Strategies and tools for designing and optimizing wind farms for prosperous operation in cold climates

19th March 2024
Simon Grenholm

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Wind power for a reliable renewable electricity supply

- Good distribution over the year
- Less power output during low wind and icing, causing rising spot prices
- Stable production during low wind and icing is increasingly important!

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Value of functional Ice Mitigation Systems (IMS)

- Rising spot prices during icing events
- Ice losses… as lost energy or as lost revenue?
- IMS availability… using regression to find the value of functional IMS

Improvements and focus areas

- Low wind speed scenarios
- Finding the perfect design!?

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Dragaliden wind farm

Dragaliden wind farm

- Markbygden, northern Sweden
- Commissioned 2010
- 12 turbines
- Enercon E-82 E2 2.1MW
- Stable data and no major IMS changes since 2016
- Varying IMS availability… used to find the value of functional IMS

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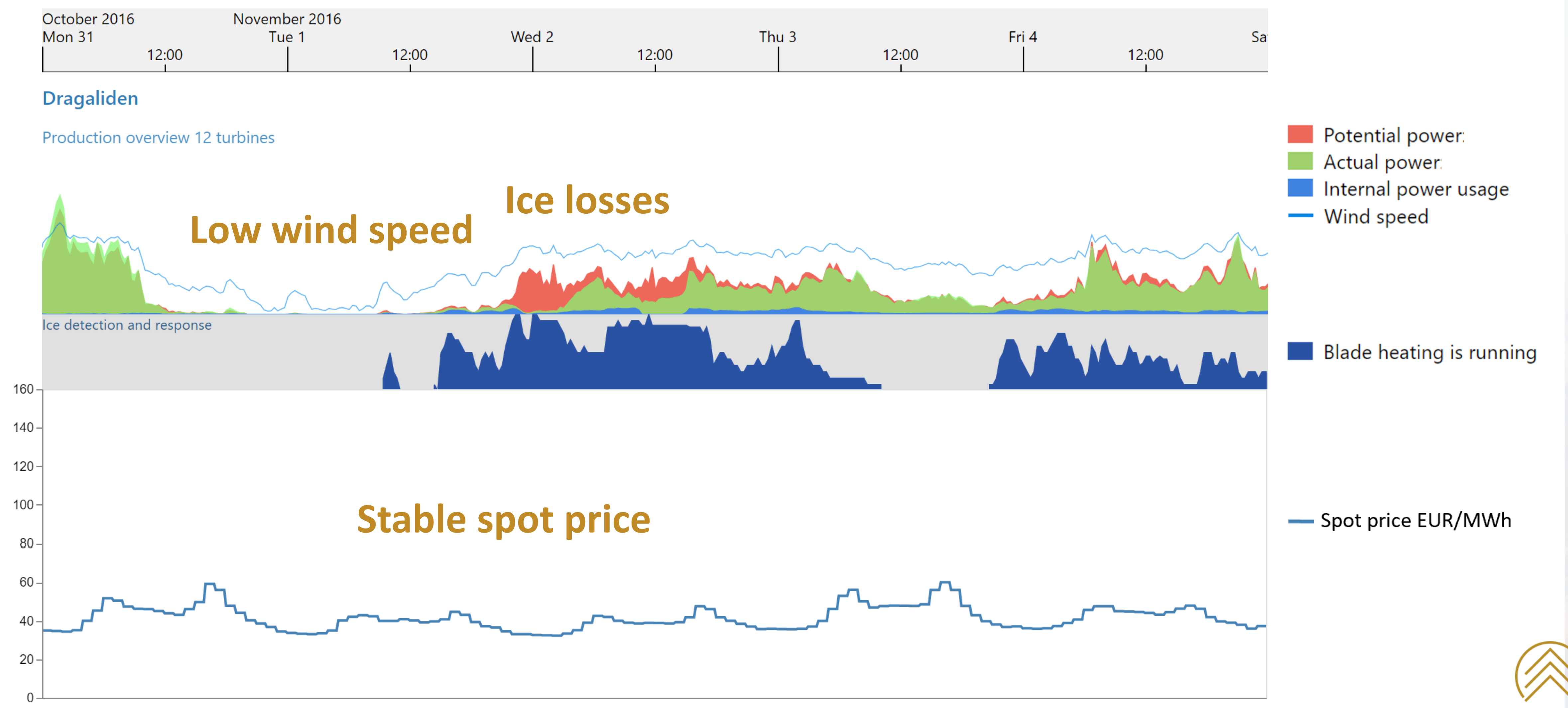
Rising spot prices during icing events

November 2016



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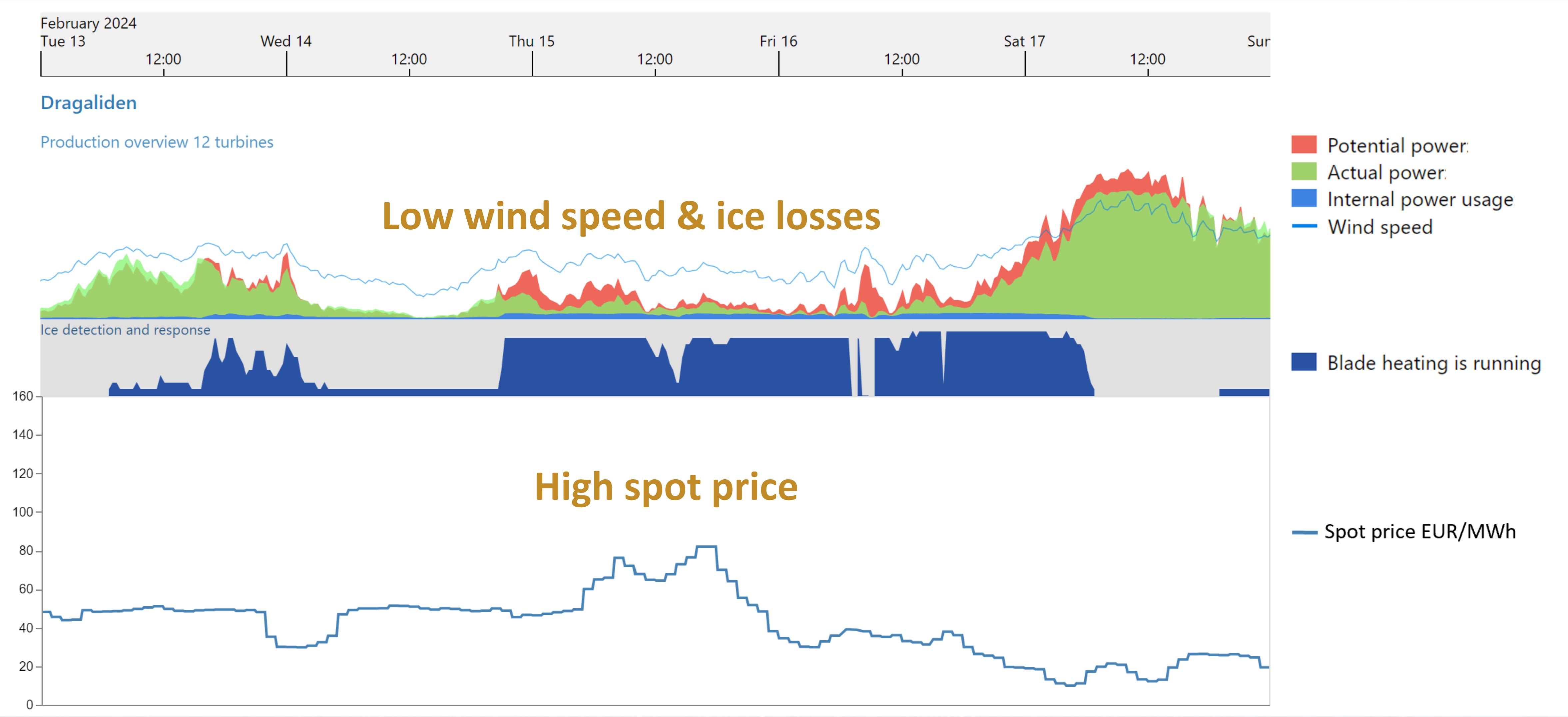
Rising spot prices during icing events

February 2024



Rising spot prices during icing events

General trends?

Use long complete time series instead of selected events

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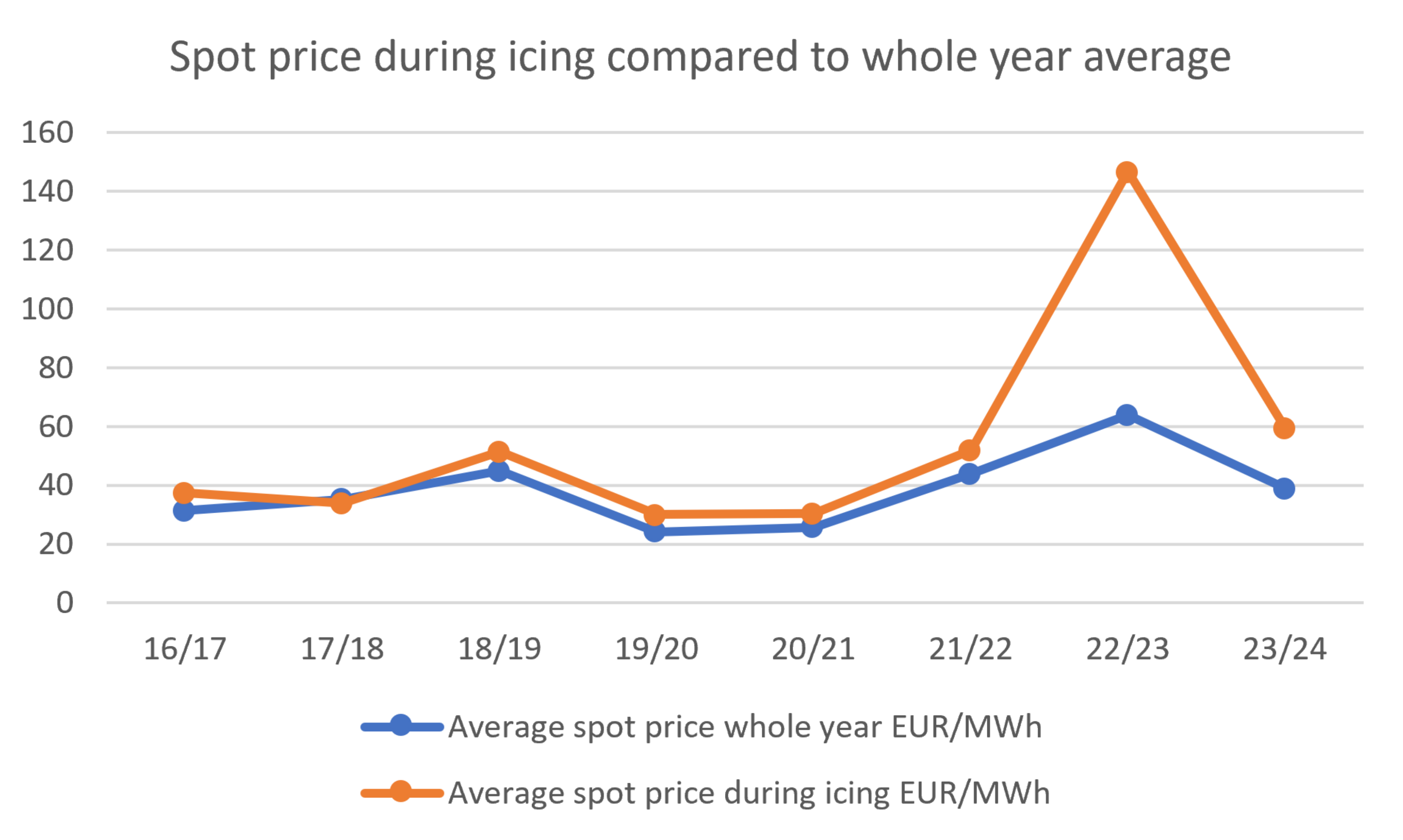
Rising spot prices during icing events



Dragaliden wind farm. Full year's data from July to June.

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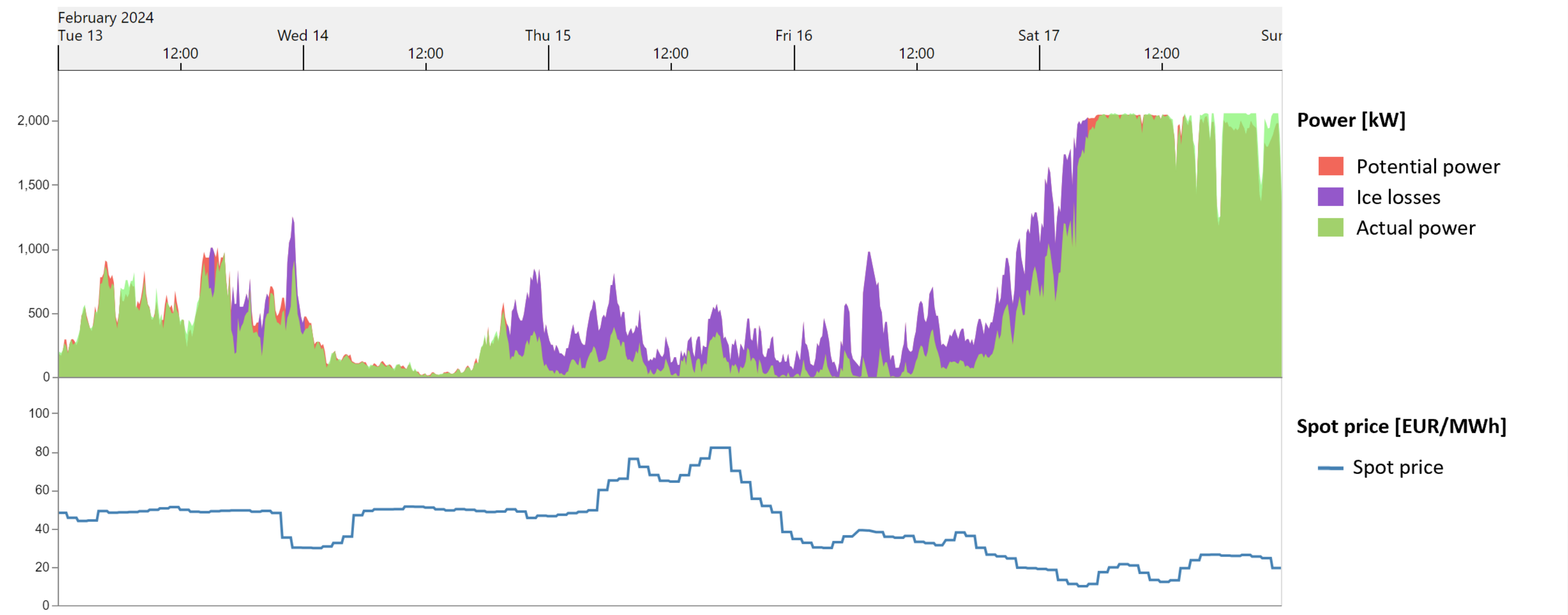
Ice losses… as lost energy or as lost revenue?



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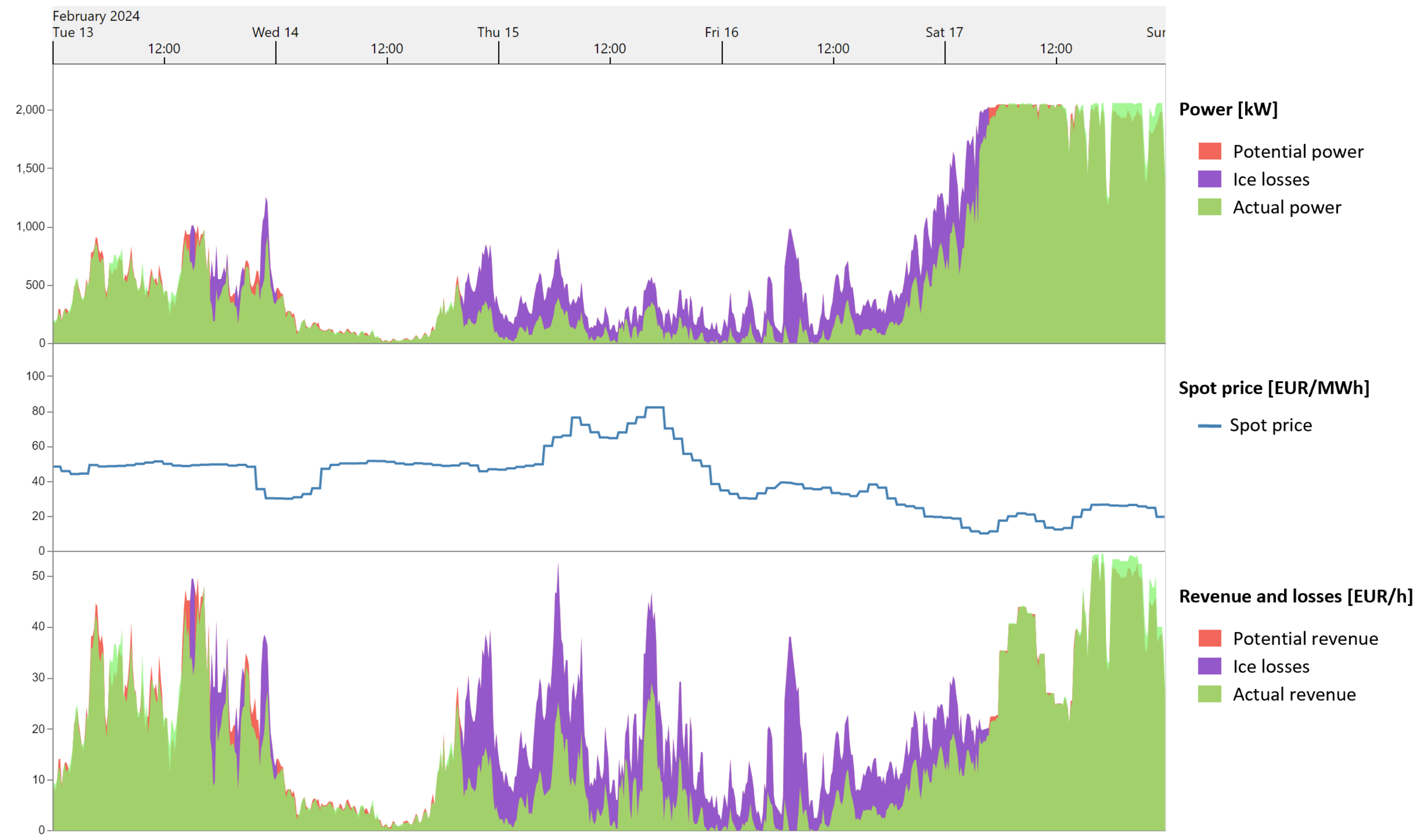

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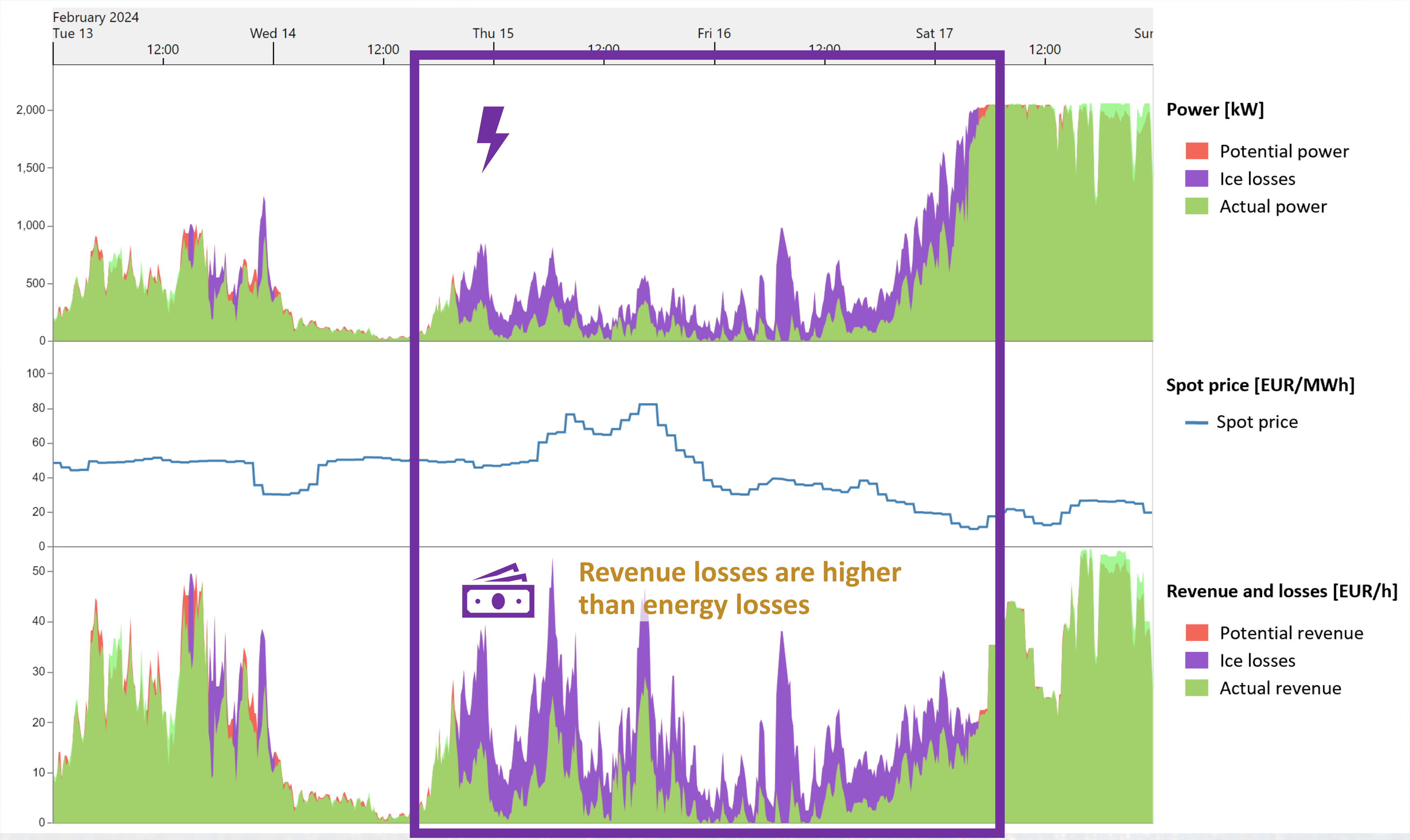

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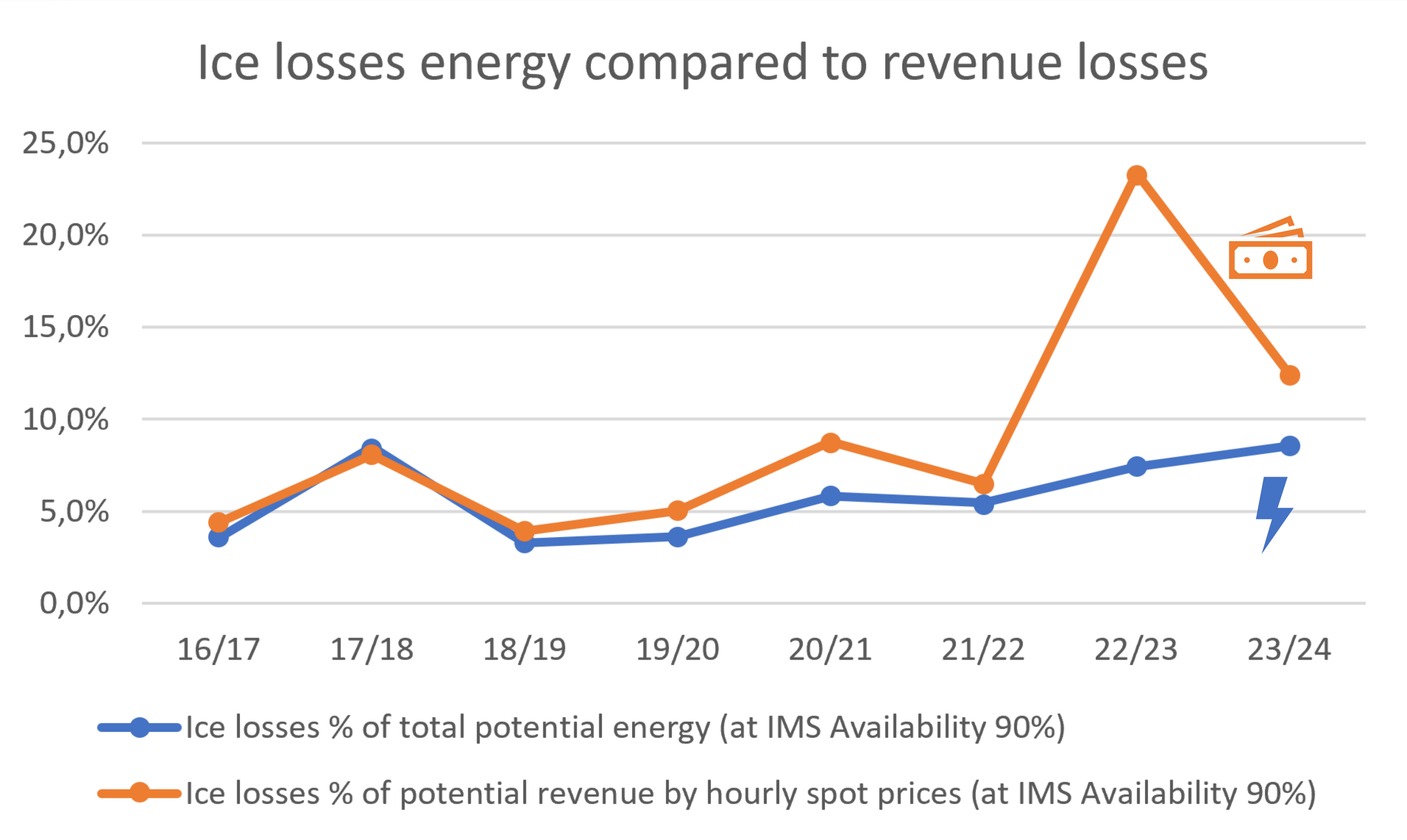

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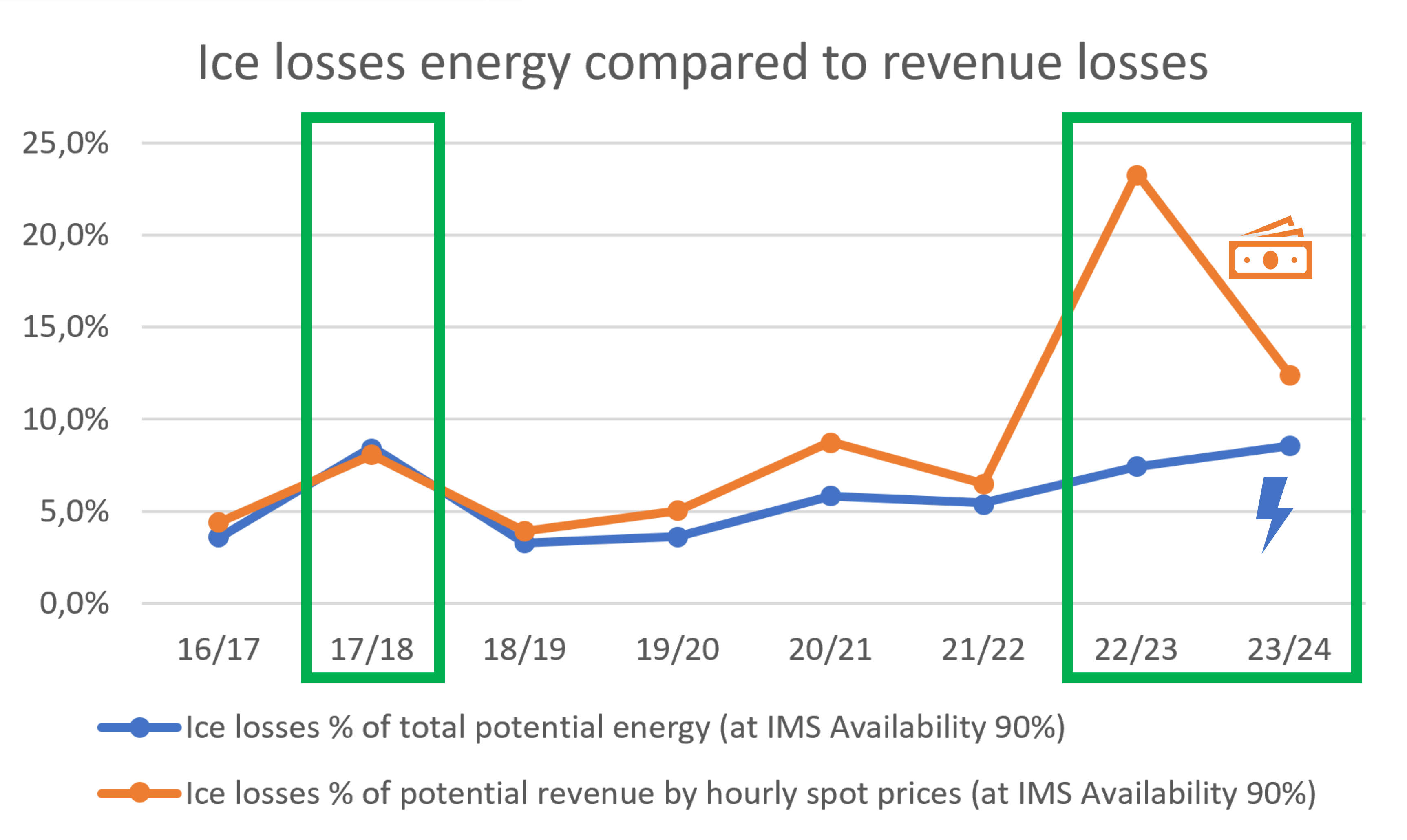

- **Equally severe winter before, but the impact on revenue is today more dominant**

Dragaliden wind farm. Full year's data from July to June.

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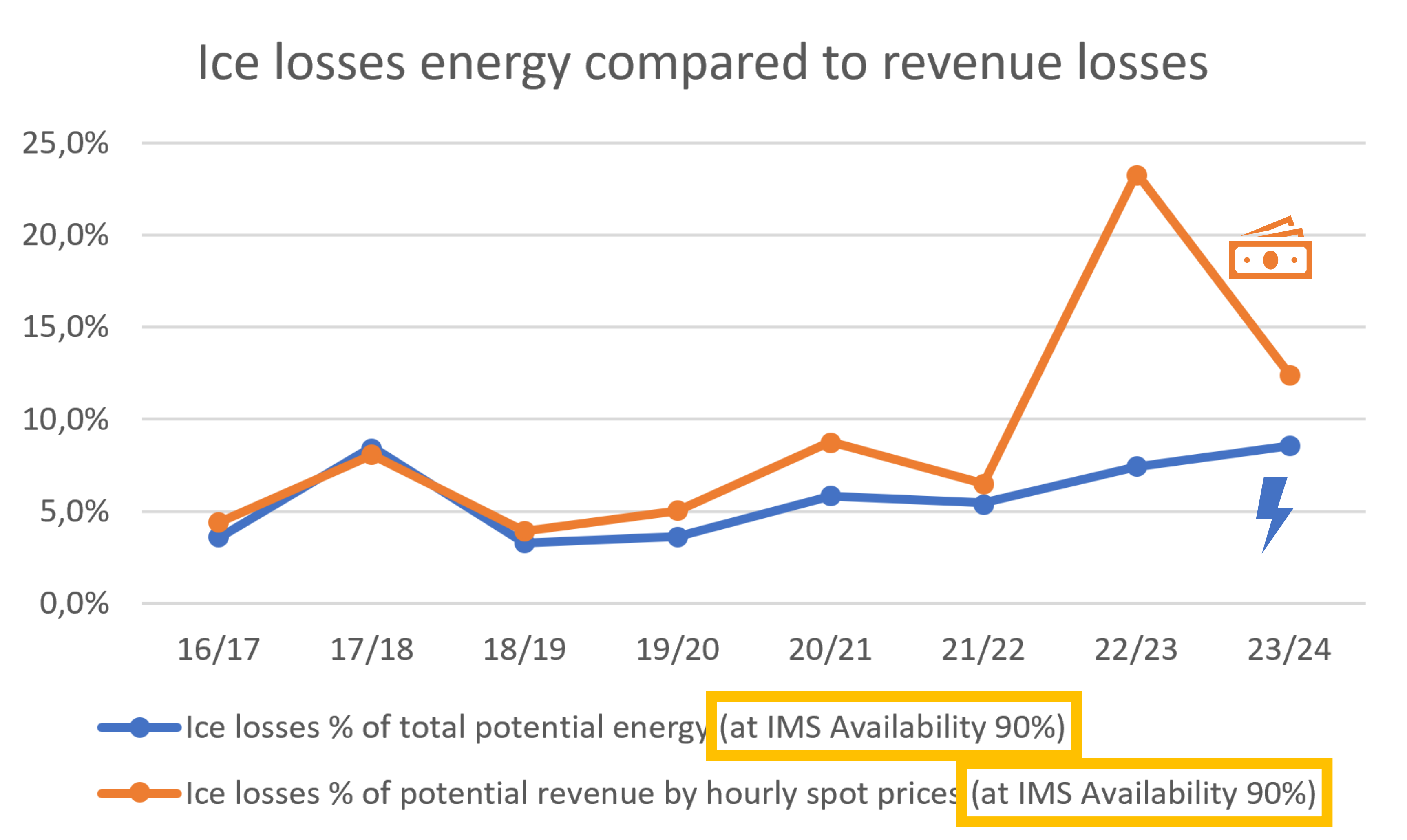

Dragaliden wind farm. Full year's data from July to June.

IMS availability, used for

- **Normalizing**
- **Finding the value of functional IMS**

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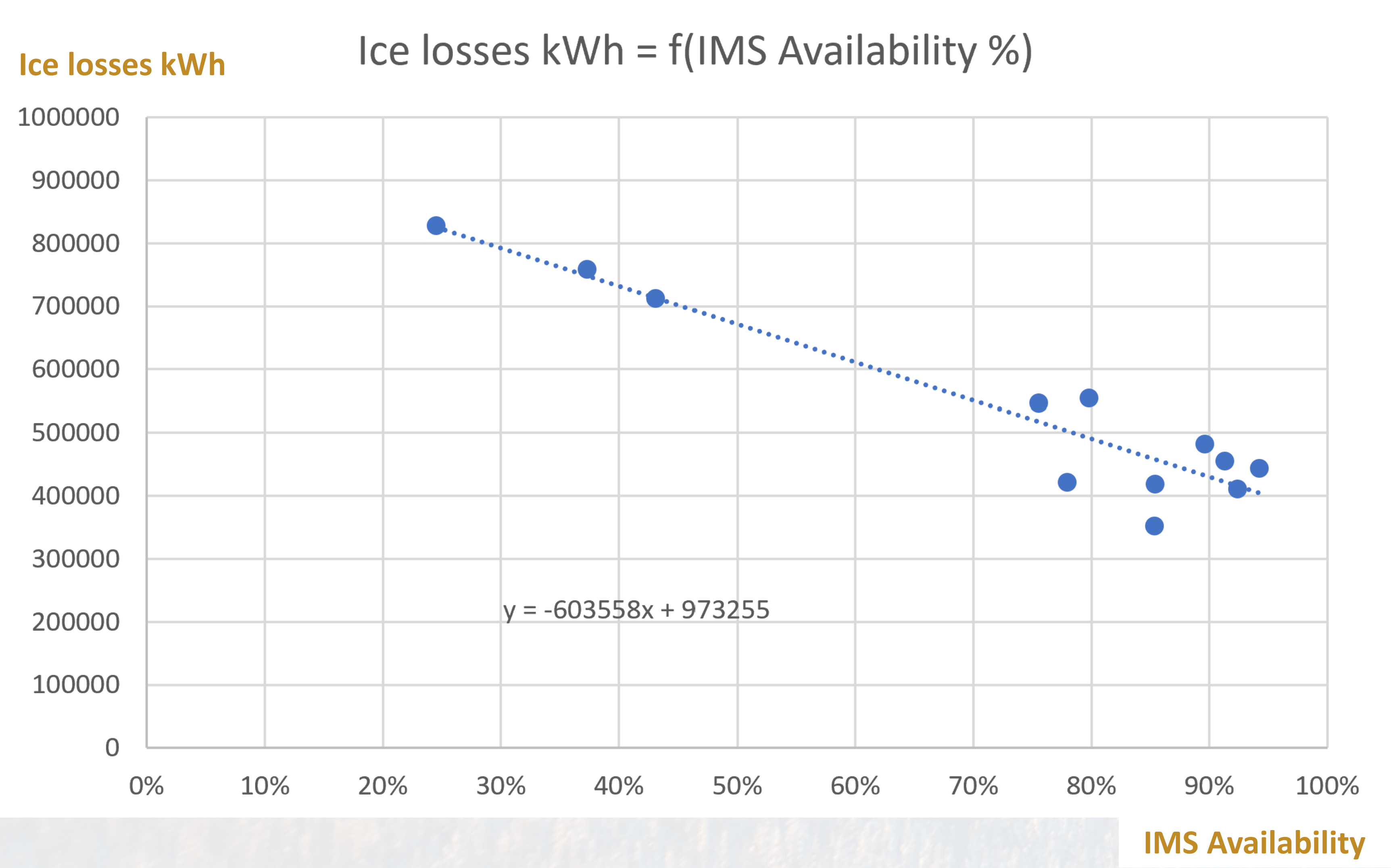
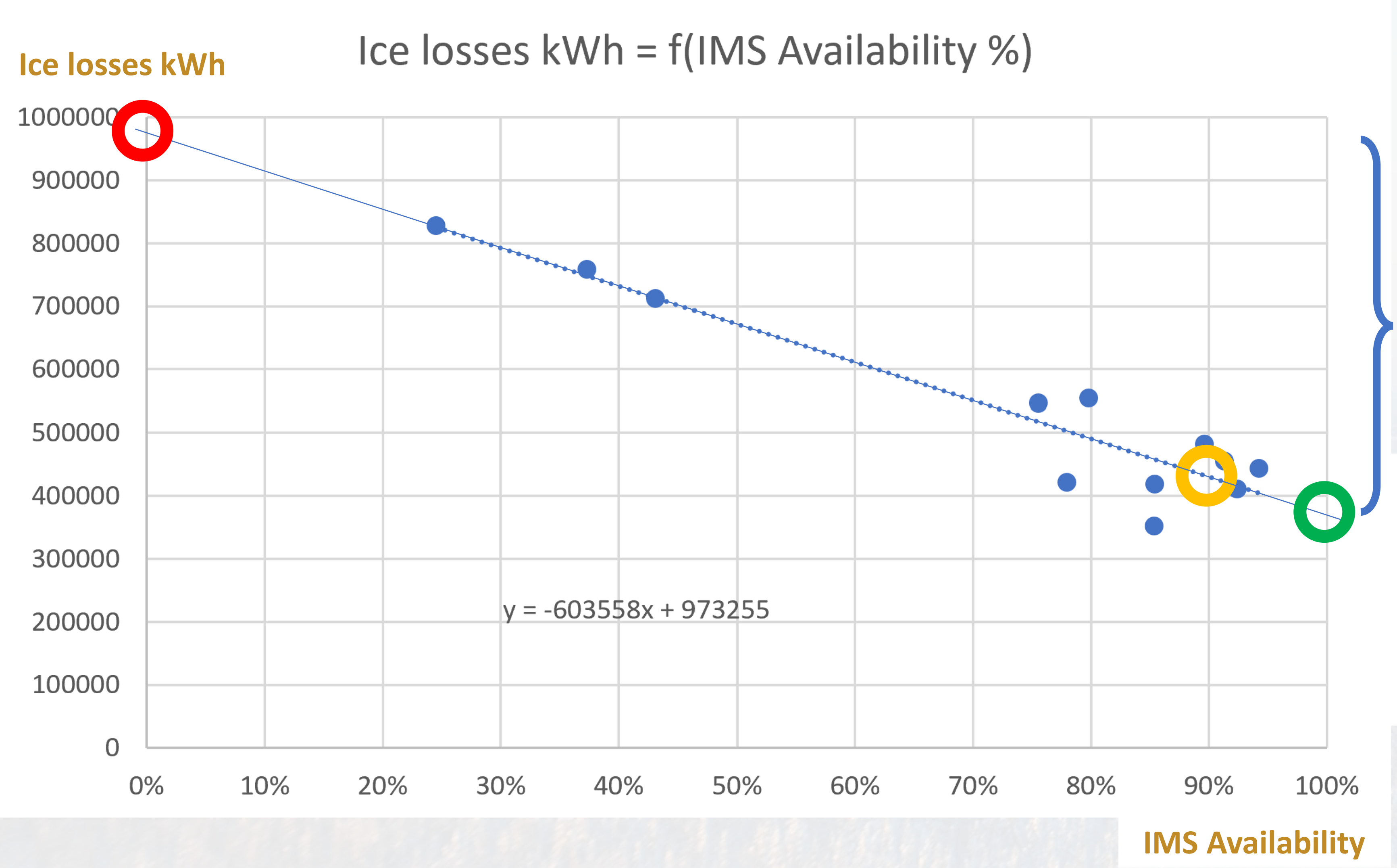
IMS availability… using regression to find the value of functional IMS



- **12 turbines**
- **IMS Availability: Time with functional IMS during icing**
- **Linear relationship can be expected**

IMS availability… using regression to find the value of functional IMS



Value of IMS

Equation: y = -603558x + 973255

IMS Availability 0%:	973 255 kWh/turbine
IMS Availability 90%:	430 053 kWh/turbine
IMS Availability 100%:	369 697 kWh/turbine
Value of IMS:	603 558 kWh/turbine

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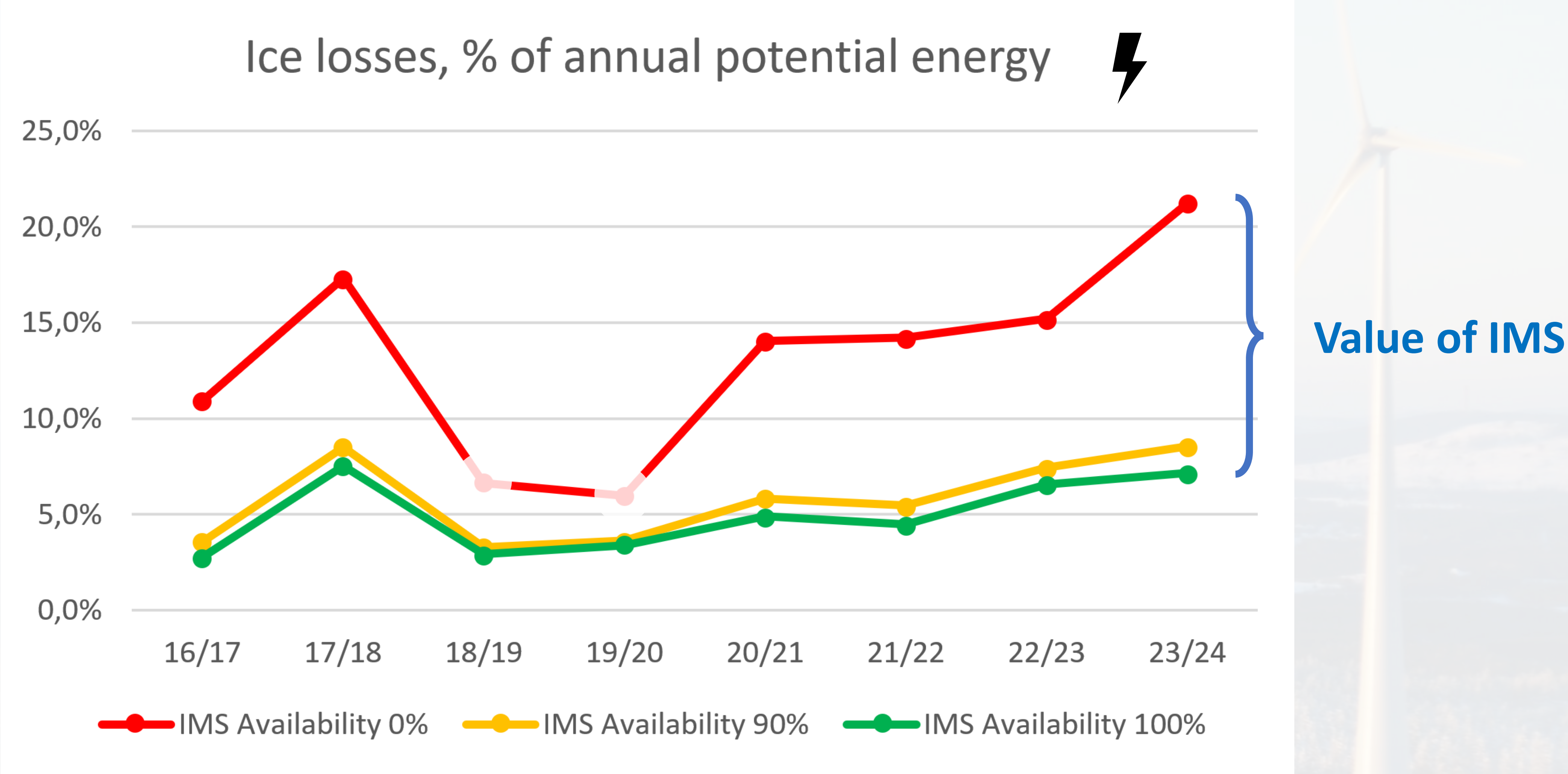
IMS availability… using regression to find the value of functional IMS



Dragaliden wind farm. Full year's data from July to June.
The statistical basis for the winters 18/19 and 19/20 for IMS Availability 0% are weak due to few IMS faulted turbines.

IMS Availability 90% can be used as indicator of winter ice severity.

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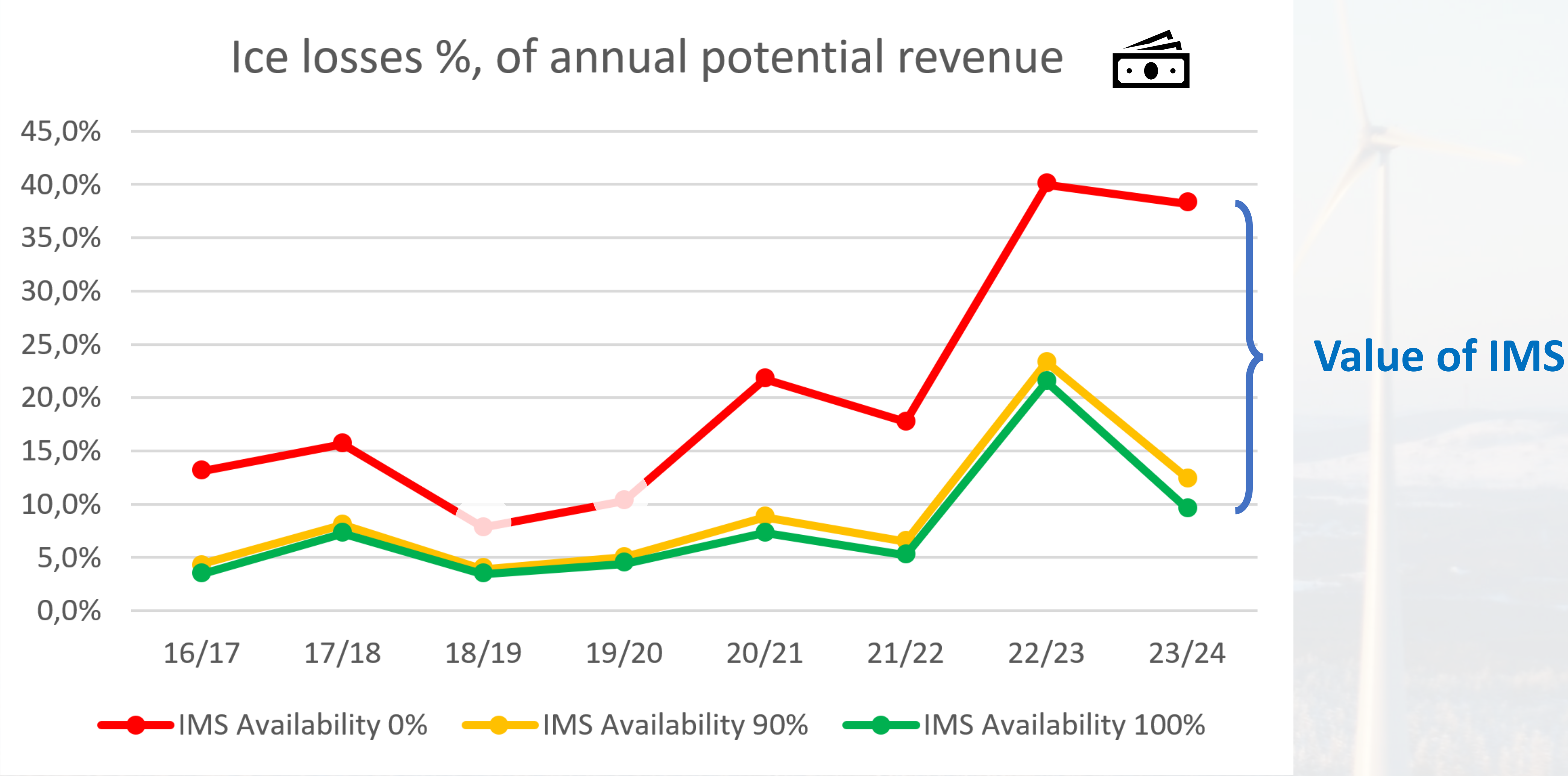
IMS availability… using regression to find the value of functional IMS



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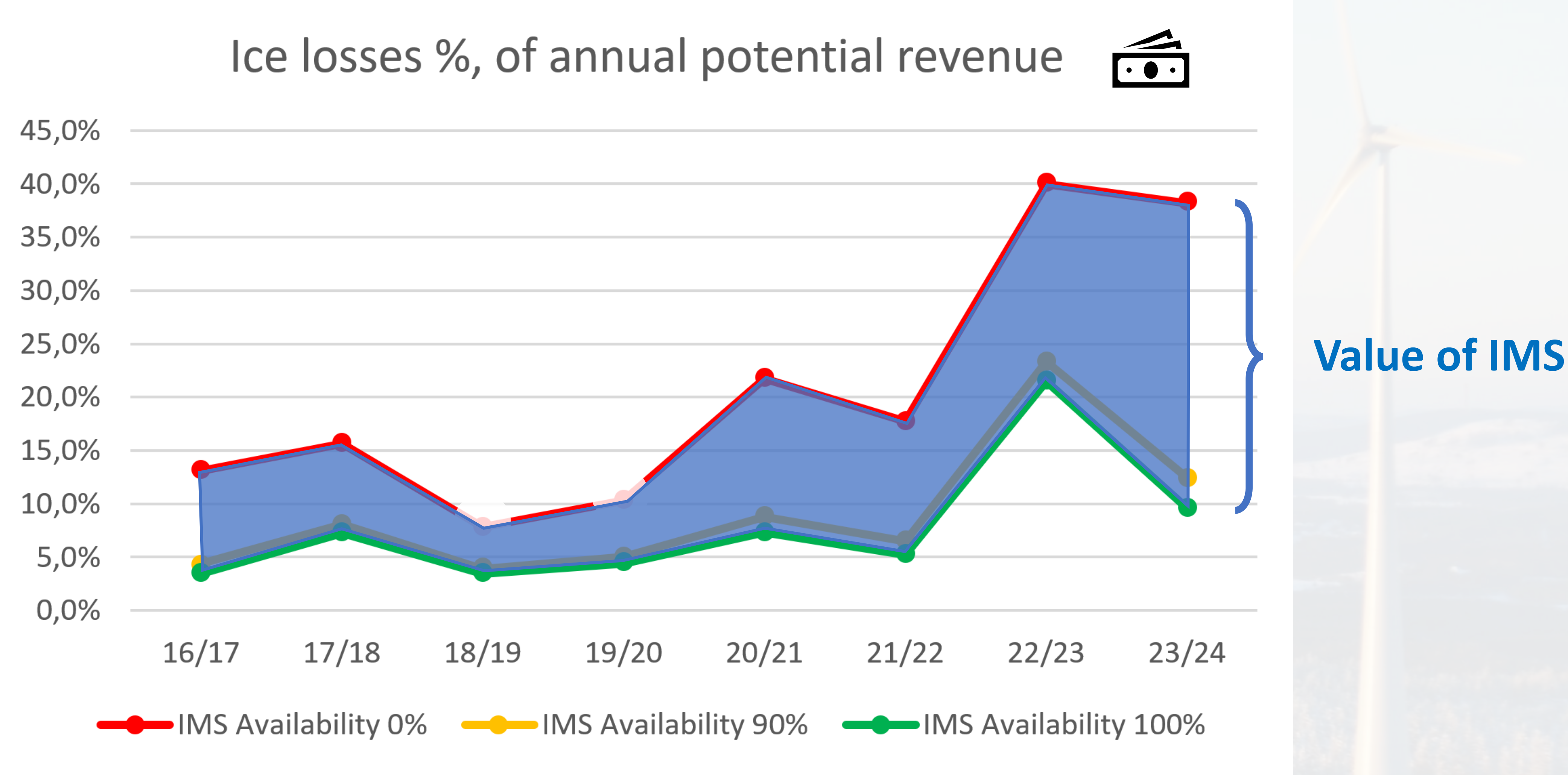

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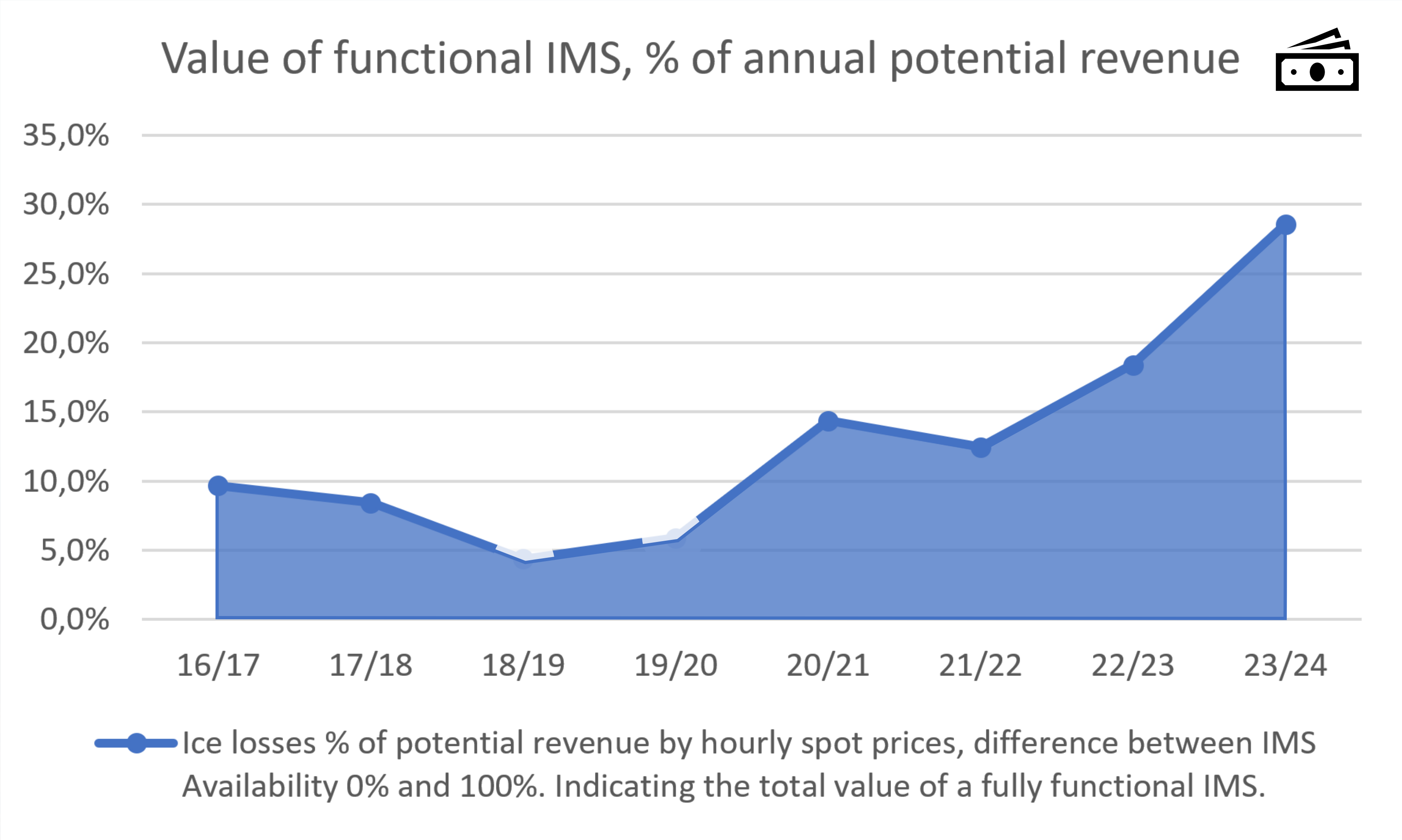

Value of IMS

Functional IMS is increasingly important

Dragaliden wind farm. Full year's data from July to June.
The statistical basis for the winters 18/19 and 19/20 for IMS Availability 0% are weak due to few IMS faulted turbines.
Trend is general, exact numbers are only valid for Dragaliden.

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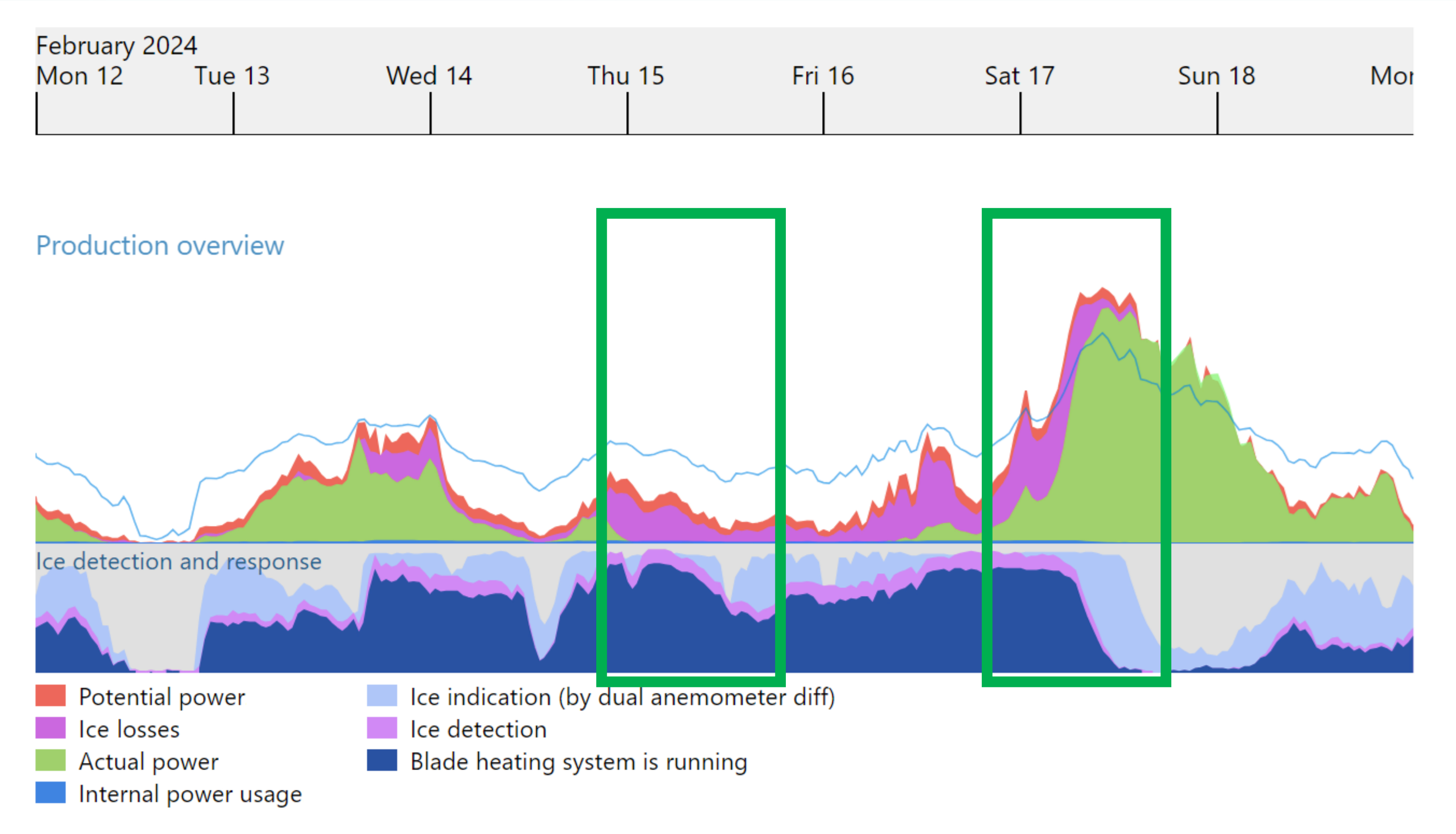
Low wind speed scenarios



Wind farm in northern Sweden

- Heavy icing starting during low wind speed periods
- Ice cleared when wind speed rises

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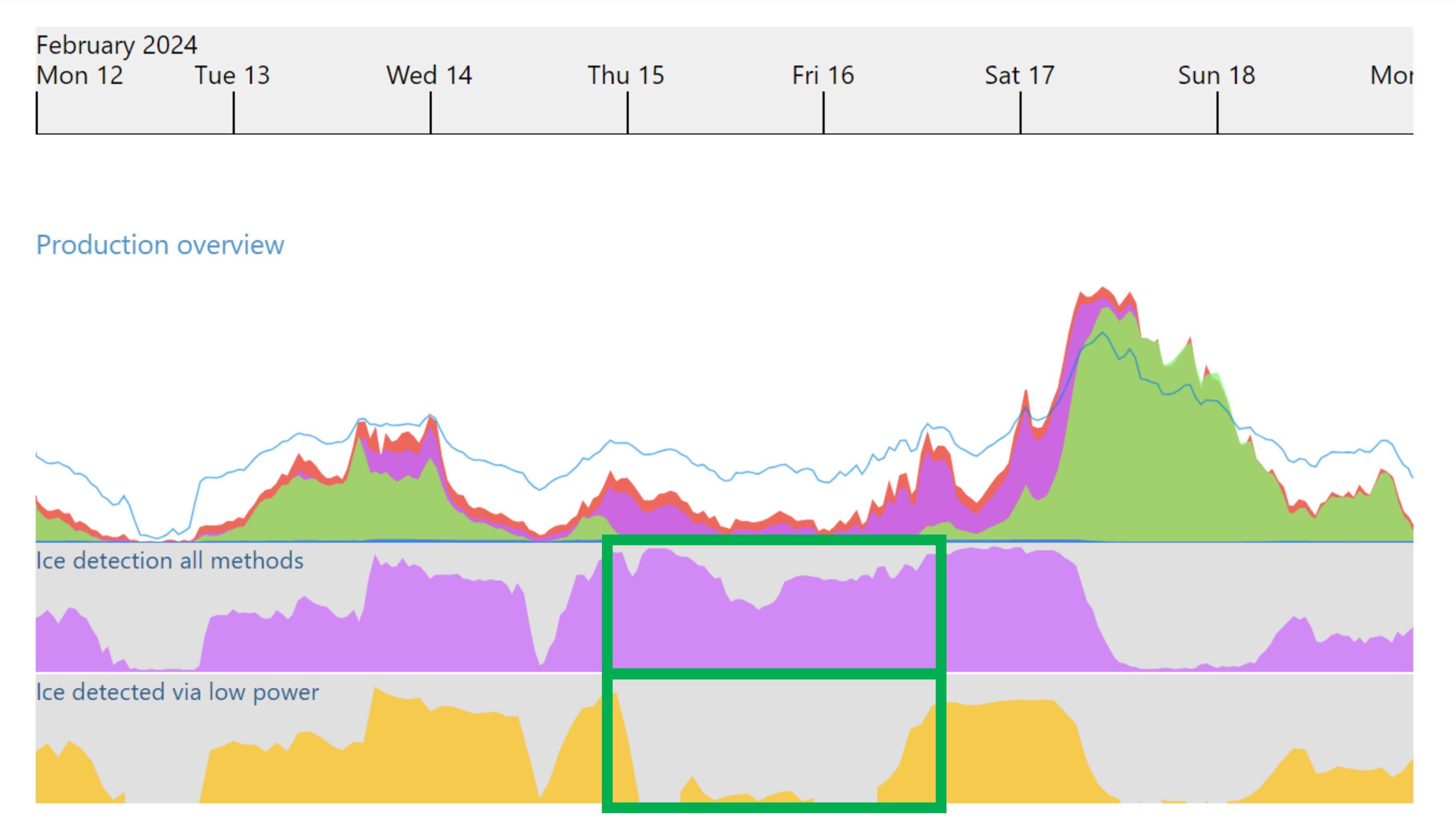
Low wind speed scenarios



Wind farm in northern Sweden

- Heavy icing starting during low wind speed periods
- Ice cleared when wind speed rises
- Less information regarding icing status during low wind speed periods (missing underperformance and dual anemometers)
- Complementary ice detection methods are important

Finding the perfect design!?

Low wind speed

- Low wind speed and start up conditions.
- Annual revenue yield instead of annual energy yield.
- New blade designs, with power curves optimized for lower wind speeds.

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Finding the perfect design!?

Robustness

- IMS as insurance. The future is unknown.
- Substantial dimensioning. Enough power supply. Adjusting parameters and logics is easier to do afterwards than to rebuild hardware.
- Reliable, easy to maintain.
- IMS availability in contracts.

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Finding the perfect design!?

Local icing conditions

- Only heating leading edge? The toughest ice can take hold on larger areas.
- Hot air system or electro-thermal heating mats? Important are enough power, blade area distribution and robustness.
- Different heating areas and power stages.

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Thank you!

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