Preventing wind turbines from catching colds

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Papers

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Towards standards in the analysis of wind turbines operating in cold climate – Part A: Power curve modeling and rotor icing detection

Cold Regions Science and Technology
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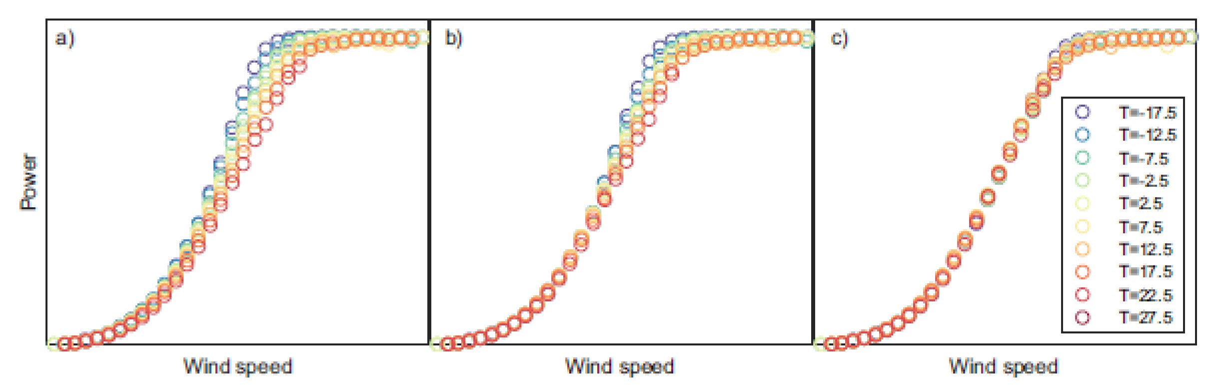
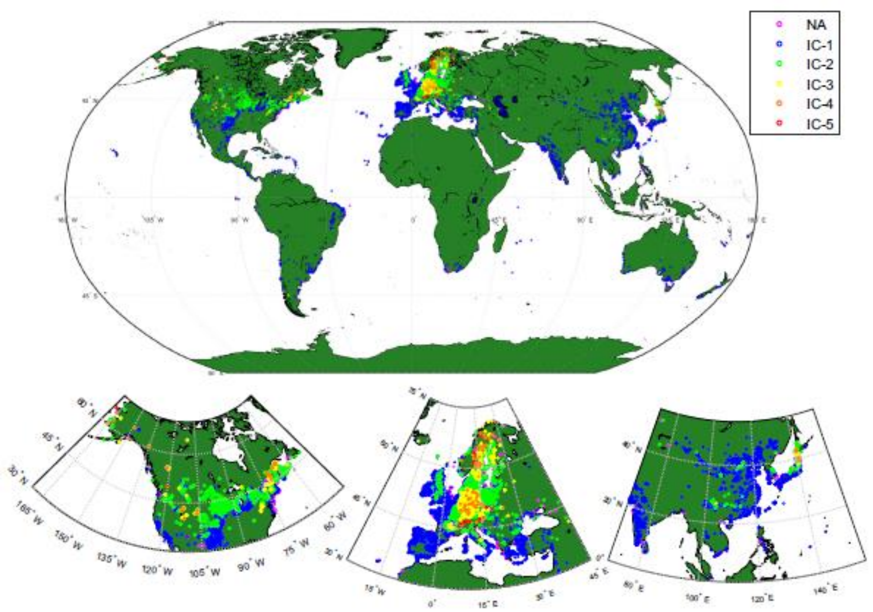
Towards standards in the analysis of wind turbines operating in cold climate. Part B: Methodology for evaluating wind turbine alternative operational strategies



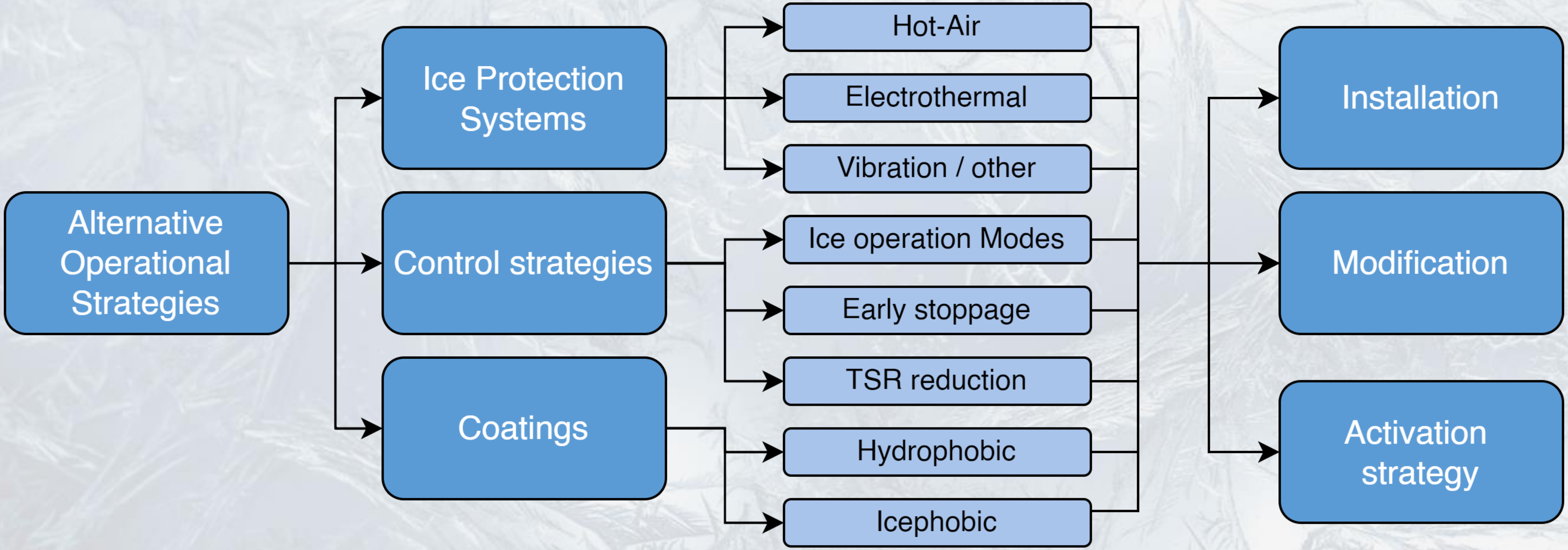


Analogy

- **Disease:** Icing on wind turbines
- **Symptoms:** Reduction of the performance, vibrations, ice throw
- **Treatment:** IPS, control strategies

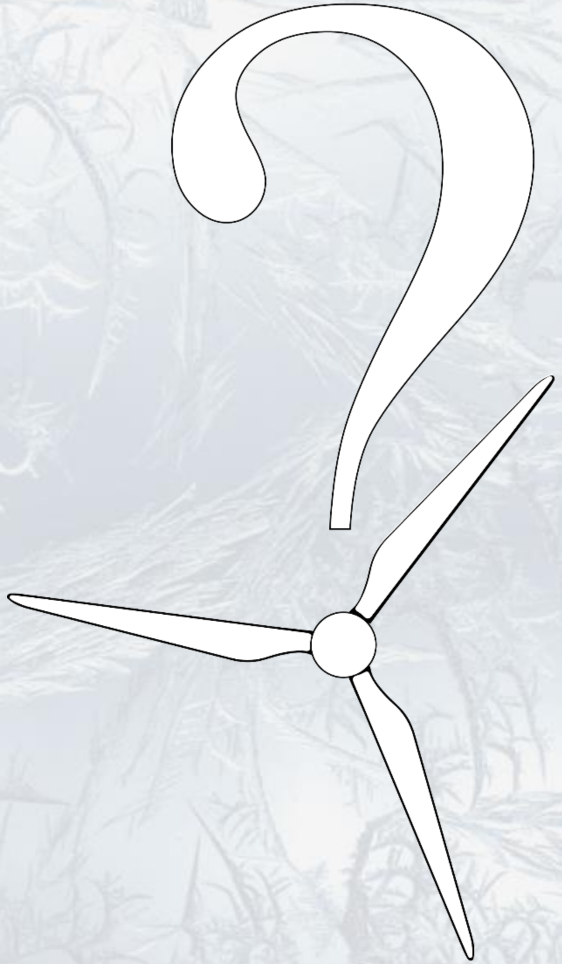
Can we draw from the other fields of science to face this issue?

Definitions



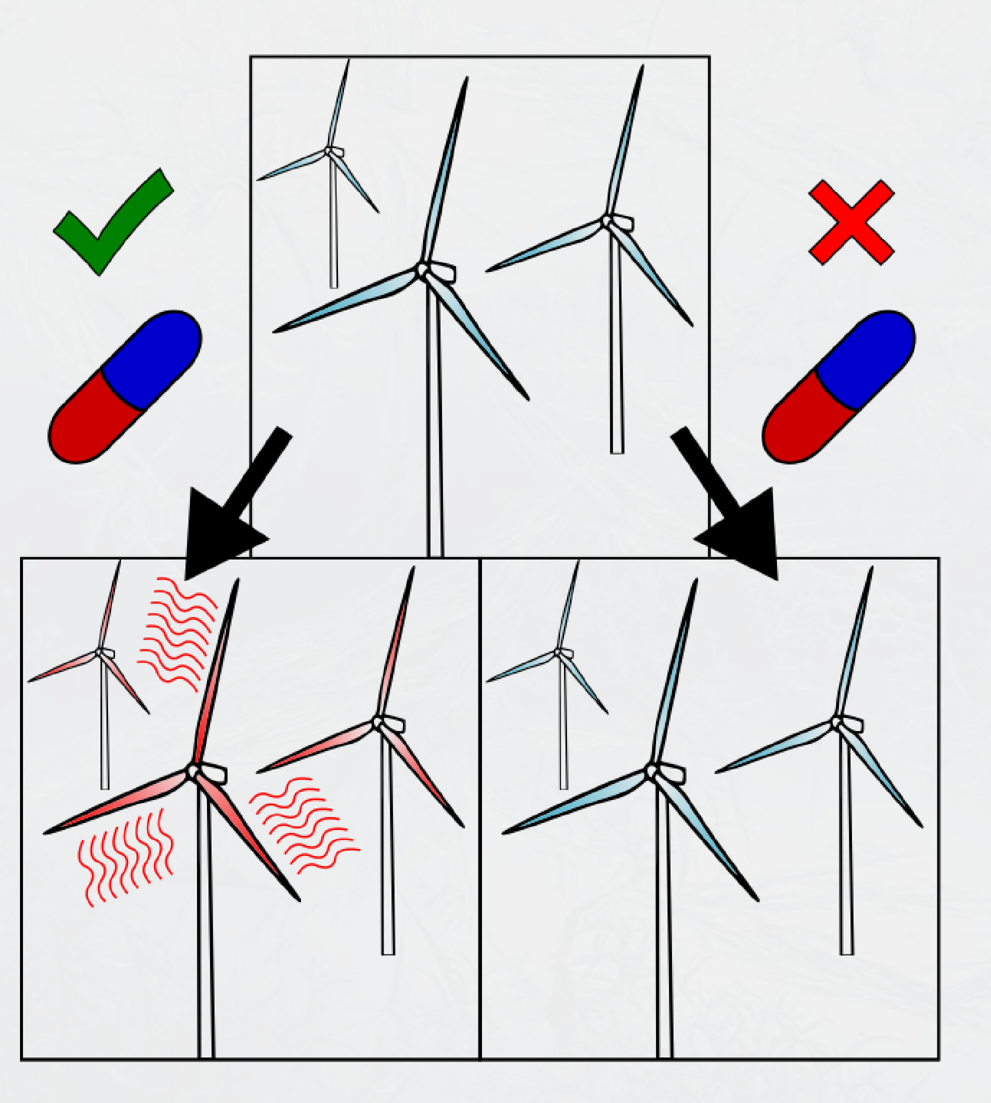
Question

Can we define a standard methodology to evaluate the performance of AOS?



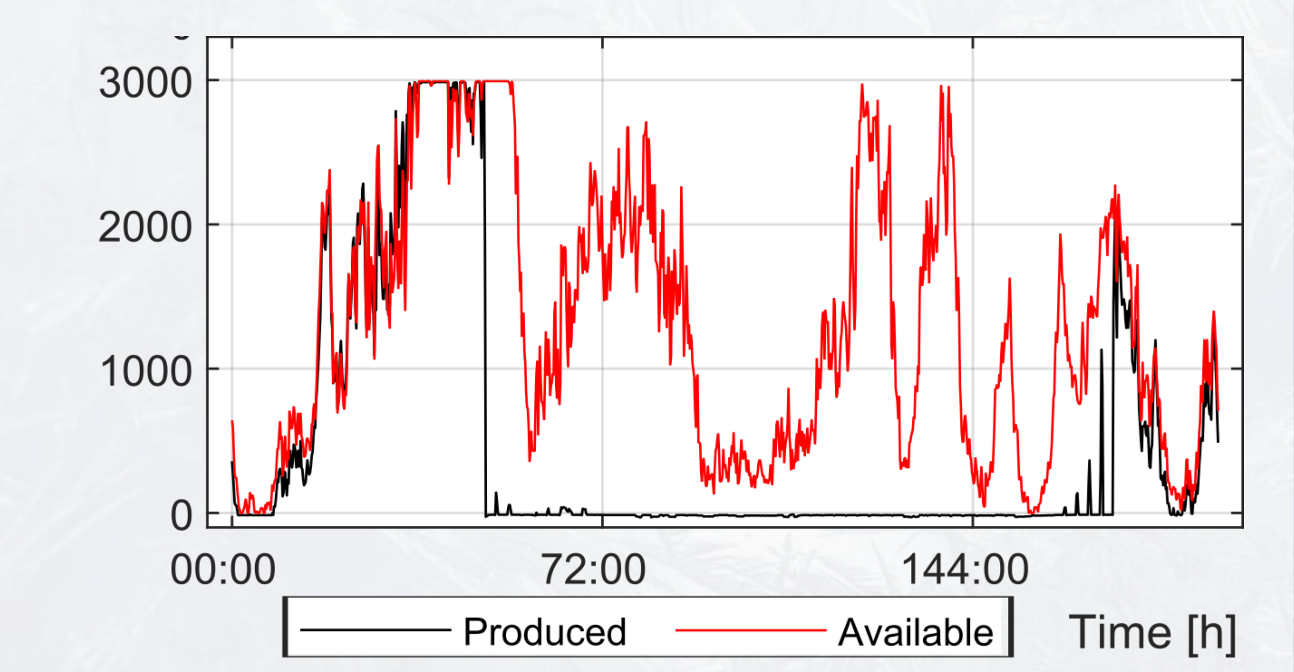
AOS performance evaluation

- Concept based on the scientific method
- Experimental and control group
- Important to make two similar groups



How to evaluate the performance ?

Time series -> numbers



Metrics: How to evaluate the performance

Criteria

- Insensitive to difference in winds
- Insensitive to the choice of the period of computiation

Metrics: How to evaluate the performance

What has been made in the past?

Difference in energy produced

- $\Delta E = E_{Produced-A} - E_{Produced-B}$
- Dependent on available wind and on period selection

Metrics: How to evaluate the performance

What has been made in the past?

Difference in energy produced	• $\Delta E = E_{Produced-A} - E_{Produced-B}$ • Dependent on available wind and on period selection
Difference in energy losses	• $\Delta EL = E_{Loss-A} - E_{Loss-B}$ • Dependent on available wind and on period selection

Metrics: How to evaluate the performance

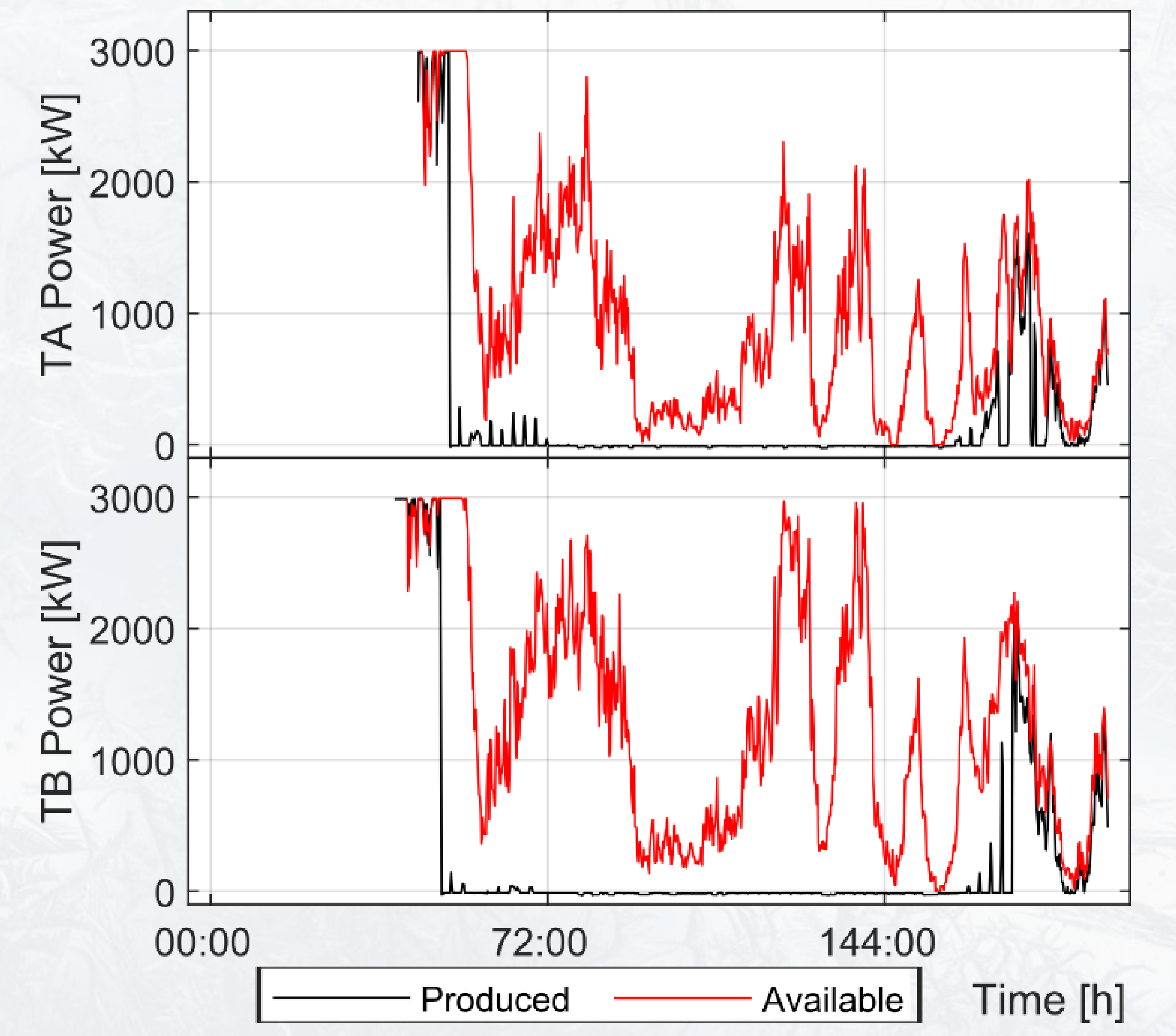
What has been made in the past?

Difference in energy produced	• $\Delta E = E_{Produced-A} - E_{Produced-B}$ • Dependent on available wind and on period selection
Difference in energy losses	• $\Delta EL = E_{Loss-A} - E_{Loss-B}$ • Dependent on available wind and on period selection
Recovered energy (Task 19)	• $RE = \dfrac{\frac{E_{Produced-A}}{E_{Available-A}} - \frac{E_{Produced-B}}{E_{Available-B}}}{1 - \frac{E_{Produced-B}}{E_{Available-B}}}$

Flaws of traditional metrics

Case study 1:

Two turbines without AOS



Flaws of traditional metrics

Case study:

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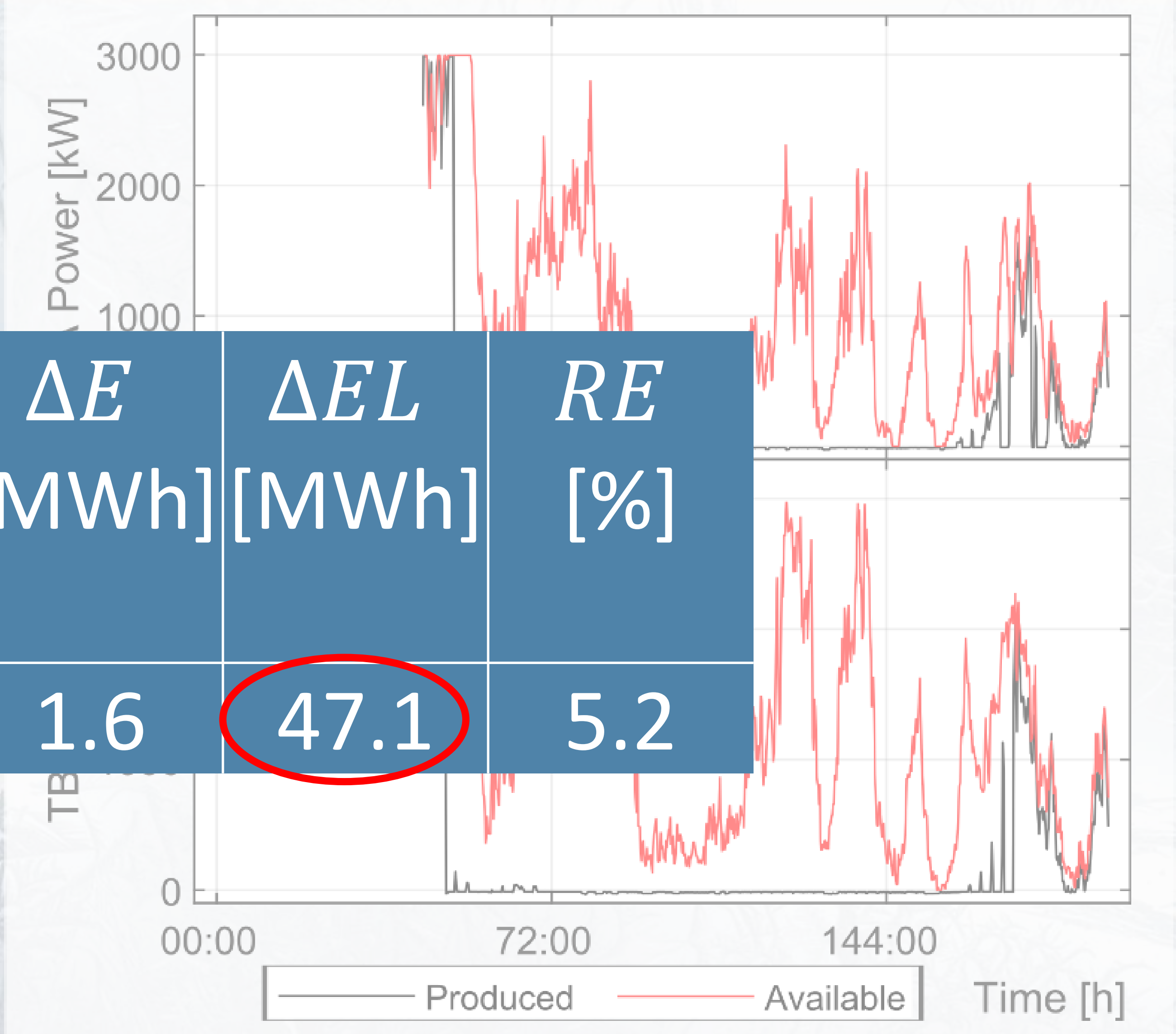
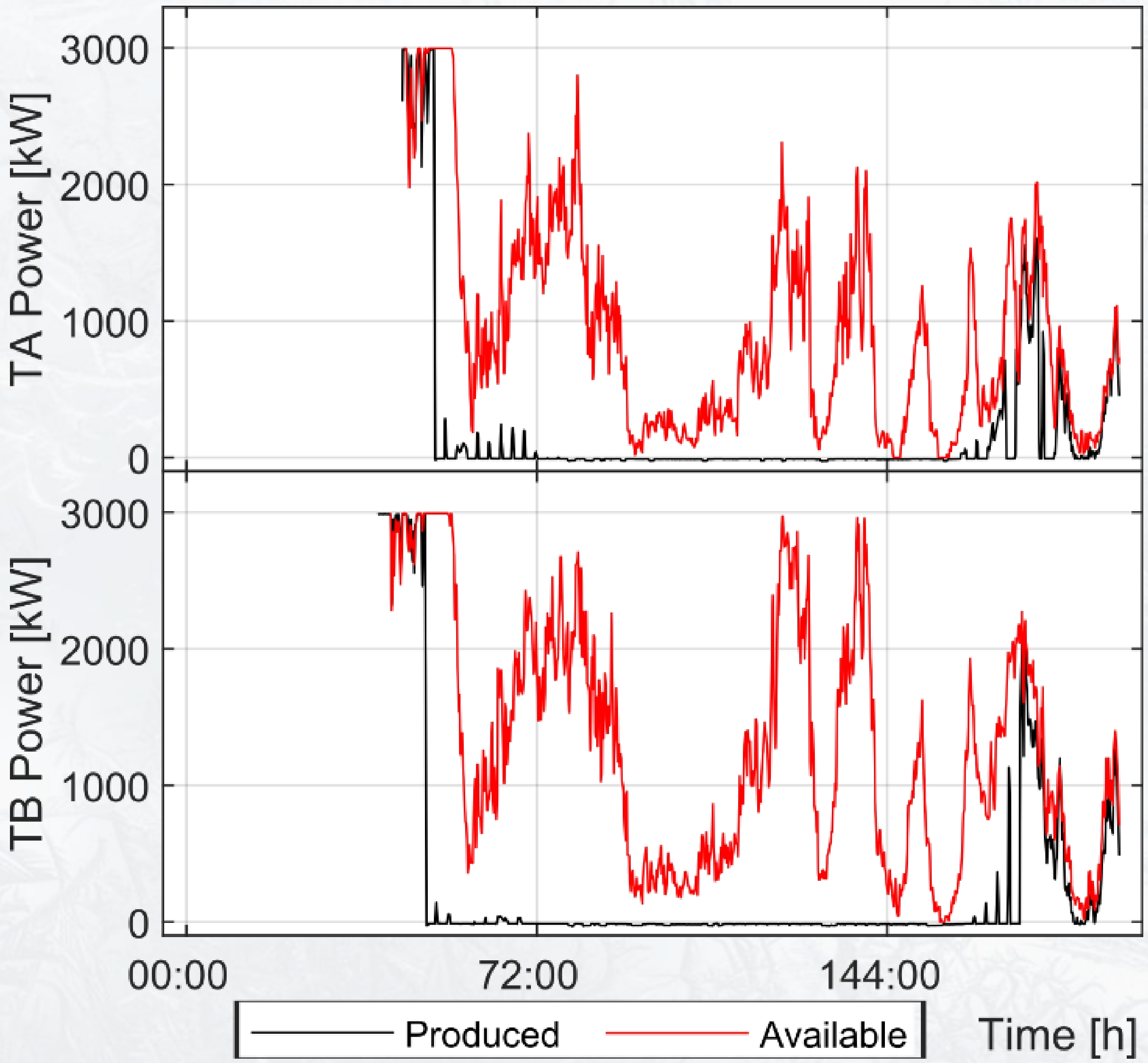


Period	ΔE [MWh]	ΔEL [MWh]	RE [%]
CS1	1.6	47.1	5.2

Flaws of traditional metrics

Case study 1:

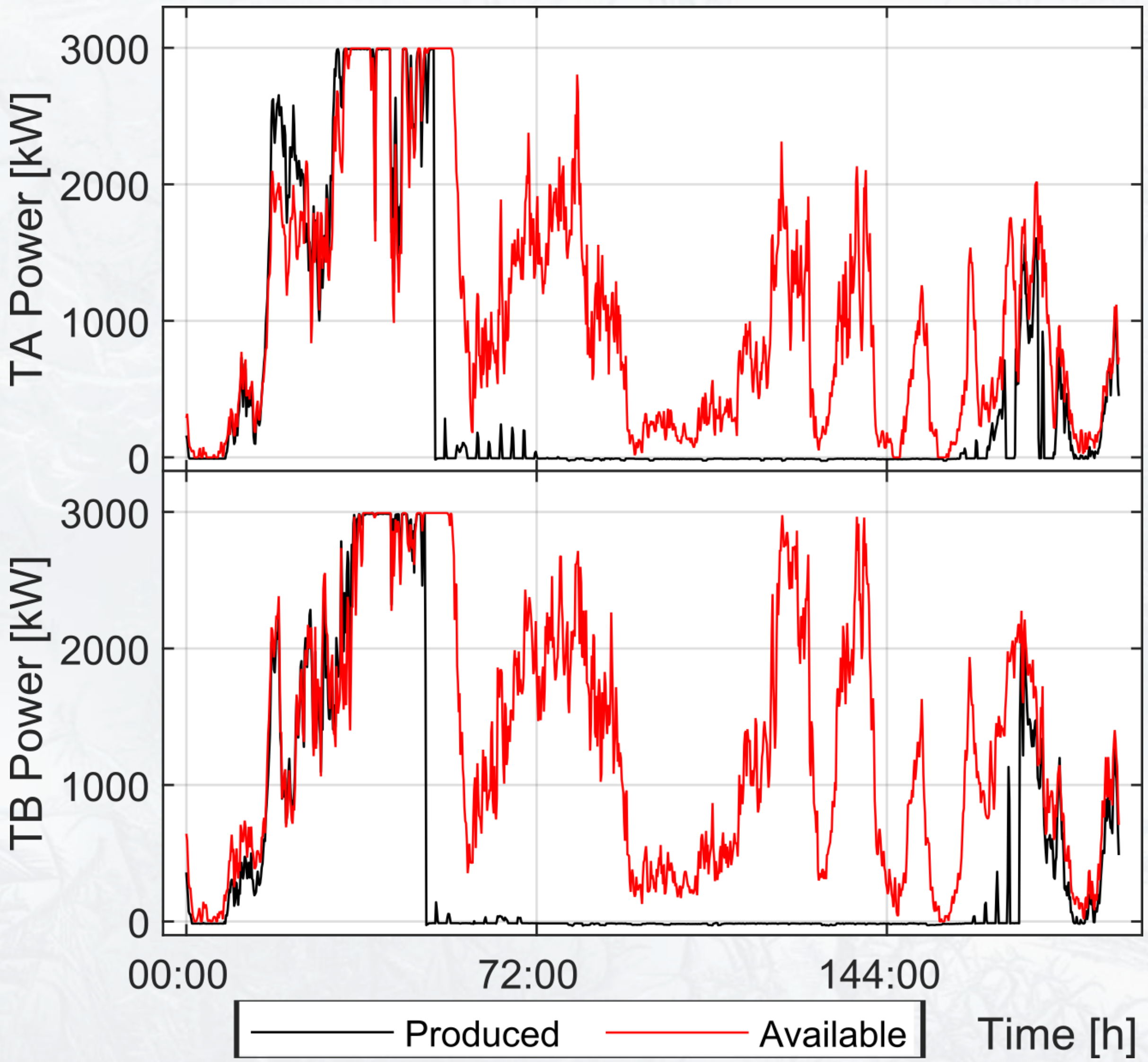
Two turbines without AOS



Flaws of traditional metrics

Case study 2:

Adding 48h without icing

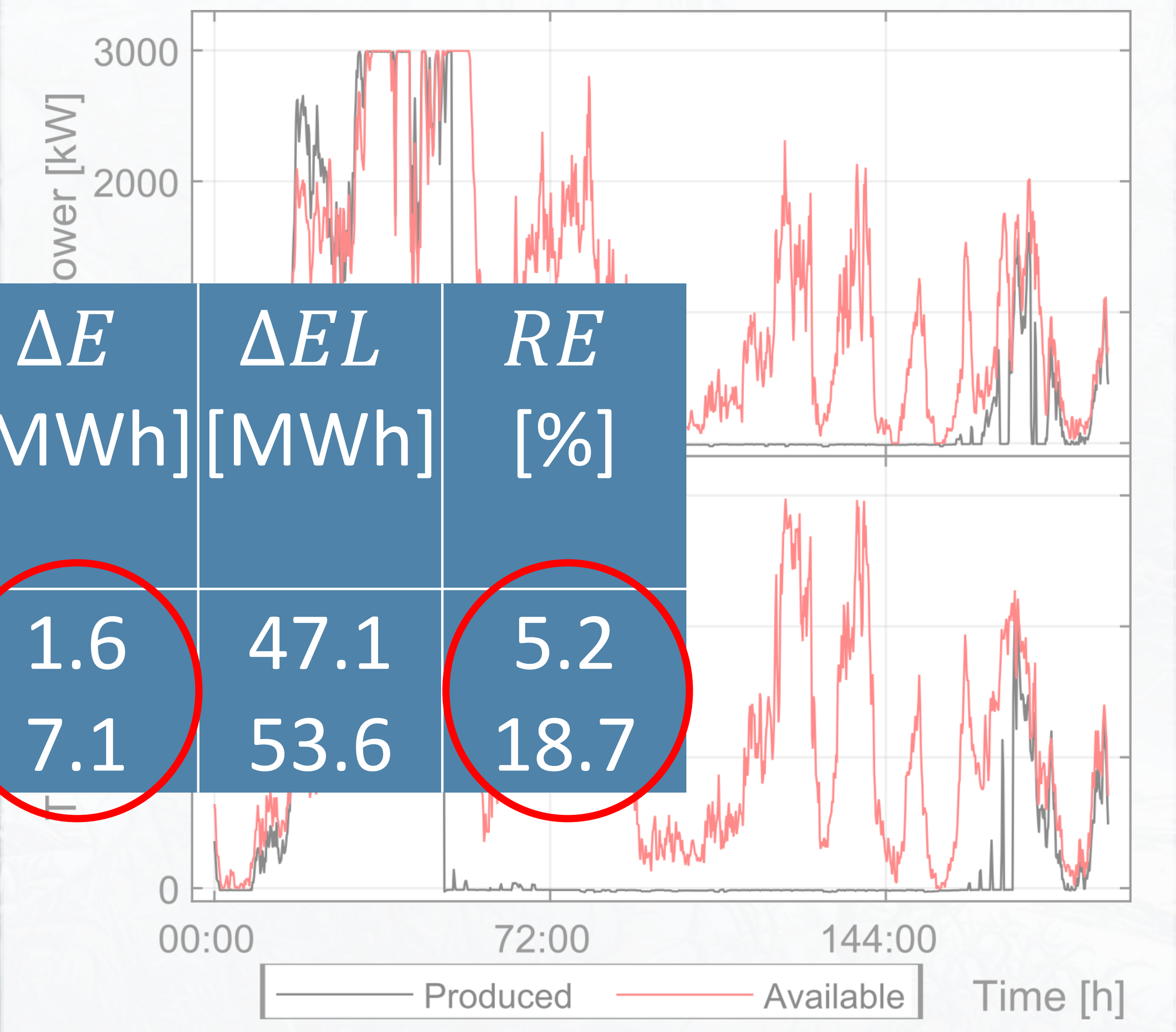


Flaws of traditional metrics

Case study 2:

Adding 48h without icing

Period	ΔE [MWh]	ΔEL [MWh]	RE [%]
CS1	1.6	47.1	5.2
CS2	7.1	53.6	18.7



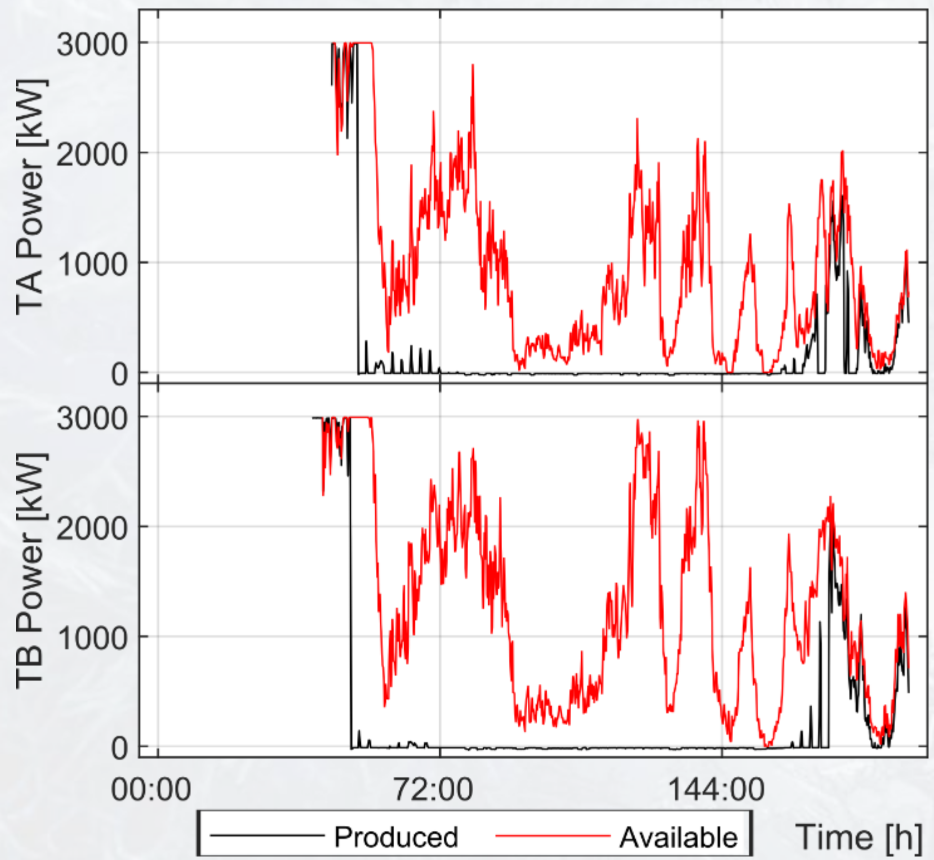
Metrics: How to evaluate the performance

New and improved metrics

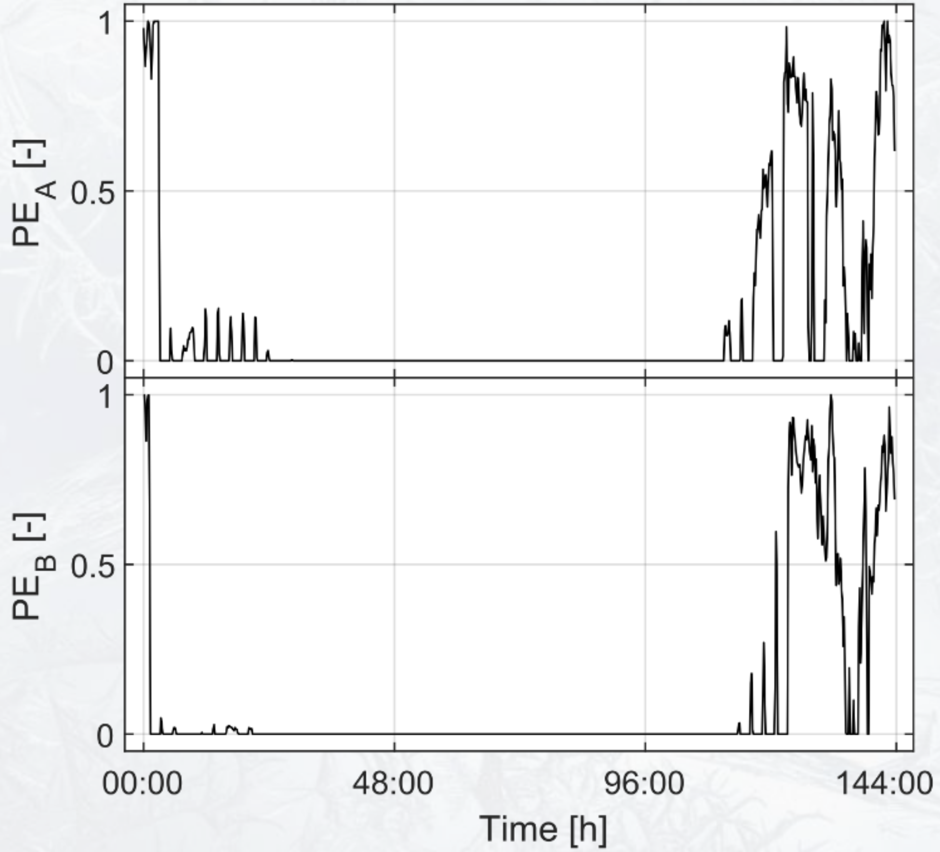
Energy gain	• Energy gained by running the AOS on the exp. Turbine compared to the control
Potential recovery	• Percentage of the losses that the control turbine would have recovered with the AOS

Energy gain

Step 1: compute the power effciencies (PE)



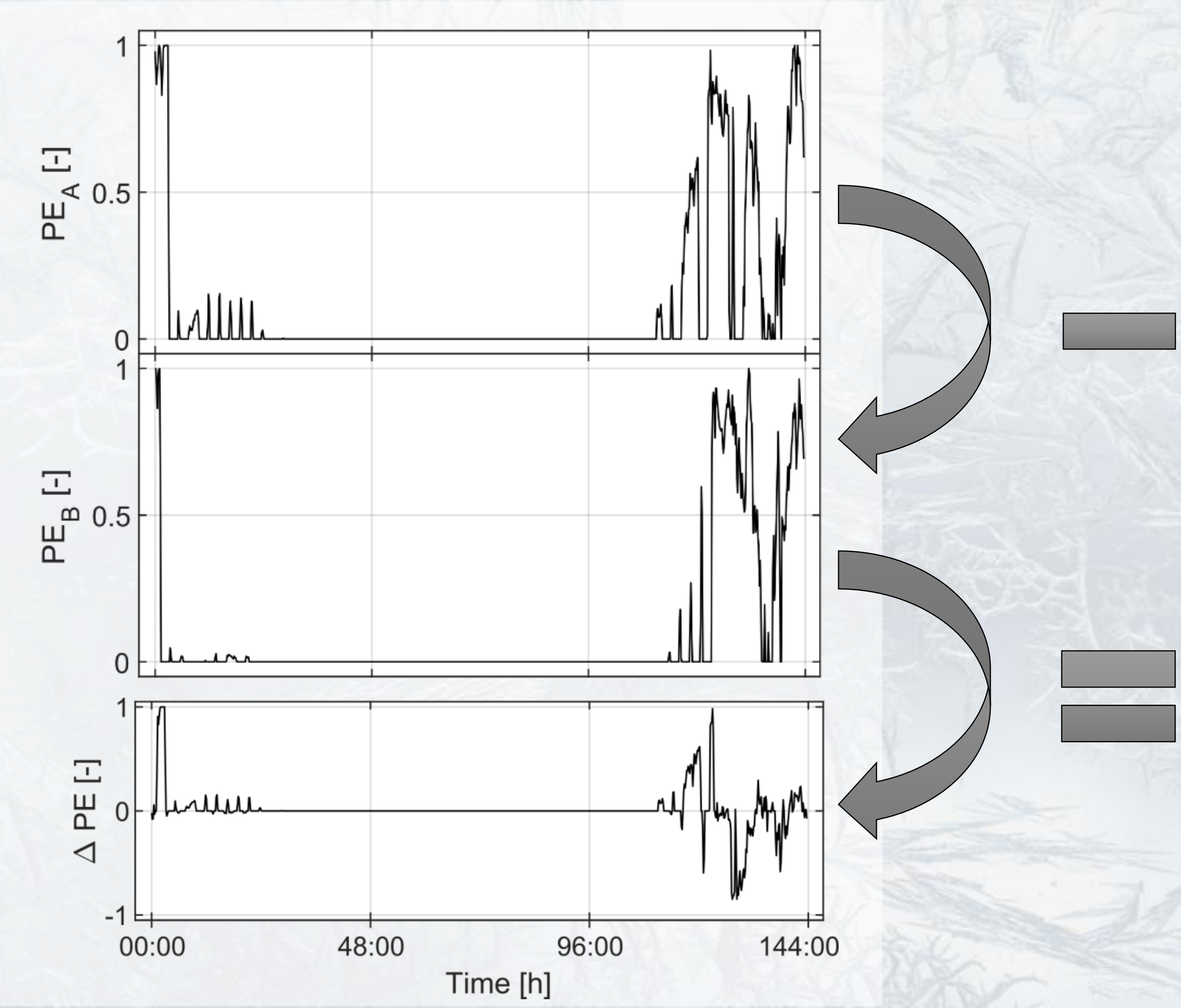
$$PE = \frac{P_{produced}}{P_{Available}}$$



Energy Gain

- Step 2:
  $\Delta PE = PE_A - PE_B$

Turbine A = Experimental turbine (with AOS)
Turbine B = Control turbine (without AOS)

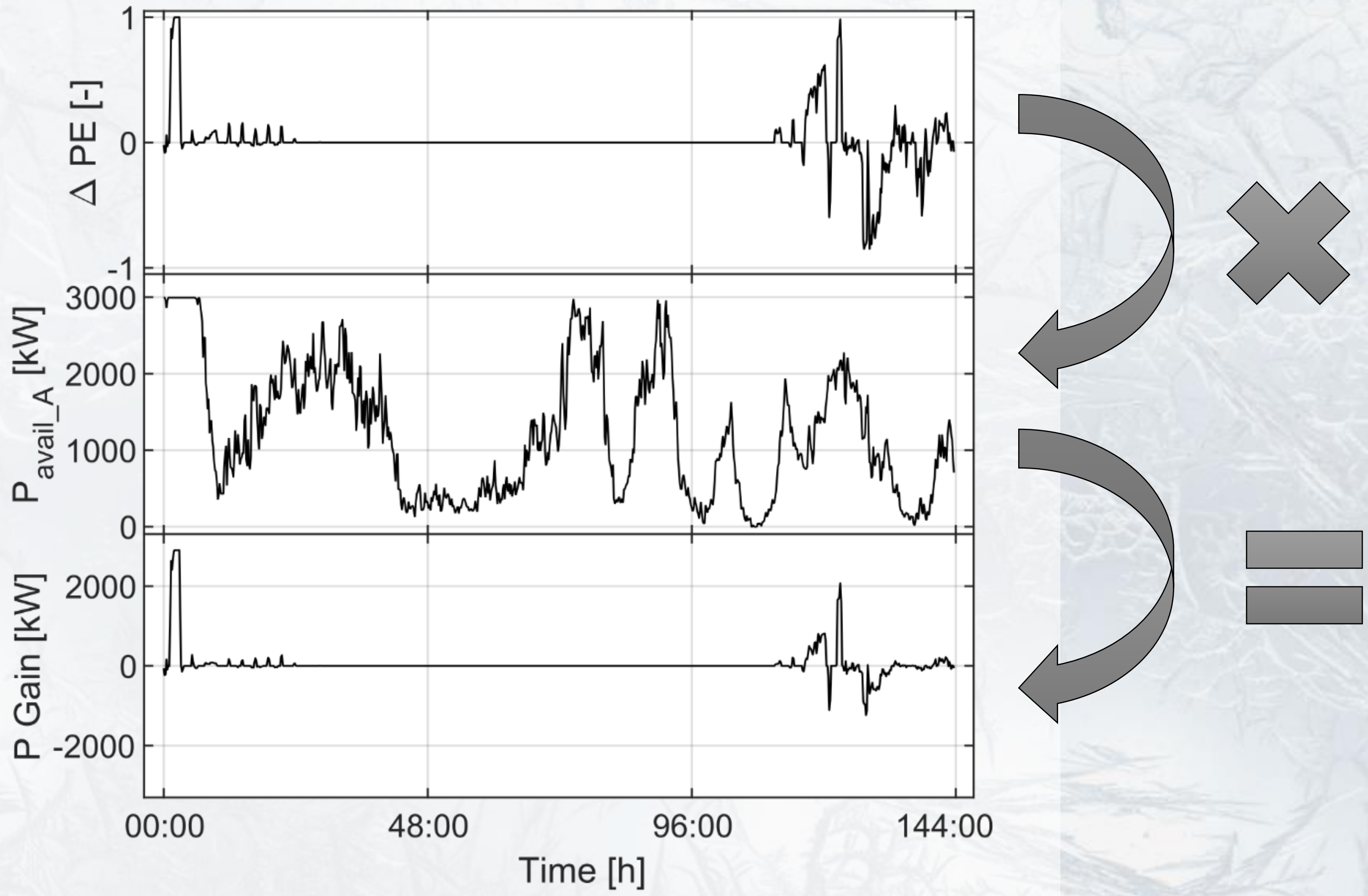


Energy Gain

- Step 3:
  $\Delta PE \times P_{availA} = P_{Gain}$

- Step 4:
  $E_{Gain} = \int P_{Gain} dt$

Turine A = Experimental turbine (with AOS)
Turbine B = Control turbine (without AOS)



Potential recovery

- Normalised version of the energy gain (G_{AB})

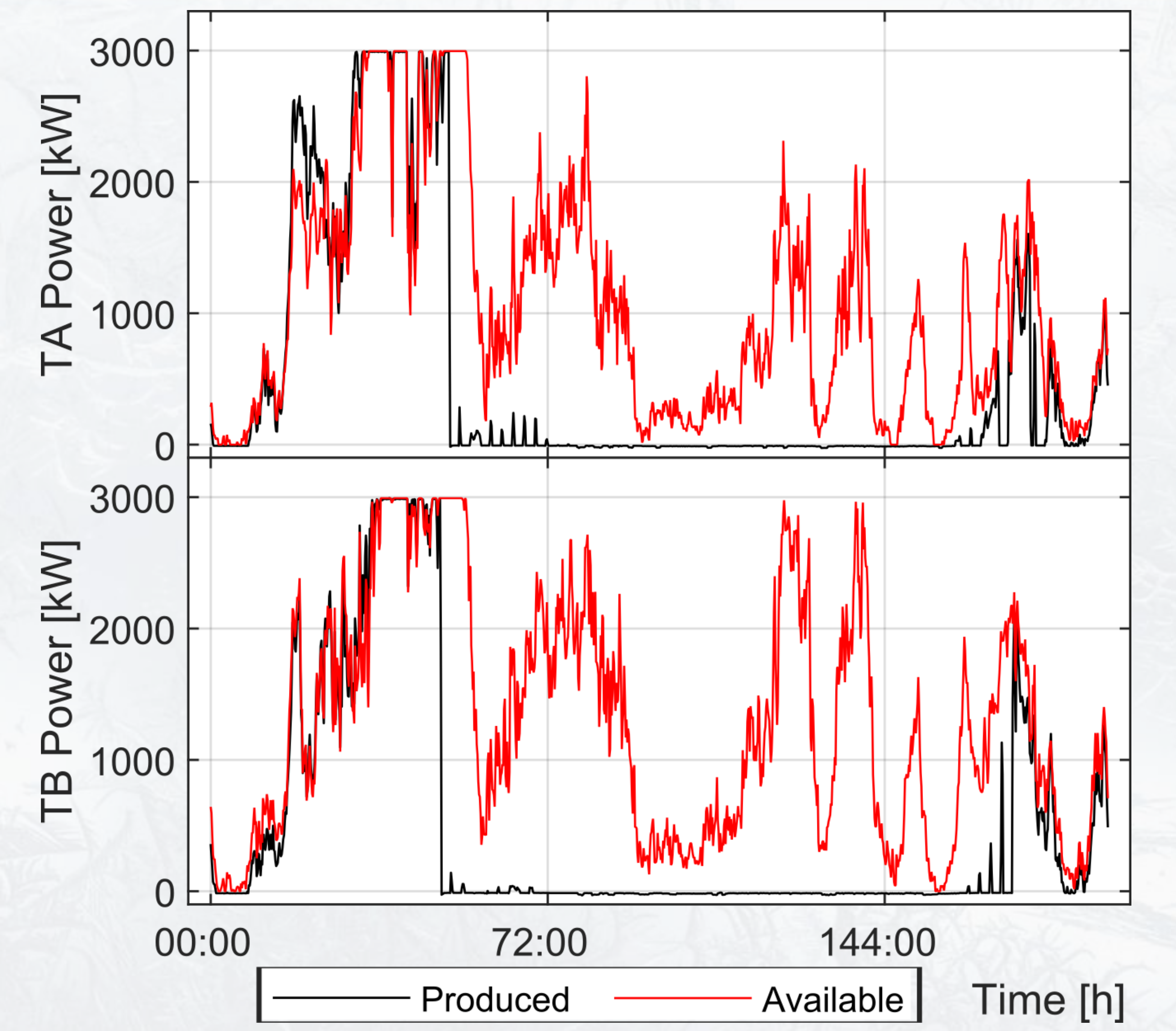
Turbine A = Experimental turbine (with AOS)
Turbine B = Control turbine (without AOS)

$$PR = -\frac{G_{BA}}{E_{Loss-B}}$$

Putting the new metrics to the test

What to expect:

- Close to 0
- Small difference between CS1 and CS2



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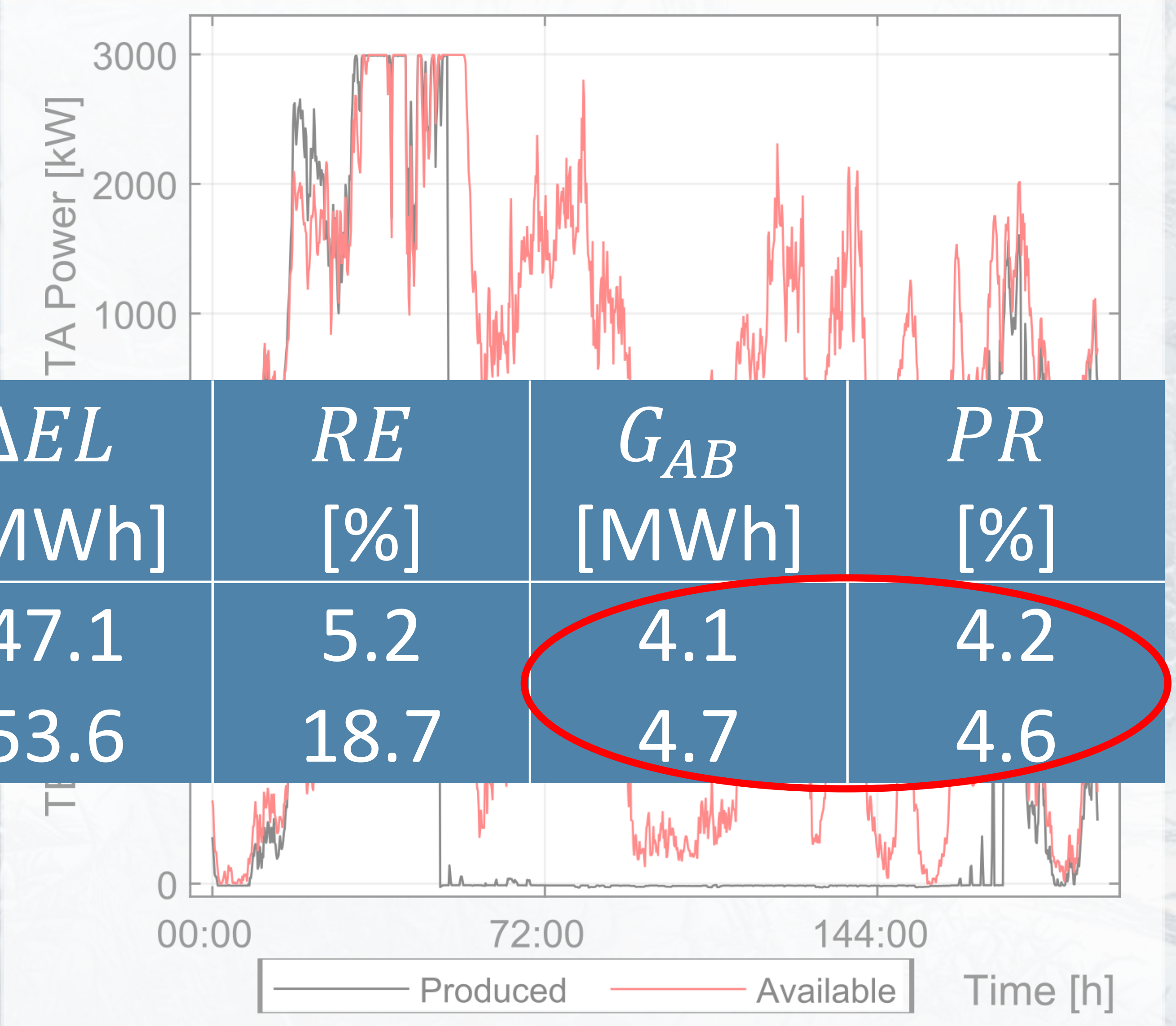
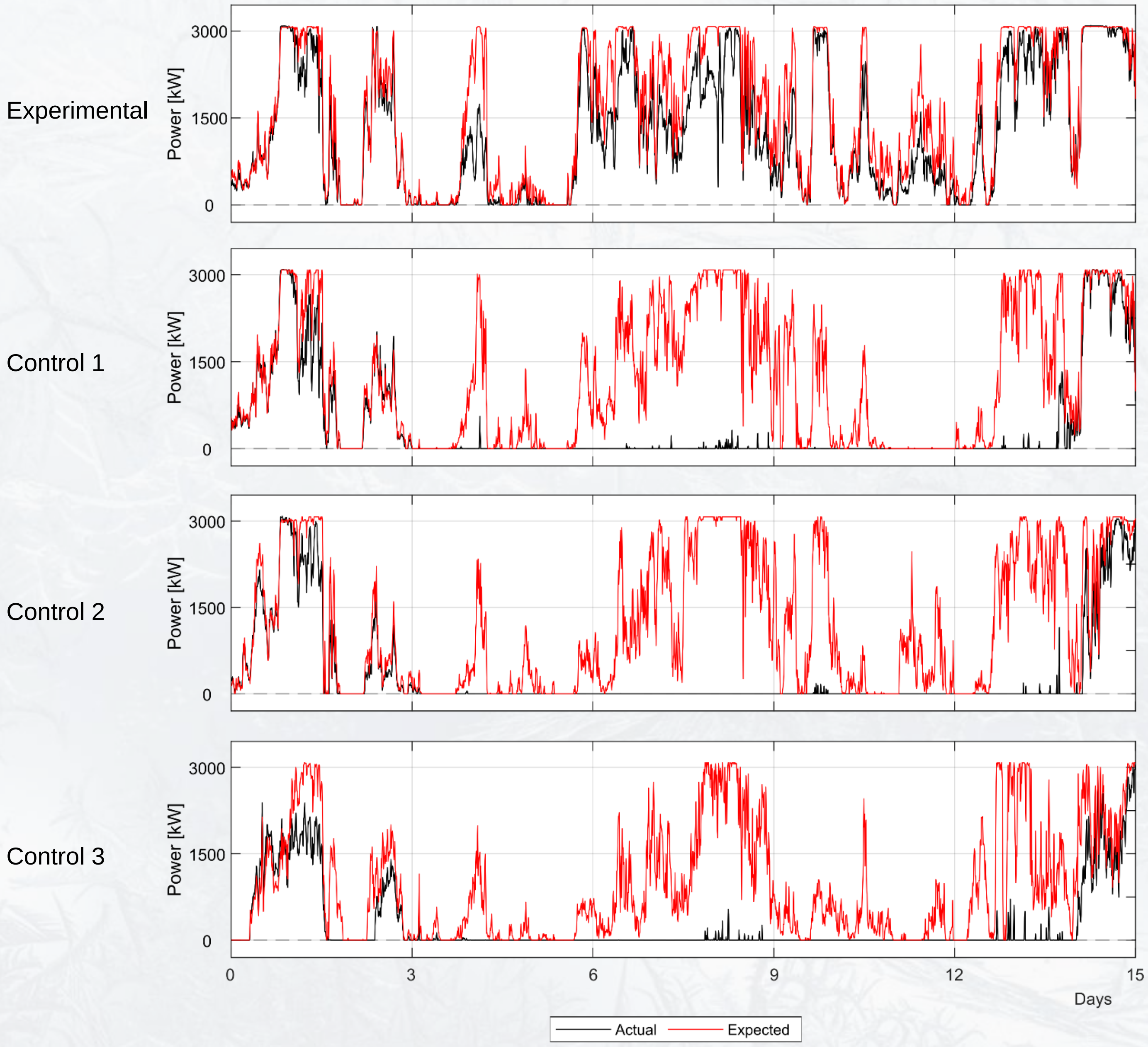


Period	ΔE [MWh]	ΔEL [MWh]	RE [%]	G_{AB} [MWh]	PR [%]
CS1	1.6	47.1	5.2	4.1	4.2
CS2	7.1	53.6	18.7	4.7	4.6

Collaboration with Borealis Wind

- Scaled to 3 MW to preserve data anonymity
- 15 day event (lots of icing)

Turbine	EE [-]	Gain [MWh]	Recovery [%]
Exp.	0.8	-	-
Control 1	0.34	251.9	71.9
Control 2	0.29	260.3	71.7
Control 3	0.28	258.5	69



Conclusion and perspectives

- Cold climate solutions are available and more field testing is needed
- Every site is different, But the methodology does not need to be

- Roberge, P.; Lemay, J.; Ruel, J. & Bégin-Drolet, A. (2022). Towards standards in the analysis of wind turbines operating in cold climate – Part A: Power curve modeling and rotor icing detection. Cold Regions Science and Technology, 196, 103436. doi:10.1016/j.coldregions.2021.103436
- Roberge, P.; Baxter, D.; Ruel, J.; Roeper, D.; Lemay, J.; & Bégin-Drolet, A. (2022). Towards standards in the analysis of wind turbines operating in cold climate. Part B: Methodology for evaluating wind turbine alternative operational strategies. Cold Regions Science and Technology, 196, 103494. doi:10.1016/j.coldregions.2022.103494.

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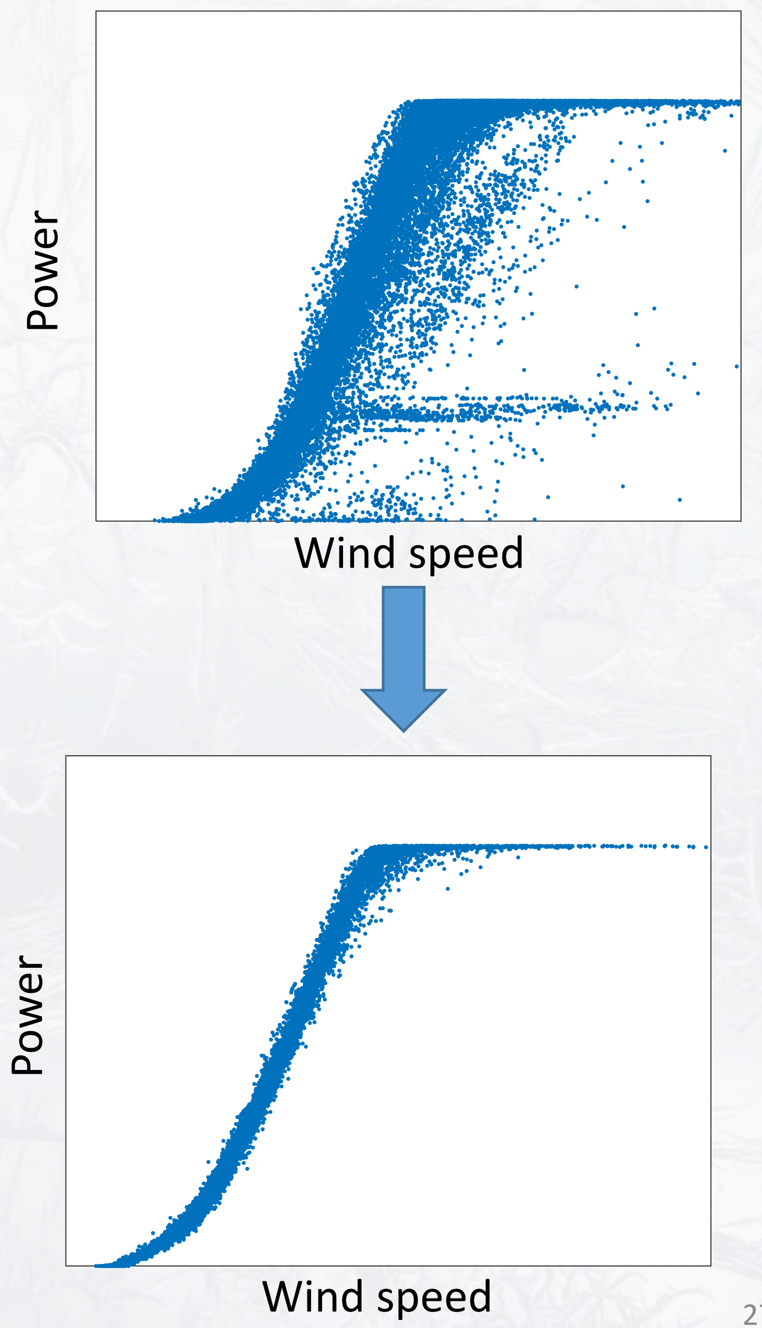
Data preparation

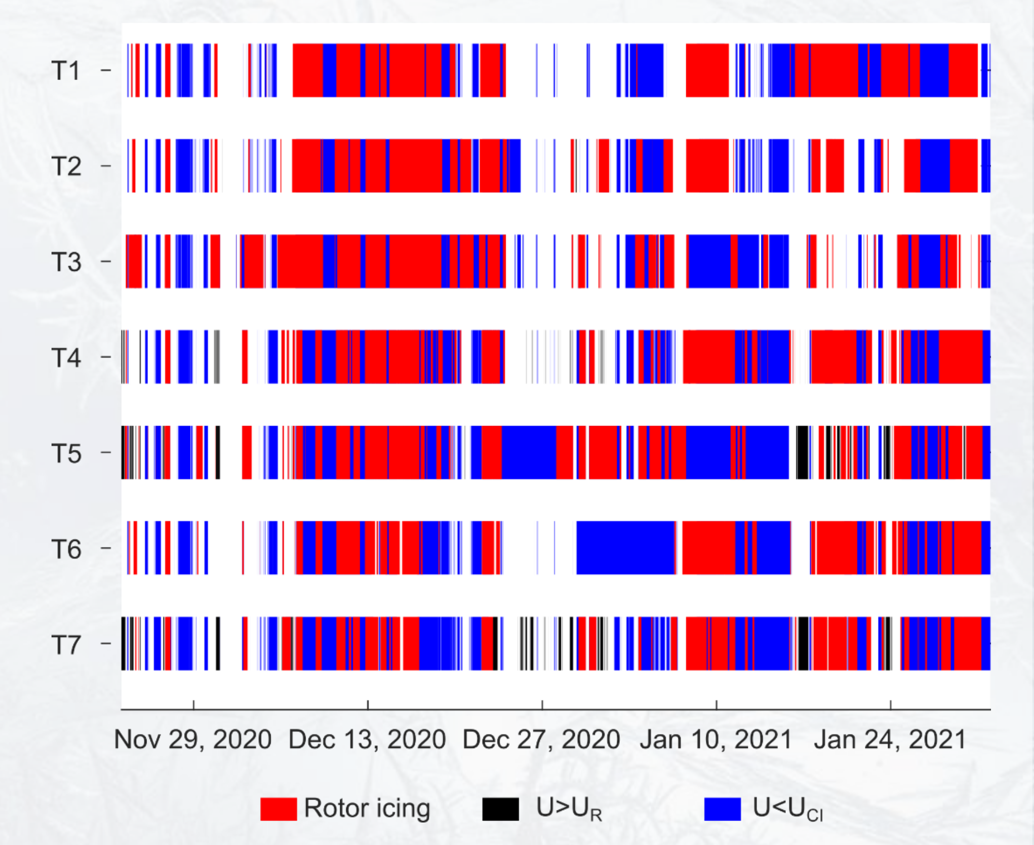
- The MOST important part of the process
- Often overlooked
- Garbage in –> garbage out



Preparation of the data

Identification of icing events

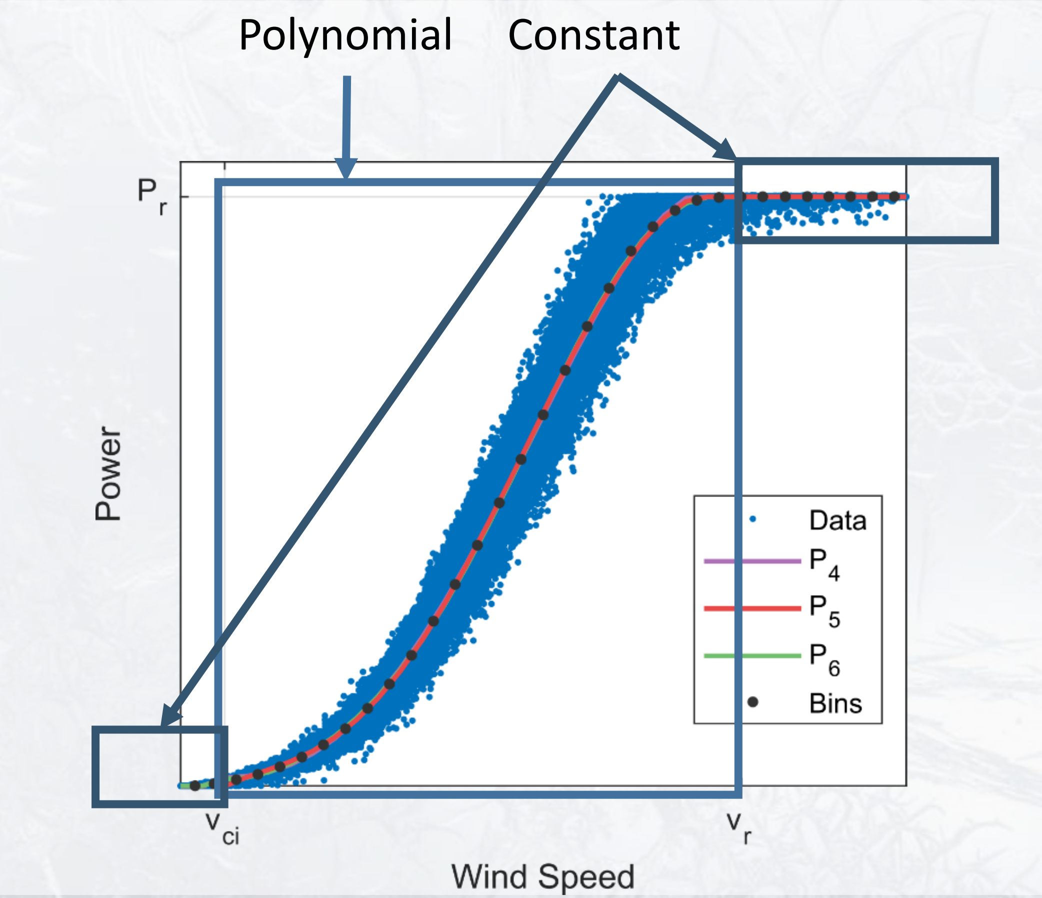
- Use the power of a large data base
- Use multiple turbines to discriminate untagged maintenance
- Know the limitations of the power curve (high and low wind speeds)



Preparation of the data

What power curve model should you use?

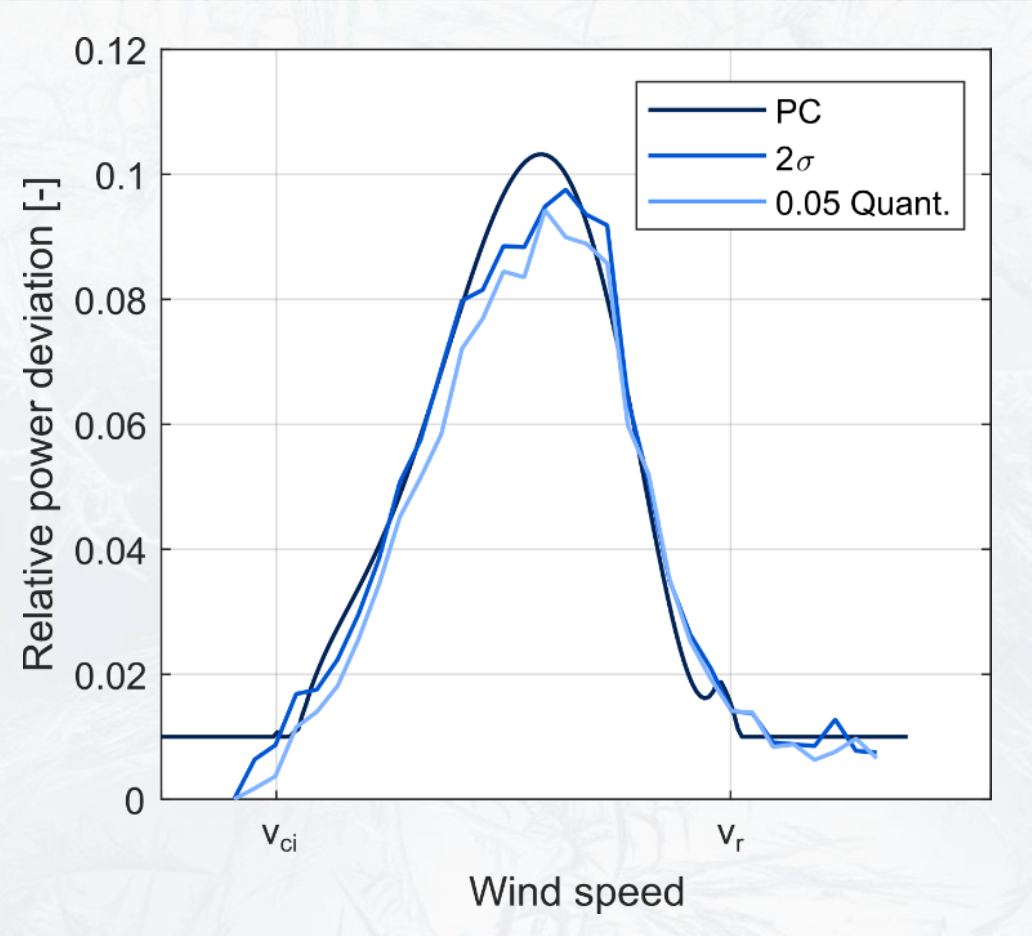
- Interpolation: too sensitive to outliers
- Single function: not accurate on non-linear relationship
- Function by parts: best of both worlds



Preparation of the data

How to set your threshold?

- Quantiles or SD: heavy and too sensitive to outliers
- Constant deviation: not accurate with high wind speeds
- Power curve slope + constant: Similar to quantiles, less sensitive to outliers, easier.

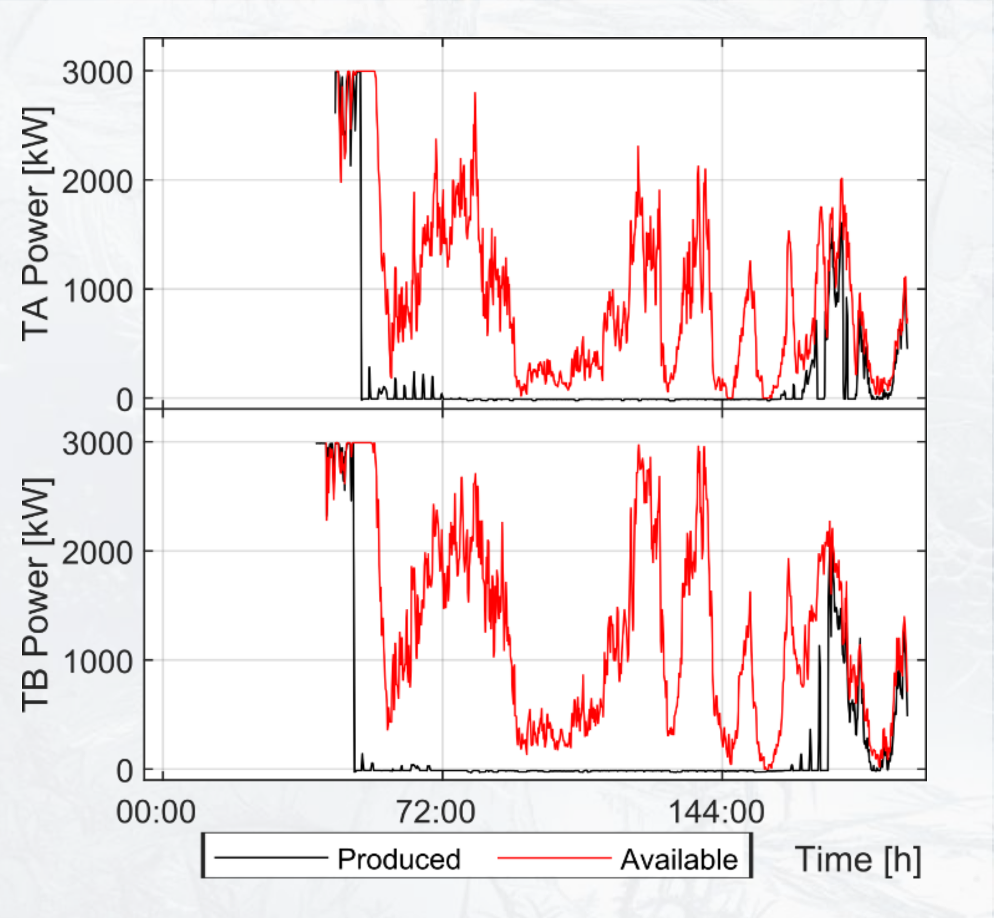


$$P_{thsld} = PC(v) - (PC(v - s_1) - s_2)$$

Energy gain

Advantages

- Not influenced by the difference in power available when both turbines are stopped
- Gives a value in MWh or $$ of the gain achieved



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Turbine	EE [-]	$E_{Available}$ [MWh]	$E_{Produced}$ [MWh]	E_{Loss} [MWh]	Gain [MWh]	Net Gain [MWh]	Recovery [%]	IPS cost [MWh]
Exp.	0.8	569.0	446.4	116.0	-	-	-	26.96
Control 1	0.34	423.3	139.8	280.5	251.9	224.9	71.9	-
Control 2	0.29	422.4	118.1	301.4	260.3	233.3	71.7	-
Control 3	0.28	336.5	94.8	242.4	258.5	231.5	69	-
		$	$	$	$	$		$
Exp.		65426	51332	13340	-	-		3100
Control 1		48678	16070	32264	19307	16207		-
Control 2		48576	13581	34658	19958	16858		-
Control 3		38688	10893	27875	19817	16717		-