Public

Plenary session – Production and Revenue

Operational Wind Power Forecasting in Winter Conditions

Éric Desrosiers, Hydro-Québec

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Éric Desrosiers

WIND POWER FORECASTING ADVISOR

I hold a B.Sc. in Physics with specialization in Operational Research, combined with an extended experience in the wind industry. I have collaborated on over 20 GW of wind energy projects over the last two decades, focusing on wind resource characterization and energy production assessment. At Hydro-Québec, I work with multidisciplinary teams to enhance wind power production forecasts, considering the local climate conditions and different meteorological numerical models.

Desrosiers.Eric.L@hydroquebec.com

Contributors

Slavica Antìc, Guillem Candille, Annie Beaulieu

Outline

Hydro-Québec | … at glance

Total assets

$92.7B

Workforce

22,051

Permanent and temporary employees

Net income

$3.3B

Contribution of more than

$4.7B

to Quebec government

Electricity sales

200.3 TWh

Including 23 TWh in exports

Investment in Quebec

$4.9B

Source: *Hydro-Québec Annual Report 2023*

Hydro-Québec | … and in numbers

37,436 MW*
of installed capacity

34,922 km
of transmission lines

228,568 km
of distribution lines

62
hydroelectric generating stations

536
transmission substations

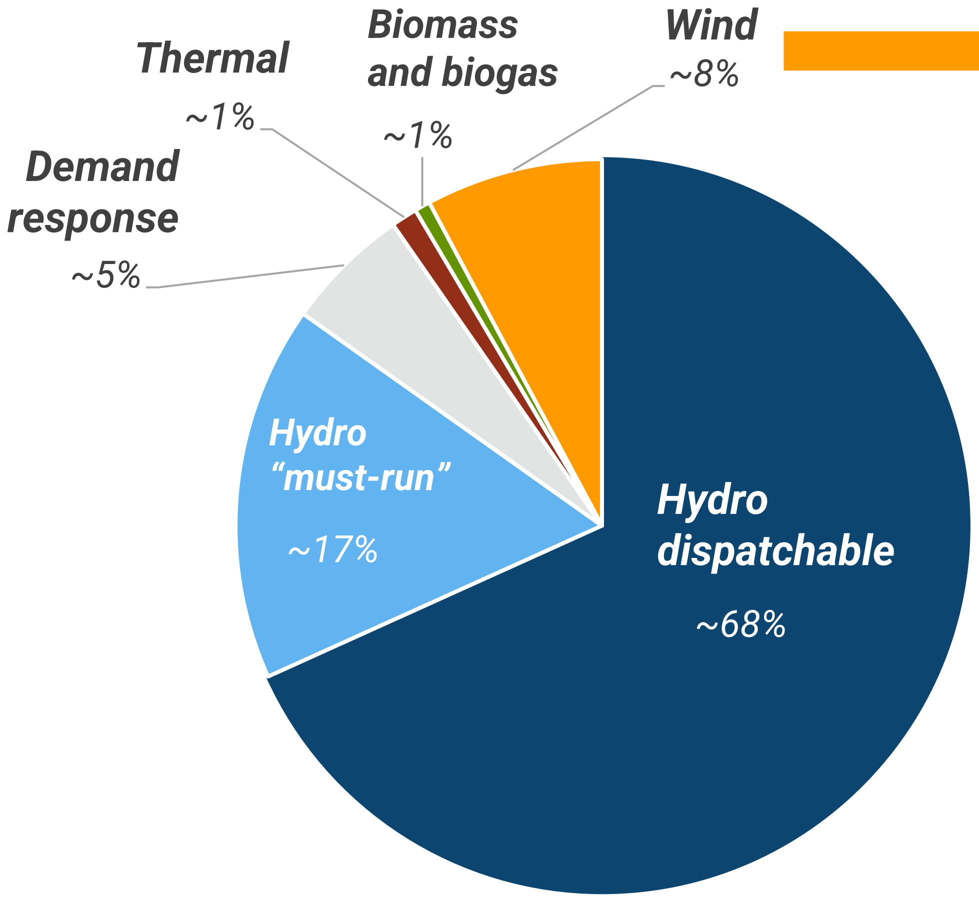
4,5 millions
customers

29
large hydroelectric reservoirs

15
interconnections with neighboring systems

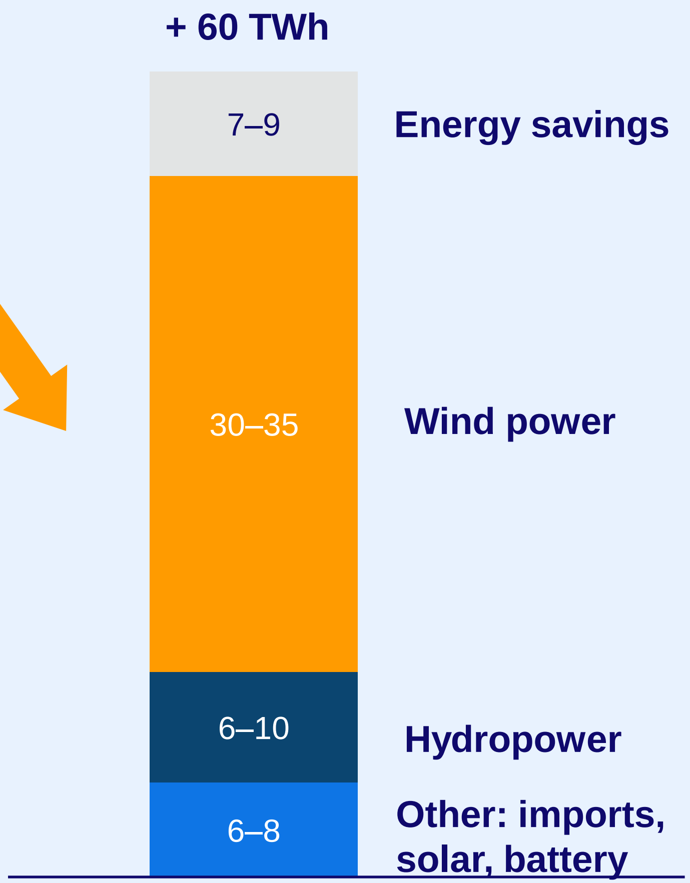
42,601 MW
historic winter peak

**Does not include the production that Hydro-Québec purchases from Churchill Falls (5,428 MW), wind farms (3,933 MW), small hydroelectric generating stations (706 MW), biomass or biogas cogeneration plants (419 MW) and others (525 MW).*

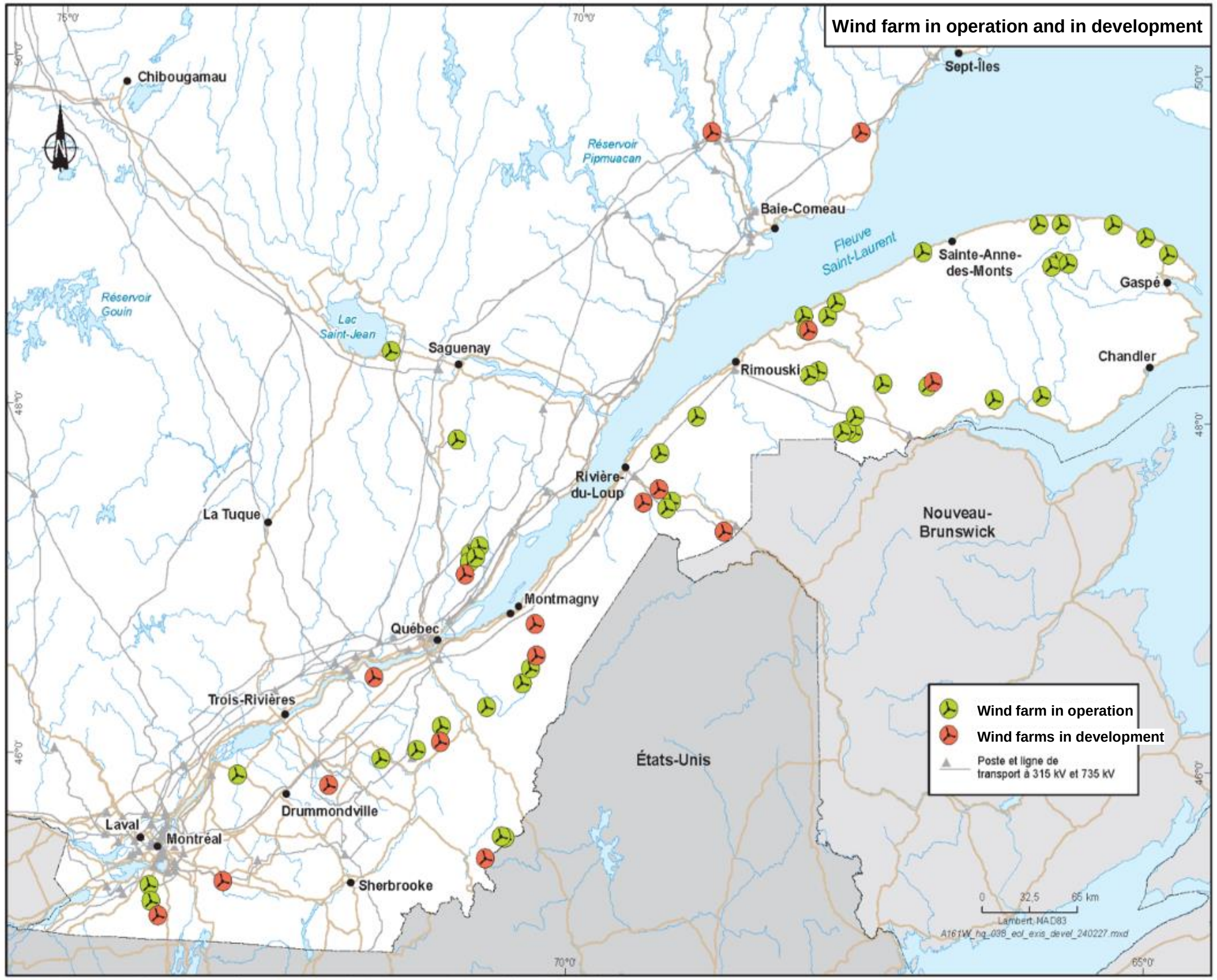


CAPACITY MIX ~ 49 500 MW

AN OBJECTIVE TO TRIPLE QUEBEC'S WIND CAPACITY BY 2035



Energy (TWh)
The average amount of electricity available during the year



Document d'information destiné aux publics concernés par le projet. Pour tout autre usage, communiquer avec : Géomatique, Hydro-Québec

Geographical distribution of wind farms

42 land-based Wind Power Plants in operation in 2024

Wind farms issued from call for tender since 2003

Take-or-pay 20-25-30 years PPA agreement

Curtailment cannot be used for grid management

Wind production is greater during cold winter months

Québec's electricity demand is the highest in winter

All wind farms are equipped with a cold weather package (can operate down to –30°C or –40°C)

Anti-icing operation and/or blade heating systems are installed at 21 of the 42 wind farms

The 1998 ice storm in numbers

Nearly 110 mm of ice accumulated over 5 days

Up to 1.4 million households without power and over 3 million people affected

Over 1 500 towers and 17 000 poles replaced

3 000 km of transmission and distribution lines and 400 km of high-voltage lines rebuilt

4 500 transformers and 88 000 insulators replaced

The last customer was finally reconnected a month after the ice storm began

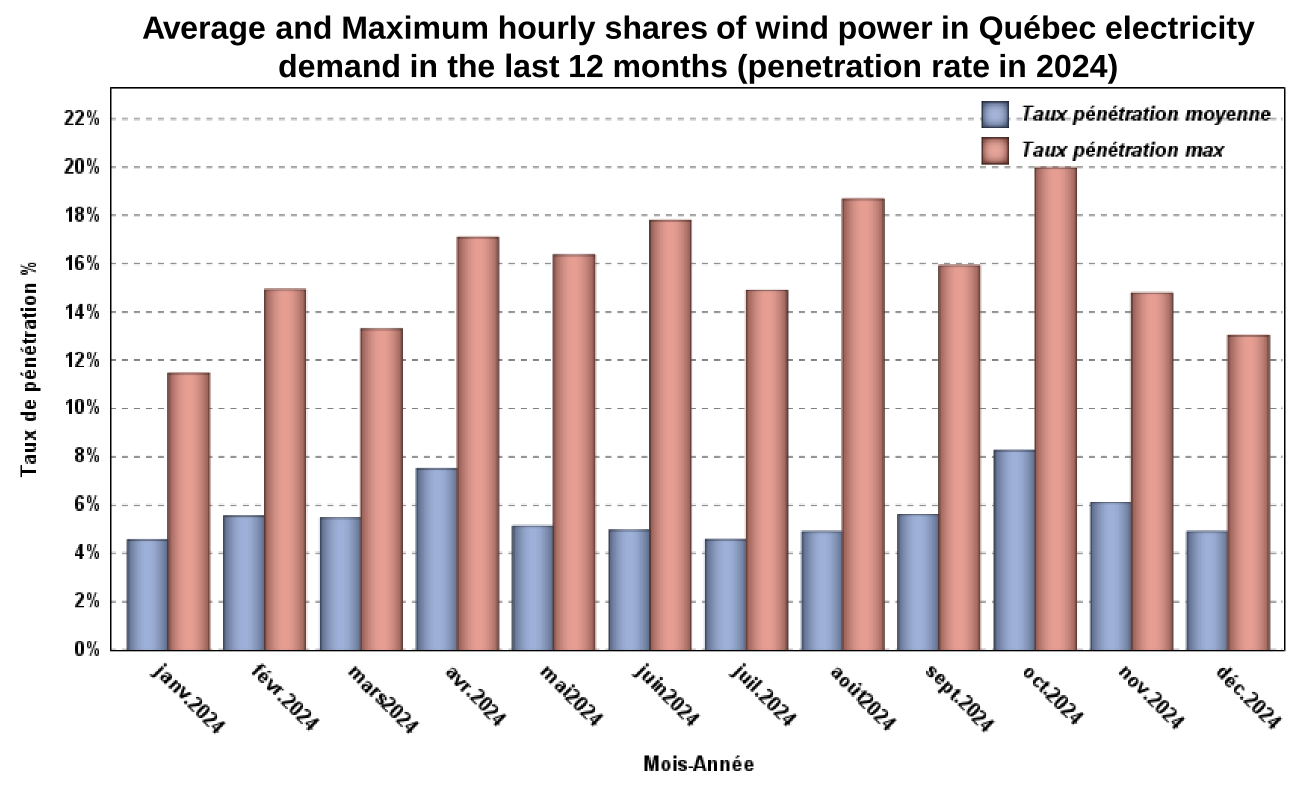
Reference

Twenty years ago, Québec was battered by an ice storm | Hydro-Québec
Extraordinary weather event | Hydro-Québec

Weather-driven energy demand and wind power generation

Hourly share of wind energy in the electricity demand in Québec (2024) →

5.7% Average	**20%** Maximum



Hydro-Québec has a centralized forecasting system for wind energy since 2006

(first wind farm commissioned following the 2003 call for tenders)

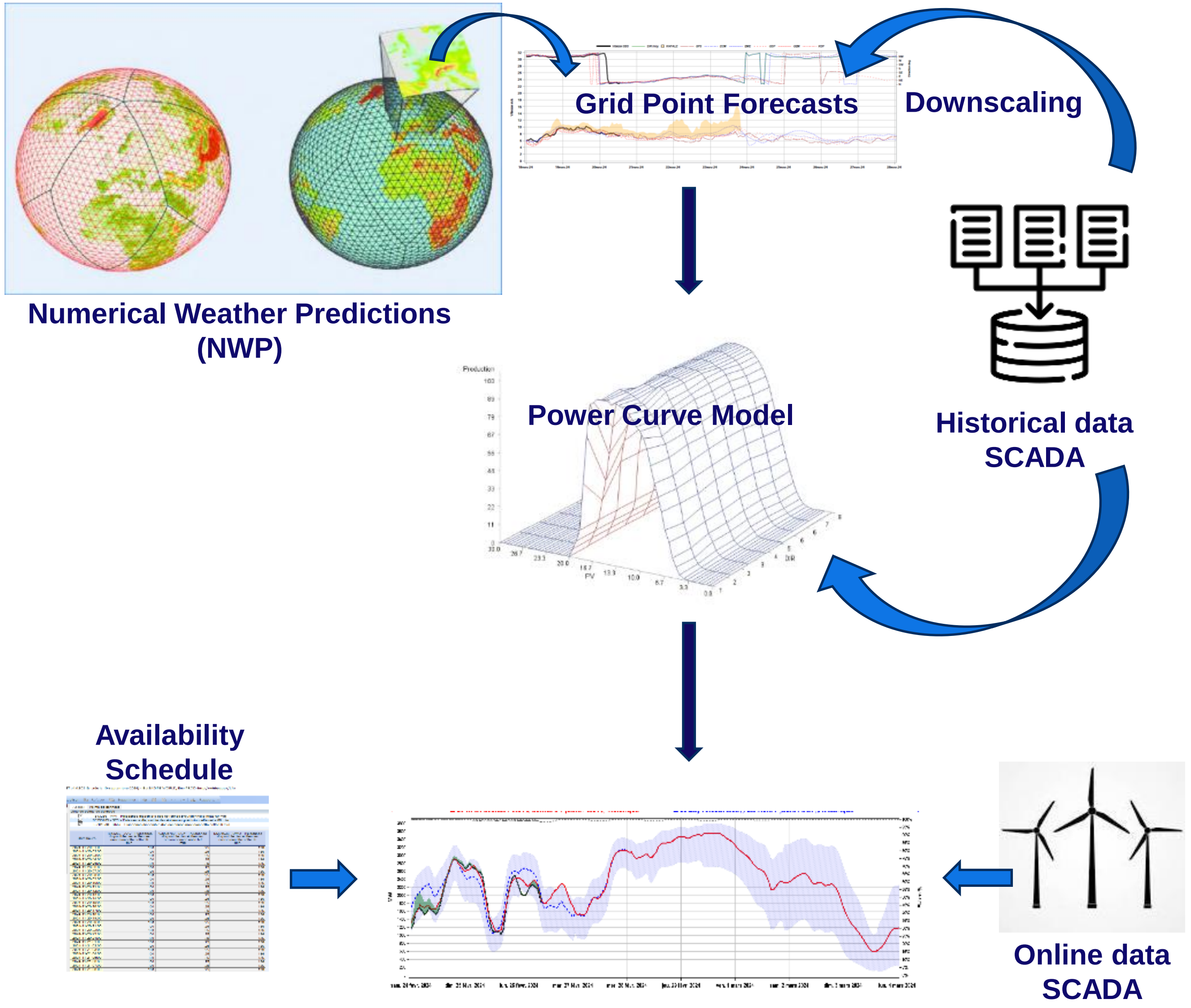
Wind Power Forecast is needed for :

Hydro-Quebec transmission system operator
(Intra-hour, Medium- and Long-term forecast)

Short and medium terms operation and hydro scheduling
(Medium- and Long-term forecast)

Wind farms operators
(Medium- and Long-term forecast)

Trading
(Medium-term forecast)



Auto-adaptative and adjustment model

Wind Power Prediction

(deterministic forecast by specific wind farm)

6 NWP models at wind farm location
(Wind speed and direction, temperature, humidity, precipitation)

Historical SCADA DATA
(Production, availability data, wind, direction, temperature)

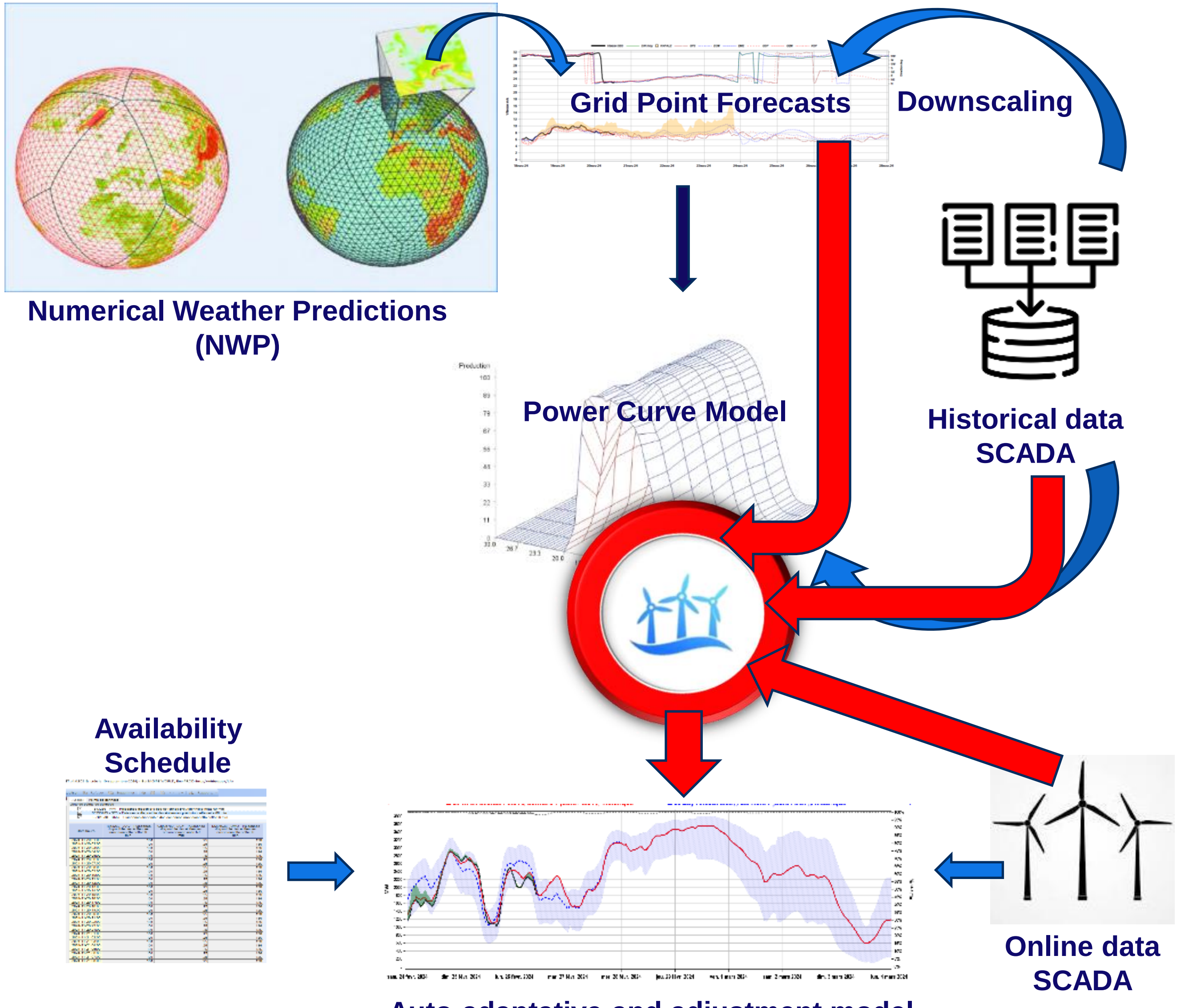
Statistical Power Curve Model
(High wind cut-out included)

Online SCADA DATA (10 min timestamp)

Turbine availability Schedule (from wind farm operator)

Statistical Data assimilation and adjustment model

Power Forecast | Specialized weather forecasting



Cold temperature and Icing losses model

These statistical models are based on:

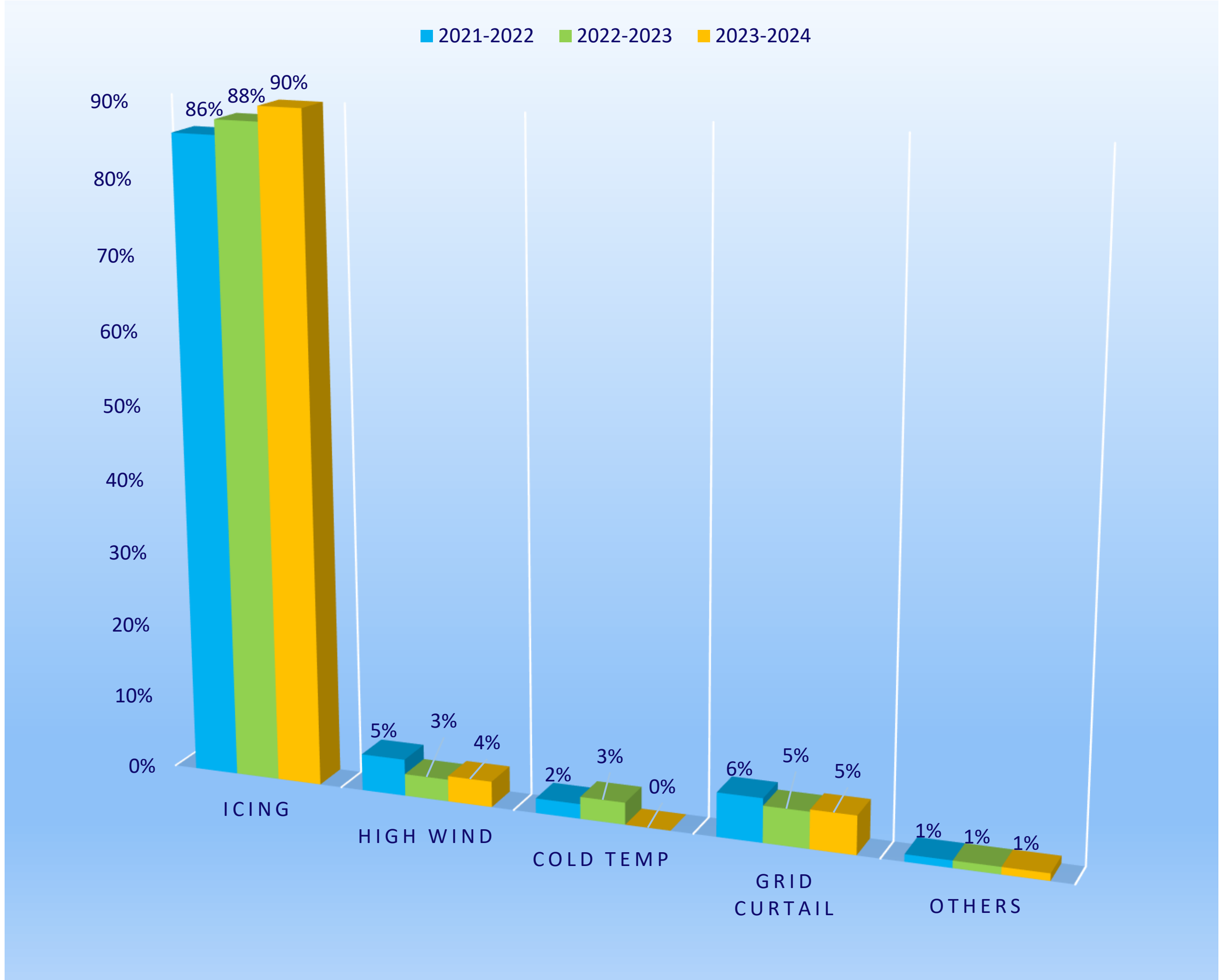
NWP forecasts (wind speed and direction, temperature, humidity) downscaled at wind farm location

Historical and online SCADA data (we use an automated algorithm to detect production losses during real-time and off-line quality control procedures)

Turbine operating mode and turbine type information

	Forecast horizon	Time step	Updated at
Forecast Type			
Intra-Hour	Rolling 24-hours	10 min	every 10 min
Medium-term	8 days	1 hour	every hour
Long-term	2-2.5 years	1 hour	Once or twice a year

Power Forecast | Winter power production losses



Wind power cold temperature and icing forecasting models estimate the losses

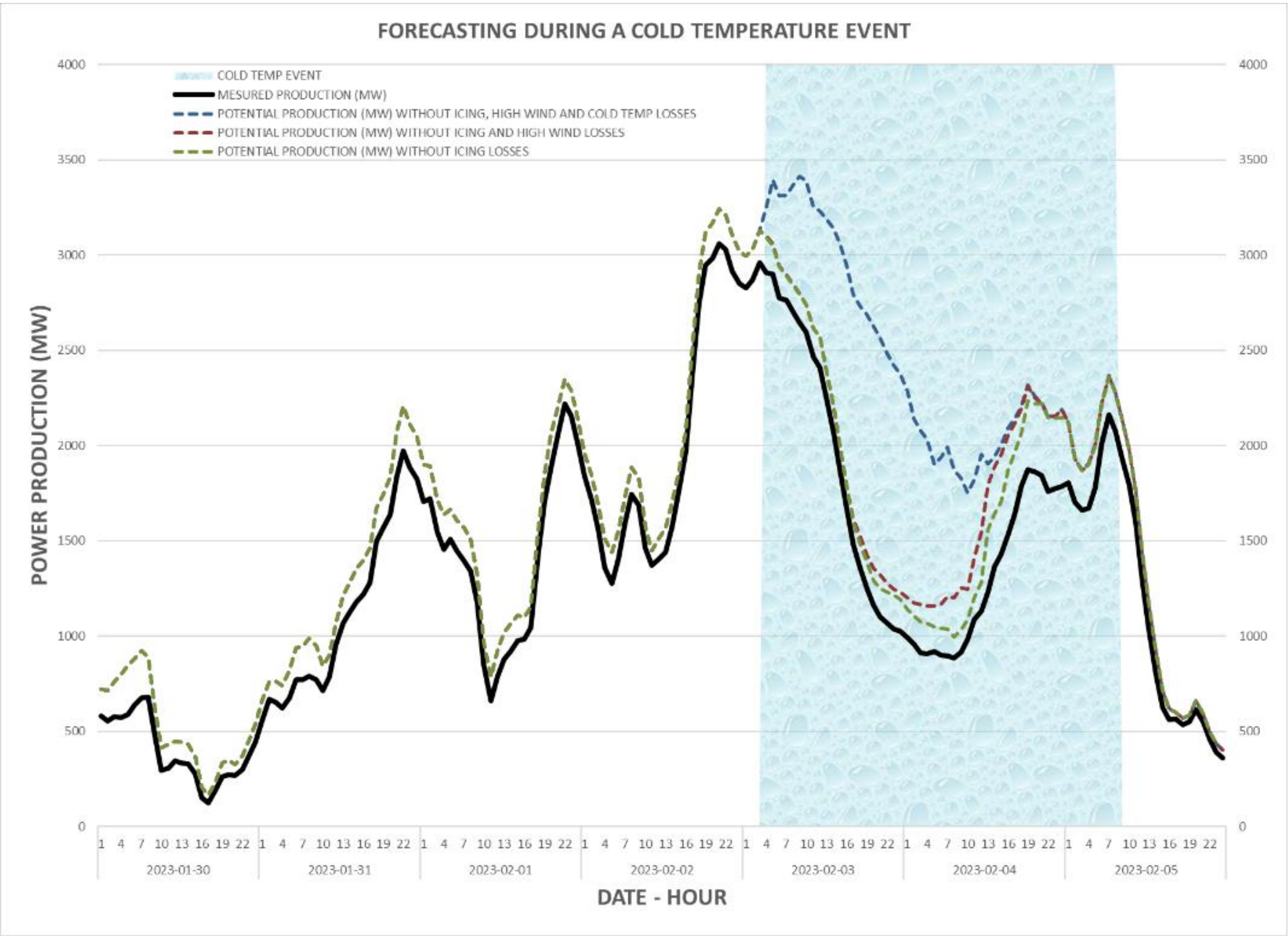
Annual average losses is about 6.4% of the 2024 annual potential production

… where 90% is coming from icing losses

Exceptionally, in 2024, near 0% of losses du to cold temperature (but about 2-3% for the previous winters)

Extreme case observed where wind farm can be stopped for weeks du to icing

Case Study | Cold Temperature Case



Case of very cold temperature throughout Québec province in February 2023 with nearly -30°C observed

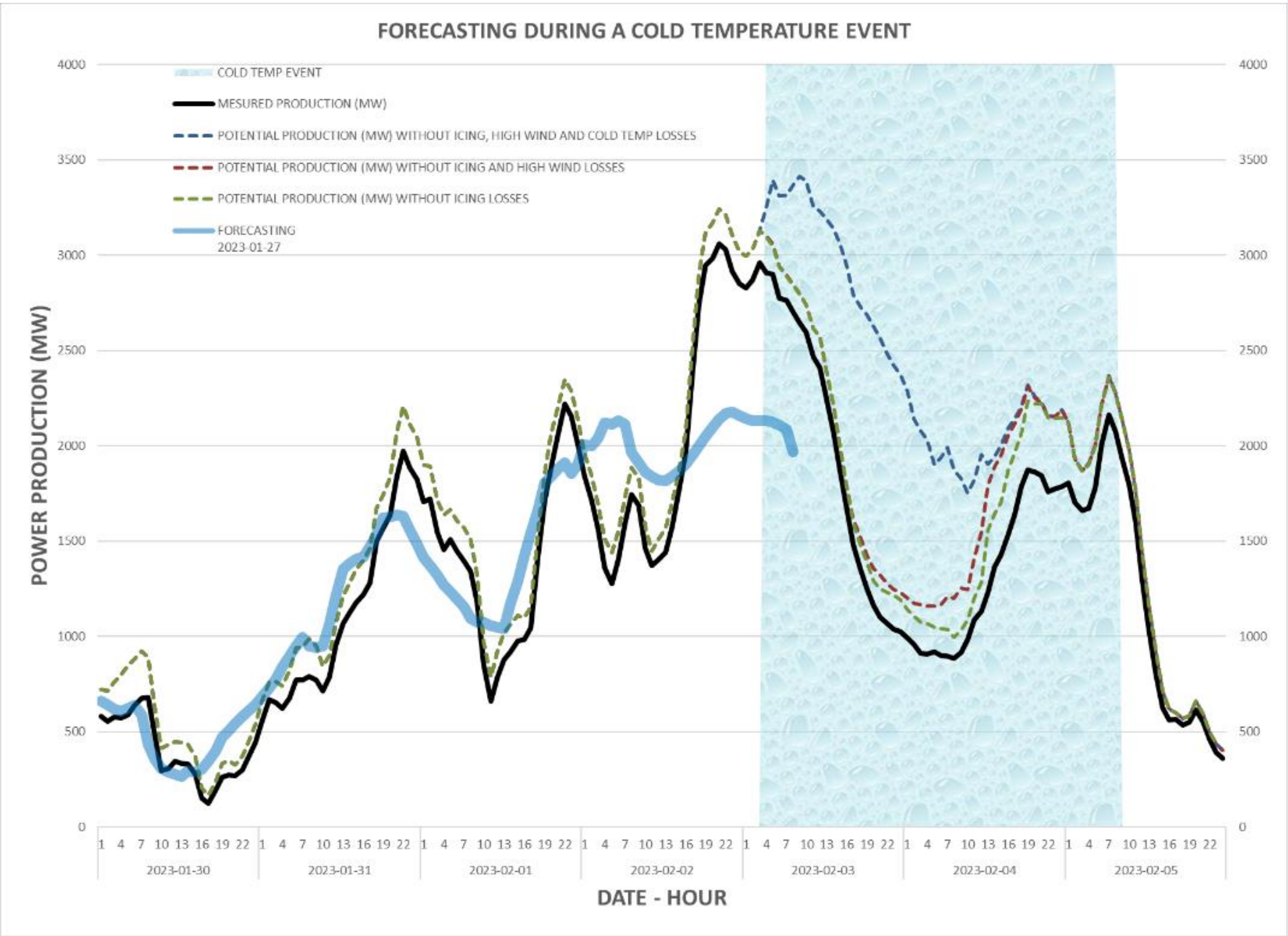
The peak of demand observed on February 3rd was nearly 43 000 MW

The forecasting model have captured the cold temperature losses and predict well the wind farm production stop

Some wind farms have experiment issue to restart the turbines after the cold event, bringing forecasting errors du to the false wind turbine availability

Case Study

Cold Temperature Case

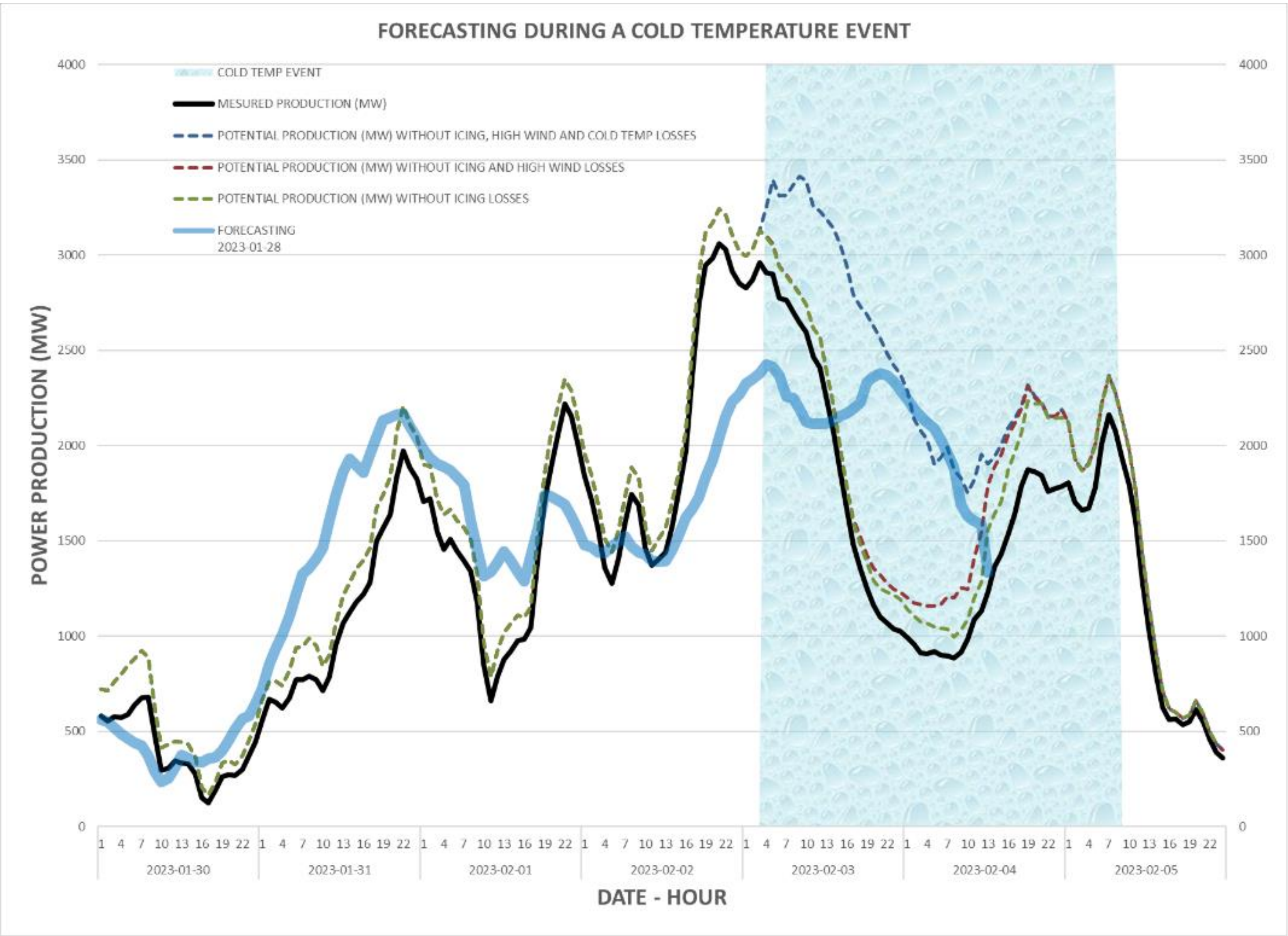


How about the cold temperature forecast?

Evolution day-to-day : 7 days before event

Case Study

Cold Temperature Case

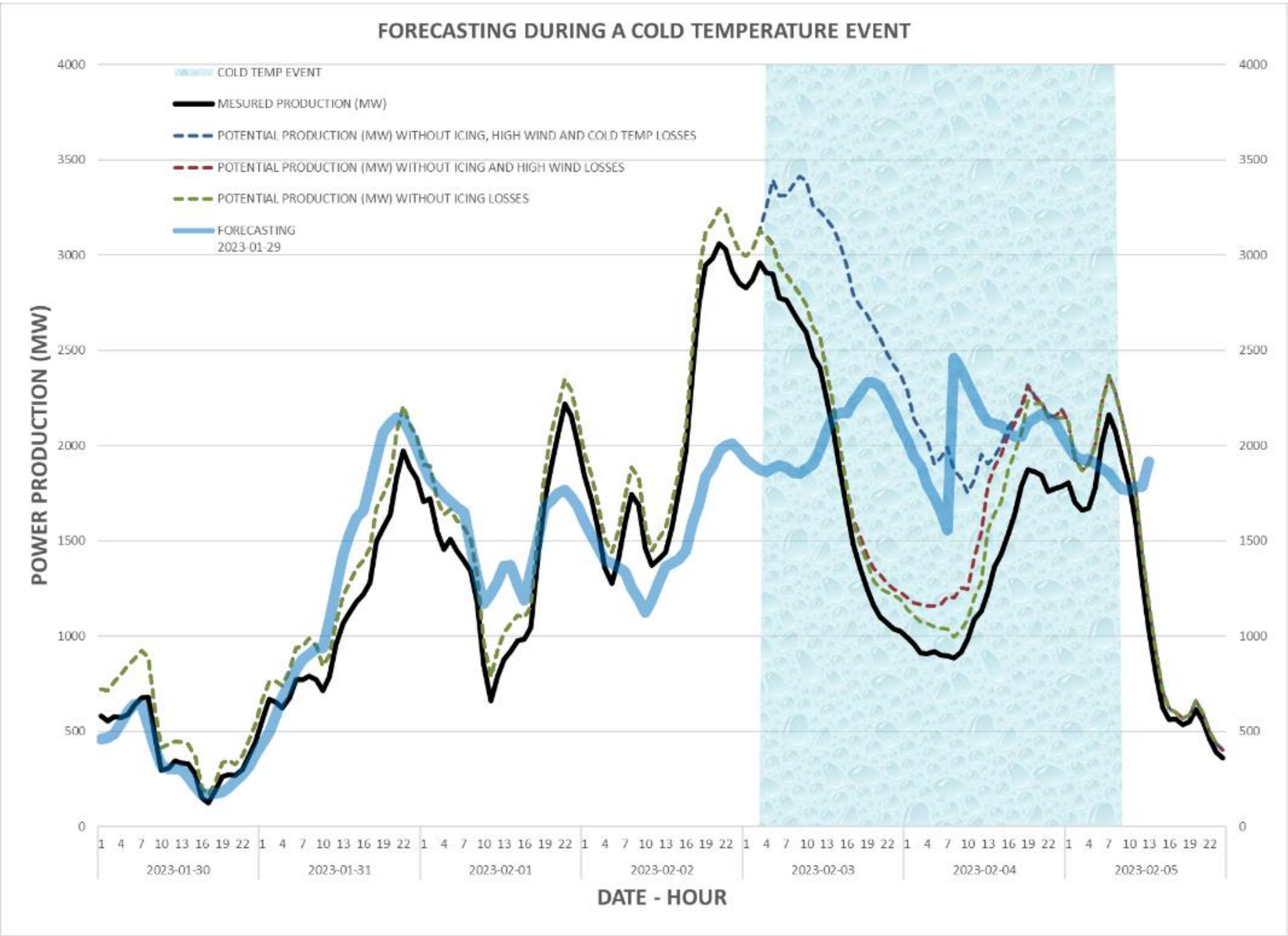


How about the cold temperature forecast?

Evolution day-to-day : 6 days before event

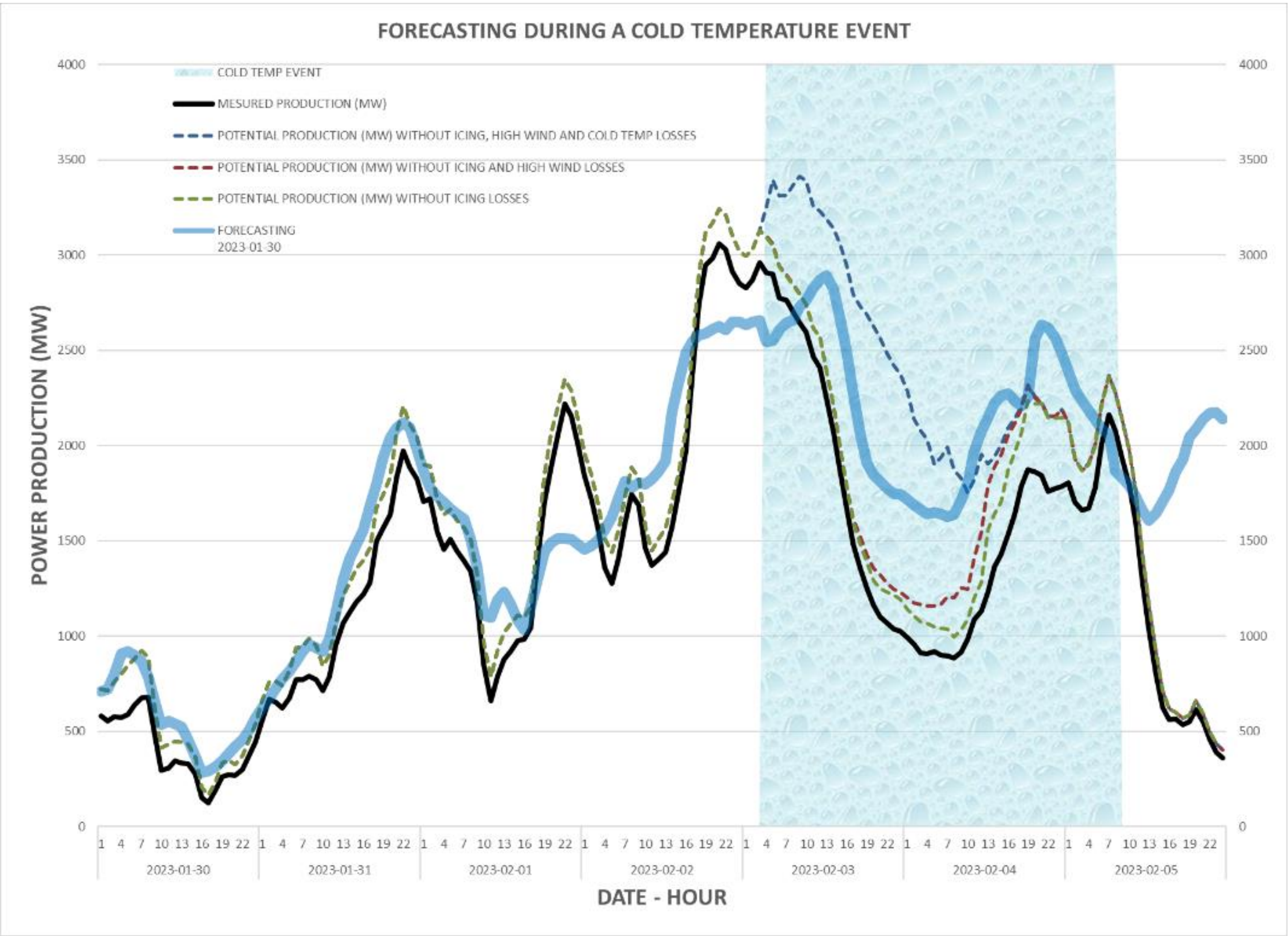
Case Study

Cold Temperature Case



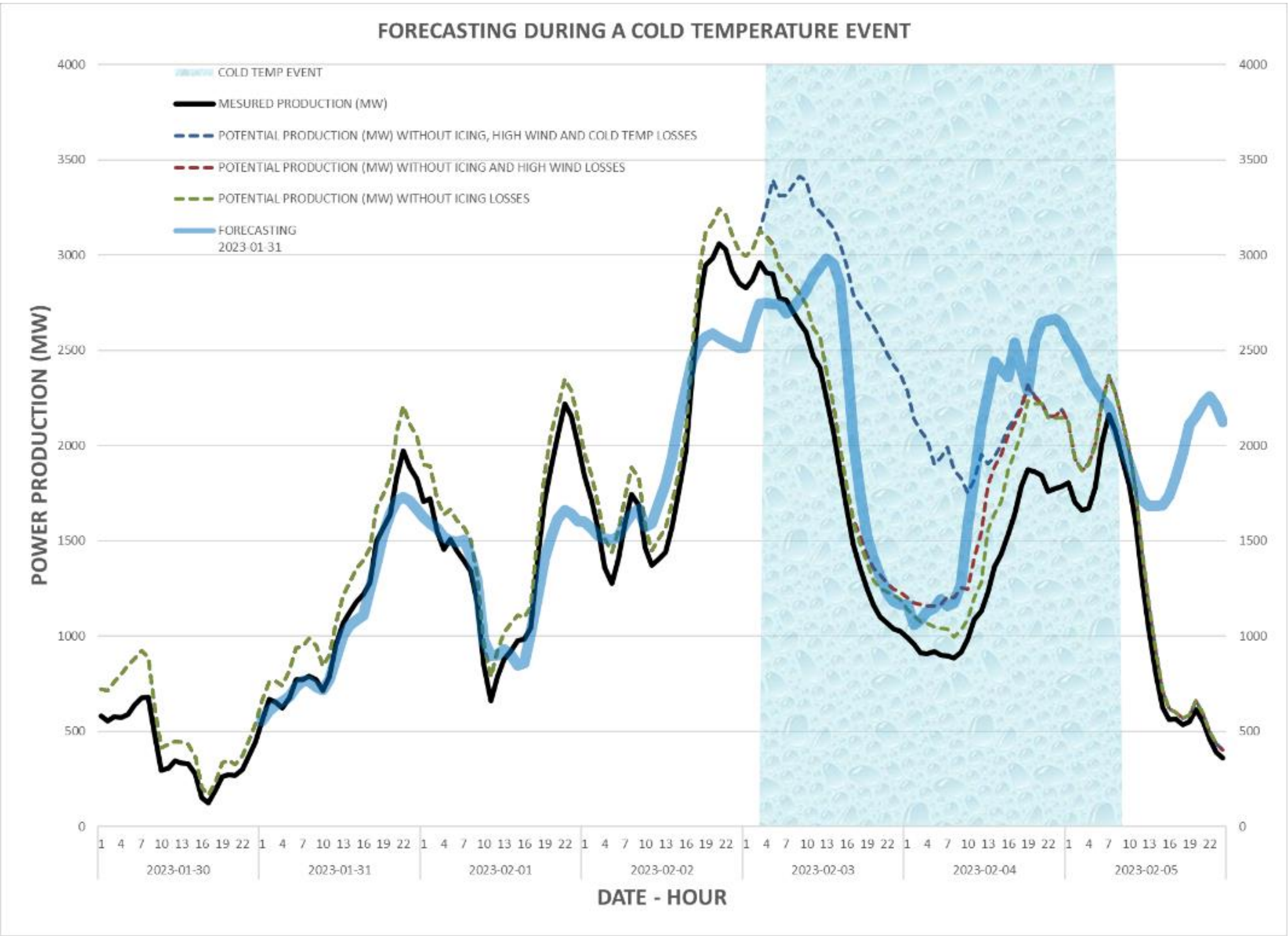
How about the cold temperature forecast?

Evolution day-to-day : 5 days before event



How about the cold temperature forecast?

Evolution day-to-day : 4 days before event

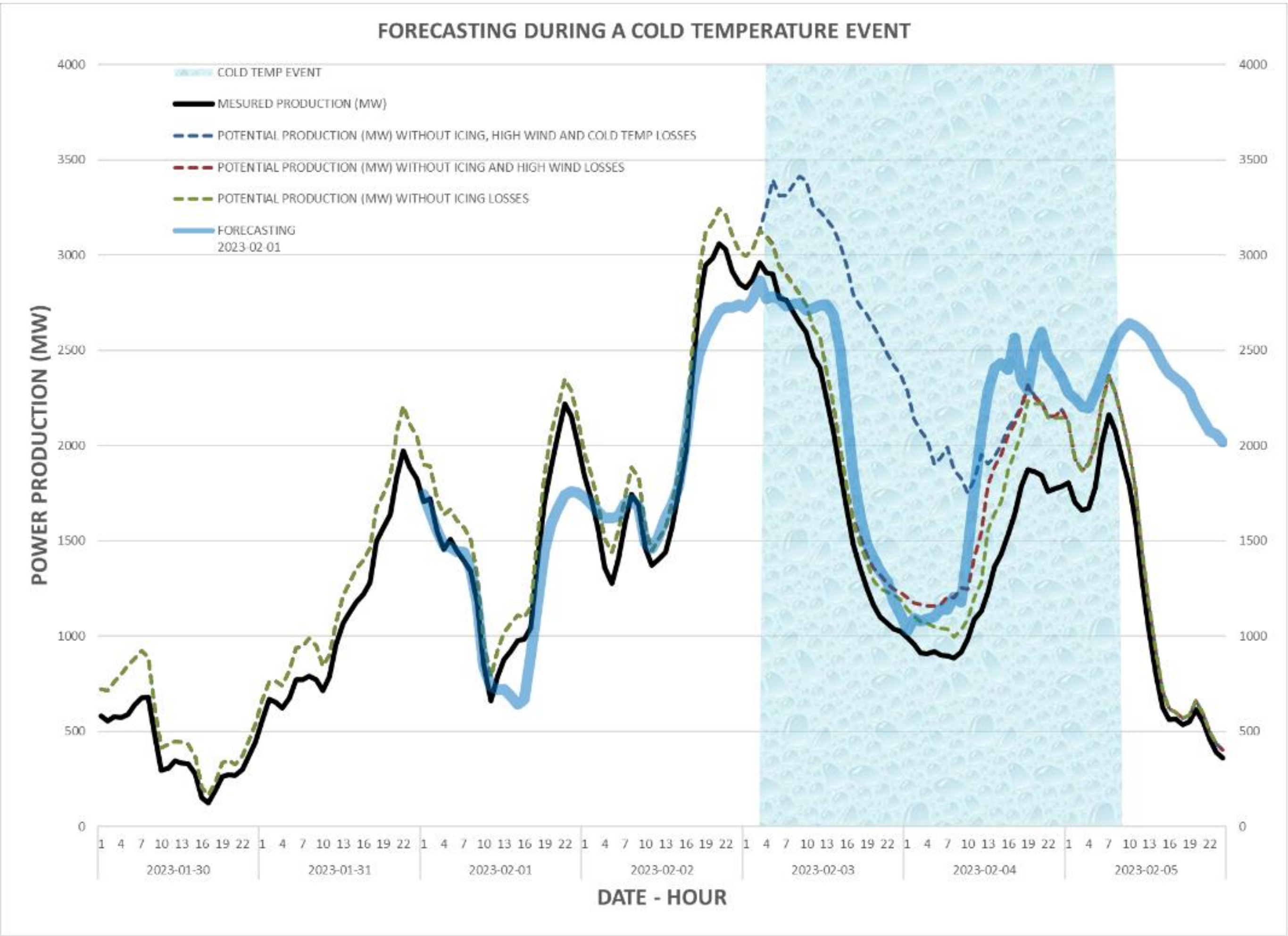


How about the cold temperature forecast?

Evolution day-to-day : 3 days before event

Case Study

Cold Temperature Case

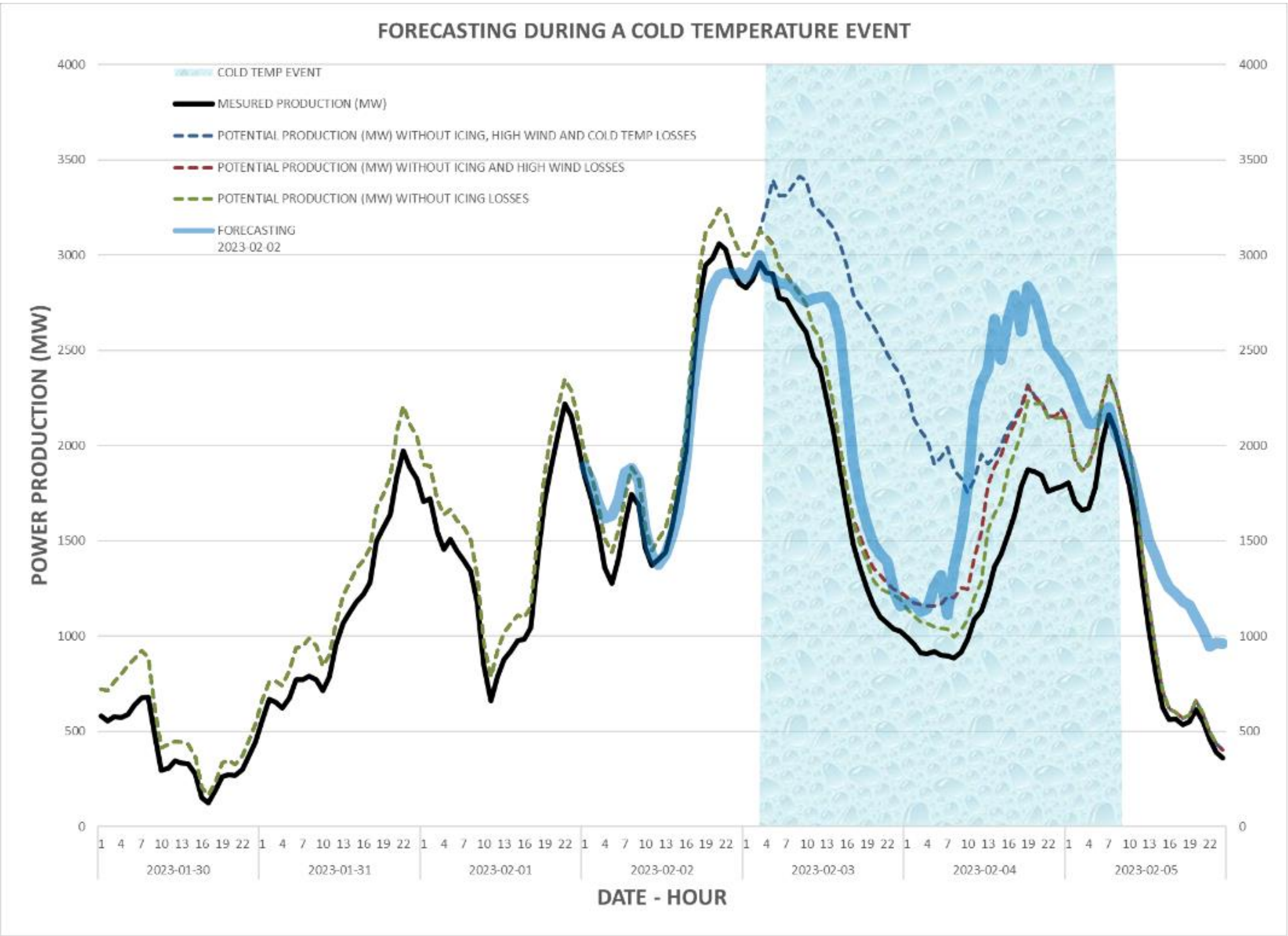


How about the cold temperature forecast?

Evolution day-to-day : 2 days before event

Case Study

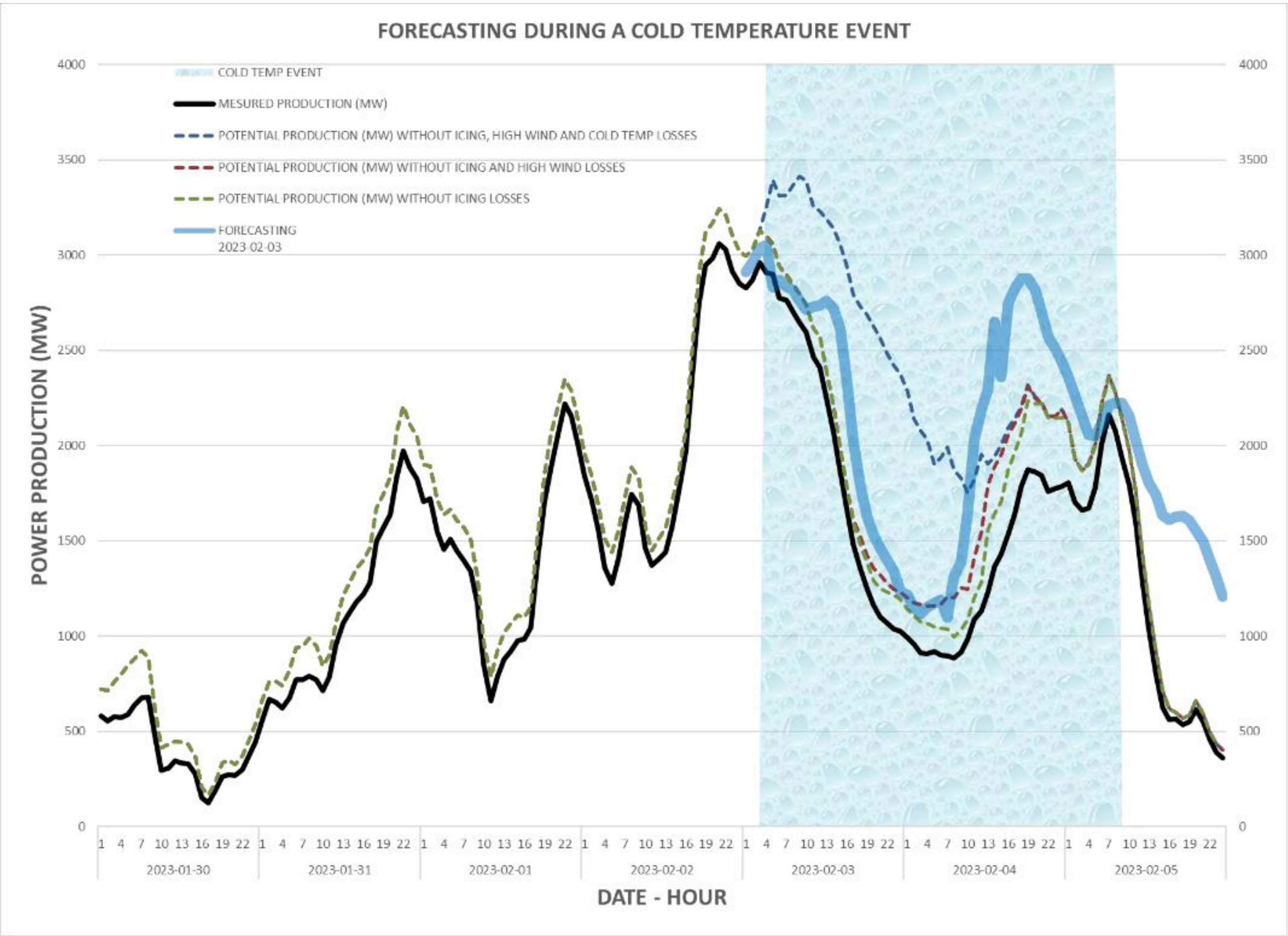
Cold Temperature Case



How about the cold temperature forecast?

Evolution day-to-day : 1 day before event

Case Study | Cold Temperature Case

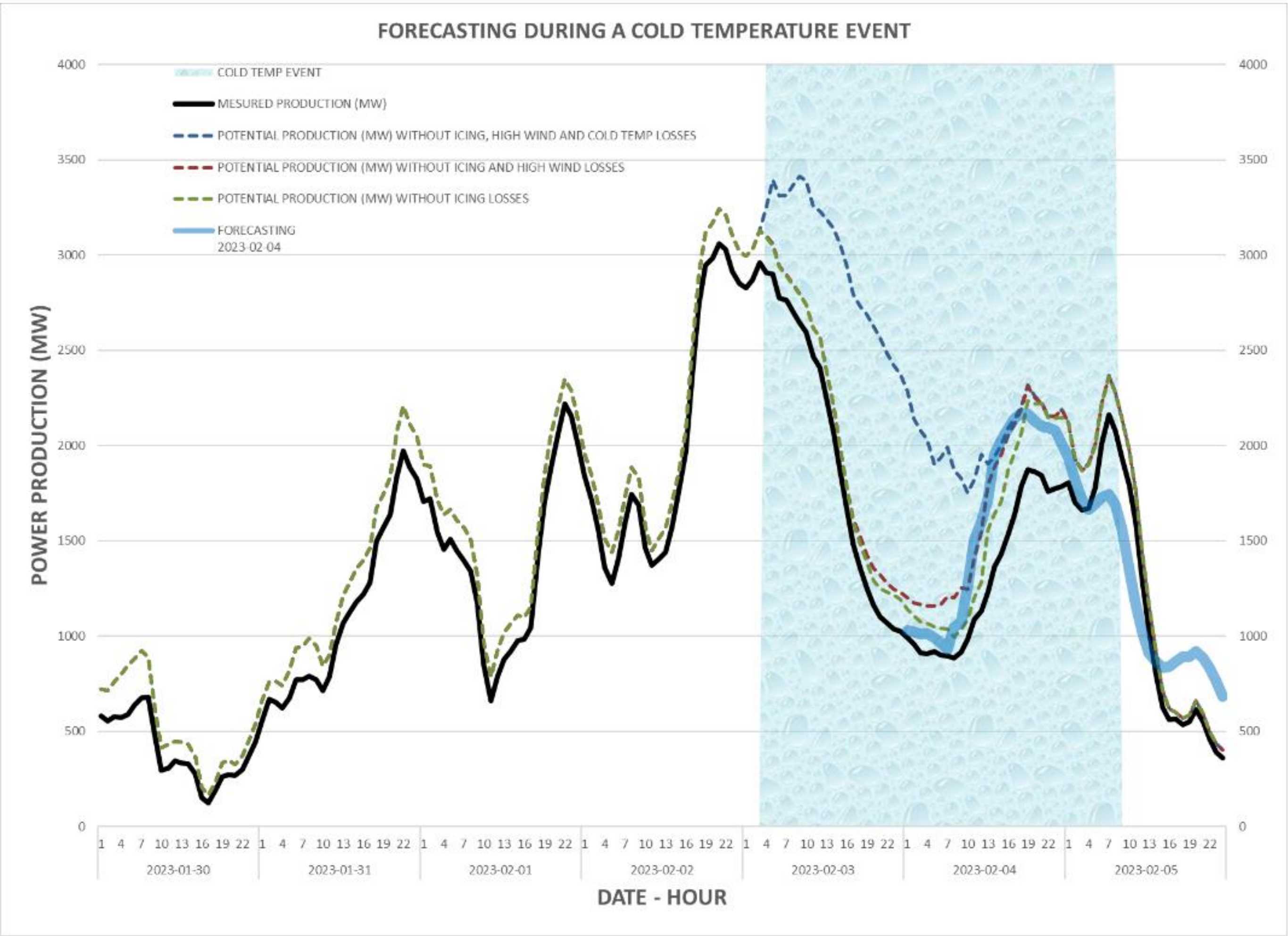


How about the cold temperature forecast?

Evolution day-to-day : COLD TEMP EVENT

Case Study

Cold Temperature Case

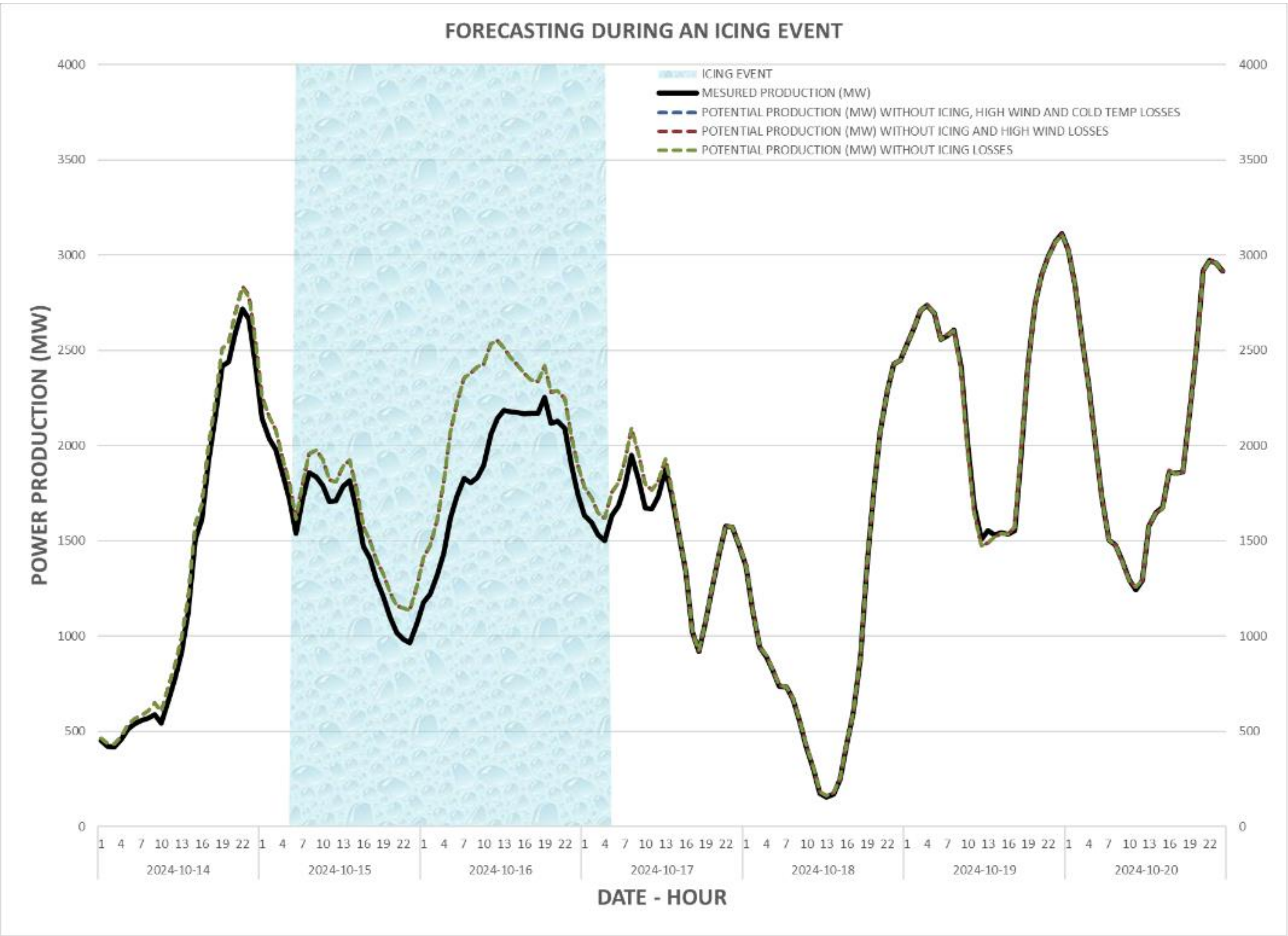


How about the cold temperature forecast?

Evolution day-to-day : 1 day after event

Case Study

Icing Case



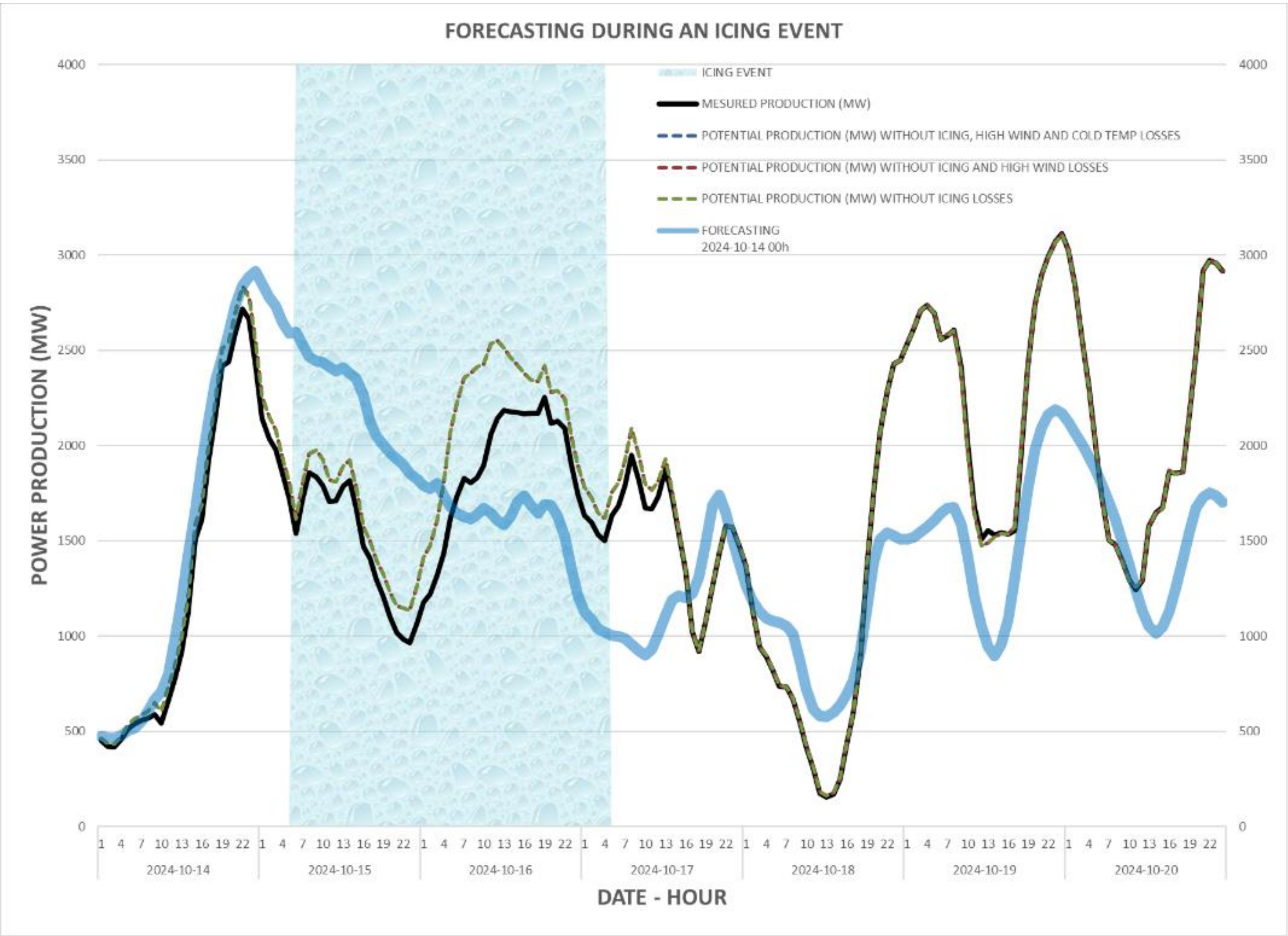
Case of early season icing event where some wind farms production has been impacted

The demand is high with the beginning of colder temperature

The forecasting model have captured the icing losses when the icing conditions have started and well predict the wind farm production reduction

Case Study

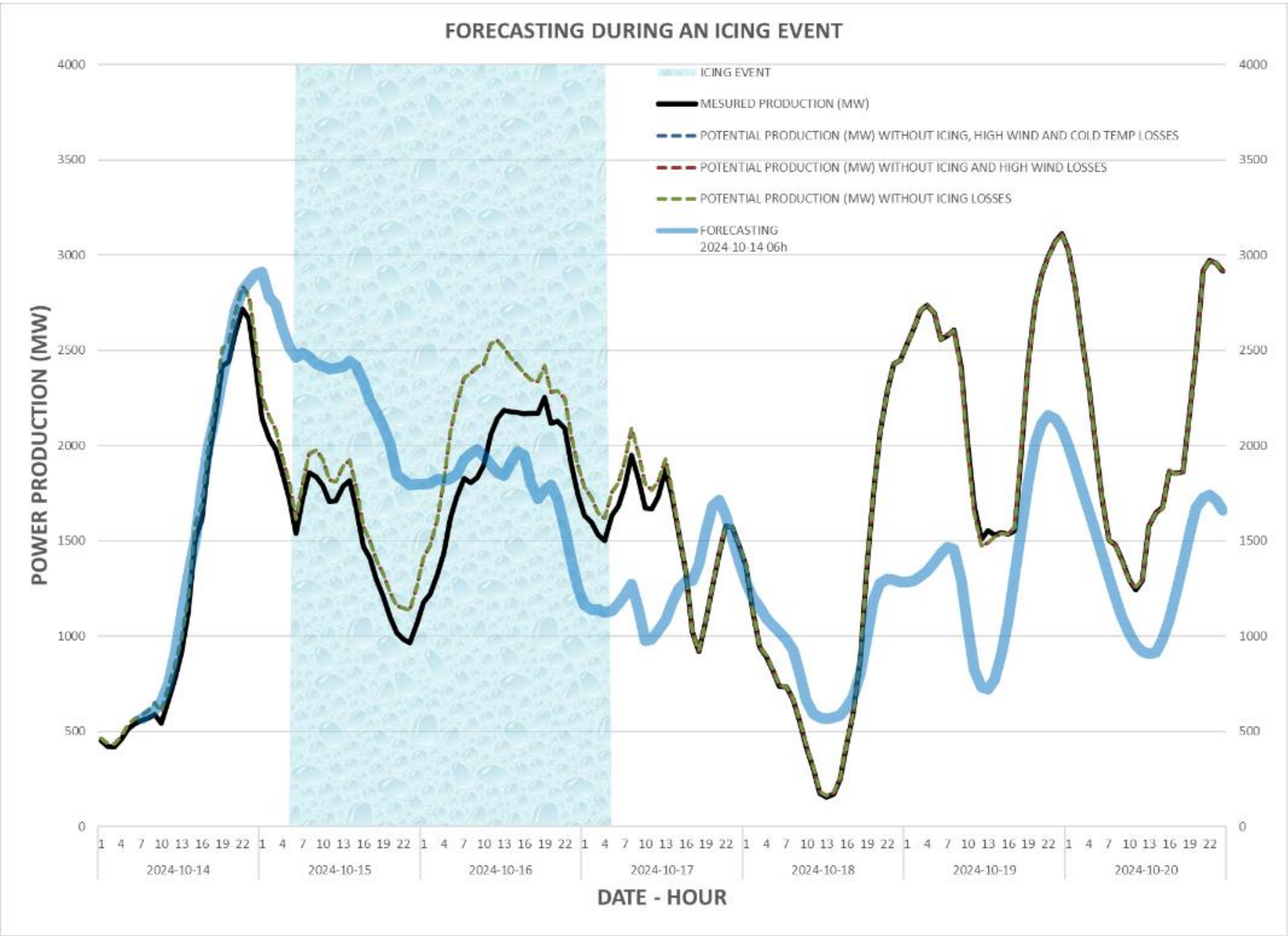
Icing Case



How about the icing forecast?

Evolution day-to-day : 30 hours before event

Case Study | Icing Case

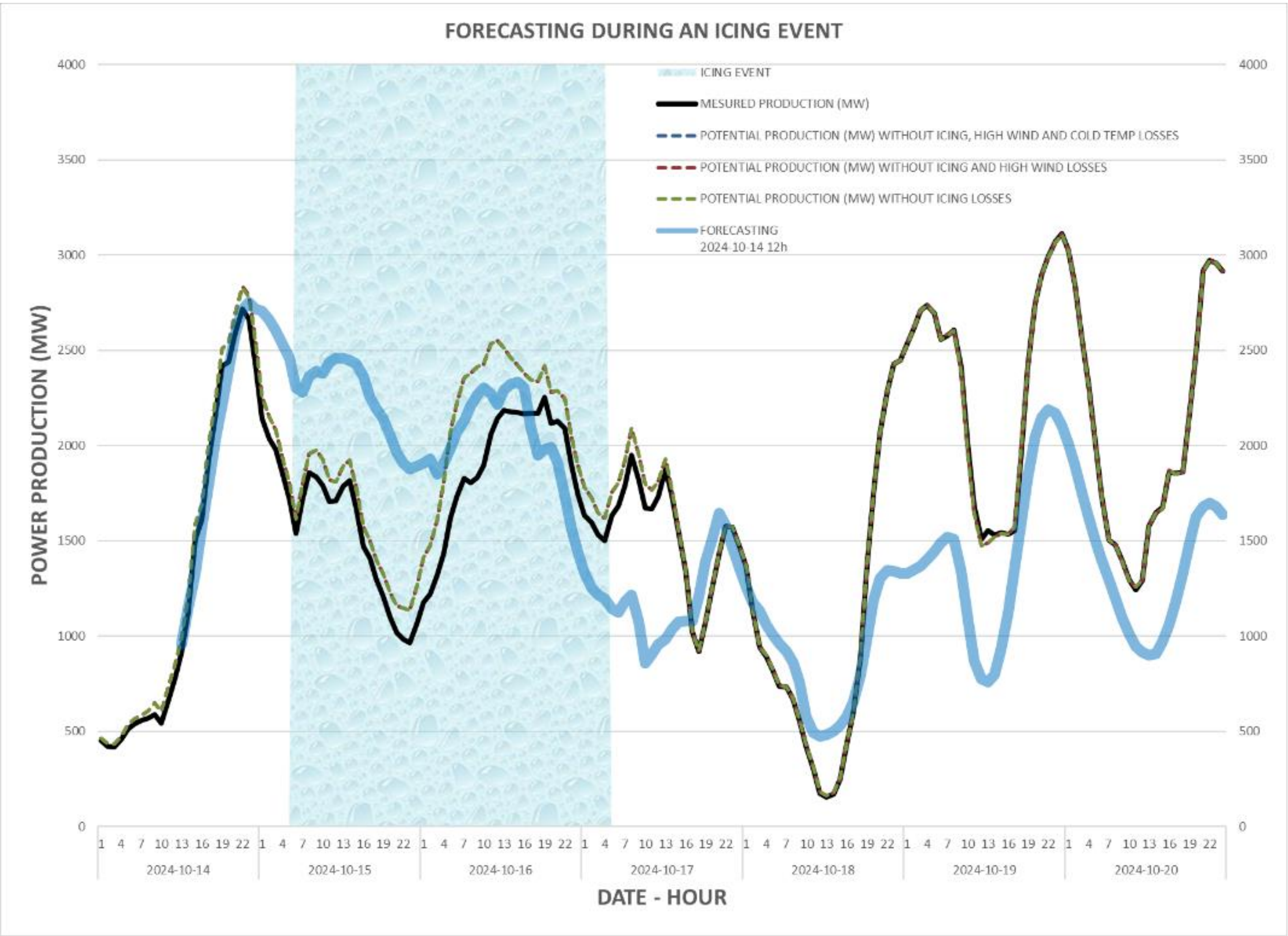


How about the icing forecast?

Evolution day-to-day : 24 hours before event

Case Study

Icing Case

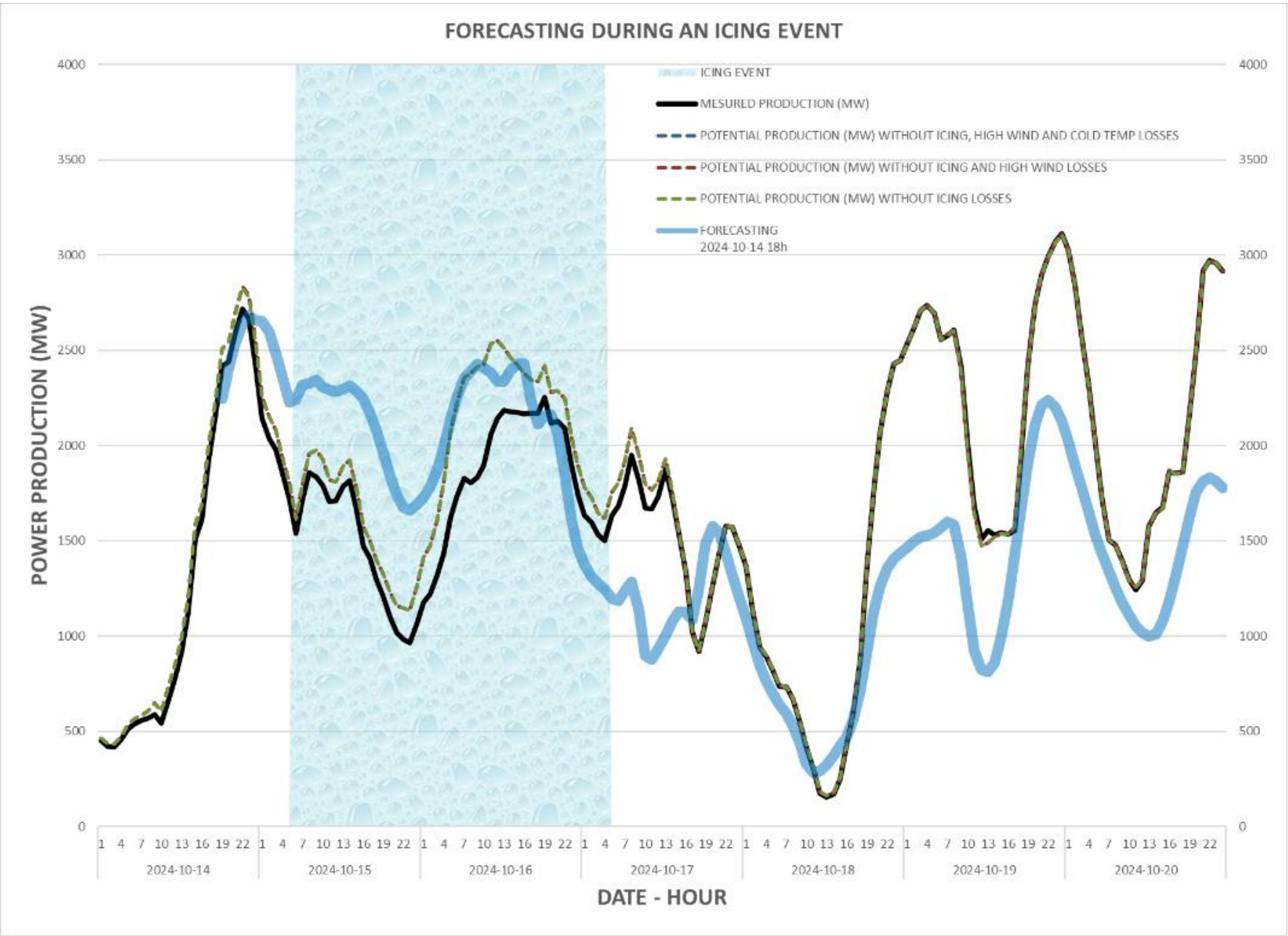


How about the icing forecast?

Evolution day-to-day : 18 hours before event

Case Study

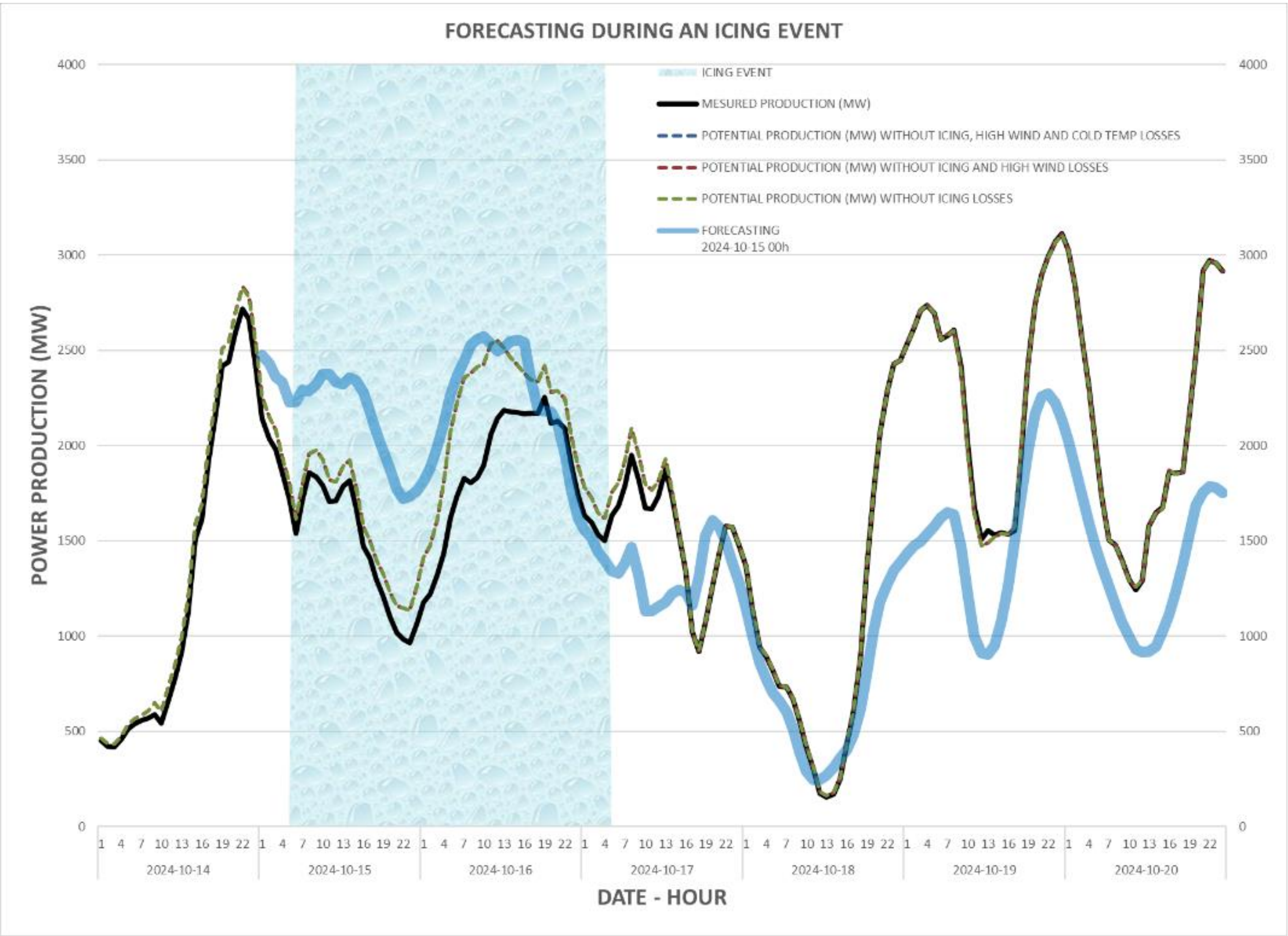
Icing Case



How about the icing forecast?

Evolution day-to-day : 12 hours before event

Case Study | Icing Case

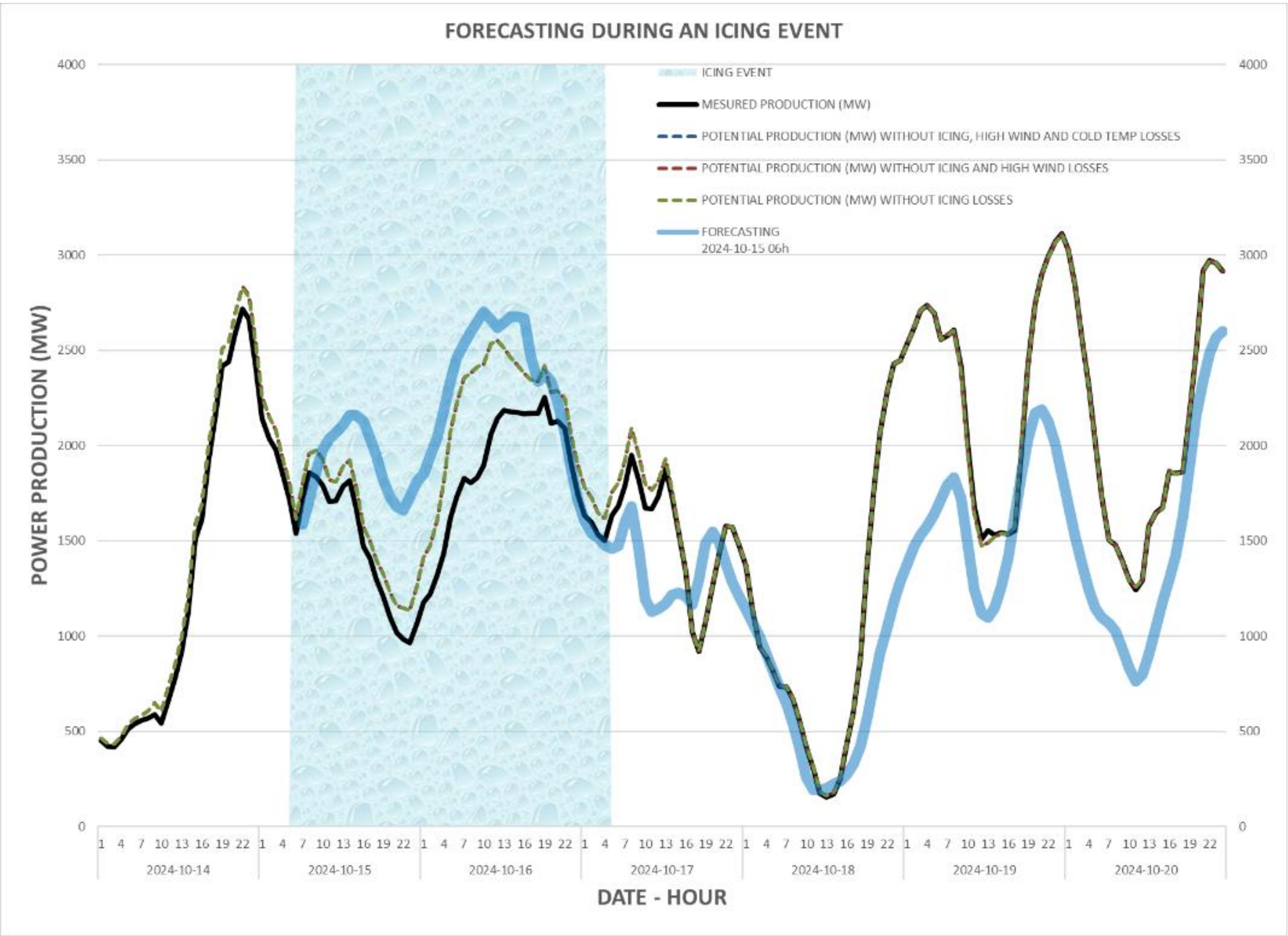


How about the icing forecast?

Evolution day-to-day : 6 hours before event

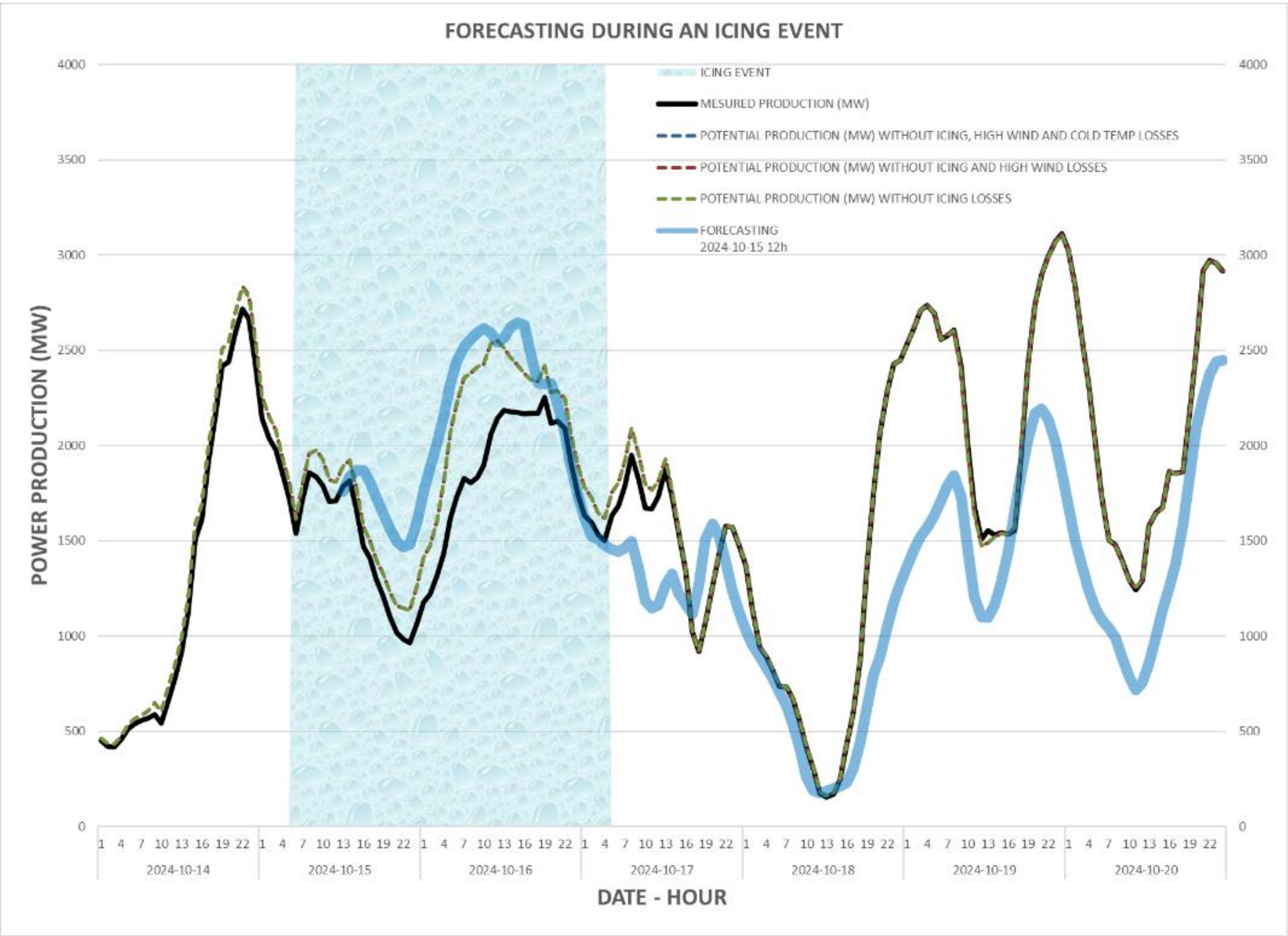
Case Study

Icing Case



How about the icing forecast?

Evolution day-to-day : ICING EVENT

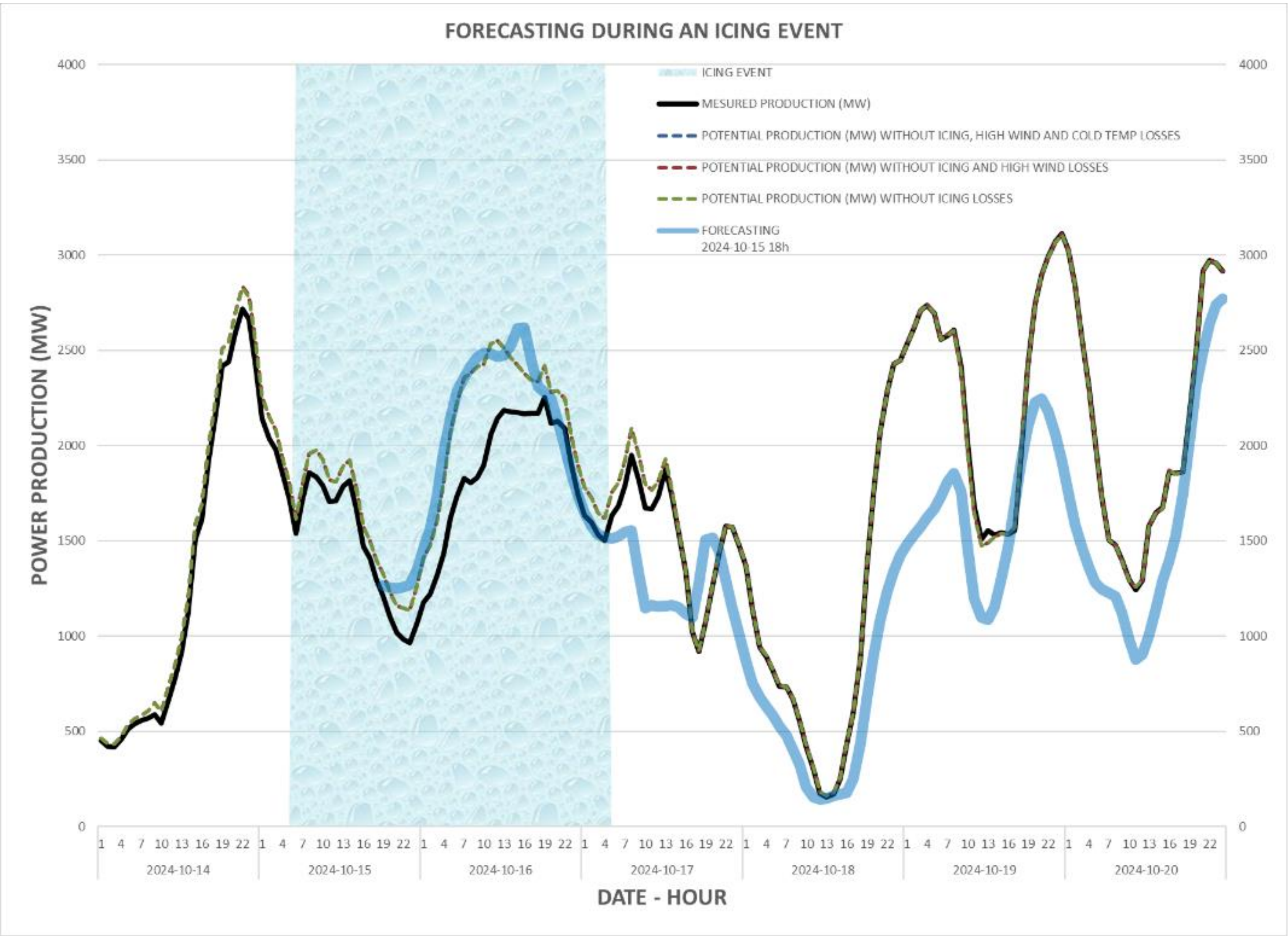


How about the icing forecast?

Evolution day-to-day : 6 hours after event

Case Study

Icing Case

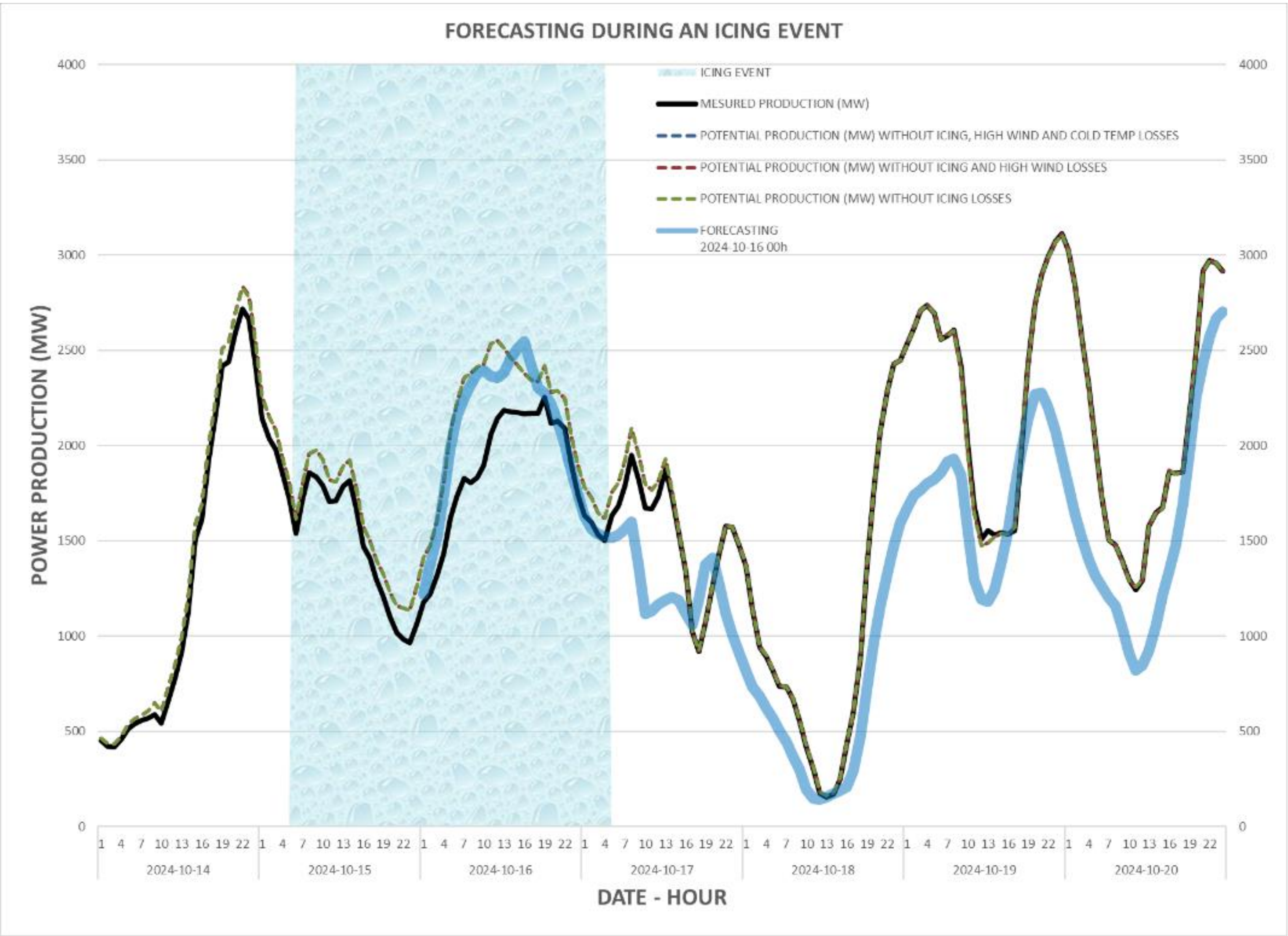


How about the icing forecast?

Evolution day-to-day : 12 hours after event

Case Study

Icing Case

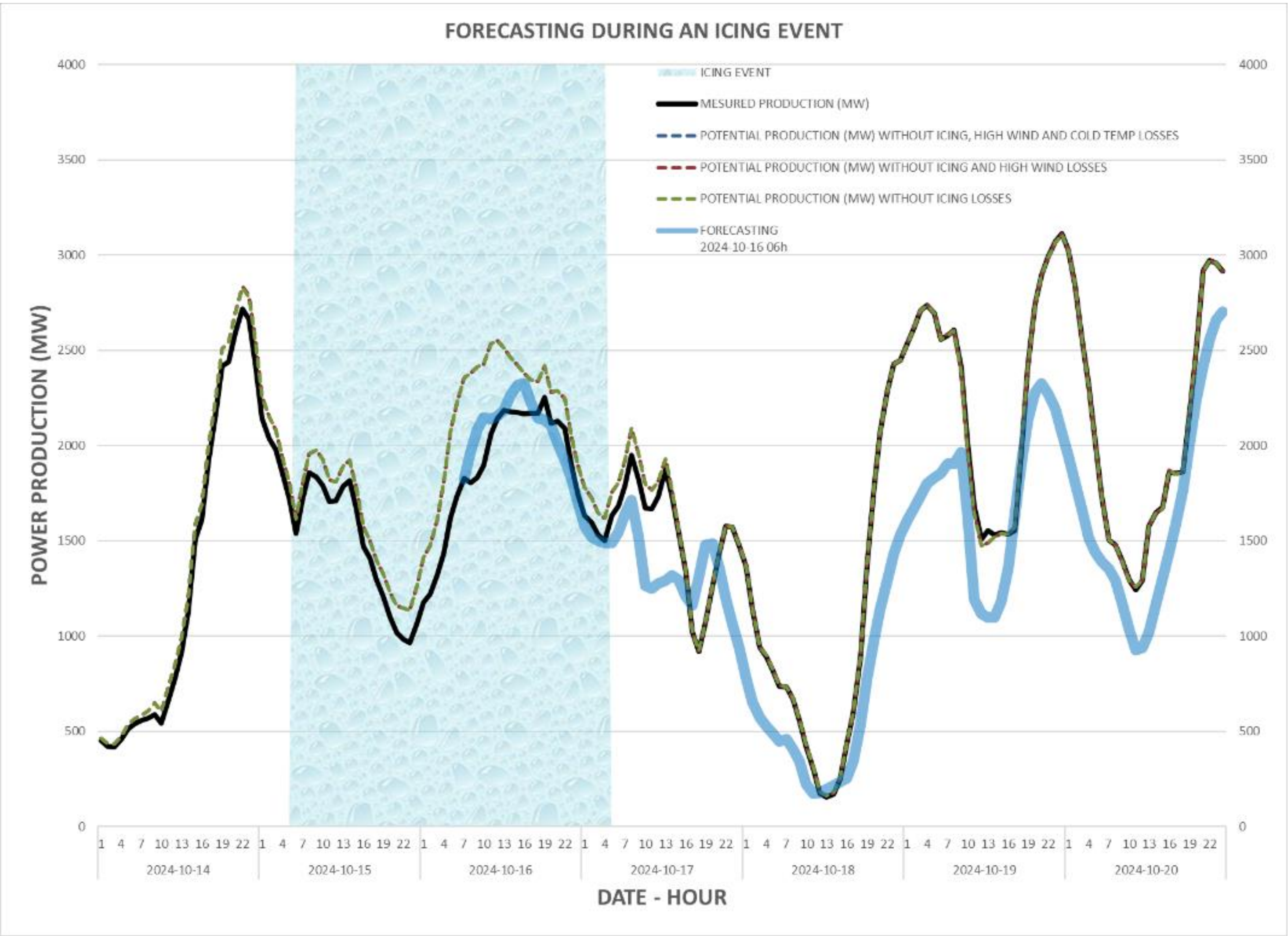


How about the icing forecast?

Evolution day-to-day : 18 hours after event

Case Study

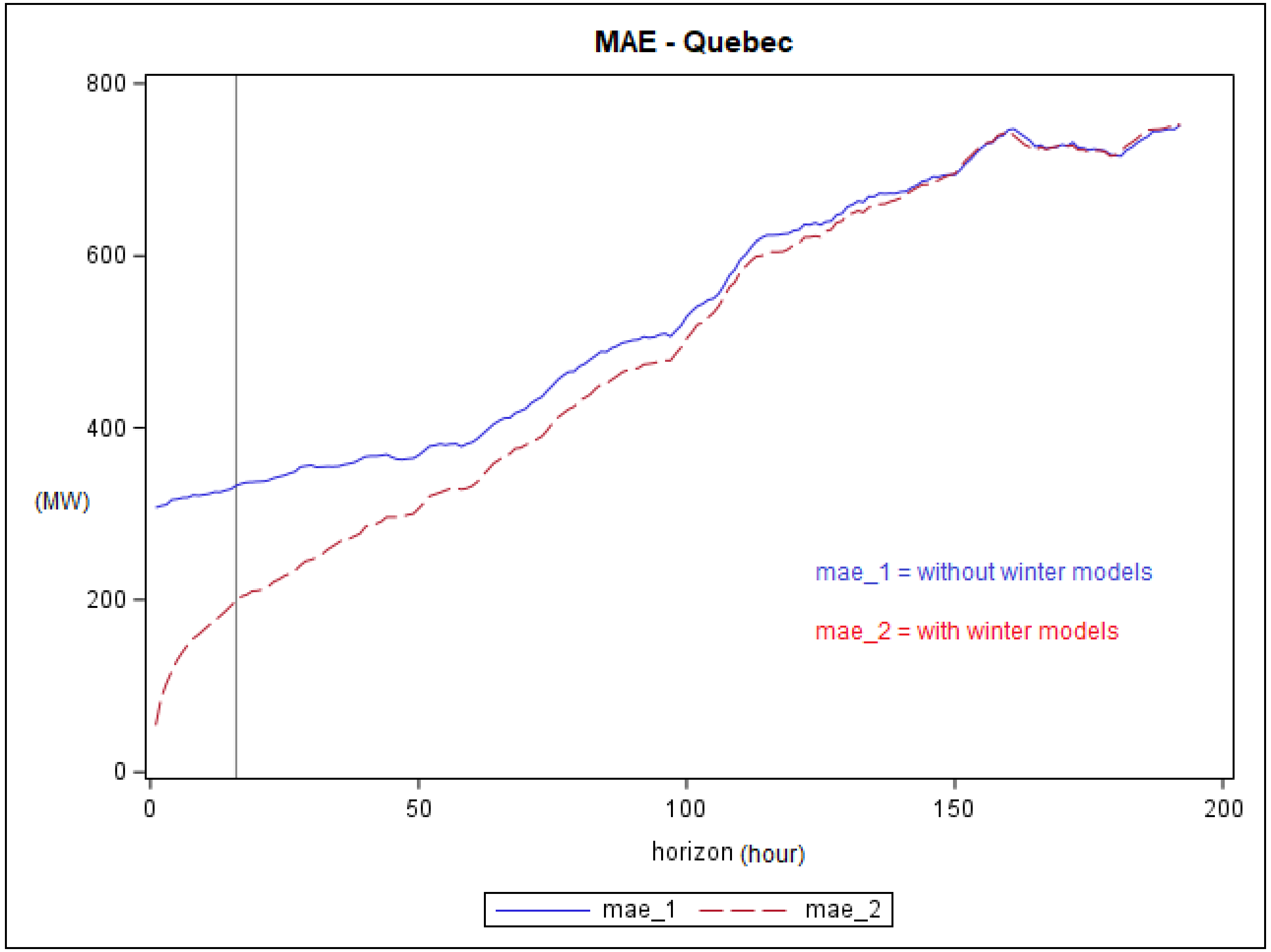
Icing Case



How about the icing forecast?

Evolution day-to-day : 24 hours after event

Forecasting Improvement Comparison



Winter 2023-2024 (Dec-Jan-Feb)

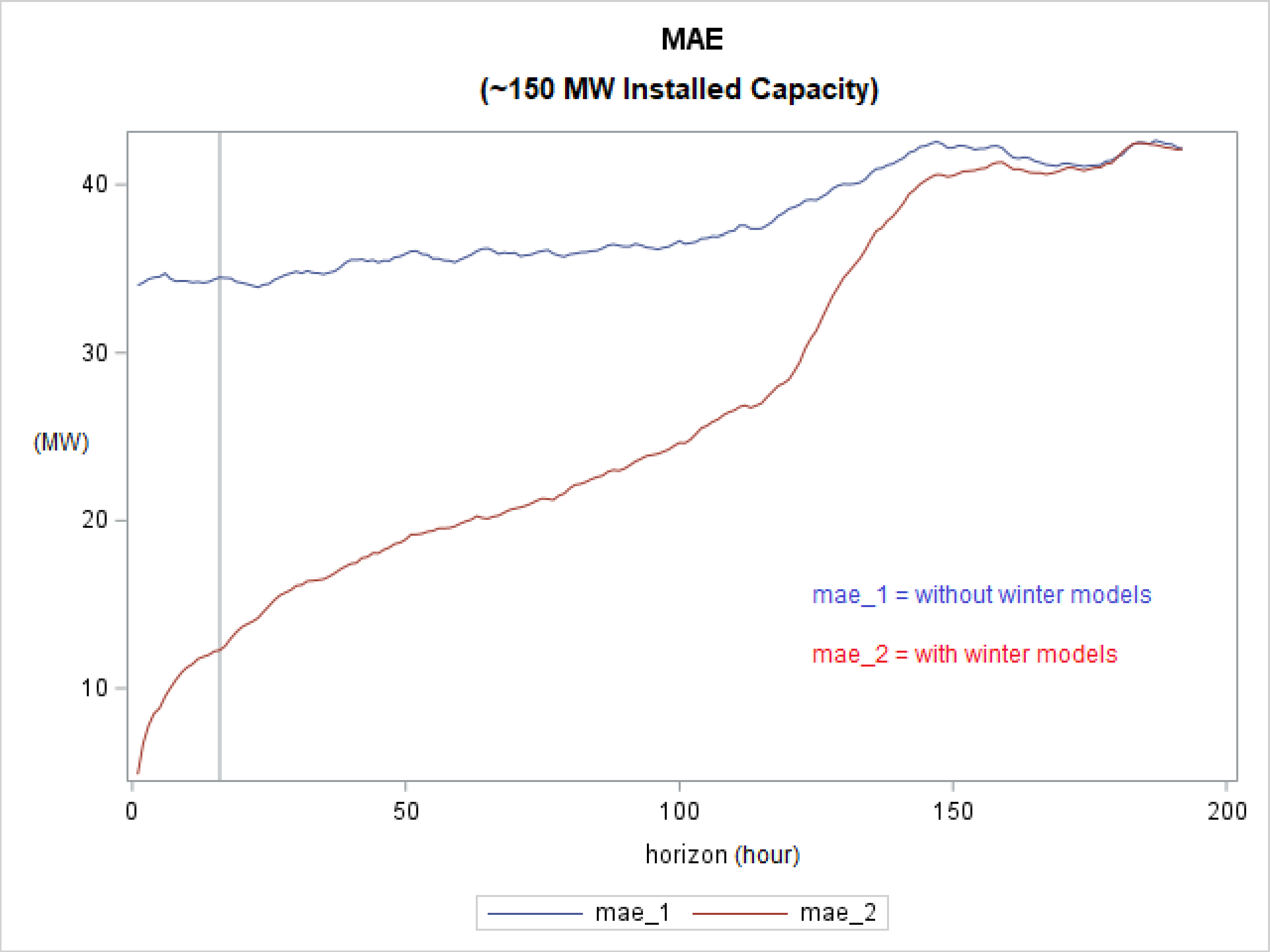
Many icing events during the winter

Improvement of cold temperature and icing models (winter models) in the forecasting

0-16 hours -> auto-adaptative algorithm widely improve the first hours

16~100 hours -> the winter forecasting models lowered the bias significantly

Forecasting Improvement Comparison



Winter 2023-2024 (Dec-Jan-Feb)

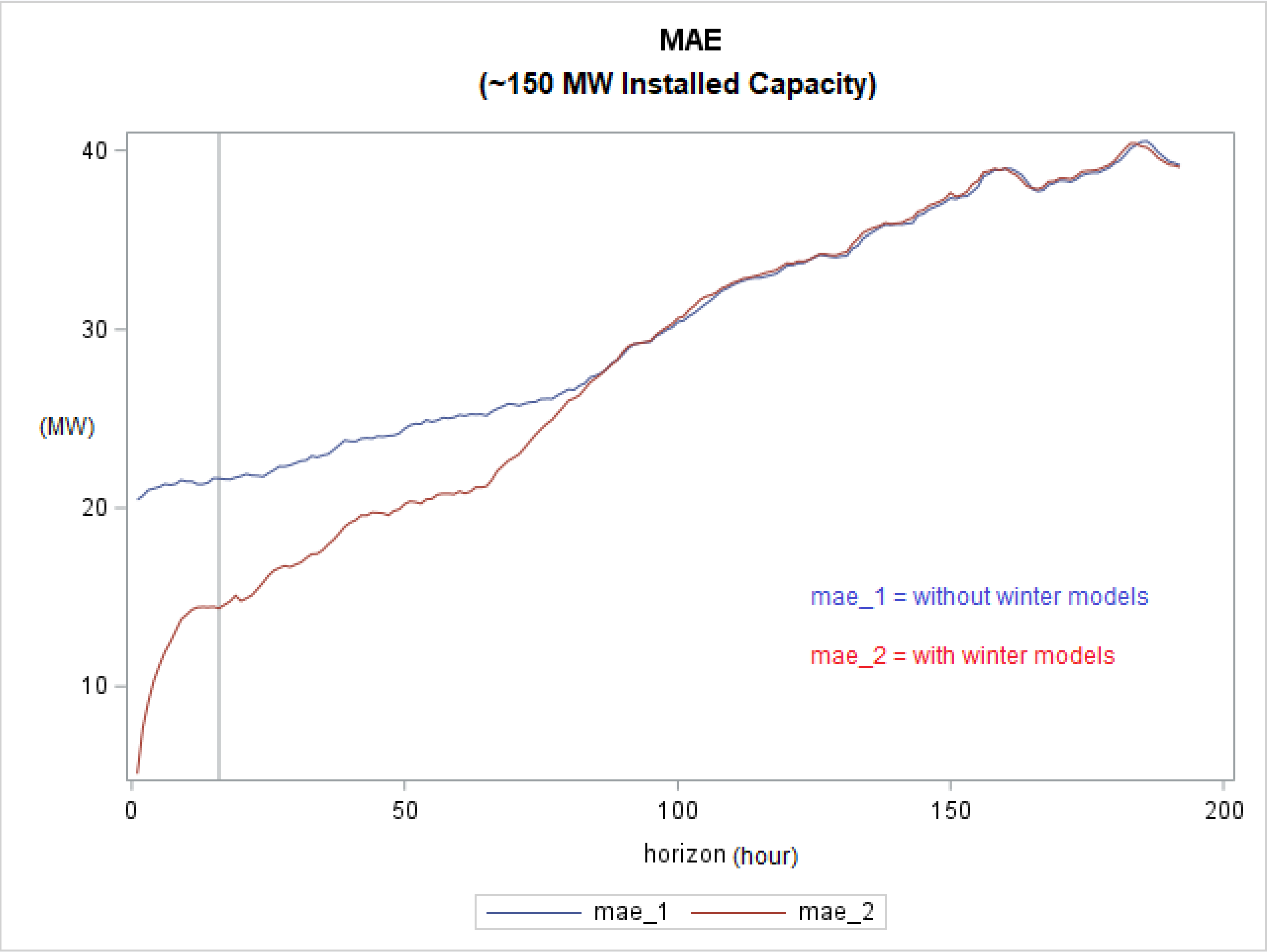
Strong case of improvement

Wind farm with harsh icing and <u>without</u> de-icing system

Long winter forecasting period

The winter forecasting model lowered the bias on the 16~160 hours horizon

Forecasting Improvement Comparison



Winter 2023-2024 (Dec-Jan-Feb)

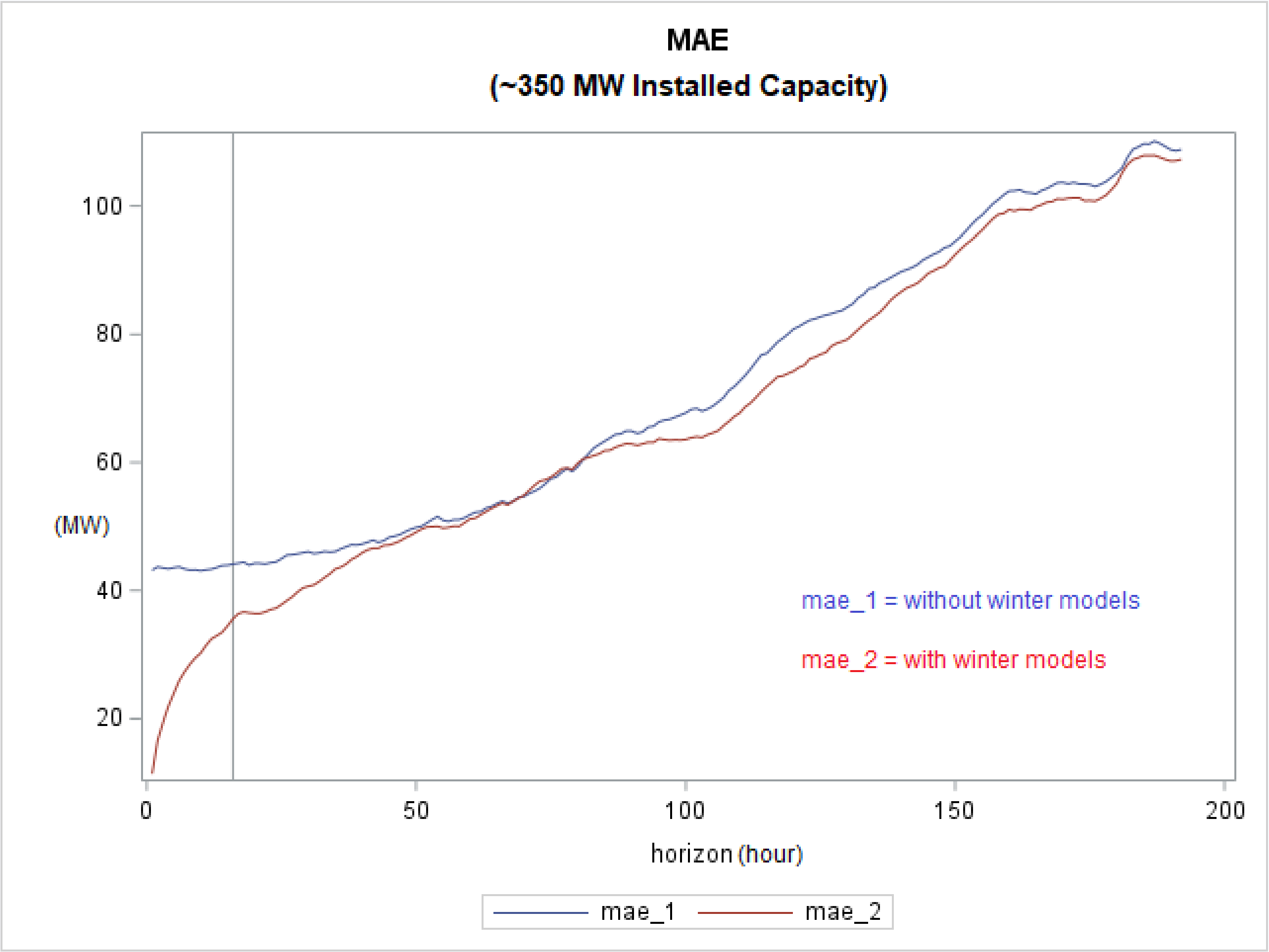
Strong to medium case of improvement

Wind farm with medium to harsh icing <u>with</u> de-icing system

Short winter forecasting period

The winter forecasting model lowered the bias on the 16~80 hours horizon

Case Study | Forecasting Improvement Comparison



Winter 2023-2024 (Dec-Jan-Feb)

Small case of improvement

Wind farm with harsh icing and <u>without</u> de-icing system

Long winter forecasting period

The winter forecasting model lowered the bias on the 16~40 hours horizon

In summary

What to retain?

The Québec's electricity demand is the highest in winter and knowing the wind power input in the grid its very important.

Most of the losses come from the icing events.

Winter forecasting models helps to reduce the bias in the prediction of wind power.

Future improvement coming :
- predicting icing,
- IA based power prediction model, …

Merci

Tack

Hydro Québec

Thank you