UiT The Arctic University of Norway

Impact of increasing share of wind energy on Nordic electrical energy market predictions

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ITS，NT

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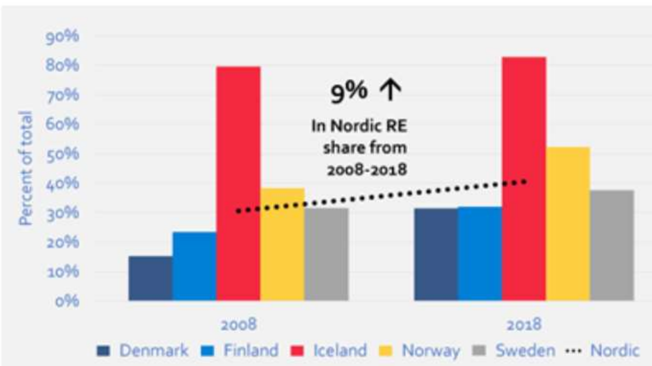
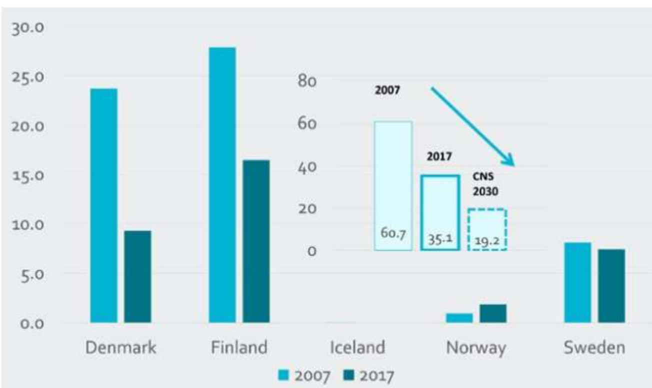
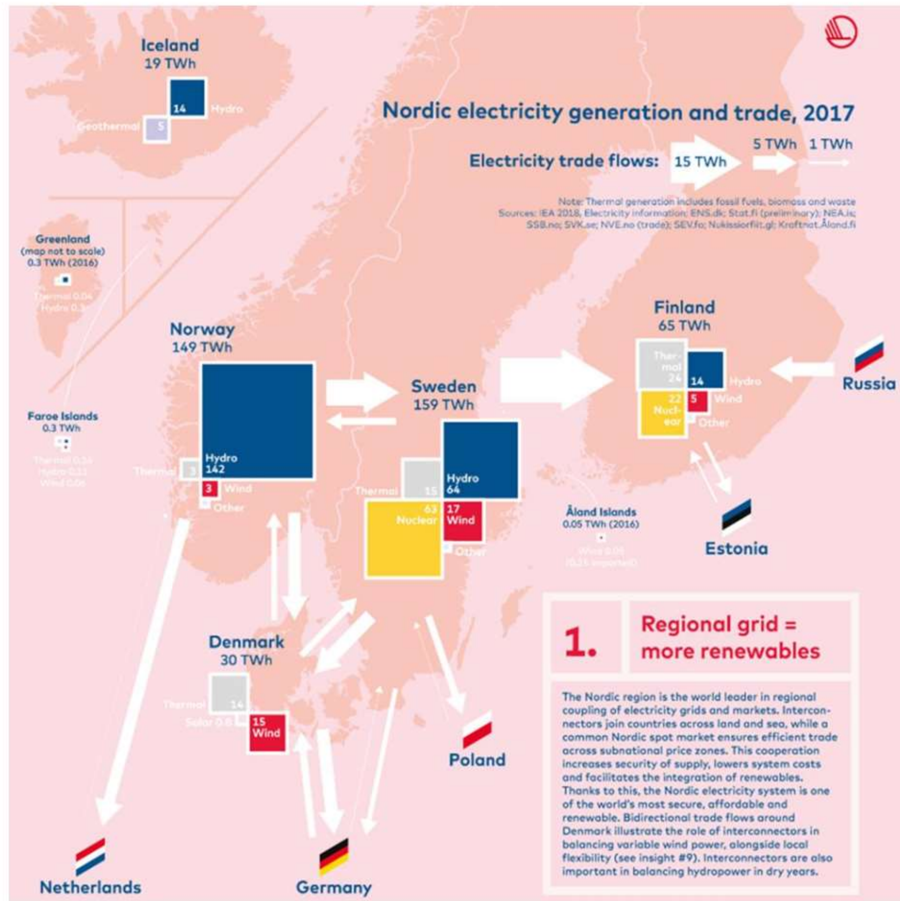
Content

Scandinavia is leading the Renewable Energy Transition





CO2 emissions from power and heat generation in the Nordic countries fell from 60.7 MtCO2 in 2007 to 35.1 in 2017, in line with the CNS 2030 target of 19.2 MtCO2.



Nordic Clean Energy Scenarios – Solutions for carbon neutrality
Renewable Energy in the Nordics 2021
Nordic Energy Research

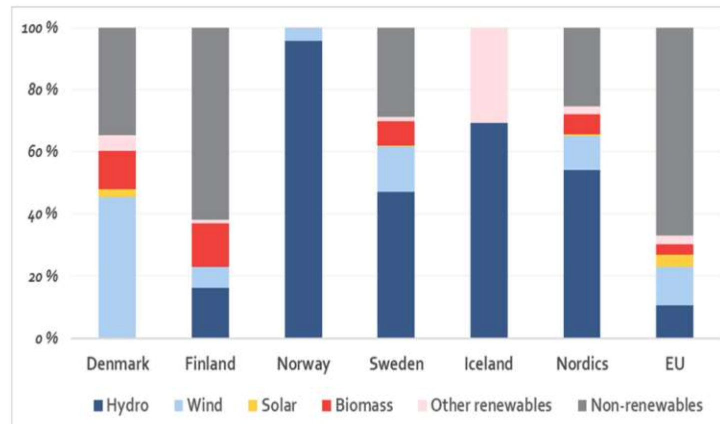
Denmark has less energy-intensive industry relative to other Nordic countries, although this is changing as more large data centers are being established. Combined heat and power together with district heating networks, often fired with renewable biomass, provide much of the country's heat supply, while wind power met 45 percent of electricity demand in 2019. *

Finland's most important forms of renewable energy are forest-based bioenergy, side streams and other wood-based fuels stemming from its large forest and paper industries. Hydropower, wind power and ground heat play important roles, and combined heat and power and district heating are both central in the country's energy system.

Iceland meets most of its heat demand with geothermal resources, via district heating. Much of the country's tapped hydropower supplies energy-intensive industries, including aluminium smelting and data centres. While Iceland is not connected to the European grid, renewable energy used to produce goods and services for export displaces carbon intensive operations elsewhere.

Norway's hydropower has fostered electric heating and energy-intensive industries, such as manufacturing and mining. The country's reservoir capacity stores and regulates fluctuating energy supply from renewable sources like wind in neighbour countries, via the common Nordic grid.

Sweden's energy intensive industries cover paper and pulp, as well as steel manufacturing. A range of low-carbon sources are found in the country's energy mix, including hydropower – mostly for electricity – and bioenergy for heating, while wind power capacity is expanding rapidly.



Renewables in the Nordic and EU electricity mix 2019 (% of consumption)

Renewable Energy in the Nordics 2021
Nordic Energy Research

Climate change impacts Nordic energy

https://www.forbes.com/sites/edwardsegal/2022/01/01/heres-how-climate-change-crisis-could-impact-business-operations-and-policies-in-2022/

- **Changes in the weather system** (faster pace in Nordic)
  - Changes in wind and large-scale atmospheric circulation
  - Increased risk of stationary weather conditions
  - Distribution of rain and snow
  - Thunder, hail, as well as extreme weather events
- **Growing focus on renewable energy**
  - Forest fires threaten transmission lines, fires in biomass storage locations
  - Hydro, severe precipitation adds pressure on dams and emergency spillways
  - Icing of turbine blades and transmission lines when temperatures increase
- **Electricity network**
  - Increased risk of icing and changes in icing in different regions
  - More intense and heavier thunder events, which in turn can affect the electricity networks, transformers, control system
  - Risks relating to the increasing number of extreme events, e.g., ice storms and hurricane winds?

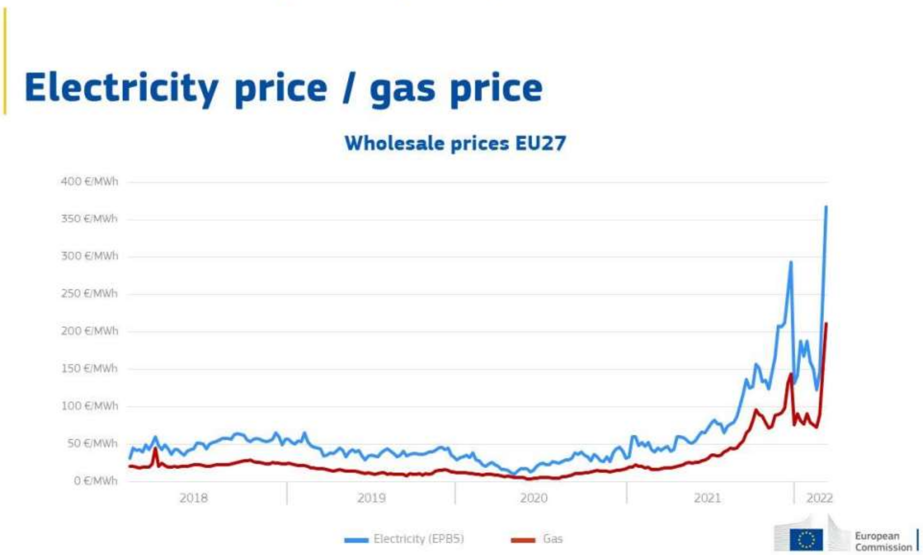
Nordic wind and wealth can wean Europe off Russia's gas

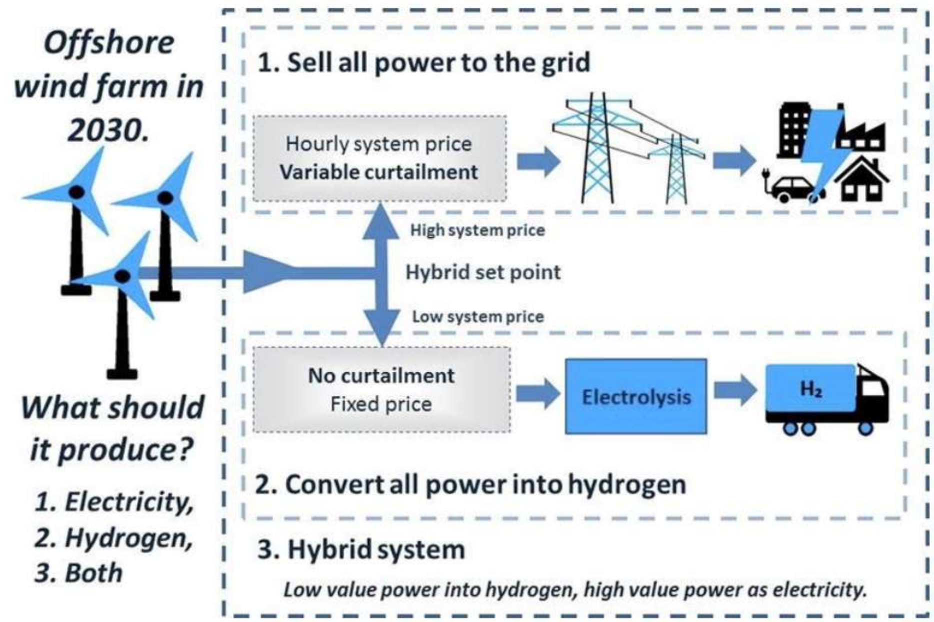
- **Before invasion of Ukraine, Russia provided the EU with 40% gas demand.**

increasing energy efficiency
switching to other suppliers LNG (short- to medium-term remedy)

- **Hydrogen, Green hydrogen (long-term)**

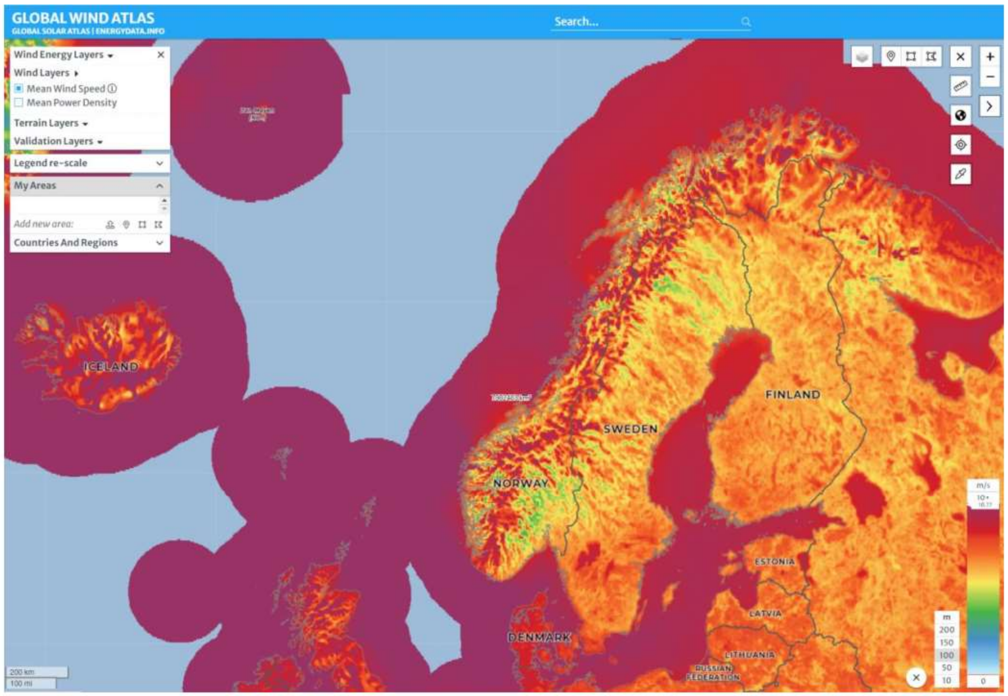
offshore wind plus hydrogen

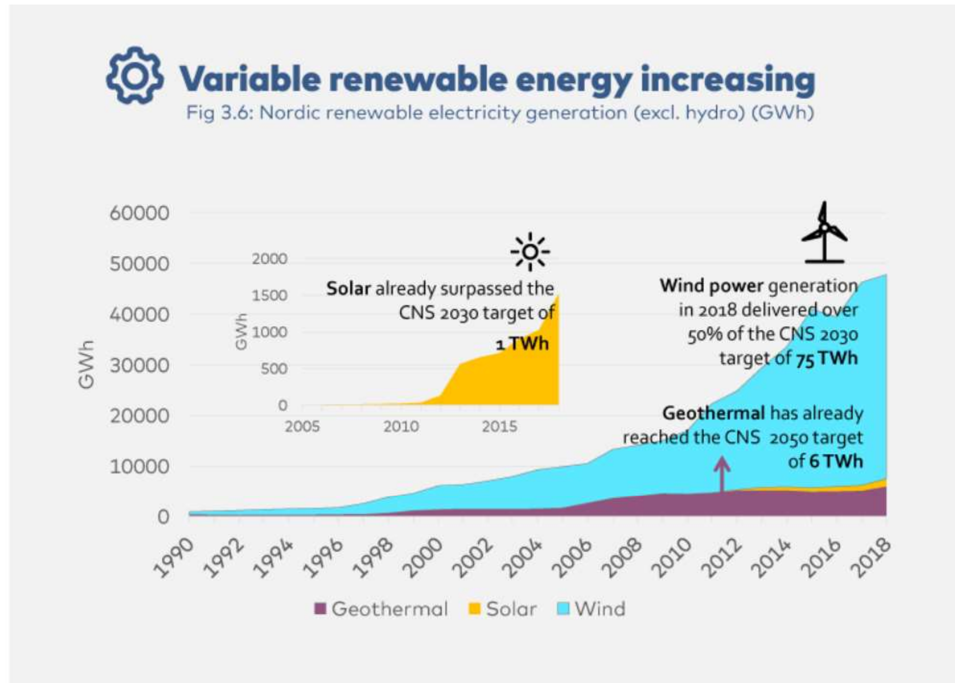




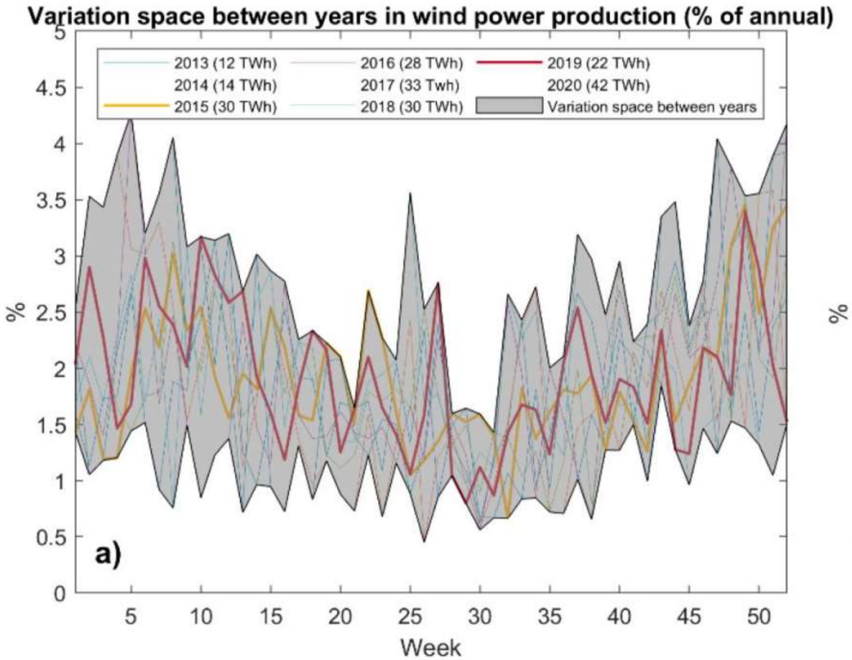
doi.org/10.1016/j.apenergy.2020.114732

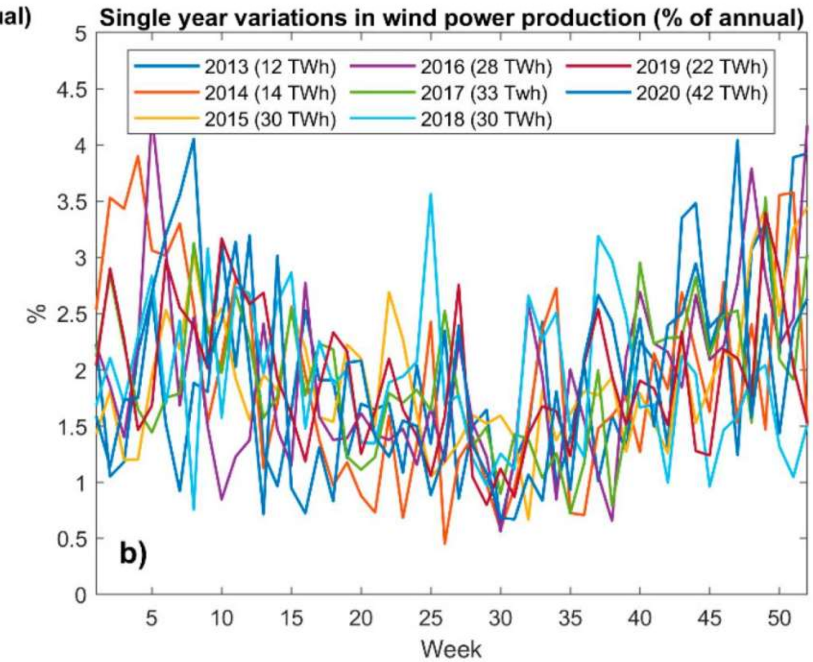
Wind energy in Nordic





Wind energy in Nordic





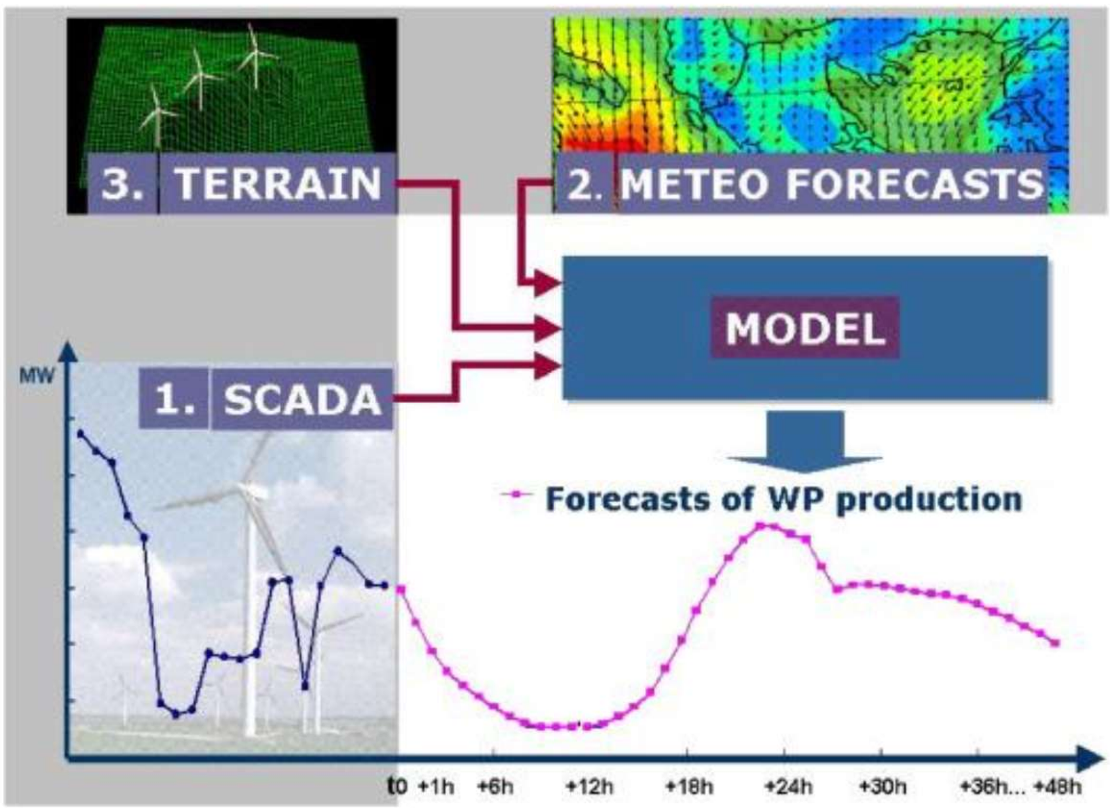
- Variation in weekly wind power electricity production (% of annual mean) on the Nord Pool market from 2013–2020 between years, with years mentioned in text highlighted (a), for every single year (b) and yearly totals.

doi.org/10.3390/cli9030046

Wind power forecasting

- Bases

$$\hat{P}_{i+n} = f\left(P_{i-j}; W_{i-j}; NWP_{i+n}\right) + \varepsilon_n$$



doi.org/10.1016/B978-0-08-100504-0.00003-2

Wind power futures: manage production risks

Wind Power Futures provides the tools to hedge production of renewable wind power and conventionally produced power.

- Ideal for volume hedging by renewable and conventional power producers
- Standardized products and solid rulebook
- Built-in clearing for all exchange transactions
- Full trading information transparency

NASDAQ OMX ▶ Transactions ▶ Markets ▶ Nasdaq Commodities ▶ Renewables

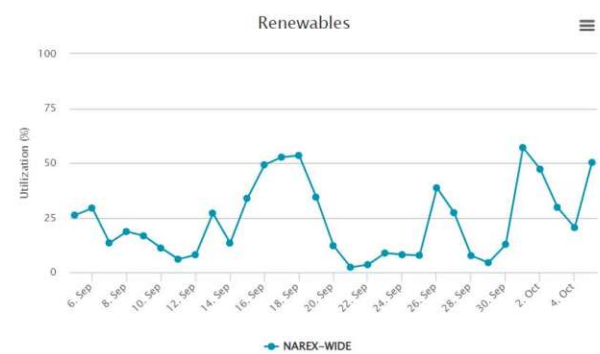
RENEWABLES

Nasdaq Renewable Index Wind Germany

Published daily at 10:00 CET

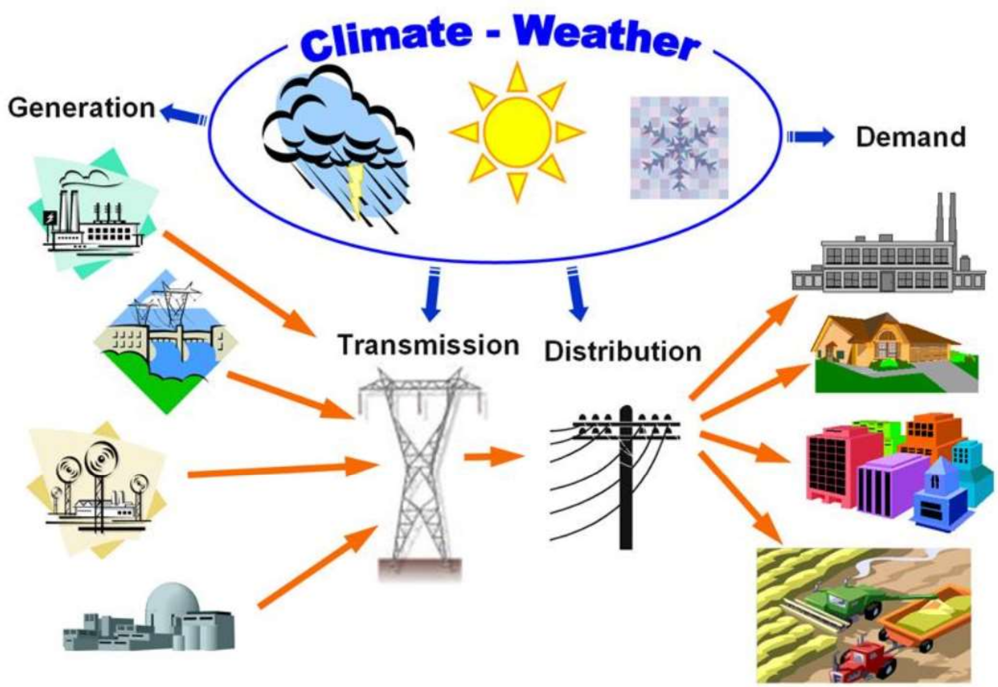
Please note, following values are missing from the chart and excel output:

January 20, 2022: **5.85**	January 9, 2022: **41.41**
January 8, 2022: **39.8**	January 7, 2022: **43.55**
December 12, 2021: **33.67**	October 31, 2021: **40.34**



Period: 2022-09-05 - 2022-10-05 Export to Excel

Weather matters in new energy



Mitigation

- Financial arrangement: A closer connection between price zones; RE Derivatives like wind futures.
- Energy storage technologies as a factor for reduced short term price differences as power can be stored in power surplus periods and used in deficit periods.
- **Advanced energy analysis**

Market balance

$$\underbrace{a_t^i + c_t^i}_{\text{demand}} \leq \underbrace{x_t^i + z_t^i + b_t^i}_{\text{supply capacity}}$$

where all the variables are measured in for instance MW and c_t^i is the consumption at time t in area i, a_t^i is the export at time t from area i, x_t^i is the production capacity at time t in area i, z_t^i is the import capacity at time t to area i, and b_t^i is backup production facilities.

Generation:

1. Drought. water reservoirs have little water.
2. Cold weather. smaller rivers are frozen. small plants do not produce.
3. Winter, less water flow in the rivers. River plants that do not have reservoirs produce less.
4. Blow too little or too much. reduced production of wind power.

Ordinary Methods:

1. Increase production using the backup system.
2. Encourage customers to reduce the desired consumption.
3. Set the price so high that the desired consumption is reduced.
4. Pay large customers to reduce consumption.
5. Disconnect some of the customers.

doi.org/10.3390/en14092701

Nordic energy in future: 4 major changes

1. Oversupply of wind power in the north
2. Growth of Nordic power consumption
3. New transmission capacities from Nordics
4. Reduced price differences between Nordics and Europe

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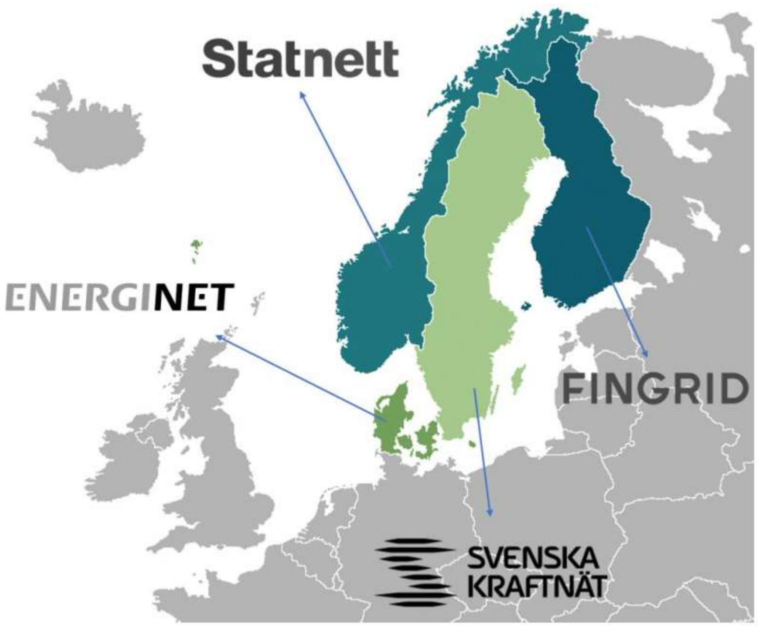
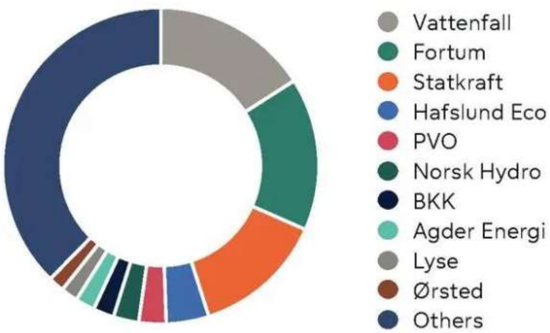
1. Energy in Nordic and wind energy
2. **Nordic electricity market and its prediction**
3. Increasing wind energy in grid
4. Case study

Nordic electricity market



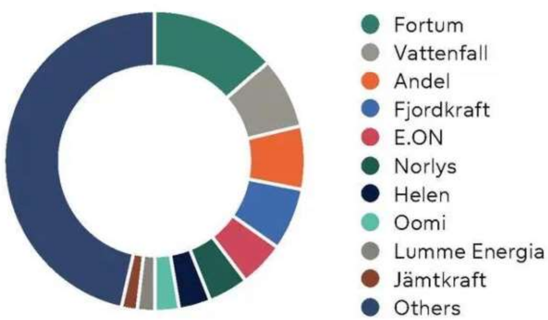
Nordic TSOs (Norway, Sweden, Finland and Denmark) and the Baltic TSOs (Estonia, Latvia and Lithuania).

Nordic power generation, 408 TWh, over 350 companies



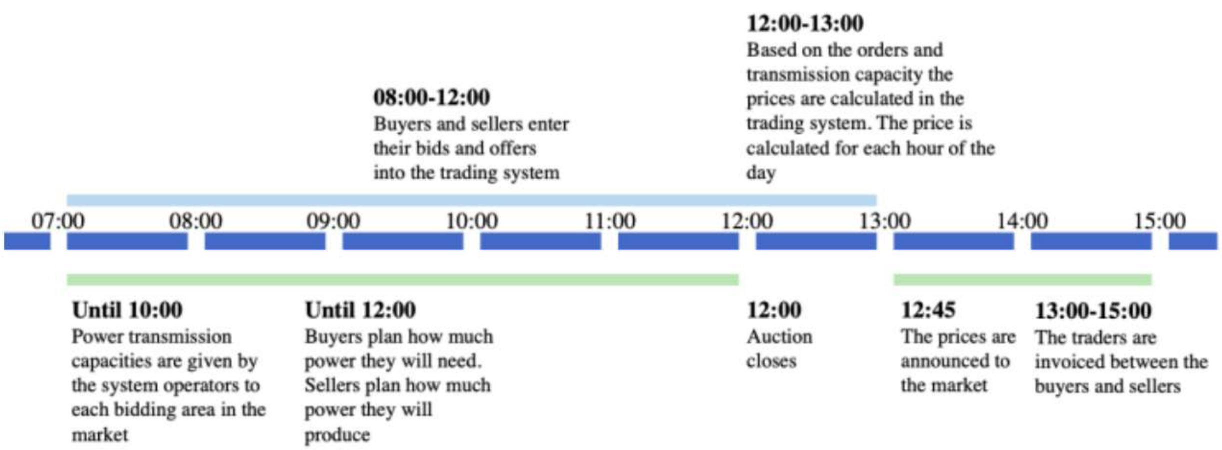
Source: Fortum, company information, 2020 figures pro forma. Fortum incl. Uniper.

Nordic electricity retail, 16 million customers, ~350 companies

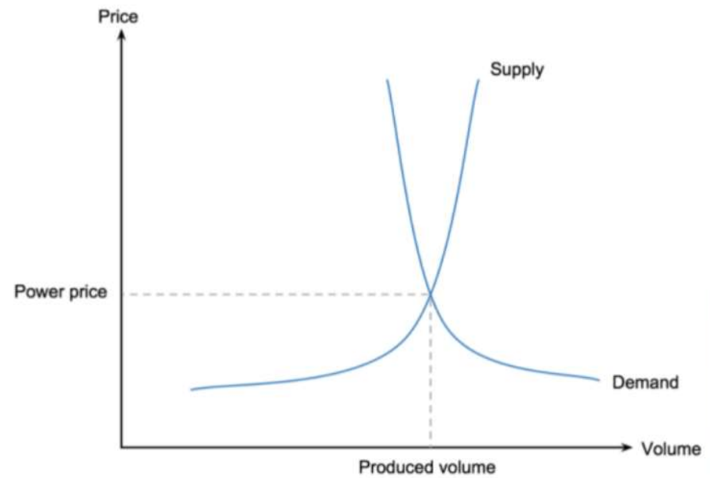


Source: Fortum, company information, 2020 figures pro forma

Nordic electrical energy market



The Nordic Elspot market clearing procedure at the day-ahead



The Nordic Elspot market equilibrium, general illustration

doi.org/10.1002/we.2383
Flow-Based Market Coupling in the Nordic Power Market, NHH 2019

Nordic power market prediction

- The market with renewables are characterized by **high volatility**. This creates a demand for securing future power prices. Large hydropower producers use a variety of instruments to **predict price changes**, and **sign derivatives contracts** to secure prices for parts of their production.
- **Predictability of costs and income** related to power prices are important both for producers, distributors and large-scale consumers in the Nordic power market.

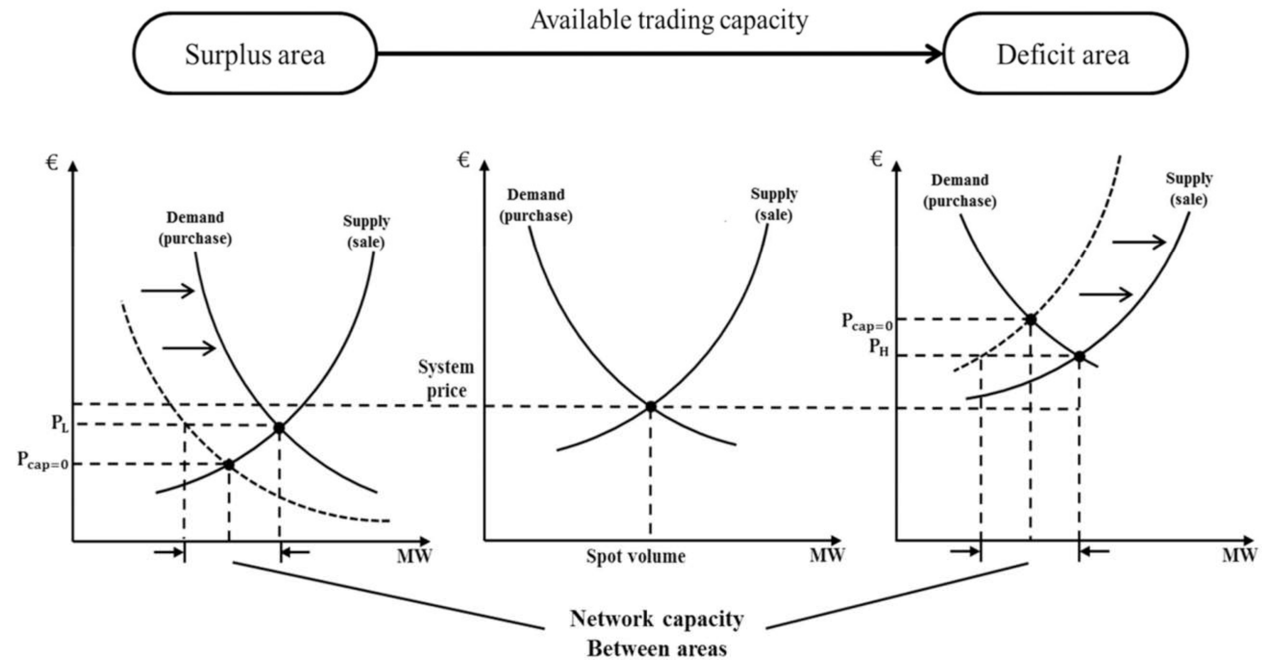
Nordic power market prediction

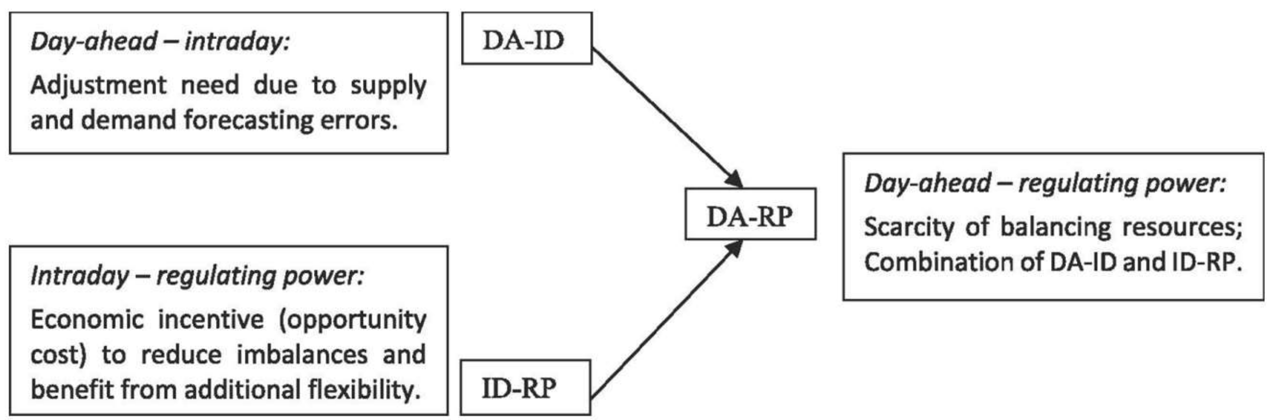
- Accurate electricity price forecasting is **important** in deregulated market
- Market participants and transmission system operators (TSOs) rely on **price forecasting to set bidding strategies.**
- Transmission constraints exist, the energy for both day-ahead and real-time markets is **priced by locational marginal prices (LMPs)** .

- **Accurate LMP forecasting is complex**

1. LMPs are affected by market behaviours and depend heavily on transmission congestion.
2. Moreover, because electrical imbalances may typically occur from transmission bottlenecks, these issues reinforce extreme electricity price volatility – or even price spikes.

doi.org/10.1002/we.2383





doi.org/10.1049/iet-gtd.2014.0957

Nordic power market prediction

- **Grid Simulation Model (GSM)** widely used energy models (SINTEF).
- Wind power, hydropower, thermal power plants and consumption need to be included as inputs to the model.

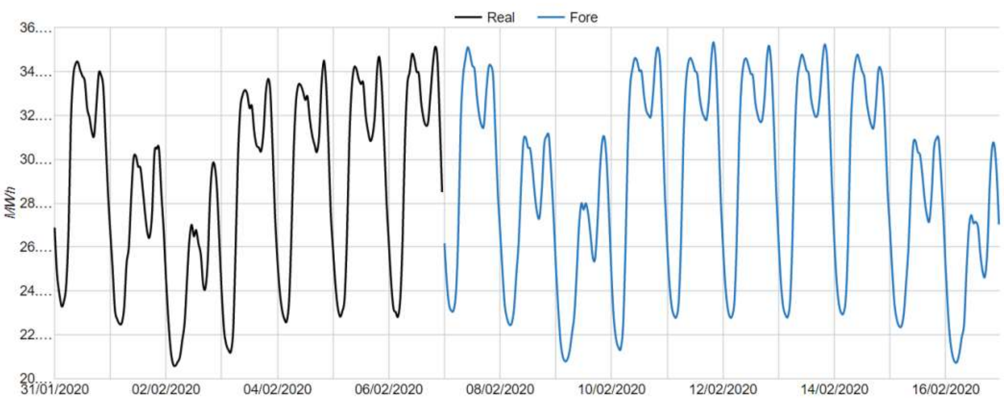
- The model takes limitations in **transfer capacity and geographical hydrological differences** into account (SINTEF).

Prediction practice

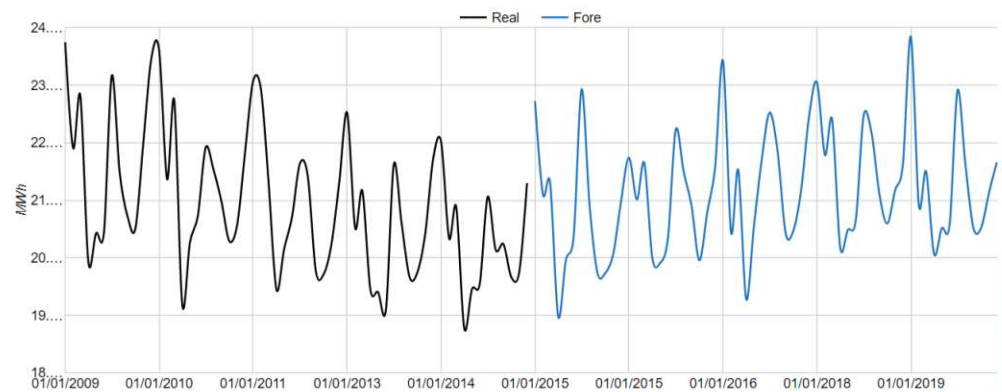
- Power production and consumption
- Temperature
- Precipitation
- Water equivalent of surface snow
- Gas, coal, oil price
- U.S. dollar exchange rate (in Nasdaq)
- CO2 price
- **Wind, solar etc. factors**

Prediction practice

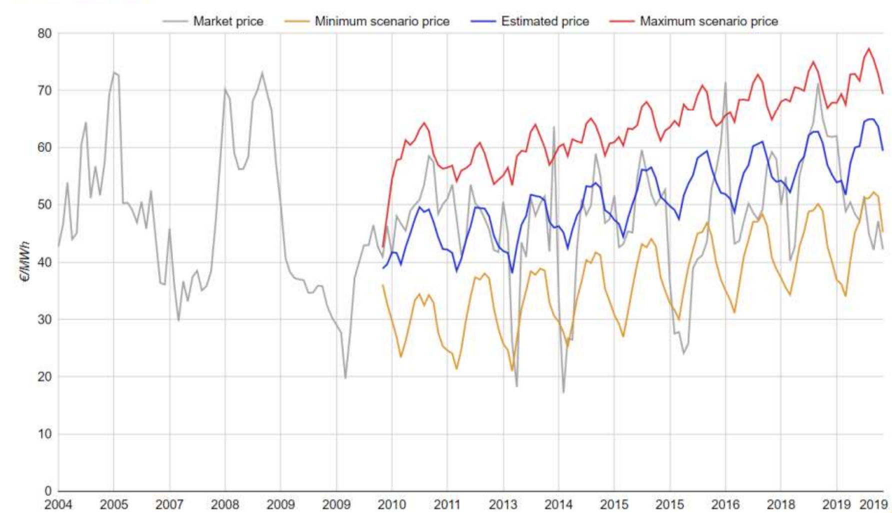
AleaDemandShort



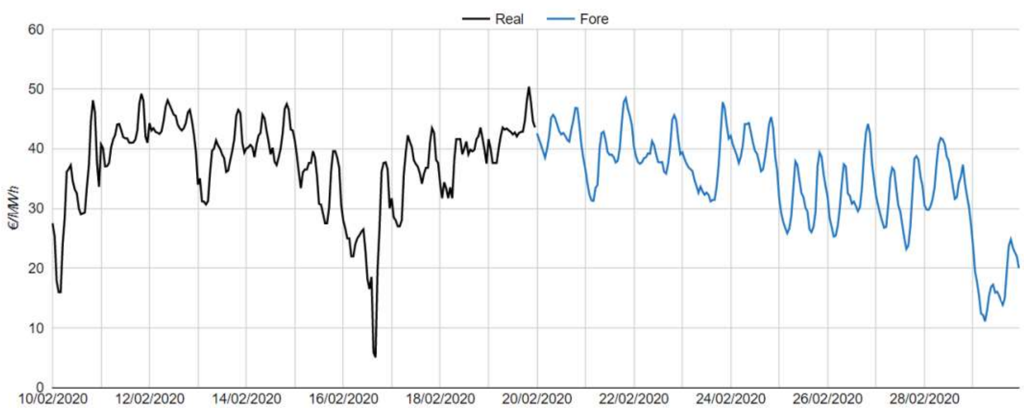
AleaDemandLong



AleaPriceLong



AleaPriceShort



AleaSoft

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3. **Increasing wind energy in grid**
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Wind power intermittency in system

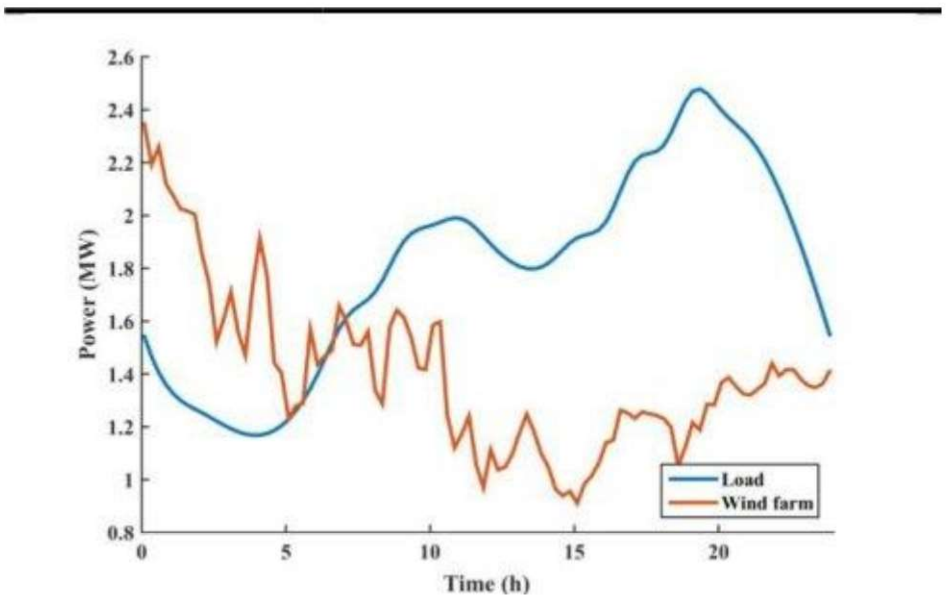
- Generated amounts of wind power **fluctuate considerably** over time due to weather patterns.

- A specific feature of power systems is that demand is **typically inelastic**, the **balance** between production and consumption should always be maintained.

- Wind power and other renewables have the **drawback of intermittency** which may cause **system imbalances** at a very short notice.

Wind power forecast errors effect

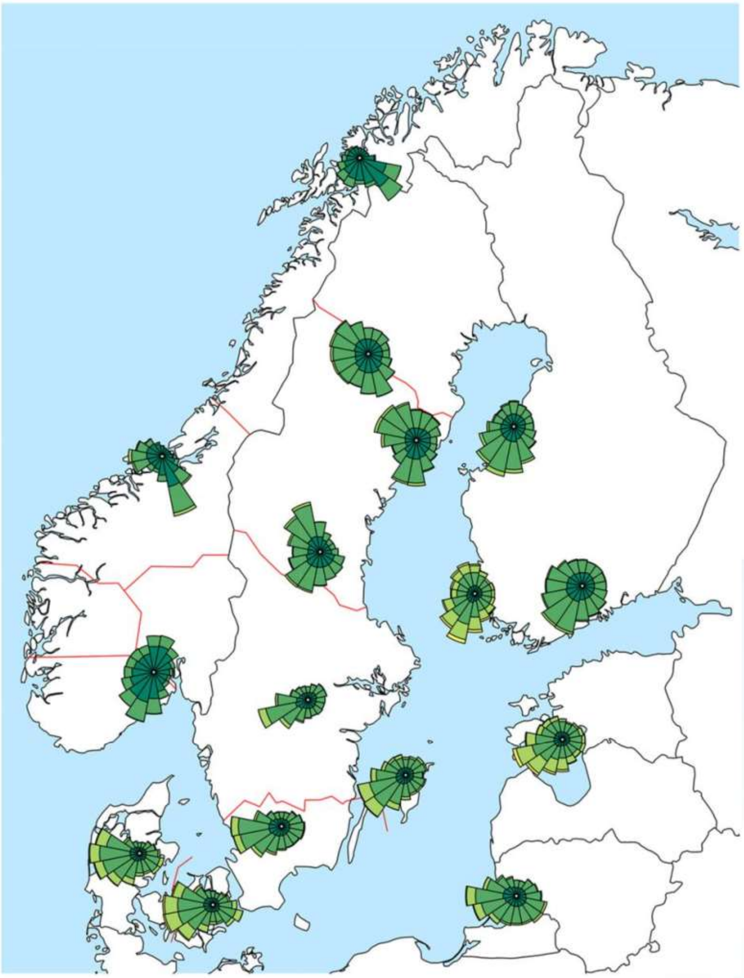
Daily load curve and output of wind farm



The forecast errors have an impact on the power system

(i) increasing the yearly balancing volume

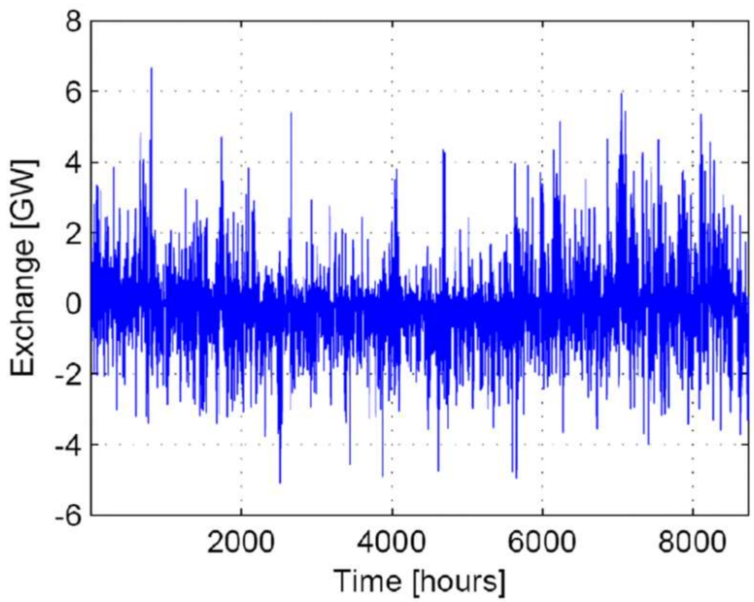
(ii) increasing the maximum anticipated real-time balancing need.



Wind rose map for wind directions at 100 m height from the reanalysis model 2017

ECMWF: ‘ERA5 data documentation’.

- Increasing wind power penetration with its uncertain production on all time scales will largely affect the system operation, requiring a higher flexibility and thus more reserve capacity providing balancing energy.



Hourly balancing energy exchange from Nordic to continental Europe in 2020 without reservation of transmission capacity.

bmwi-energiewende.de

DOI: 10.1109/TSTE.2012.2203157

Ensuring short term reliability

- Operating reserves BALANCING CHALLENGE
- Stability STABILITY CHALLENGE

↓

- Changing operational practices – sharing reserves with neighbors, faster operation
- Reduces need for short-term reserve more than added wind

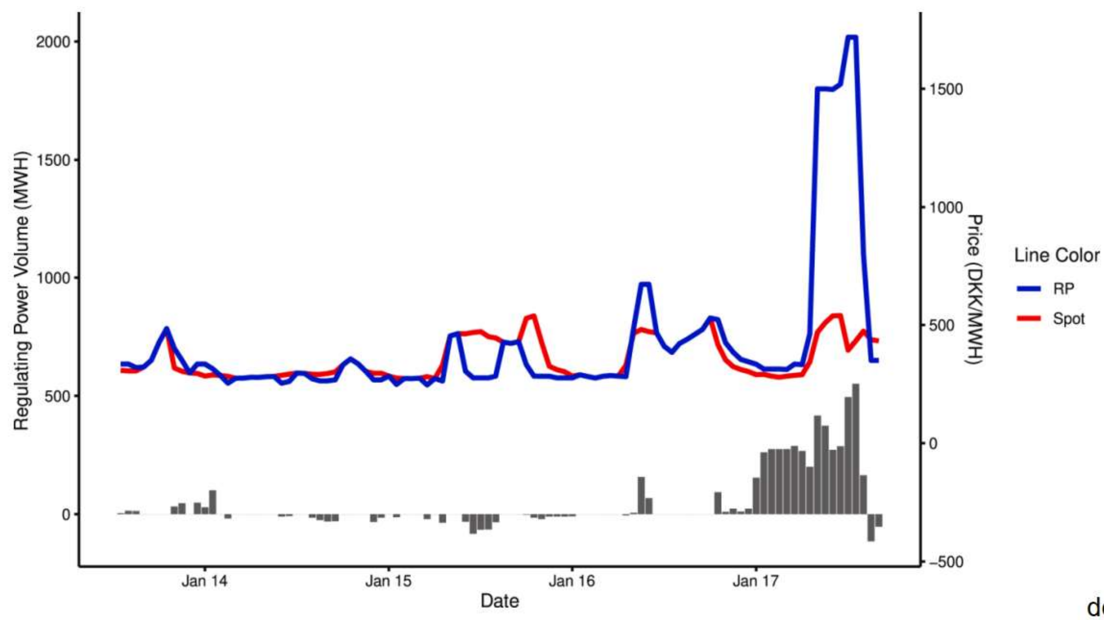
Balancing power market

- Nord Pool has a system known as **the balancing power market (BPM)** for dealing with these imbalances.
- Only producers who can produce power **within 15min** notice can participate in the BPM, along with some major consumers.
- Therefore, a balancing power producer uses typically either hydropower, gas turbines or combined heat and power.

doi.org/10.1016/j.eneco.2021.105381

Balancing power market

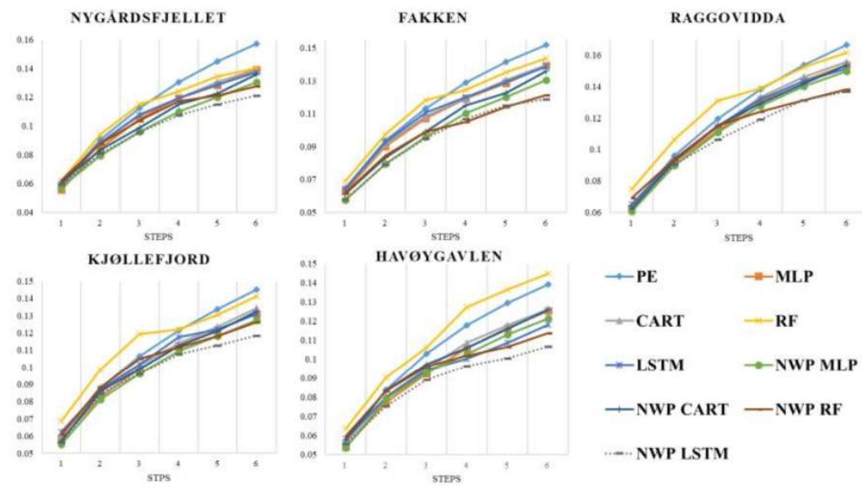
	Up-regulation	Down-regulation
Produces too little	Balancing power price	Spot price
Produces too much	Spot price	Balancing power price



doi.org/10.1016/j.eneco.2021.105381

Balancing power market

- Wind power producers have a **natural disadvantage** in the market because of **the lower predictability** of produced amounts.
- This can lead to **high losses** for incorrect predictions if the producers in the BPM can make last minute changes to their bids.



- **Reduce the time** between bidding in the day-ahead market and BPM
- Organizing the first round of bidding **on an hourly basis a few hours before** the bidding BPM

(Prediction error decreases as the time between prediction and delivery gets shorter.)

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Case study

- **The impact of wind power and electricity demand on the relevance of different short-term electricity markets: The Nordic case**

Spodniak, Petr, Kimmo Ollikka, and Samuli Honkapuro. Applied Energy 283 (2021): 116063.

doi.org/10.1016/j.apenergy.2020.116063

Questions:

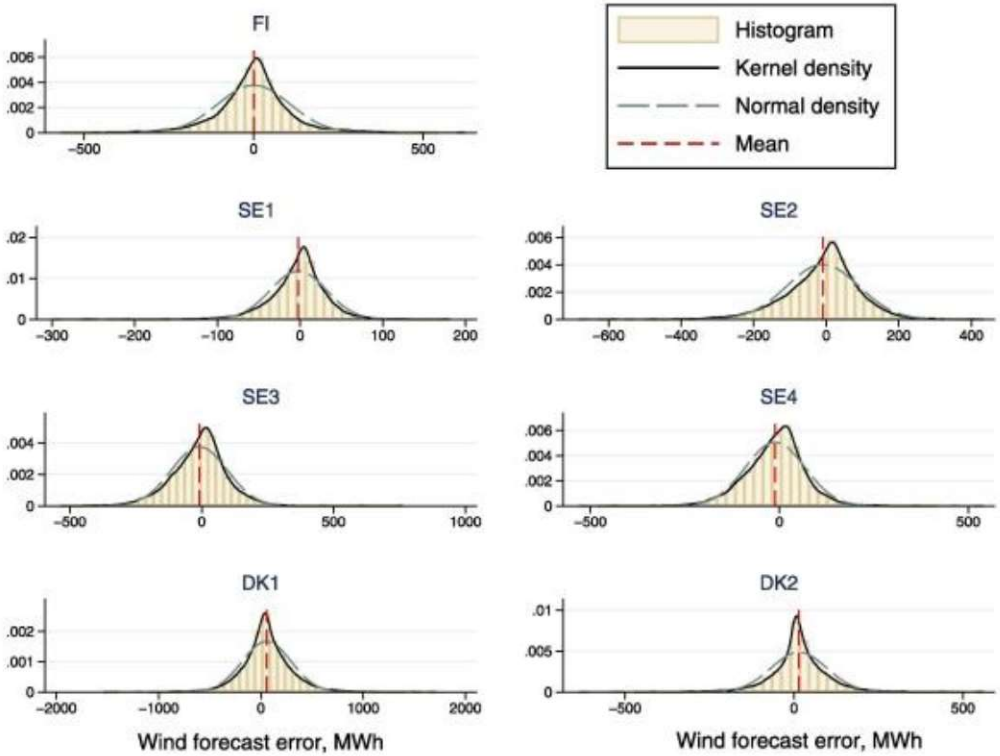
- How relevant is each electricity marketplace in power systems with increasing shares of vRES in Nordic countries?
- Is the dominant position of the day-ahead market diminishing and are the markets closer to real time becoming more important in terms of trading activity and price discovery?

Wind power generation (TWh) and the shares of wind power in total electricity production (%) in Nord Pool bidding areas in Finland (FI), Sweden (SE1-SE4), and Denmark (DK1-DK2).

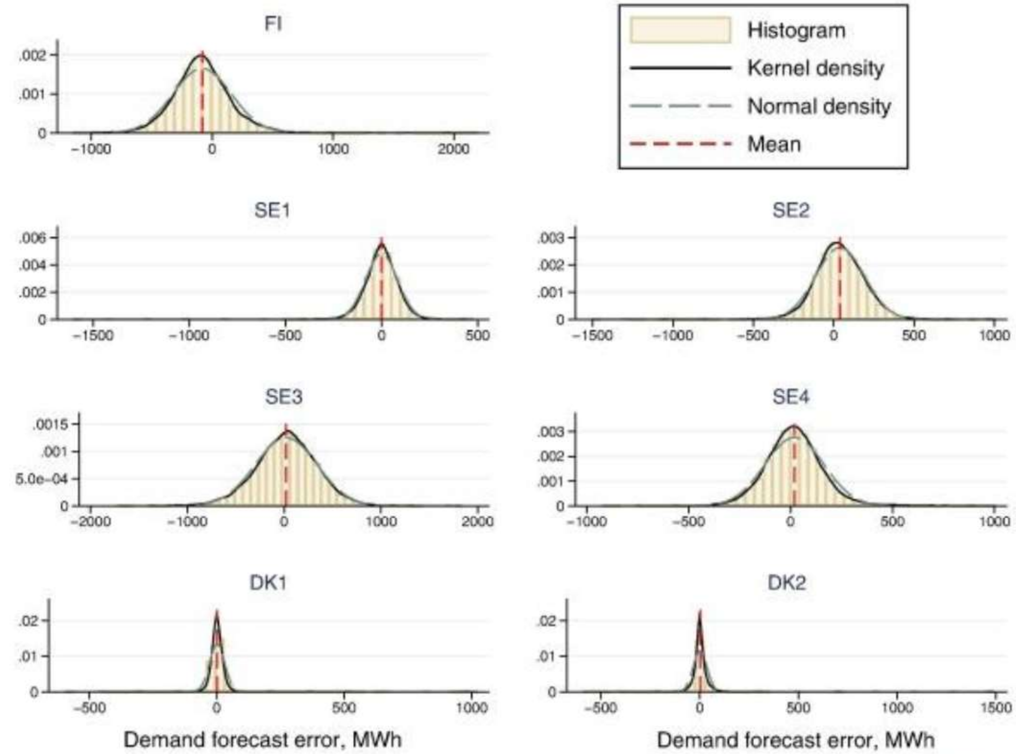
		2015	2016	2017
FI	TWh	2.1	2.8	4.1
	%	3.2%	4.4%	6.5%
SE1	TWh	1.4	1.3	1.4
	%	6.6%	5.6%	6.4%
SE2	TWh	4.7	4.9	5.4
	%	10.4%	12.9%	12.4%
SE3	TWh	5.5	5.5	5.8
	%	7.5%	6.6%	6.8%
SE4	TWh	3.8	3.8	4.3
	%	51.6%	50.2%	54.1%
DK1	TWh	10.8	9.4	10.9
	%	56.1%	48.7%	56.9%
DK2	TWh	2.9	2.4	3.0
	%	36.7%	29.6%	34.0%
FI-SE-DK	TWh	31.1	30.1	34.9
Total	%	13.0%	12.4%	14.0%

The mean of the forecast errors was slightly positive (overforecast) in Denmark (DK1-DK2) and negative (underforecast) in Sweden (SE1-SE4).

The very high kurtosis (peakedness) of the Danish demand forecast errors was due to a couple of rare events



Distribution of wind forecast errors for Finland (FI), Sweden (SE1-SE4), and Denmark (DK1-DK2) from 2015 to 2017.



Demand forecast errors for Finland (FI), Sweden (SE1-SE4), and Denmark (DK1-DK2). 2015–2017.

Methods

Dynamics of three electricity market prices in a vector autoregression (VAR) with the linear functions of their own lags, the lags of every other variable in the vector, and exogenous variables.

We focused on three endogenous (response) variables, namely, price spreads (DA-ID, DA-RP, ID-RP), wind forecast errors, and demand forecast errors in 7 bidding areas (3 countries), which gave us 63 response variables that were studied for the years from 2015 to 2017[15]. The VAR model is specified in Eq. (3) as follows:

$$y_t = \alpha_0 + A_1 y_{t-1} + \cdots + A_p y_{t-p} + B x_t + \epsilon_t \tag{3}$$

where y_t is a 3x1 vector of endogenous variables (PriceSpread$_t$, $WindError_t$, $DemandError_t$)', $x_t = (x_{1t}, x_{2t}, \cdots x_{dt})$ ' is a dx1 vector of exogenous variables, A_i are 3x3 matrices of the lag coefficients to be estimated, B is a 3xd matrix of the exogenous variable coefficients to be estimated, α_0 is a 3x1 vector of the constant terms, and ϵ_t is a 3x1 vector of the white noise innovation process, with $E(\epsilon_t) = 0$, $E(\epsilon_t, \epsilon_t') = \Sigma_\epsilon$, and $E(\epsilon_t, \epsilon_s') = 0$ for $t \neq s$.

Because correlation does not necessarily imply causation and because we were primarily interested in the latter, we focused on testing the causality among our endogenous variables. Granger defined a testable definition of causality that tests whether, for instance, y2 causes y1 by testing whether the lagged values of y2 improve the explanation of y1 in comparison to using the lags of the y1 process alone.

Results

The main finding from the table was that spreads in the areas with large shares of wind power were significantly driven by wind forecast errors, especially in DK1, DK2 and SE4. Moreover, when looking at the test statistics for the whole period, it seemed that the wind forecast errors did not cause spreads in bidding areas with lower shares of wind power generation (FI, SE1, SE2), at least in the case of DA-ID spreads.

Table 7
Granger causality between wind and demand forecast errors and price spreads

DA-ID

	Wind forecast error 2015	Wind 2016	Wind 2017	Wind 2015–2017	Demand forecast error 2015	Demand 2016	Demand 2017	Demand 2015–2017
FI	0.433	0.438	0.015**	0.152	0.003***	0.013**	0.000***	0.000***
SE1	0.687	0.599	0.542	0.454	0.921	0.495	0.145	0.418
SE2	0.602	0.158	0.008***	0.751	0.000***	0.684	0.002***	0.141
SE3	0.669	0.386	0.048**	0.493	0.000***	0.173	0.013**	0.000***
SE4	0.056*	0.031**	0.008***	0.004***	0.016**	0.242	0.000***	0.070*
DK1	0.000***	0.000***	0.012**	0.000***	0.900	0.008***	0.769	0.513
DK2	0.002***	0.281	0.000***	0.000***	0.010**	0.146	0.770	0.193

DA-RP

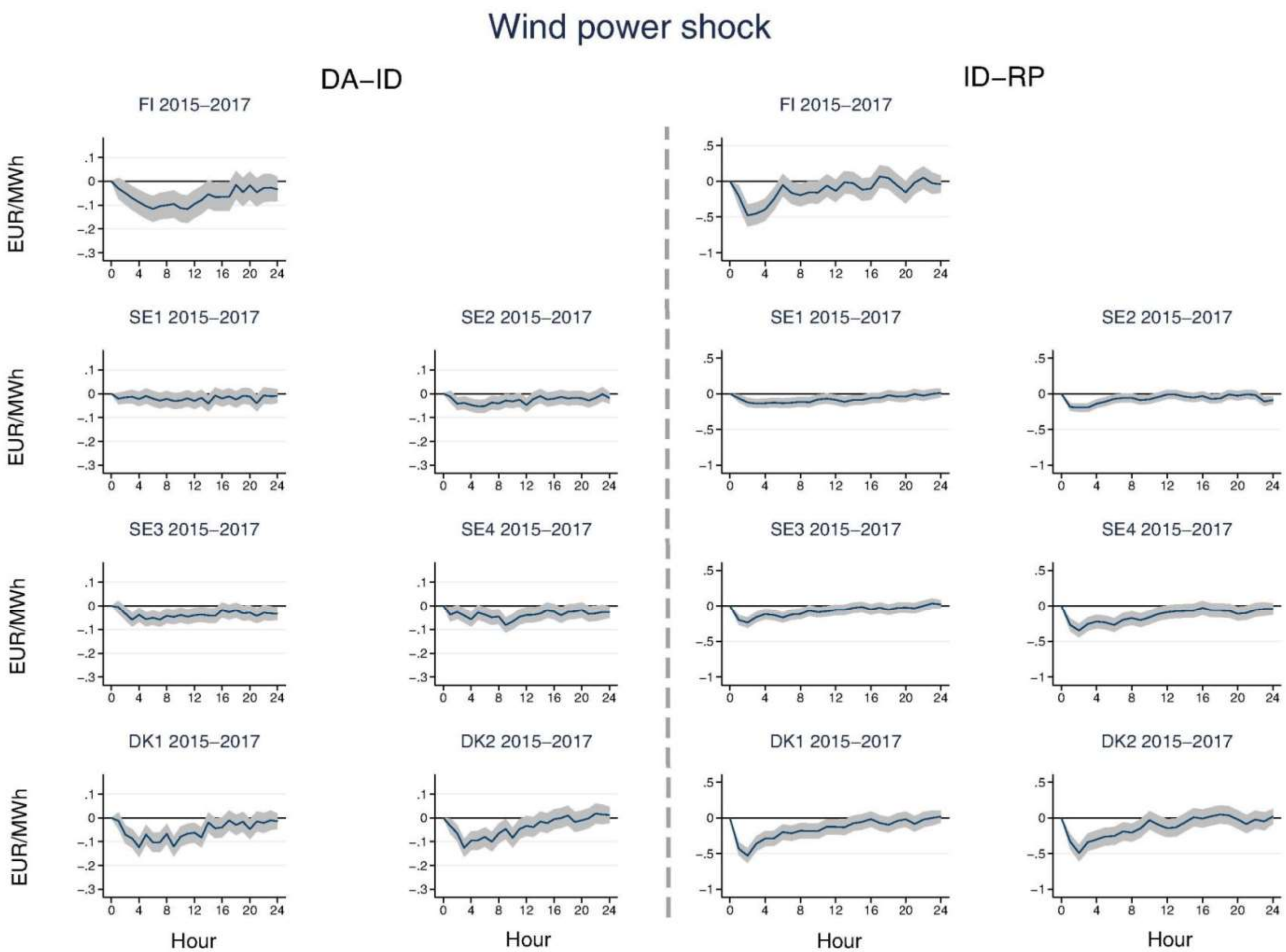
	Wind forecast error 2015	Wind 2016	Wind 2017	Wind 2015–2017	Demand forecast error 2015	Demand 2016	Demand 2017	Demand 2015–2017
FI	0.458	0.038**	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
SE1	0.029**	0.188	0.021**	0.000***	0.000***	0.000***	0.648	0.003***
SE2	0.203	0.435	0.115	0.006***	0.000***	0.000***	0.000***	0.000***
SE3	0.939	0.633	0.000***	0.034**	0.000***	0.000***	0.000***	0.000***
SE4	0.116	0.015**	0.065*	0.001***	0.000***	0.000***	0.000***	0.000***
DK1	0.000***	0.000***	0.000***	0.000***	0.025**	0.001***	0.057*	0.000***
DK2	0.000***	0.040**	0.000***	0.000***	0.002***	0.004***	0.538	0.003***

ID-RP

	Wind forecast error 2015	Wind 2016	Wind 2017	Wind 2015–2017	Demand forecast error 2015	Demand 2016	Demand 2017	Demand 2015–2017
FI	0.533	0.037**	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
SE1	0.118	0.230	0.037**	0.003***	0.007***	0.000***	0.721	0.003***
SE2	0.184	0.060*	0.038**	0.001***	0.000***	0.000***	0.000***	0.000***
SE3	0.872	0.703	0.000***	0.041**	0.000***	0.000***	0.000***	0.000***
SE4	0.180	0.051*	0.152	0.009***	0.000***	0.000***	0.000***	0.000***
DK1	0.000***	0.000***	0.000***	0.000***	0.030**	0.000***	0.032**	0.000***
DK2	0.000***	0.038**	0.000***	0.000***	0.002***	0.010***	0.565	0.001***

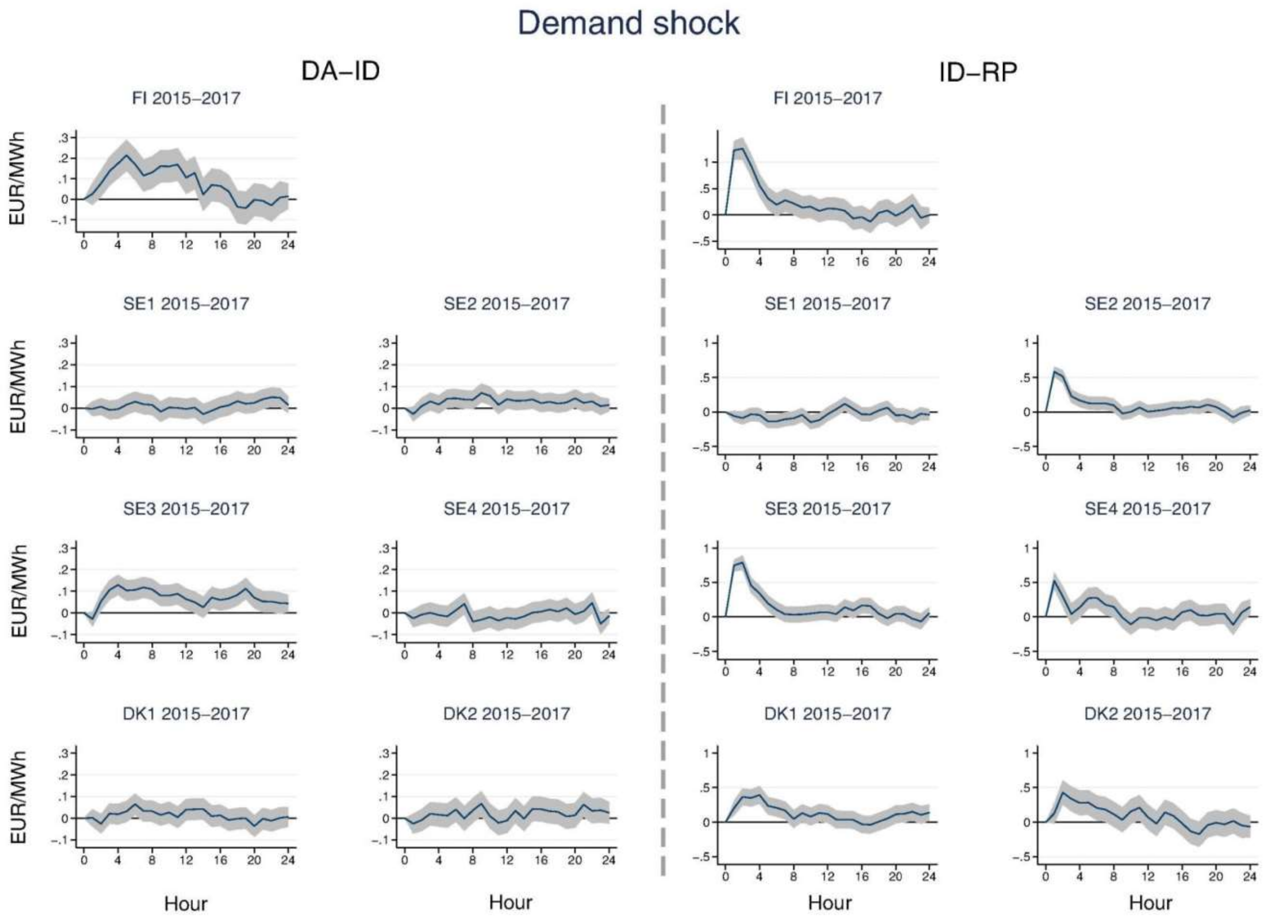
Note: The table shows the results of Granger causality test, which tests whether wind or demand forecast errors Granger cause the price spreads, i.e., divergence between the prices of wholesale electricity marketplaces. The table shows the p values of the χ^2 statistics with significance levels, where *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Test statistics are based on the model ignoring the price outliers of the regulating power (RP) markets, i.e., when $p < -150$ euro/MWh or $p > 400$ euro/MWh.

Effects of wind forecast errors on the price spreads



Impulse response functions showing responses of the price spreads ID-RP to shocks in wind forecast errors during the next 24 h in bidding areas FI, SE3 and DK1 for the whole study period from 2015 to 2017 (right column) and for each year separately. Note: The figure shows the responses of price spreads to one standard deviation in wind or demand forecast error during the following 24 h. The grey area represents the 95 percent confidence intervals. The IRFs are based on the model ignoring the price outliers of the regulating power (RP) markets, i.e., when $p < -150$ euro/MWh or $p > 400$ euro/MWh.

Effects of wind forecast errors on the price spreads



Impulse response functions showing responses of the price spreads DA-ID and ID-RP to shocks in the demand forecast errors during the next 24 h in Finland (FI), Sweden (SE1-SE4), and Denmark (DK1-DK2) for the whole study period from 2015 to 2017. Note: The figure shows responses of price spreads to one standard deviation in wind or demand forecast error during the following 24 h. The grey area represents 95 percent confidence intervals. IRFs are based on the model ignoring the price outliers of the regulating power (RP) markets, i.e., when p < -150 euro/MWh or p > 400 euro/MWh.

Discussion

- Wind **forecast errors did affect** the price spreads in areas with **large** shares of wind power generation.
  E.G. Denmark and in southern Sweden

- For low share, no statistically significant effect.
  E.G. northern Sweden and Finland

- Demand forecast errors did have an impact on almost all price spreads. Also has a threshold for spread.

- Quantitative threshold for the wind and demand forecasts could be an interesting avenue

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Conclusion

- Nordic Power is **accelerating** its **green transition** in global warming.
- The Nordic electricity market has the **physical capacity** and the **financial means** to meet this transition.

- Wind energy, the most promising source of fast-growing energy, poses **problems** for grids due to its instability.
- The **volatility of wind power and the errors in wind power forecasts** not only present **electrical technical challenges**, but also place higher expectations on **power spot and futures trading mechanisms.**

❖ In summary, in handling REs in Nordic market, more **reserve energy**, **more accurate forecasting**, and **electrical technology** and **financial tools** need to be developed.

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Thank you for your attention!