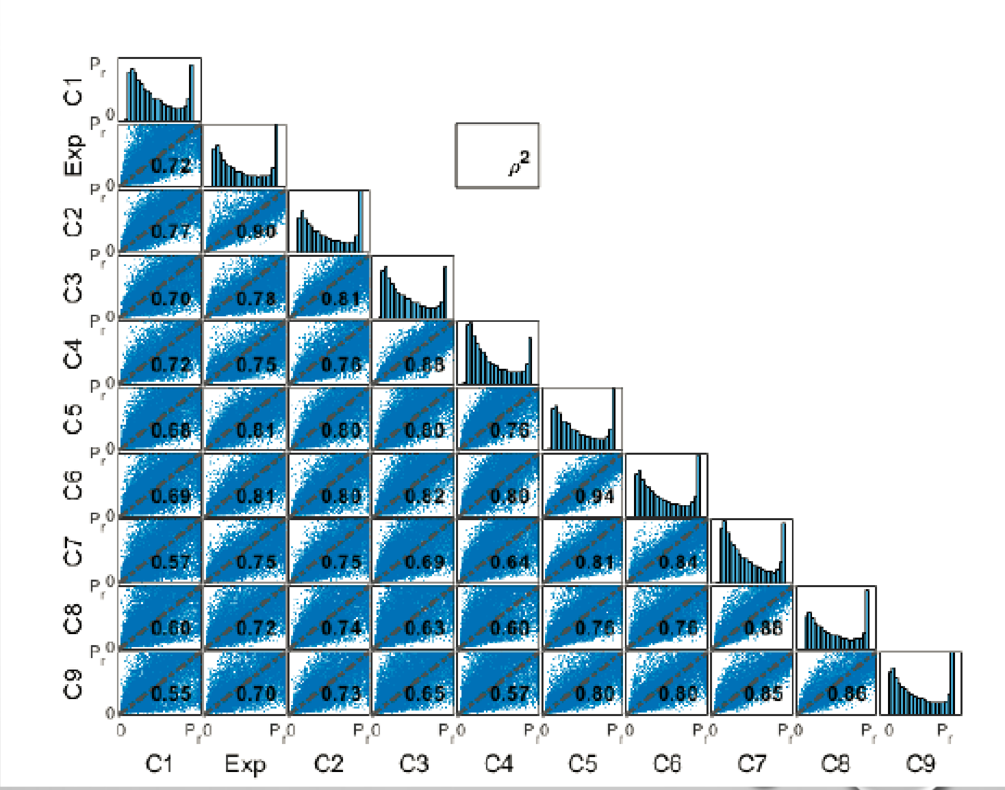
Roberge *et al.* (2021), under review

HOW TO ASSESS ALTERNATIVE OPERATIONAL STRATEGIES?

1st step: good modelling of turbine expected behaviour;

2nd step: ability to identify/classify events;

3rd step: select control turbine and reference turbines to test the AOS;



Roberge *et al.* (2021), under review

HOW TO ASSESS ALTERNATIVE OPERATIONAL STRATEGIES?

1st step: good modelling of turbine expected behaviour;
2nd step: ability to identify/classify events;
3rd step: select control turbine and reference turbines to test the AOS;
4th step: select appropriate metrics (figure of merits);

Traditionnal metrics:

- The energy production difference (ΔE_{AB});
- The energy loss difference (ΔEL_{AB});
- The energy efficiency difference (ΔEE).

New proposed metrics:

- The energy gain (G_{AB});
- The potential recovery.

From our experience, accurate metrics should be independent of the selected period (if no new icing losses are added) and metrics should have low sensitivity to the wind differences between the two turbines under evaluation.

MATHEMATICAL DEFINITION OF METRICS

$$\Delta E_{AB} = E_{prod\_A} - E_{prod\_B}$$

$$\Delta EL_{AB} = E_{loss\_B} - E_{loss\_A}$$

$$E_{loss} = E_{avail} - E_{prod}$$

$$\Delta EE_{AB} = EE_A - EE_B$$

$$EE = \frac{E_{prod}}{E_{avail}}$$

$$G_{AB} = \int (PE_A - PE_B) P_{avail\_A} dt^*$$

$$PE = \frac{P_{prod}}{P_{avail}}$$

$$PR_{BA} = \frac{-1 \cdot G_{BA}}{E^*_{loss-B}}$$

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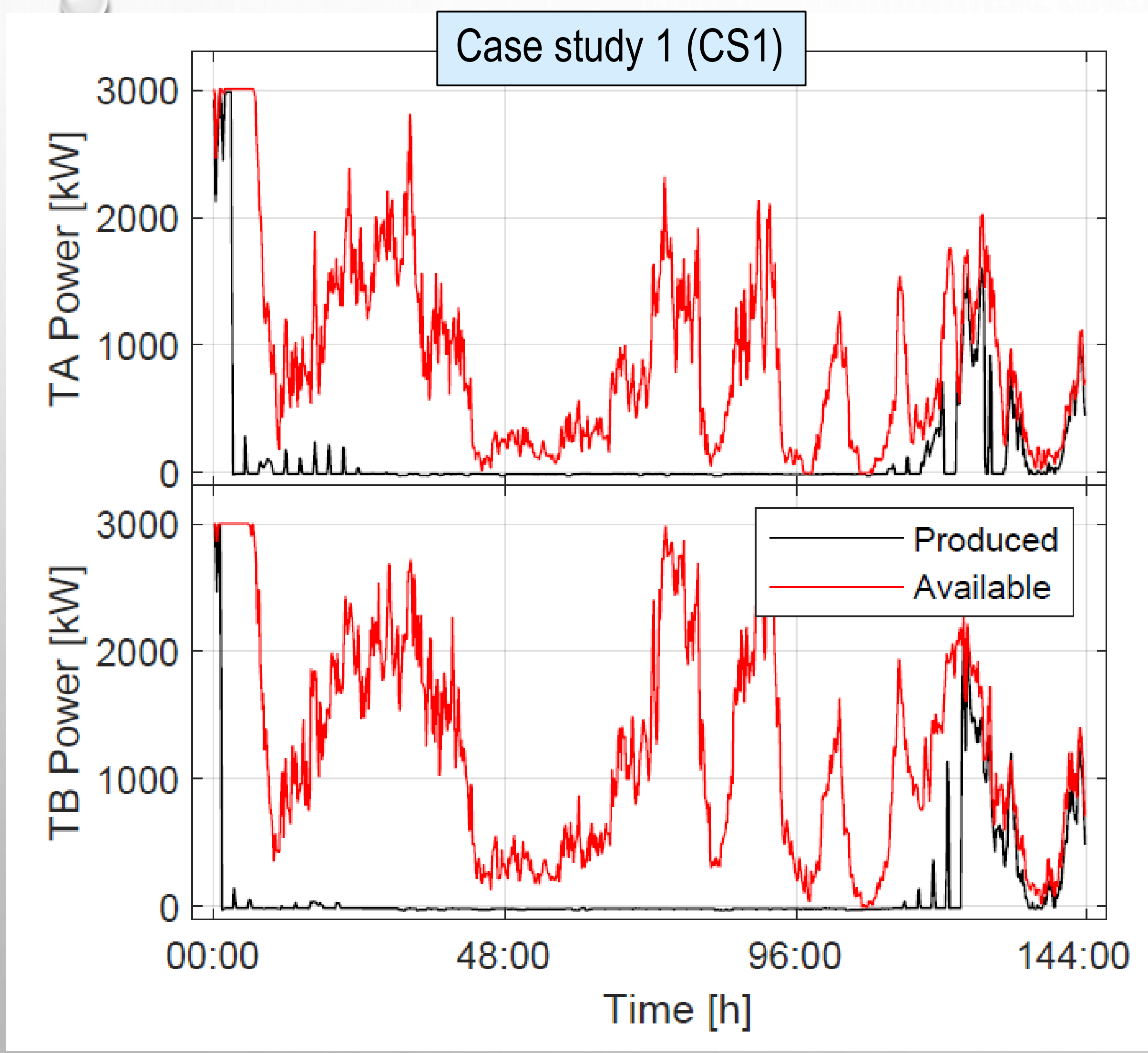

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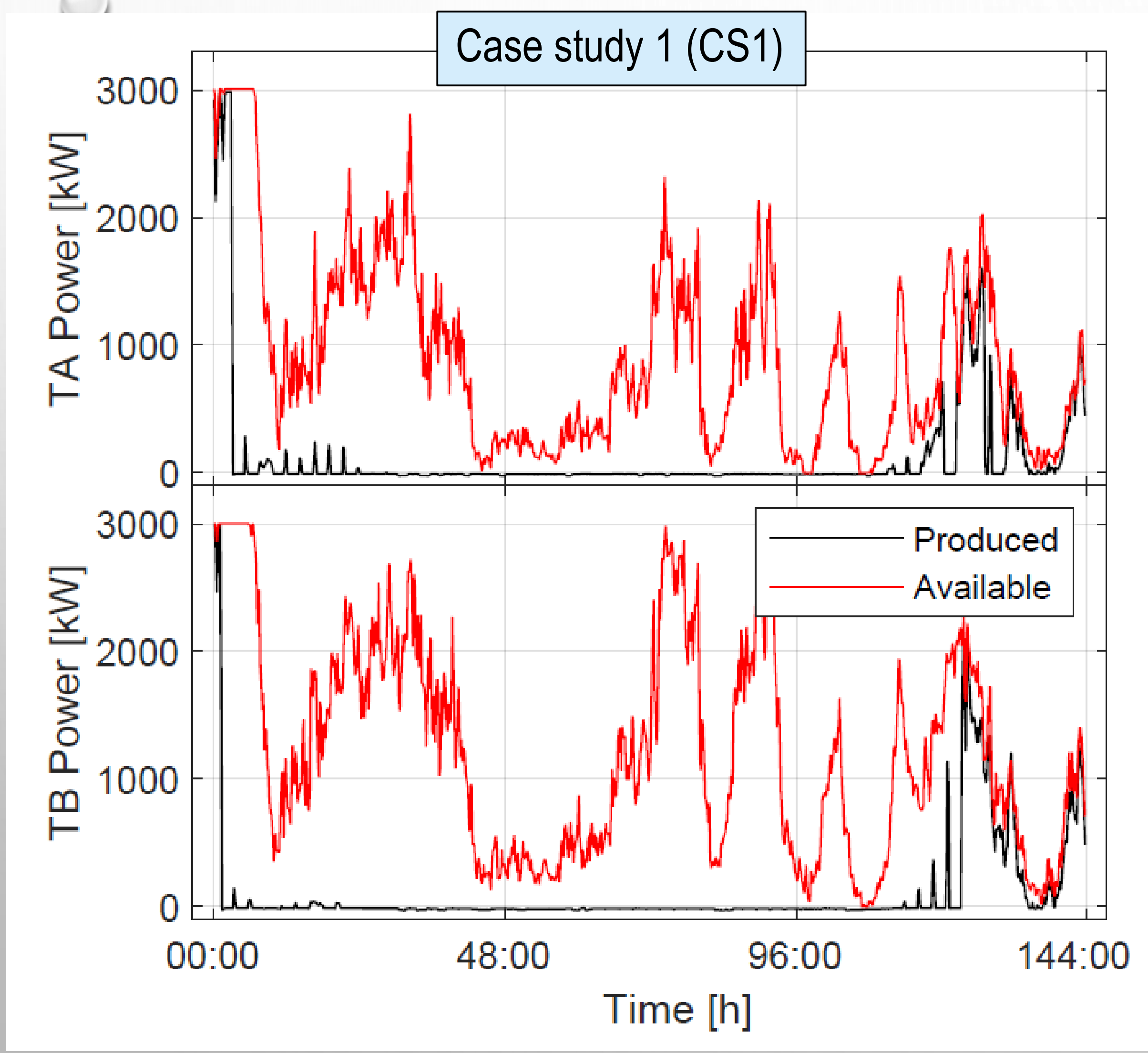

Roberge *et al.* (2021), under review

	$E_{available}$ [MWh]	$E_{produced}$ [MWh]
Turbine A	129.6	19
Turbine B	175.1	17.4

Period	ΔE [MWh]	ΔEL [MWh]	ΔEE [%]
CS1	1.6	47.1	4.7%

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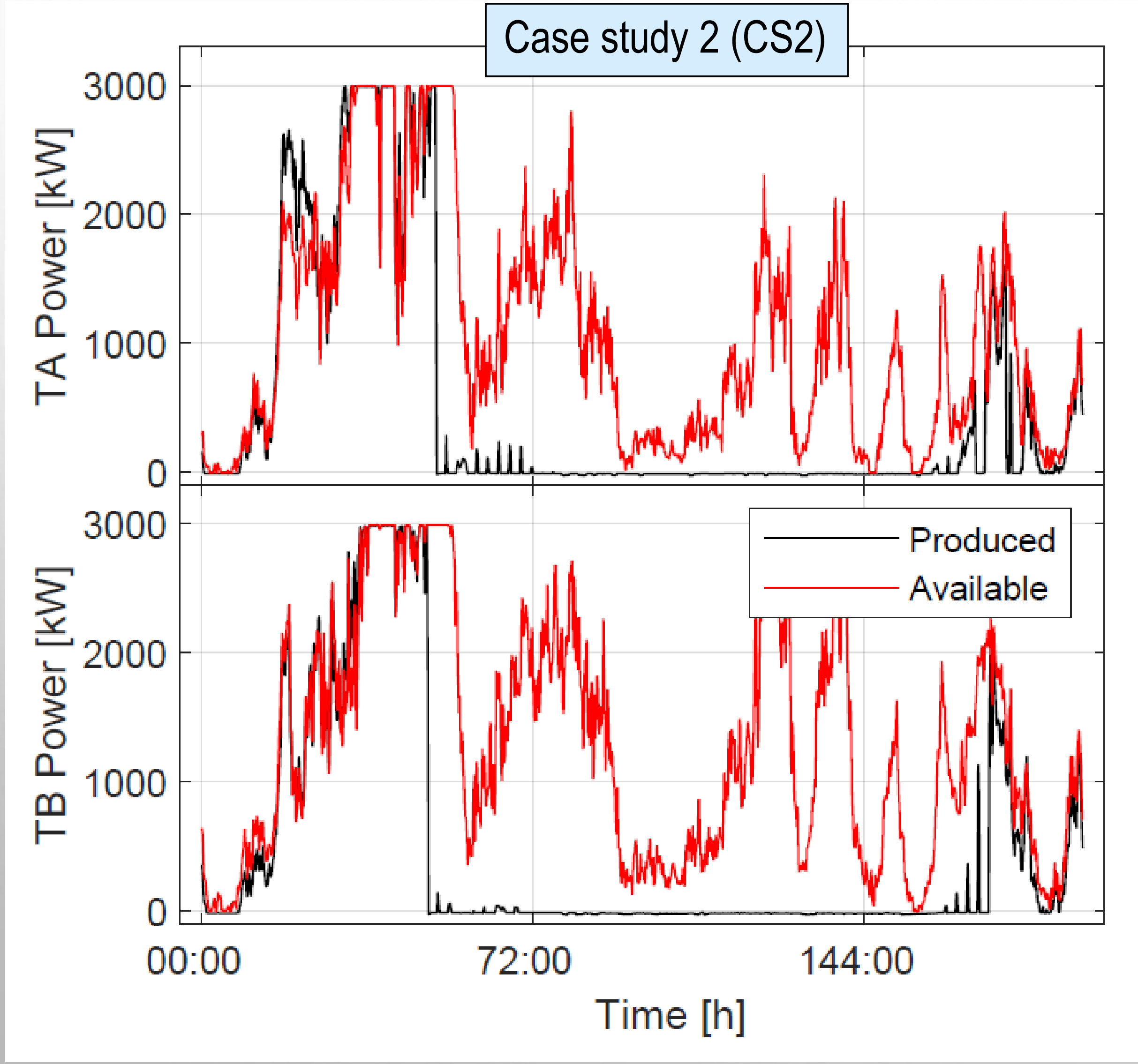

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Turbine A	202.8	97.8
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CS2	7.1	54	11.9%

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HOW TO ASSESS ALTERNATIVE OPERATIONAL STRATEGIES?

Case study 1 (CS1)

	$E_{available}$ [MWh]	$E_{produced}$ [MWh]
Turbine A	129.6	19
Turbine B	175.1	17.4

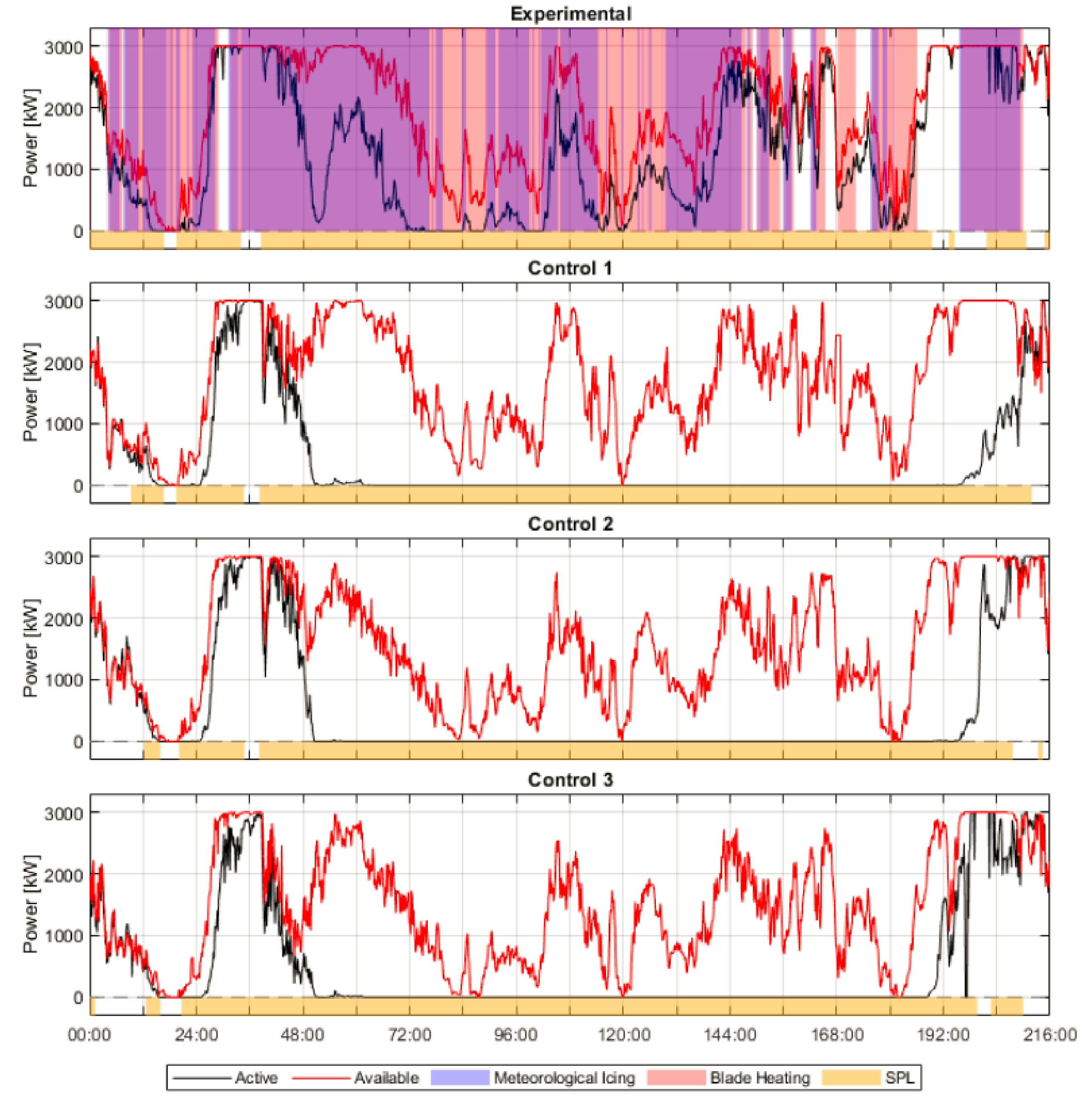
Case study 2 (CS2)

	$E_{available}$ [MWh]	$E_{produced}$ [MWh]
Turbine A	202.8	97.8
Turbine B	249.7	90.7

How much more energy is produced by turbine A if turbine B was experiencing the same wind as turbine A.

What would happen if AOS of turbine A was applied to turbine B?

Period	ΔE [MWh]	ΔEL [MWh]	ΔEE [%]	G [MWh]	PR [%]
CS1	1.6	47.1	4.7%	4.1	4.2%
CS2	7.1	54	11.9%	4.7	4.6%



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Case study 3 (CS3)
9-day event

Project in collaboration with Borealis Wind

- Experimental turbine equipped with Borealis Ice Protection System.
- Turbine 1-2-3 left in normal operation (no IPS).
- Turbine rated power normalized to 3MW to preserve confidentiality in the data.

Turb.	E_{Avail} [MWh]	E_{Prod} [MWh]	E_{Loss} [MWh]	EE [%]
Exp.	414.2	273.1	141.0	0.66
C. 1	404.4	91.4	312.7	0.23
C. 2	361.1	117.6	243.8	0.32
C. 3	342.4	116.6	225.7	0.34

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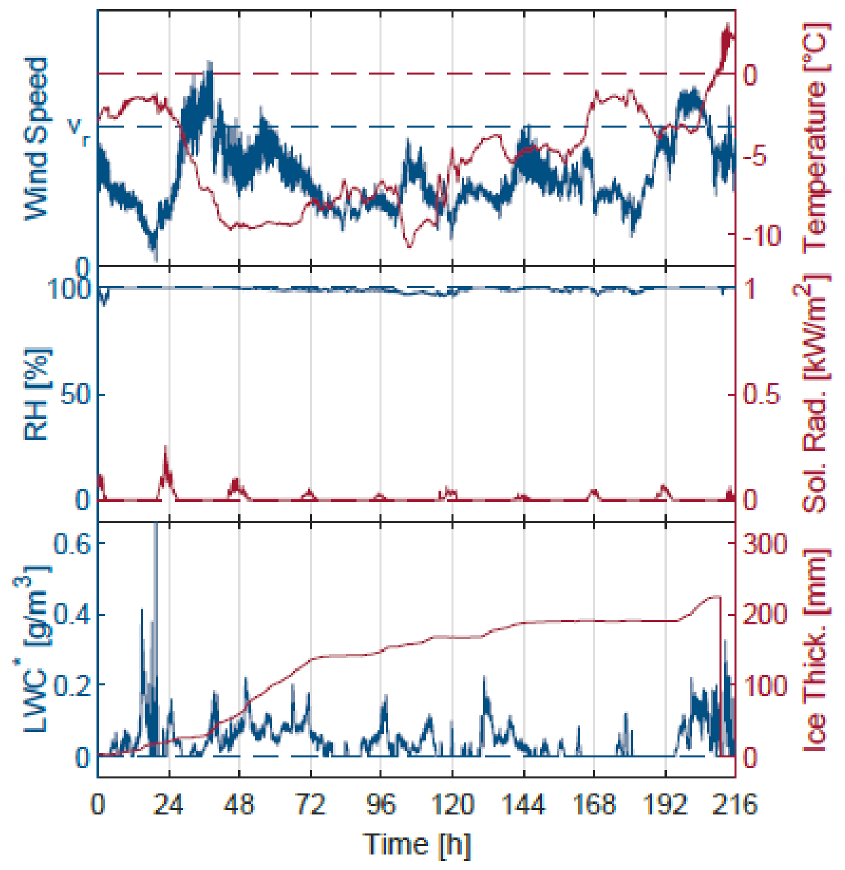

Roberge *et al.* (2021), under review

Period	ΔE [MWh]	ΔEL [MWh]	ΔEE [%]	RILR [%]	G [MWh]	PR [%]
C1	181.7	171.7	43	56	176.1	56
C2	155.5	102.8	34	50	157.7	56
C3	156.5	84.7	32	48	148.0	54

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136.5 MWh

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CONCLUSION AND PERSPECTIVES

- Guidelines are important but data analysis is crucial.
- Gains can be quantified through appropriate analysis.
- Look a your data (or have someone look at them for you)!

Contact information

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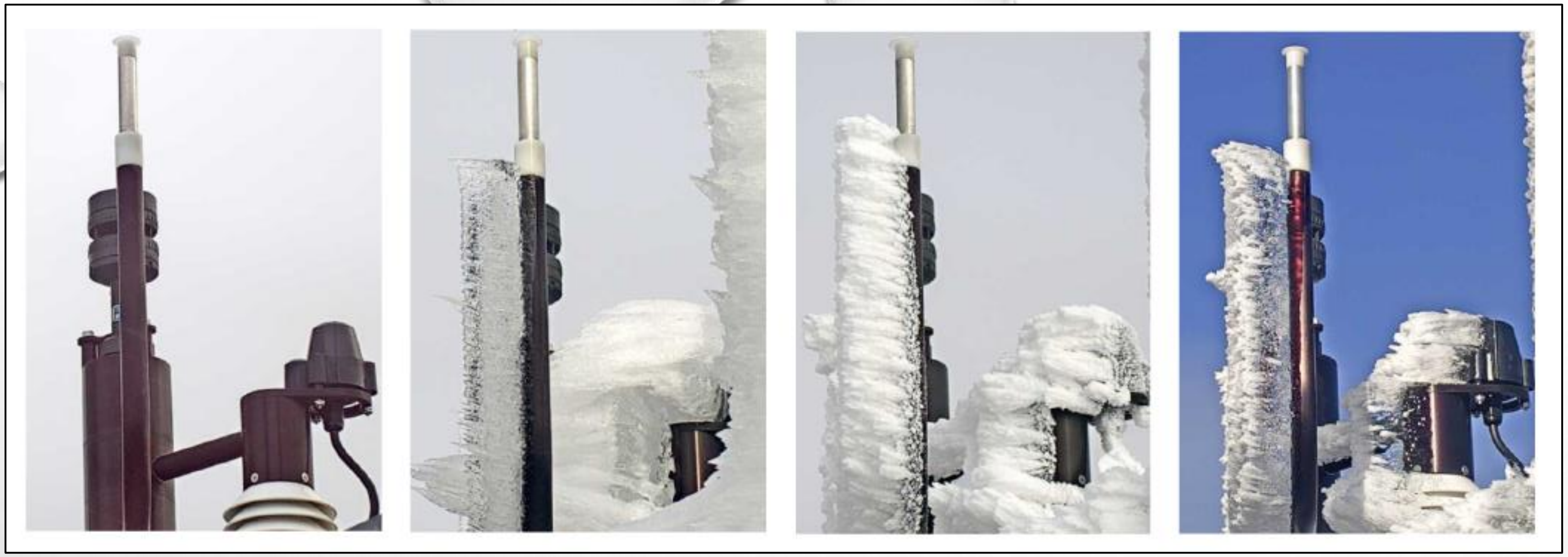

Measurements		
Wind speed	0 to 50 m/s	± 0.5 m/s (0 to 15 m/s) ± 4 % (>15 m/s)
Wind direction	0 to 360°	± 4°
Temperature	-40 to 60 °C	± 0.1°C (-18°C to 30°C) ± 0.5°C (else)
Relative humidity	0 to 100 %	± 3 % RH
Barometric pressure	30 to 110 kPa	± 0.1 kPa
Solar radiation	0 to 1800 W/m²	± 5 %
Liquid water content[2]	Typ. 0 to 1 g/m³	
Icing severity[2]	Typ. 0 to 10 g/(sm²)	
Ice accumulation[2]	mm	
Icing type[2]	glaze, soft rime, hard rime	
Precipitation	on/off	
Meteorological icing	on/off	
Instrumental icing	on/off