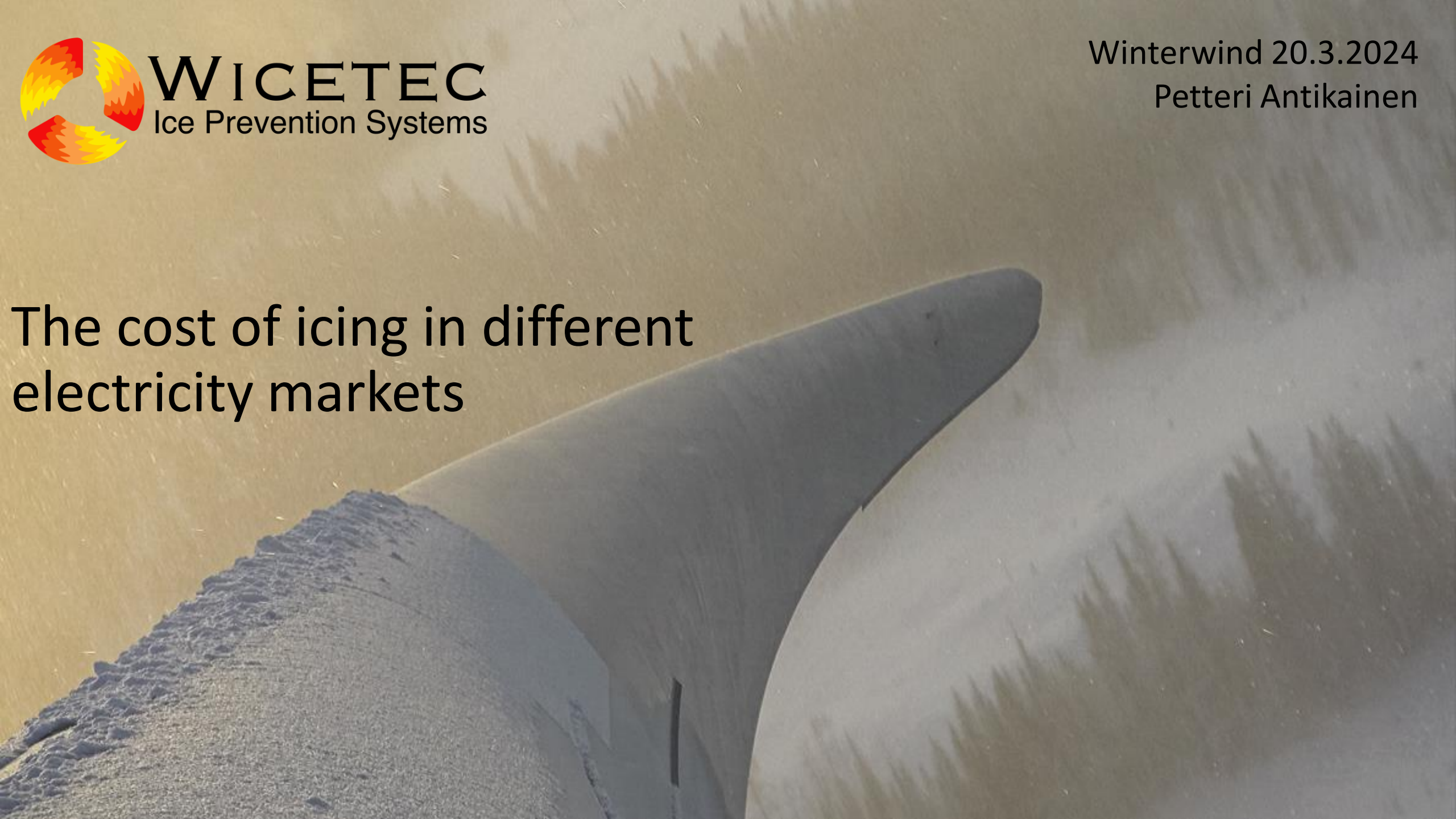

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Winterwind 20.3.2024
Petteri Antikainen

The cost of icing in different electricity markets

Winter 2023-2024 icing cases in Finland

- Finnish wind fleet in total
- Production forecast and realized production data from Fingrid
- Cloud height, temperature observations
- Nordpool Urgent Market Messages backing up conclusion
- Comparison with Kjeller IceLossForecast

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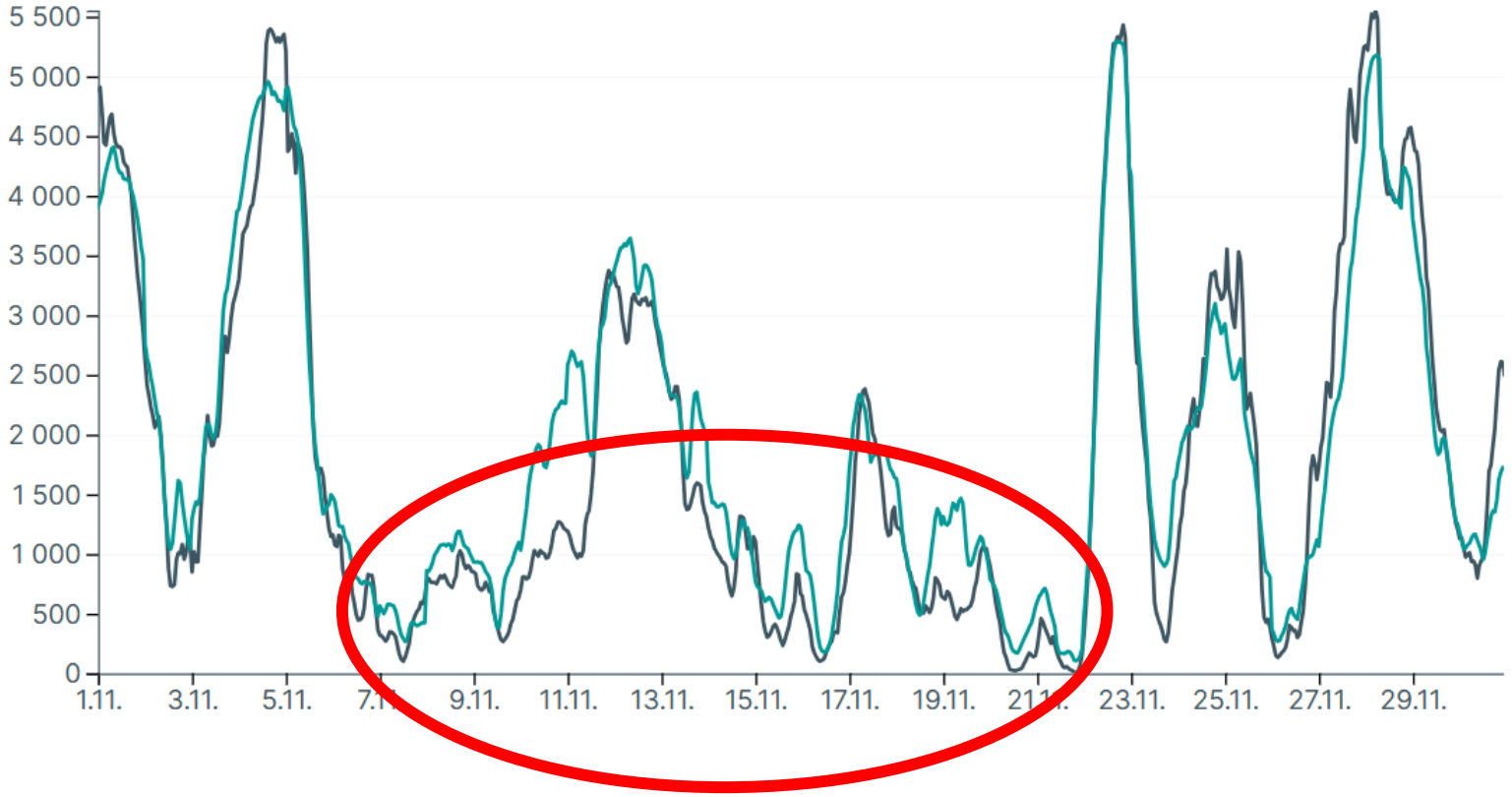
2023 November



	Name	Minimum	Maximum	Average
●	Wind power generation	6	5551	1796 MWh/h
●	Day ahead wind power forecast	108	5297	1923 MWh/h

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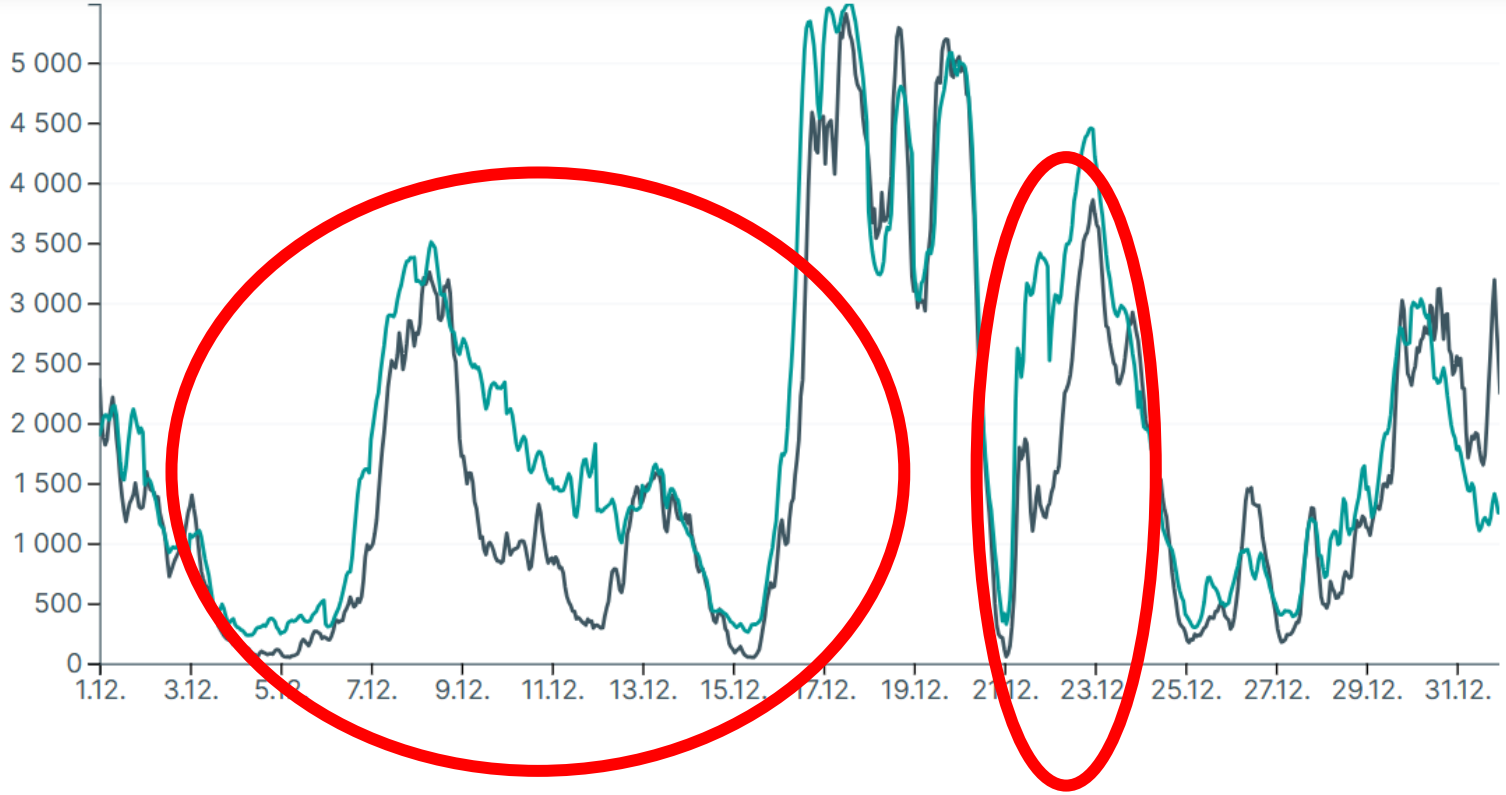
2023 December



	Name	Minimum	Maximum	Average
●	Wind power generation	49	5403	1620 MWh/h
●	Day ahead wind power forecast	234	5488	1935 MWh/h

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2024 Week 1

	Name	Minimum	Maximum	Average
●	Wind power generation	137	3684	1631 MWh/h
●	Day ahead wind power forecast	215	4062	1605 MWh/h

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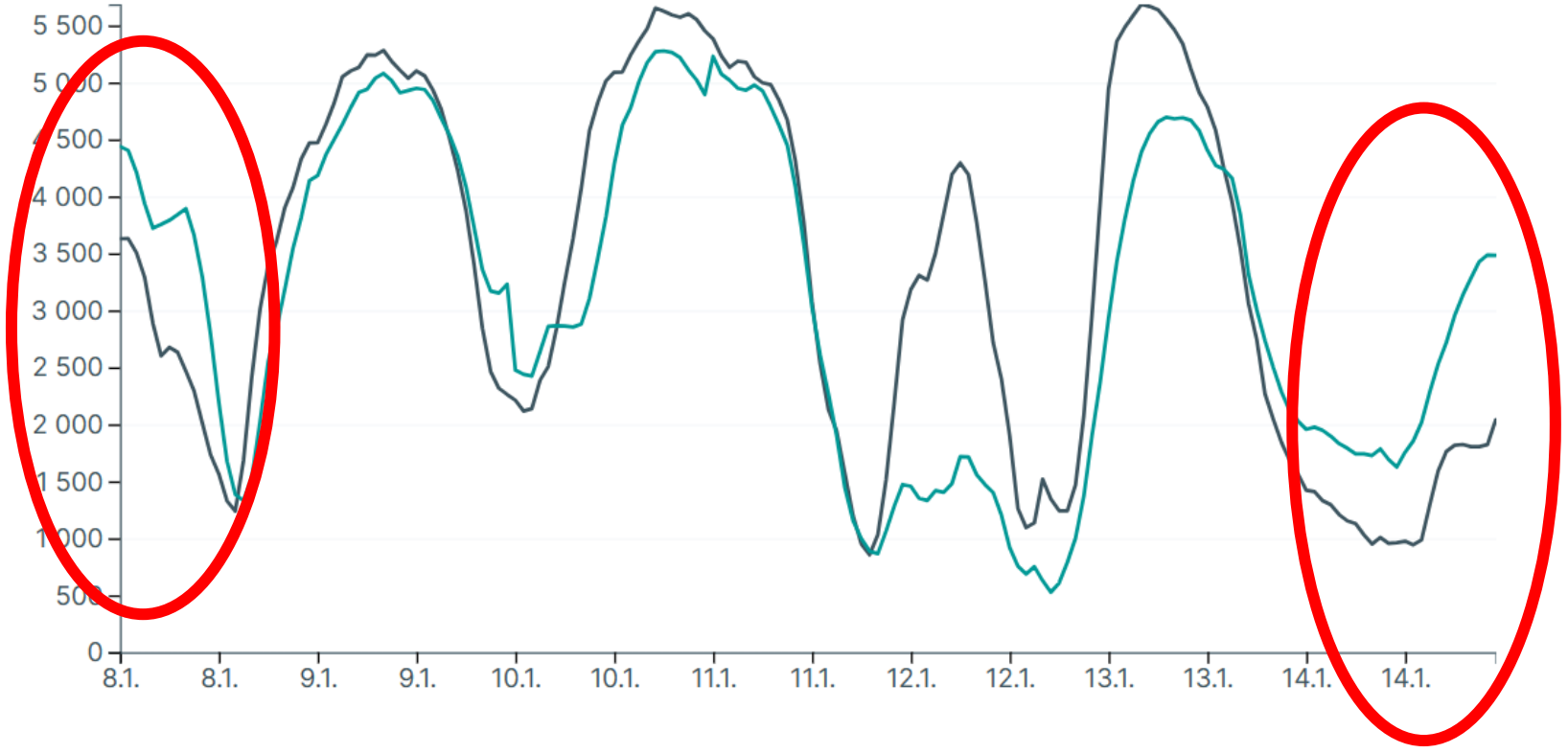
2024 Week 2



	Name	Minimum	Maximum	Average
●	Wind power generation	854	5686	3309 MWh/h
●	Day ahead wind power forecast	527	5277	3137 MWh/h

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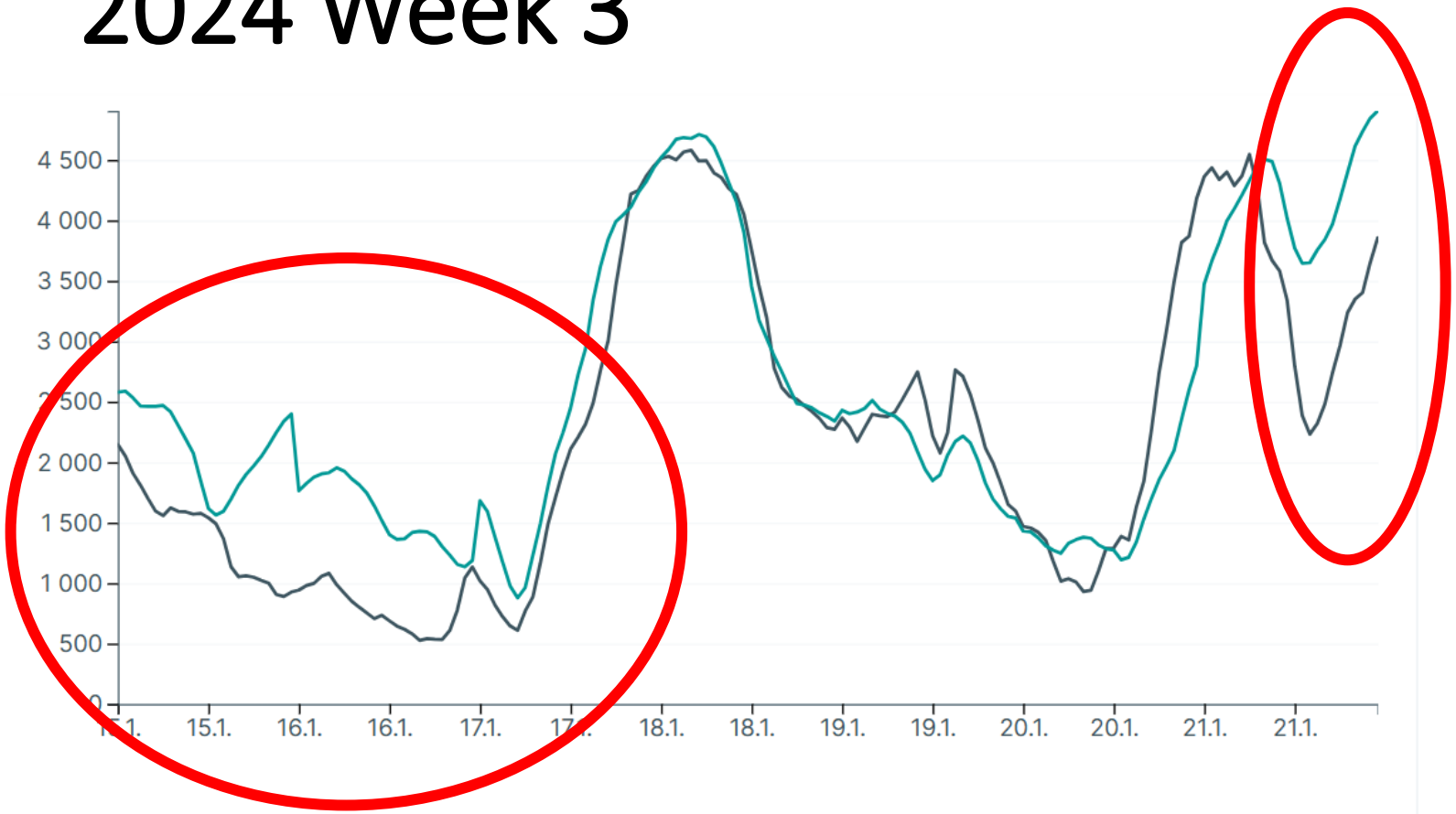
2024 Week 3



	Name	Minimum	Maximum	Average
●	Wind power generation	526	4580	2248 MWh/h
●	Day ahead wind power forecast	878	4906	2532 MWh/h

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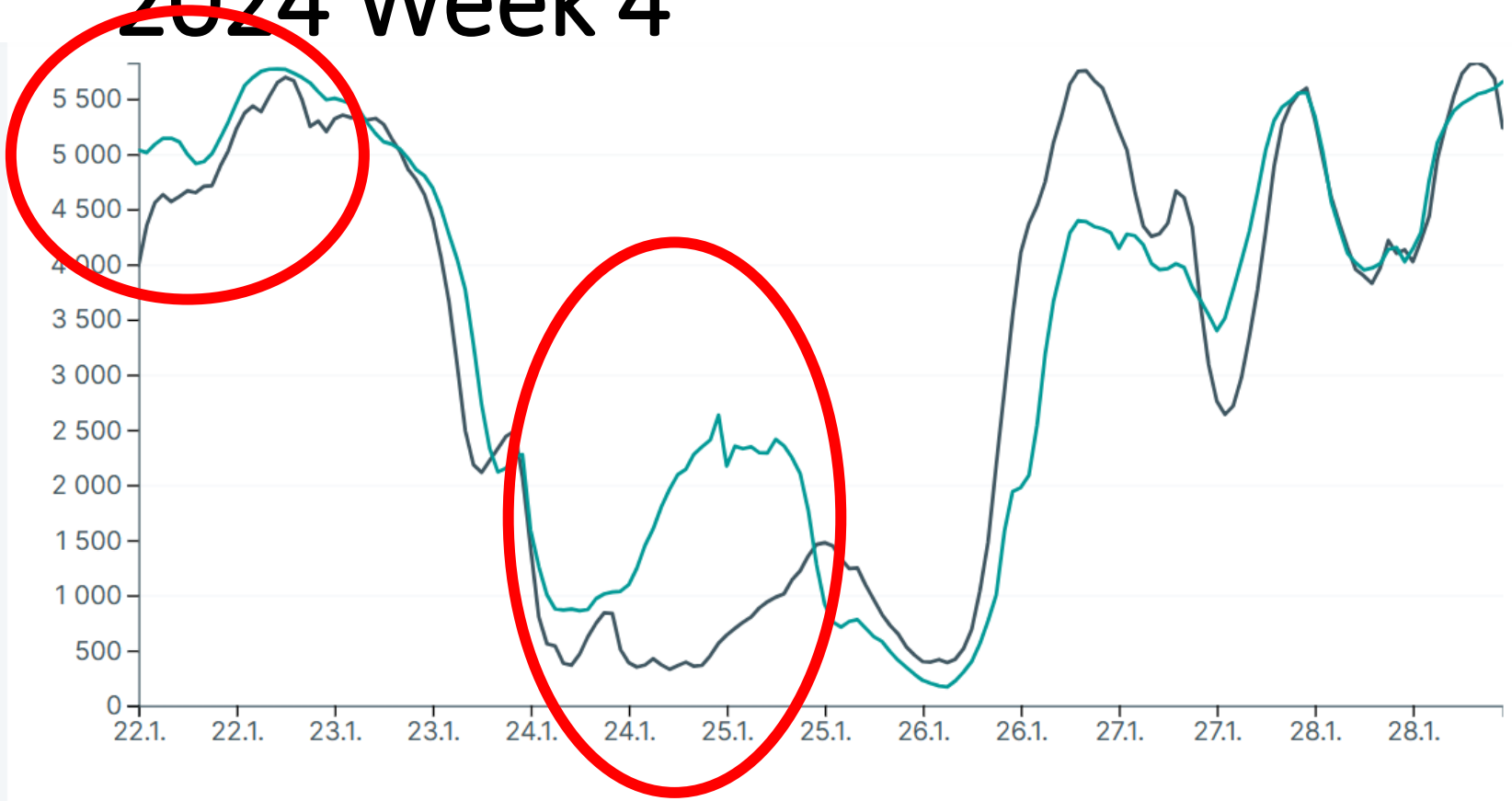
2024 Week 4



	Name	Minimum	Maximum	Average
●	Wind power generation	328	5827	3241 MWh/h
●	Day ahead wind power forecast	167	5770	3372 MWh/h

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2024 Week 5

	Name	Minimum	Maximum	Average
●	Wind power generation	1944	5958	4530 MWh/h
●	Day ahead wind power forecast	1974	5941	4740 MWh/h

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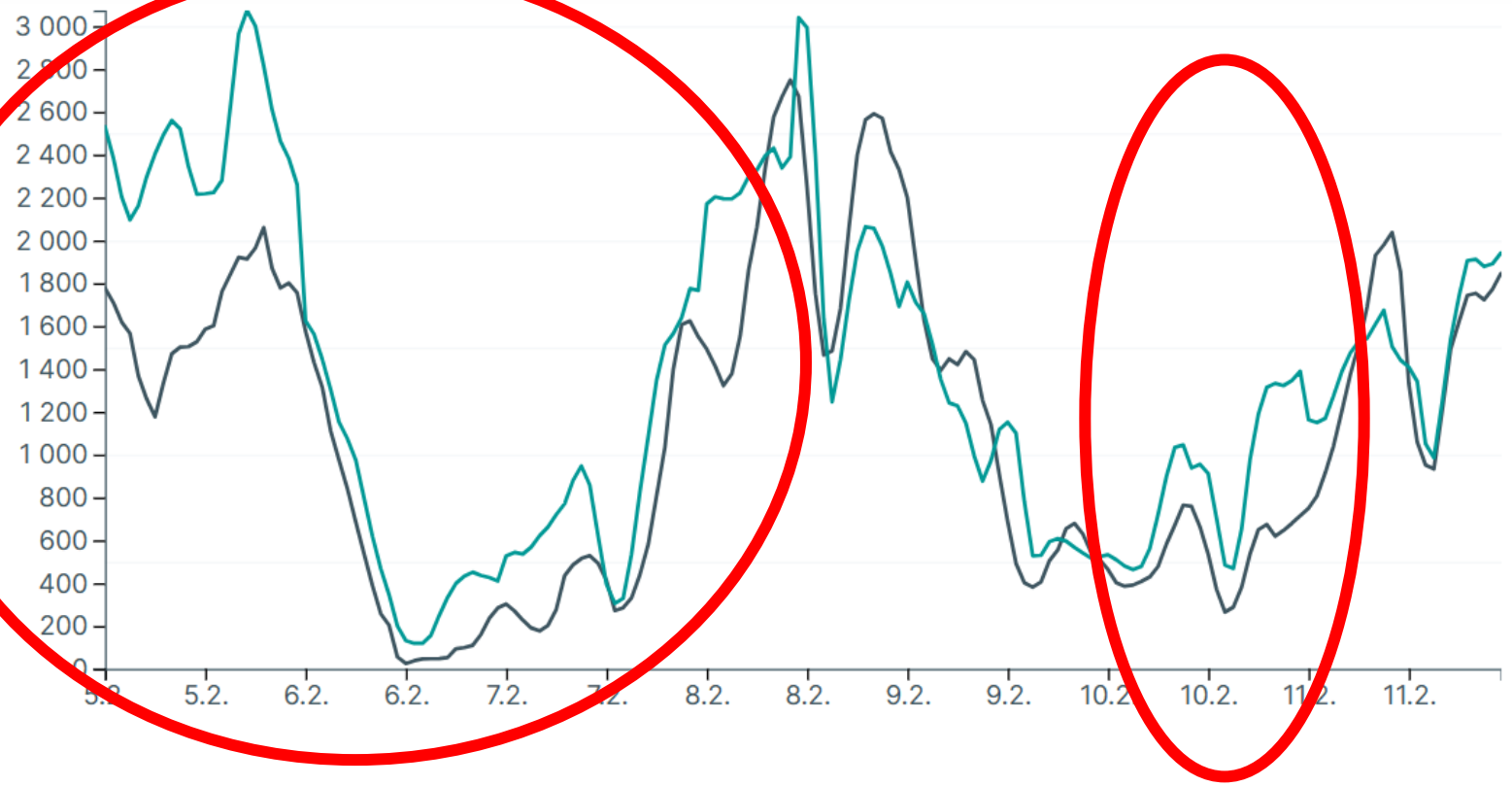
2024 Week 6



	Name	Minimum	Maximum	Average
●	Wind power generation	25	2749	1104 MWh/h
●	Day ahead wind power forecast	119	3073	1351 MWh/h

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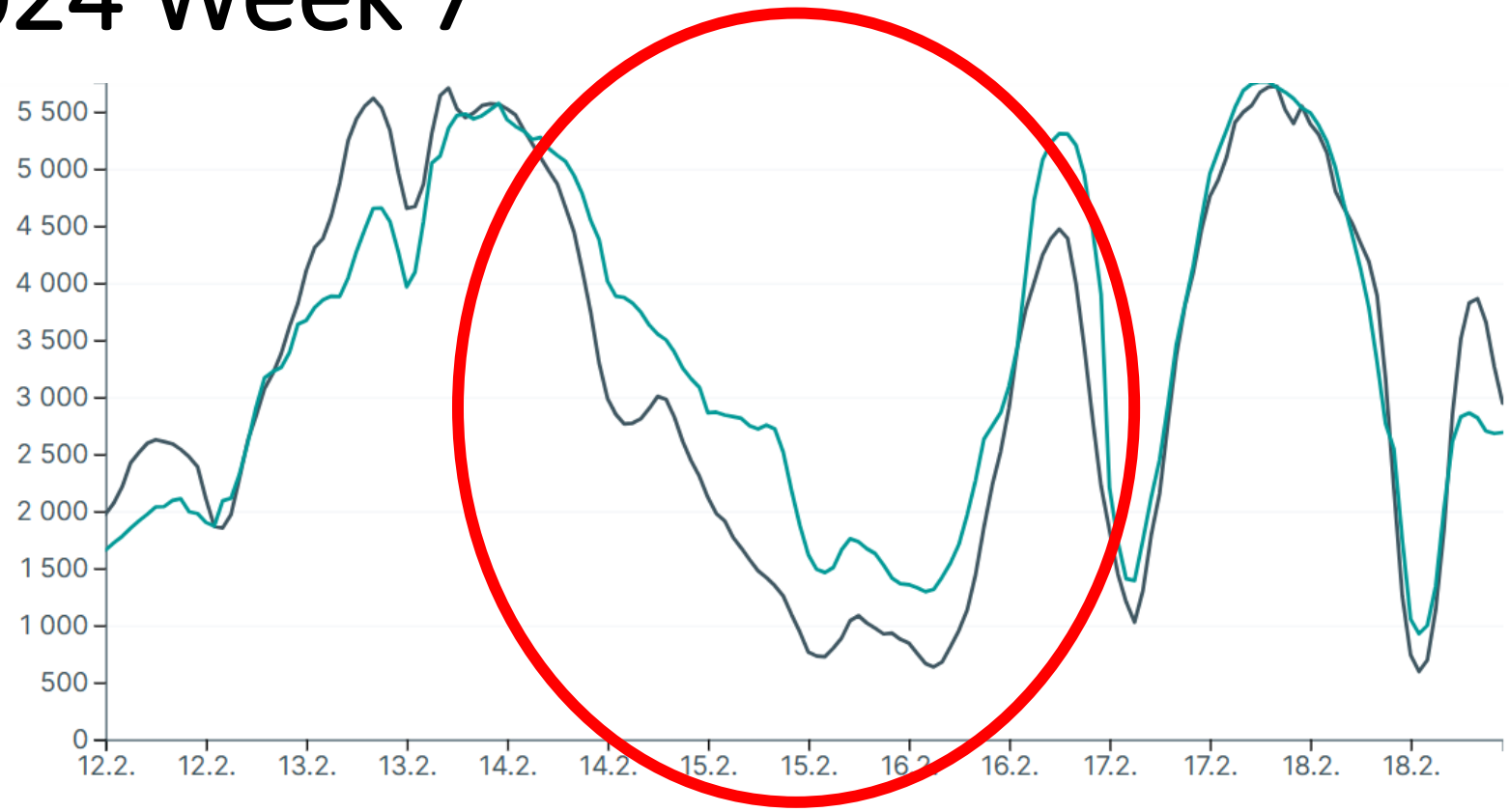
2024 Week 7



	Name	Minimum	Maximum	Average
●	Wind power generation	595	5723	3195 MWh/h
●	Day ahead wind power forecast	925	5763	3396 MWh/h

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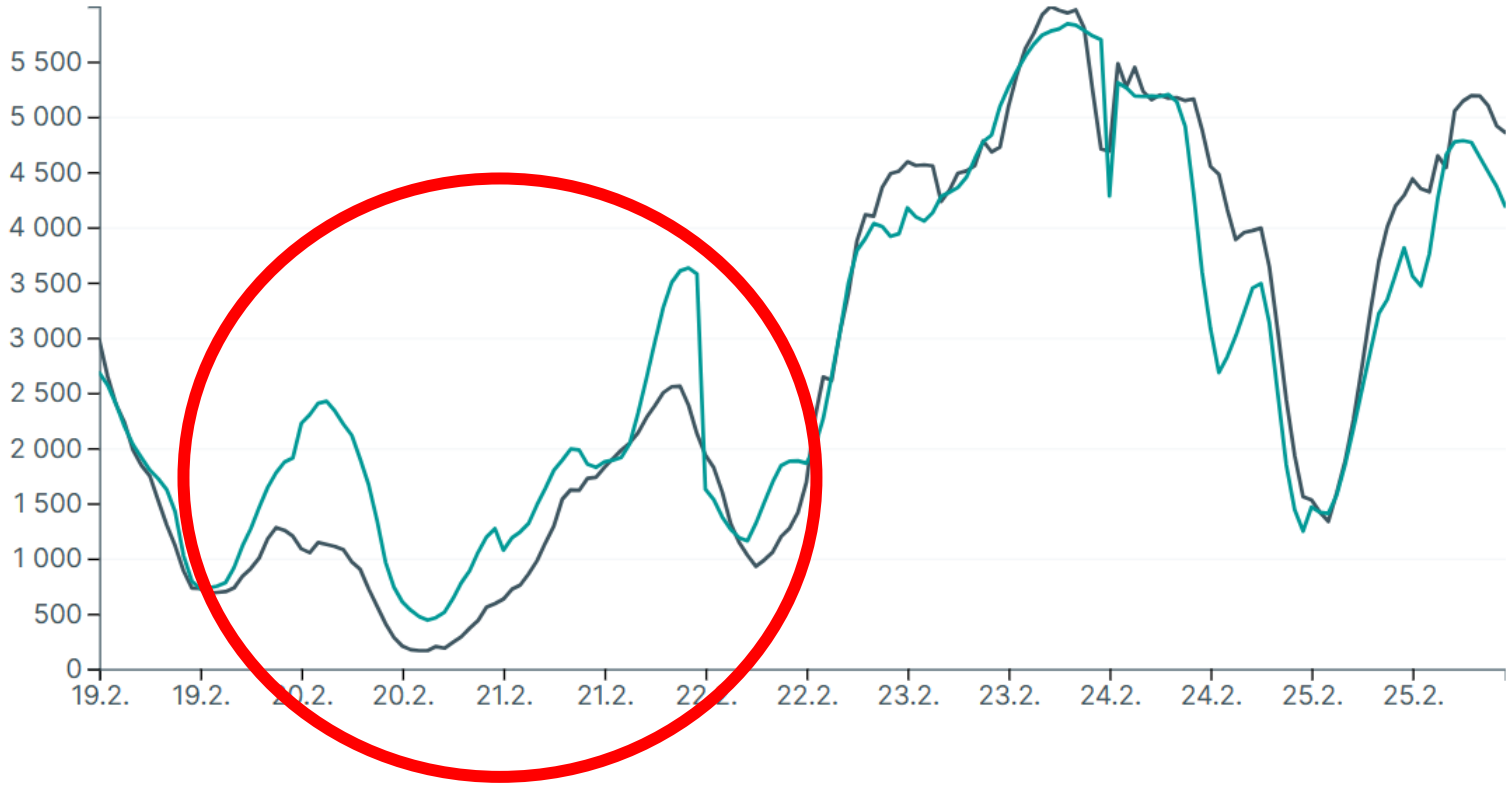
2024 Week 8



	Name	Minimum	Maximum	Average
●	Wind power generation	165	5999	2739 MWh/h
●	Day ahead wind power forecast	441	5842	2805 MWh/h

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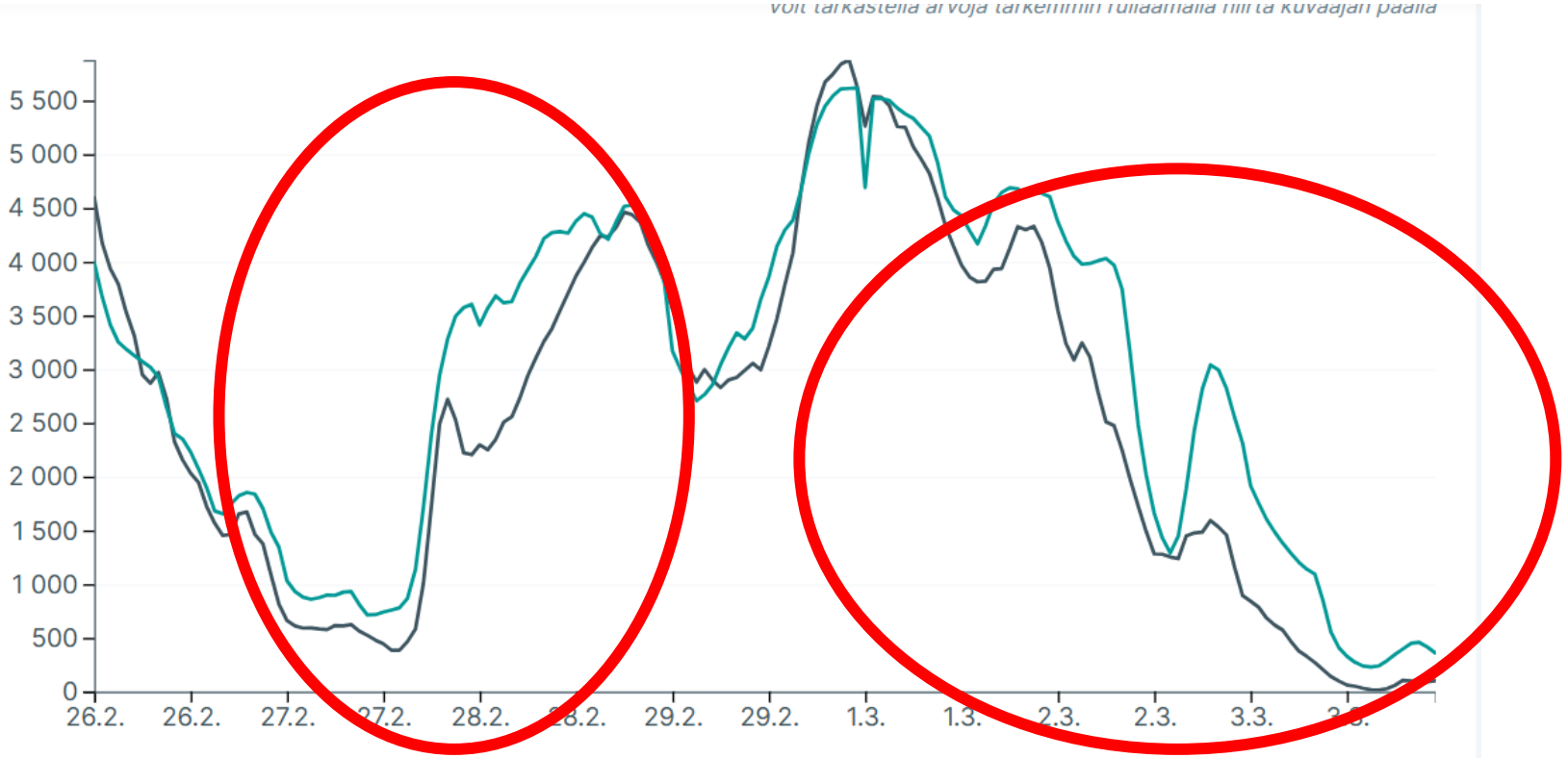
2024 Week 9



	Name	Minimum	Maximum	Average
●	Wind power generation	14	5877	2522 MWh/h
●	Day ahead wind power forecast	229	5617	2944 MWh/h

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2024 Week 10

	Name	Minimum	Maximum	Average
●	Wind power generation	22	2538	463 MWh/h
●	Day ahead wind power forecast	223	1943	556 MWh/h

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Definition of “market”

- In this presentation a word market refers to
  - a geographical market area or,
    - Examples feed-in: Finland 2011-2017, Quebec Canada.
  - within a geographical area there can be different kind of markets based on sales strategy
    - Example open market: Finland 2017 -> direct sales to electricity market or different kind of PPA’s

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Production related costs of icing

- Direct AEP loss, lost sales, risk is always on producer
  - Applies to all markets.
  - Traditional way of defining loss

- Missing production, from the producer point of view

  Case a. No worries, someone else is paying my mistakes.

  - this applies to feed-in market, pay-as produced PPA

  Case b. Full responsibility to market, intraday and balance obligations.

  - sales directly to the market, base load PPA
  - no other significant assets, single or few wind farms
  - can limit balance risk by buying balance service, for a price

  Case c. Something in between of a and b

  - other significant assets to cut extreme costs in balance market
  - the variation of risks and business opportunities is huge

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WIPS benefit calculator - intro

WIPS benefit calculator

Versio 1.0

This calculator helps You to estimate the benefit of investing in Wicetec Ice Prevention System (WIPS) for Your wind power projects in sites where icing can occur, in different electricity market situations.

The calculator considers two important aspects, which are not considered in the standard “icing loss % of gross AEP” approach:

1. Electricity is on average more expensive in winter time
2. Market risk. The economical losses due to icing depends on the electricity markets where the project is going to operate: feed-in vs. open market, low vs. high penetration of wind in the system, balancing power costs of a stand alone project vs. balancing power costs of a project part of large amount of different assets.

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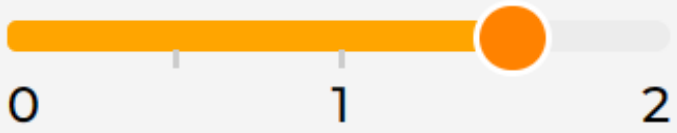
WIPS benefit calculator– Market risk factor

Market risk factor



Market risk factor 0 *represents situation you receive constant feed-in rate, pay-as-produced etc, and do not need to pay for balance power.*

Market risk factor 1 *represents situation, you have significant other assets which help you with balancing power if failing to fulfill day-ahead sales promises.*

Market risk factor 2 *represents situation you have full market risk, project is stand-alone,needs to buy from intraday what is lacking from day-ahead sales.*

Reference: According to Finnish owners/operators Market risk factor lands usually somewhere between 1 and 2.

Economic loss %
= AEP loss% * (1+MRF)

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WIPS benefit calculator - input

Wind turbine rated power MW	Number of turbines in wind farm
7	20
Full load hours	Meterological icing hours at 150 meters
3500	250
Price of electricity in winter €/MWh	WIPS investment per wind turbine €
70	180000
WIPS efficiency %	Expected rate of return of investment %
90	10

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Calculator - results

Investment metrics

IRR

137.8 %

Payback time

0.7 years

NPV for WIPS per turbine

1 862 000 €

Results

Icing loss % of AEP

6.4 %

Icing loss with market risk

16.1 %

AEP theoretical

Per turbine, annual	Per wind farm, annual	Project, 25 years
24.5 GWh	490 GWh	12250 GWh

Lost production without WIPS

Per wind turbine, annual	Per wind farm, annual	Project, 25 years
1.6 GWh	31.5 GWh	786.6 GWh

Lost income without WIPS

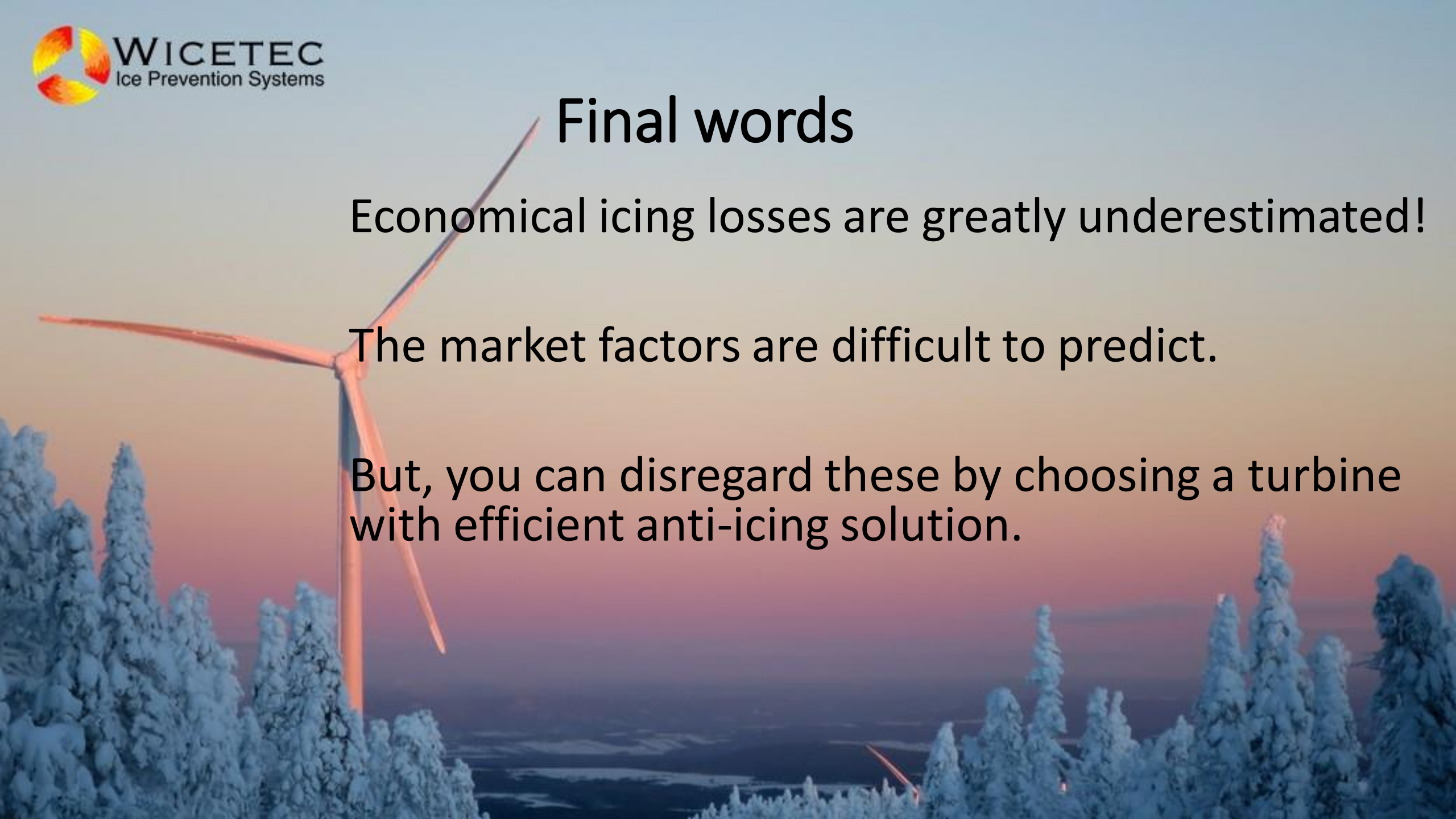
Per wind turbine, annual	Per wind farm, annual	Project, 25 years
275 300 €	5.5 M€	137.7 M€

Increased production with WIPS

Per wind turbine, annual	Per wind farm, annual	Project, 25 years
1.4 GWh	28.3 GWh	707.9 GWh

Increased income with WIPS

Per wind turbine, annual	Per wind farm, annual	Project, 25 years
248 000 €	5.0 M€	123.9 M€



Final words

Economical icing losses are greatly underestimated!

The market factors are difficult to predict.

But, you can disregard these by choosing a turbine with efficient anti-icing solution.