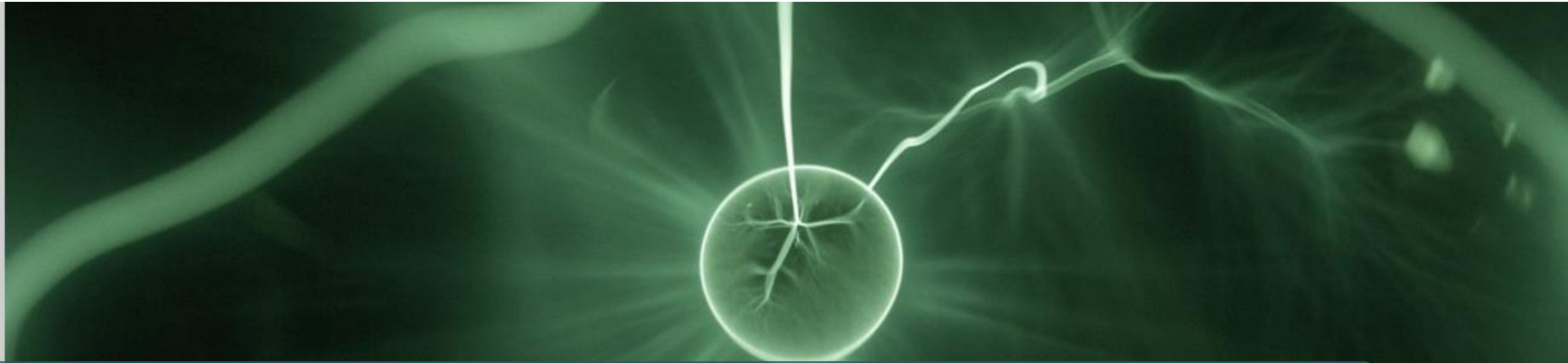

A report prepared for Heimdall Power – Final Report 11-08-2021

EFFECTS OF HIGHER AVAILABLE CAPACITY AND INCREASED MARKET INTEGRATION

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Executive Summary

In a study prepared for Heimdall Power, THEMA Consulting has studied the effects of increasing transmission capacities between and within bidding zones in the Nordic synchronous area. Investing in new lines or line upgrades are traditional ways of increasing available transmission capacities. Alternatively, one can increase the available capacities by applying new technologies or improving flow forecasts (e.g. measuring temperatures or other line data).

Overall, we identify the following benefits of increasing available transmission capacities:

- **Market integration:** Higher transmission capacities allow for tighter market integration, and contribute to price convergence between zones. Prices in low price zones increase (in particular with hours with excess renewable generation), and prices in areas with higher prices decrease (in particular in peak price hours). Instead of increasing capacities on all lines, a large effect is already observed when targeting the most utilised lines.
- **Increased RES output:** Transmission capacities can be a limiting factor for RES output, particularly in zones with excess power (e.g. Northern Sweden). This can lead to (voluntary) curtailment of RES generation, for example reduced output from onshore wind. When increasing transmission capacities, we observe a decrease in curtailment and hence an increase in renewable generation. This is an effect of both increasing trade capacities between zones and transmission capacities within zones. In zones with excess power, capture prices for RES increase, thereby also incentivising additional investments in renewable generation.
- **Reduced carbon emissions:** As RES output increases, carbon emissions decrease. A large part of the decrease would occur outside the Nordics, as the additional RES output is typically exported to Continental Europe and the UK. The reduction in carbon emissions would need to be weighted against the carbon footprint of the investment that increases the available capacity.
- **Security of supply:** Security of supply increases. In areas with higher prices and more frequent price spikes, we see that increased transmission lowers the number of hours in which these price spikes occur.
- **Welfare:** Overall, generation assets can be better utilized across the Nordic system, resulting in an overall welfare gain when considering changes in consumer and producer surplus. Please note that any increase in welfare would need to be calculated against costs for investing in increasing transmission capacity. Such calculations were outside the scope of the assignment.
- **Other considerations (non-model based)**: An increase in transmission capacities can also create opportunities for sector coupling and provide more room for new consumption. It could also reduce the need for reserves needed in the system.

THEMA studied the effect of increased grid integration on behalf of Heimdall

Background

- The energy transition implies increasing amounts of intermittent generation and increasing peak demand.
- In this context, available grid capacity, both between markets and within bidding zones, is an important element.
- In general, increasing the available capacity can contribute to price convergence and tighter market integration, reducing curtailment of renewable generation, and increasing security of supply.

Options for increasing grid capacity

- The traditional way of increasing capacity is to build new or upgrade existing transmission lines.
- An alternative way is to use new technologies to increase available capacity, for example by better estimating security margins or power flows.
- The dynamic line rating provided by the Heimdall Power neuron can, according to Heimdall, enable grid operators to utilize more of their transmission capacities.

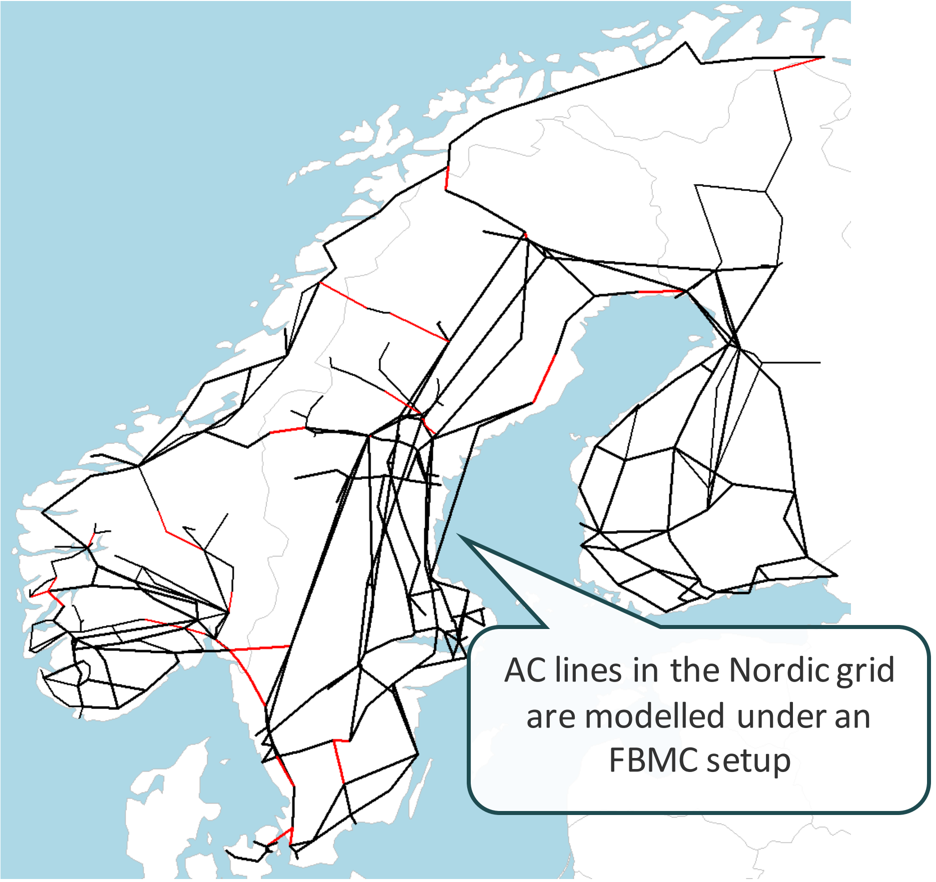
THEMA's analysis in this context

- In our study for Heimdall, we assess the overall affect of increased grid integration from a high-level perspective.
- However, we assumed an increase in available capacity that is of similar magnitude to what Heimdall claims its technology can achieve, namely a 25% increase. In reality, this number may vary per line and by time of year, but was used as a general proxy. In order to test the robustness of the results, we also ran additional sensitivities with alternative values or with upgrades only being applied to certain lines.
- The scenarios presented here are meant to illustrate potential effects of increased grid integration, and are not to be mistaken as predictions.

Our analysis focuses on the year 2030, with varying assumptions on trade capacities

We model 4 different scenarios to determine the effect of higher available capacity of the AC lines in the power market

We use grid data with a FBMC setup to model the Nordic grid



Modelled scenarios and scenario setup

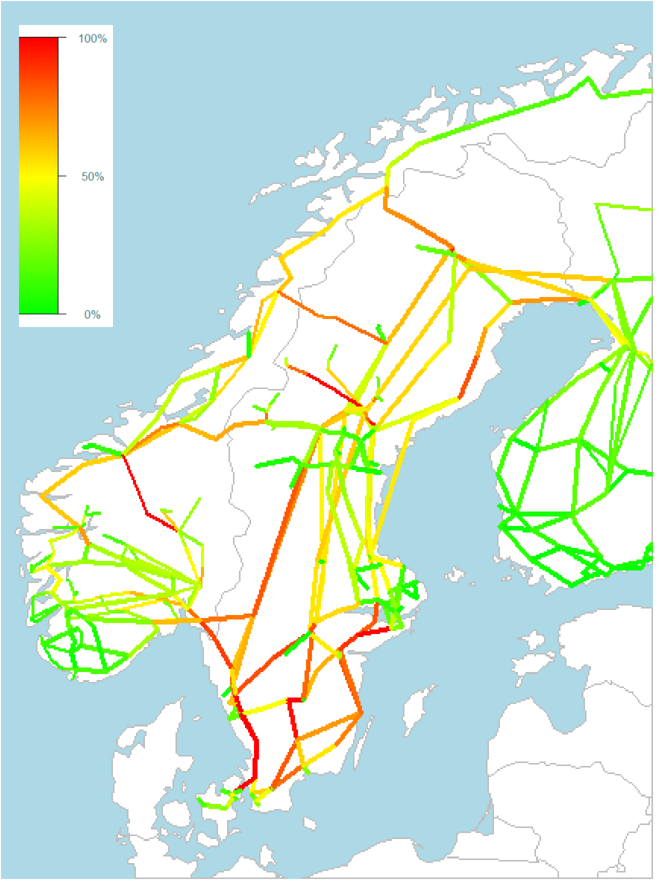
- We model the Nordic synchronous area and consider prices outside the Nordics as exogenous.
- We used a grid model in combination with a market model using a flow-based-market-coupling (FMBC) algorithm to model the power market and the outcome for different line upgrades. The grid model and data was used to determine the so-called power-transfer-distribution-factors (PTDFs) and trade capacities (often referred to as RAMs – reliable available margins) that were then used in the market simulations.
- We then modelled 4 different scenarios for the year 2030 :
  - **Base Scenario**: We model the Nordic market for 2030 under the current grid and include all expected upgrades as stated by each country's TSO's development plans.
  - **Increased Capacity – All lines 10%** : We assume that all AC lines' RAM is increased by 10%. This is lower than the 25% stated by Heimdall, and used to see the sensitivity of results.
  - **Increased Capacity – Selected Lines:** We assume that the most utilized lines' RAM is increased by 25%. We use the utilization degree of each line as criteria for selection. We selected the most utilised quintile (20%) of the lines and increased their capacity by 25%.
  - **Increased Capacity – All lines**: We assume that all AC lines' RAM rises by 25%.

An increase in transmission capacity decreases congestions

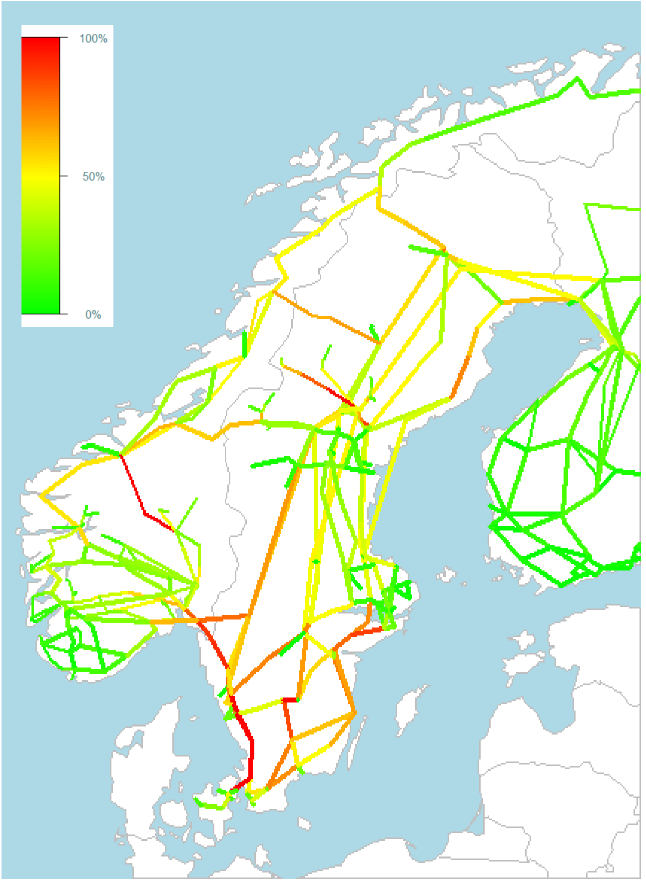
Commentary

- The utilisation of lines varies significantly across the Nordic synchronous area. Utilisation can be an indicator for where the critical bottlenecks in the system are.
- When increasing the available line capacities in the Nordic synchronous area, we see that the utilisation decreases, as one would expect.
- This concerns also some critical North-South lines in Sweden, that can be a bottleneck in the Nordic system.

Line utilization in 2030 in the Reference scenario



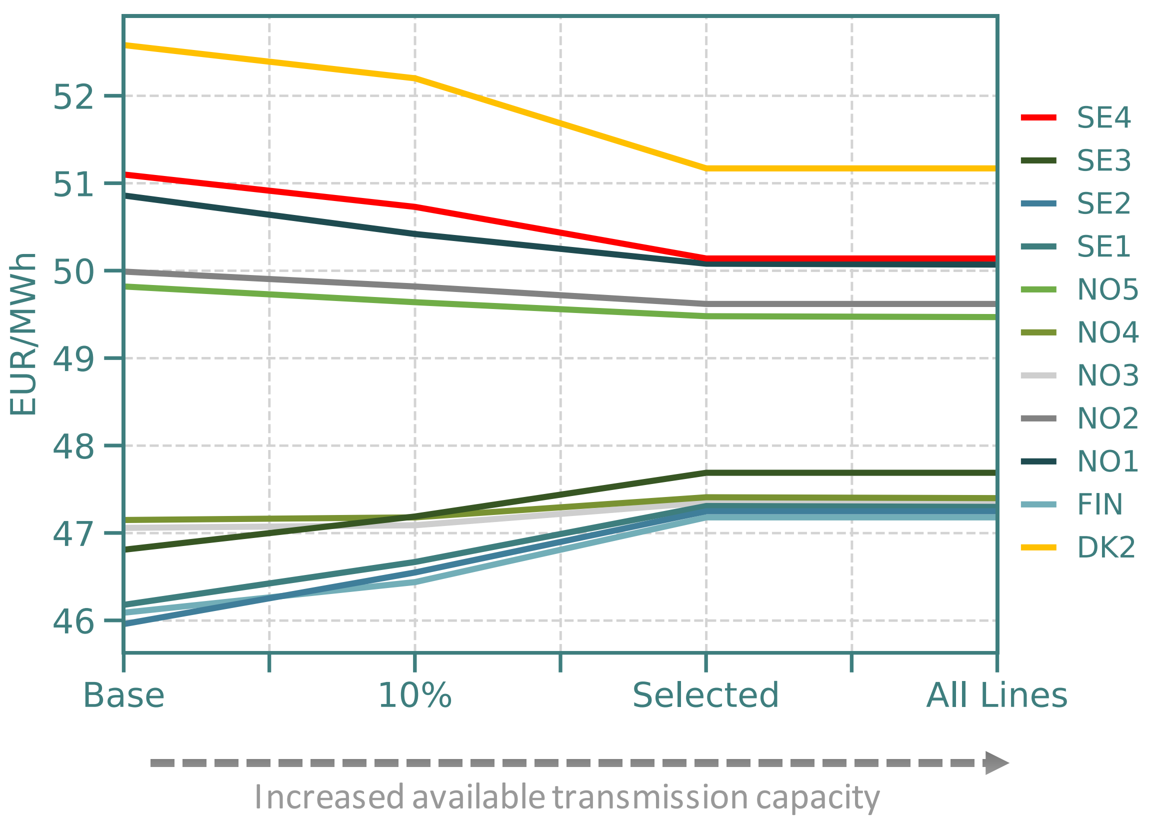
Line utilization in 2030 with increased capacity on all lines



Increased transmission capacity leads to price convergence

Price convergence can lead to increased market integration and also foster liquidity in financial markets

Power Prices in Nordic Zones in all scenarios for 2030



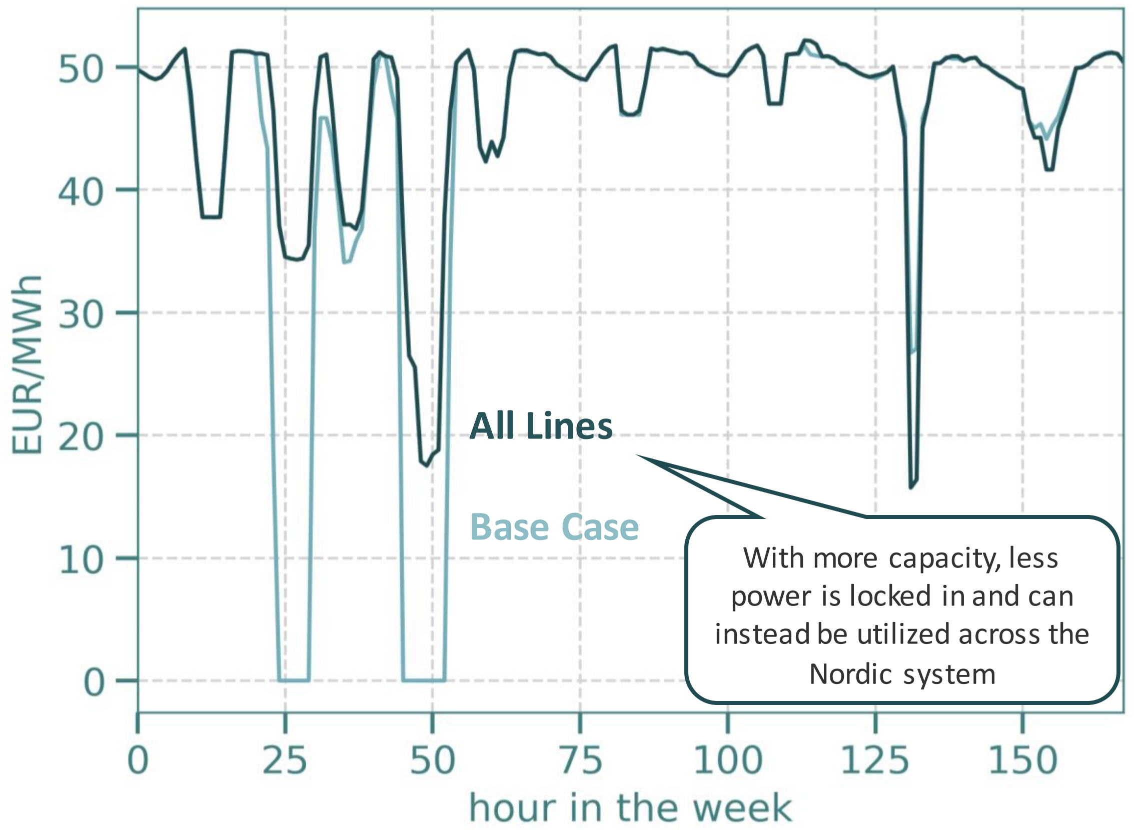
Commentary

- We observe price changes in the magnitude of +/- 0.25-1.40 EUR/MWh in ***the All Lines scenario*** compared to the ***Base case***.
- The additional 25% available capacity on AC lines allows for higher price zones to benefit from cheaper power generation, while prices in low-price zones increase, also increasing the value of generation in these zones.
- Even with a 10% increase in capacity, prices experience a change in most zones (albeit to a lower extent) as seen in the ***10% scenario***. In this case, the price change lies in the range of +/- 0-0.6 EUR/MWh.
- If the technology is applied only to selected lines (those with the highest utilization degree), a similar effect could be achieved in terms of price effect, as shown in the ***Selected Lines Scenario***. Thus, applying grid upgrades to the most utilized lines can already result in a significant effect.

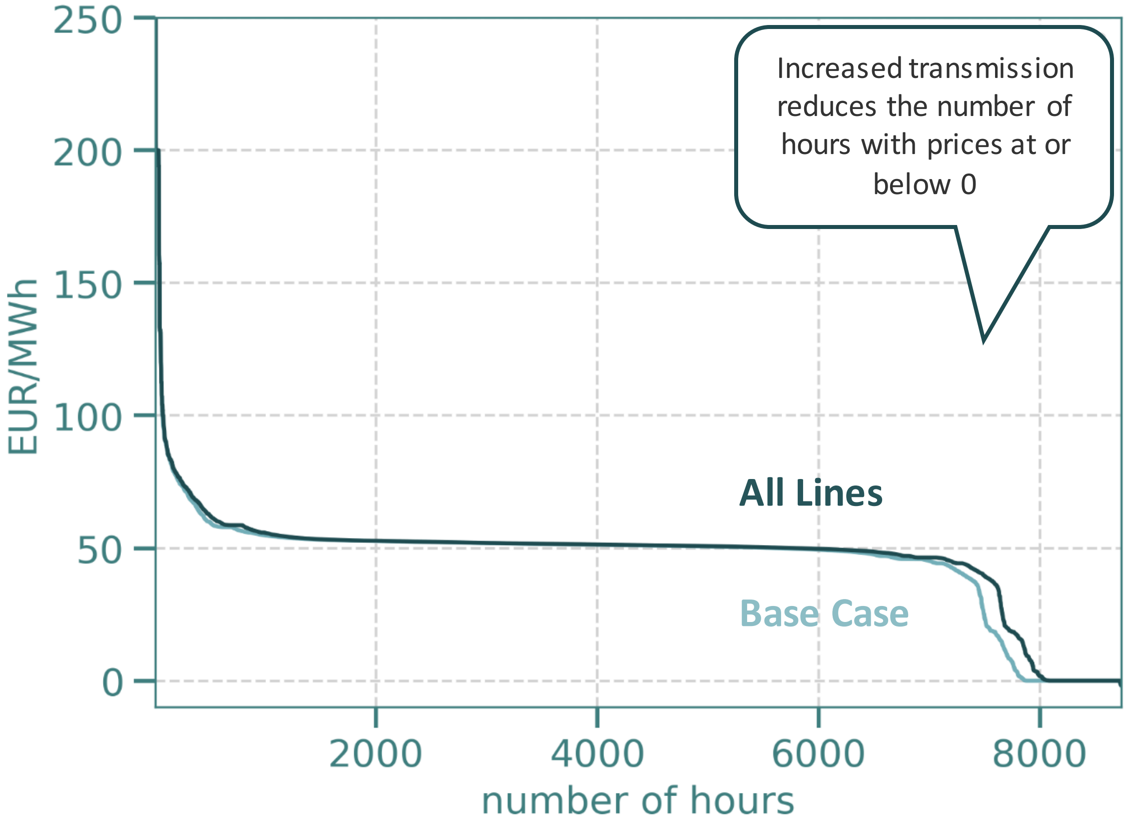
When looking at hourly data, we see that in particular very low price hours can be lifted

The increased transmission capacity decreases the amount of "locked-in" generation

Hourly prices in SE2 for Week 33



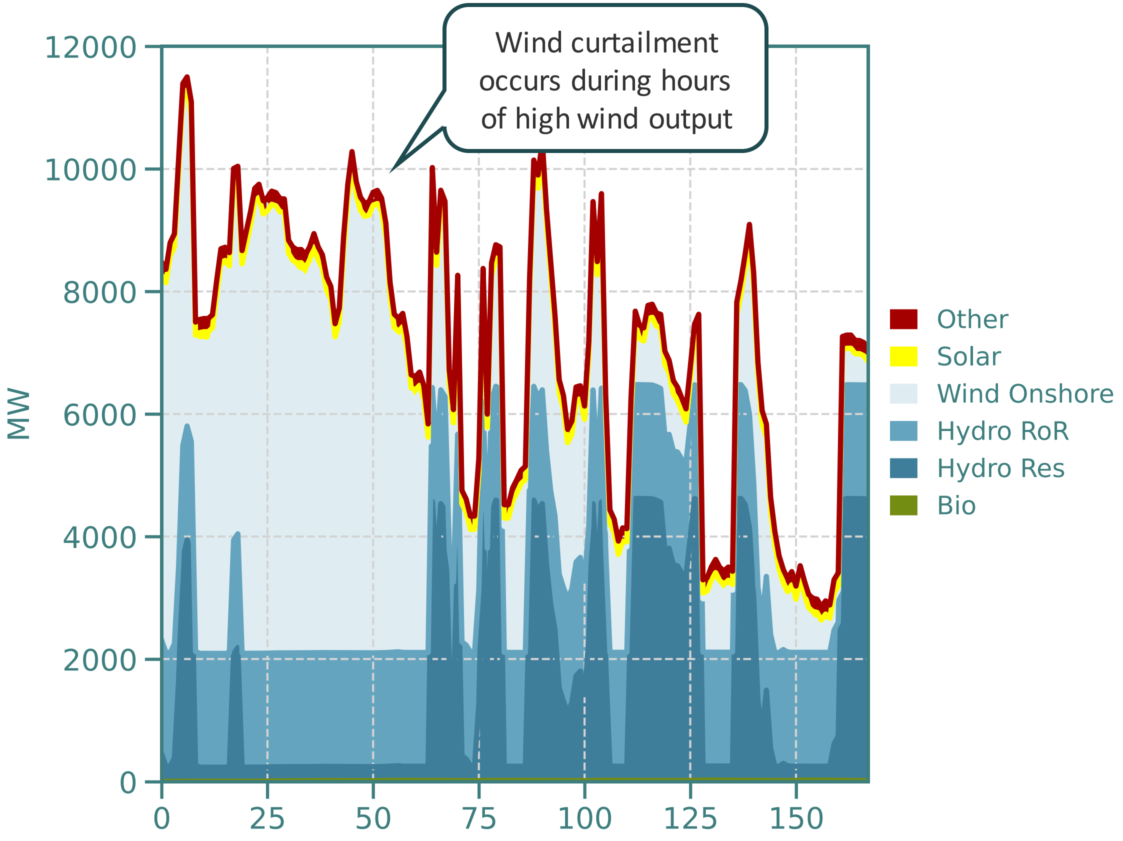
Price Duration Curve for SE2



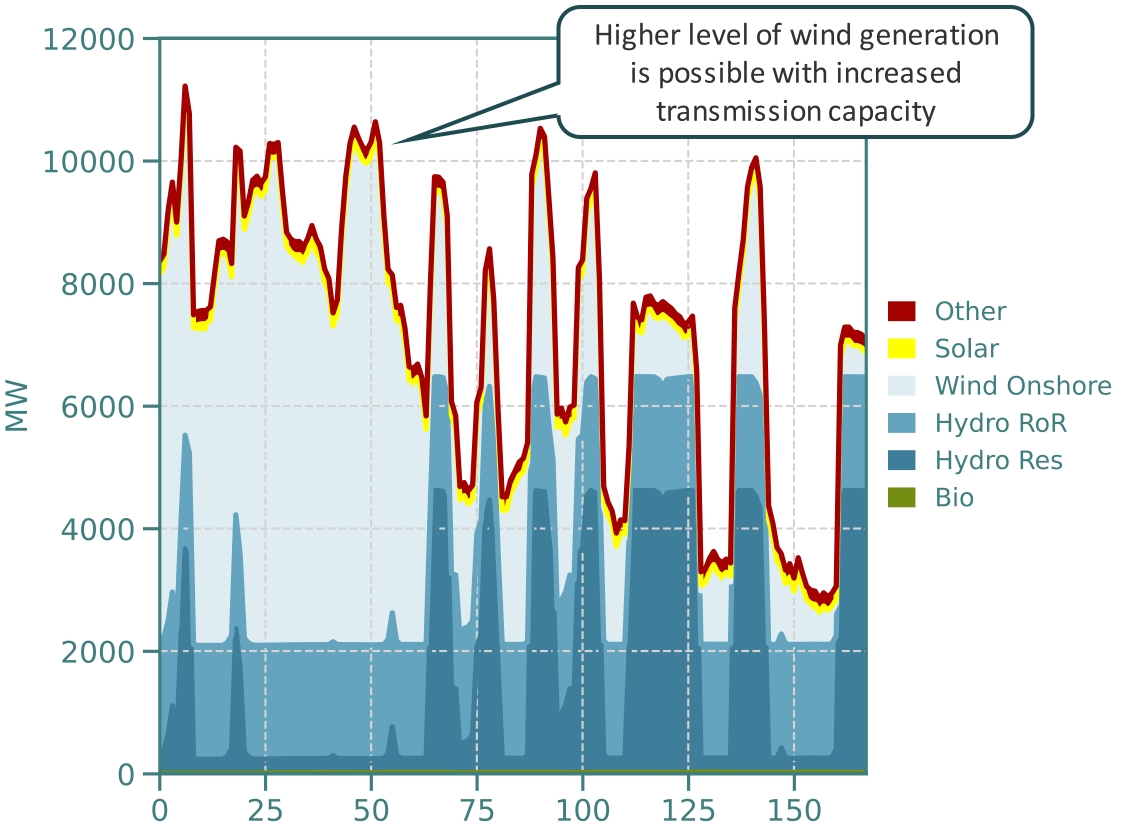
A consequence is that higher transmission availability reduces (voluntary) curtailment

Below is an example during a week with high RES production and the difference in generation between both scenarios

Generation in the Base Scenario for SE2 – Week 33



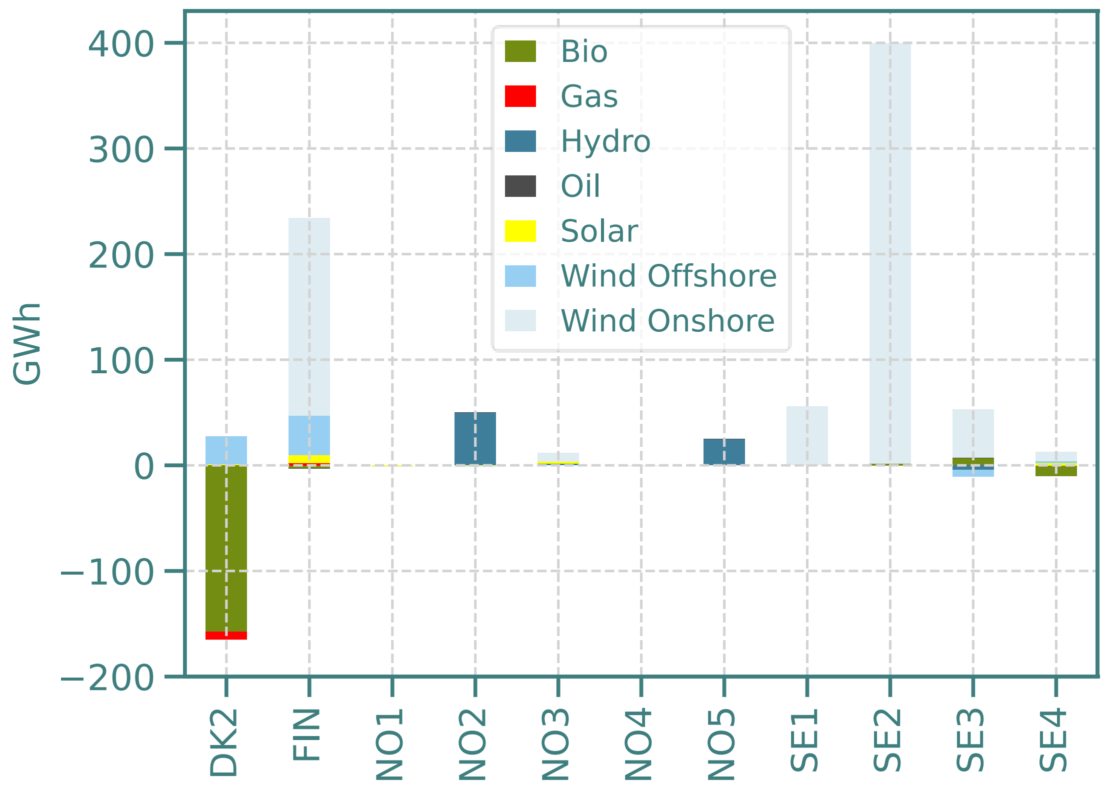
Generation Mix in the All Lines Scenario for SE2 – Week 33



As a result, increased transmission decreases renewables curtailment

Overall, dispatchable generation decreases, while intermittent RES generation increases (e.g. wind onshore)

Generation change [GWh] (All Lines – Base) for 2030



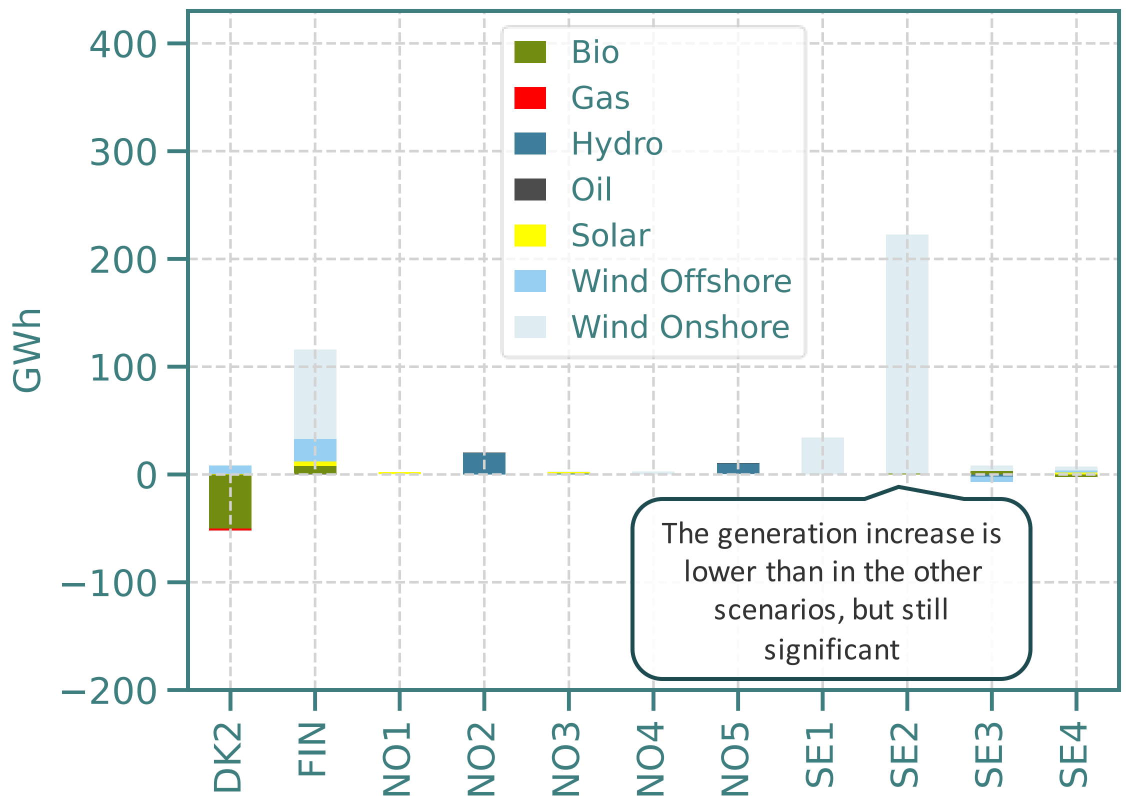
Commentary

- The increase in power generation can mostly be attributed to a decrease in curtailment, particularly that of wind onshore. The increased transmission capacity allows for the locked-in wind to be utilised, avoiding curtailment
- Other renewable sources, such as hydro and wind offshore, also increase their generation output, as seen in Norway and Denmark (DK2), or Finland.
- This increase in production allows for the decrease of some thermal generation, such as in DK2 (in this case Bio – assuming that Bio has flexibility).

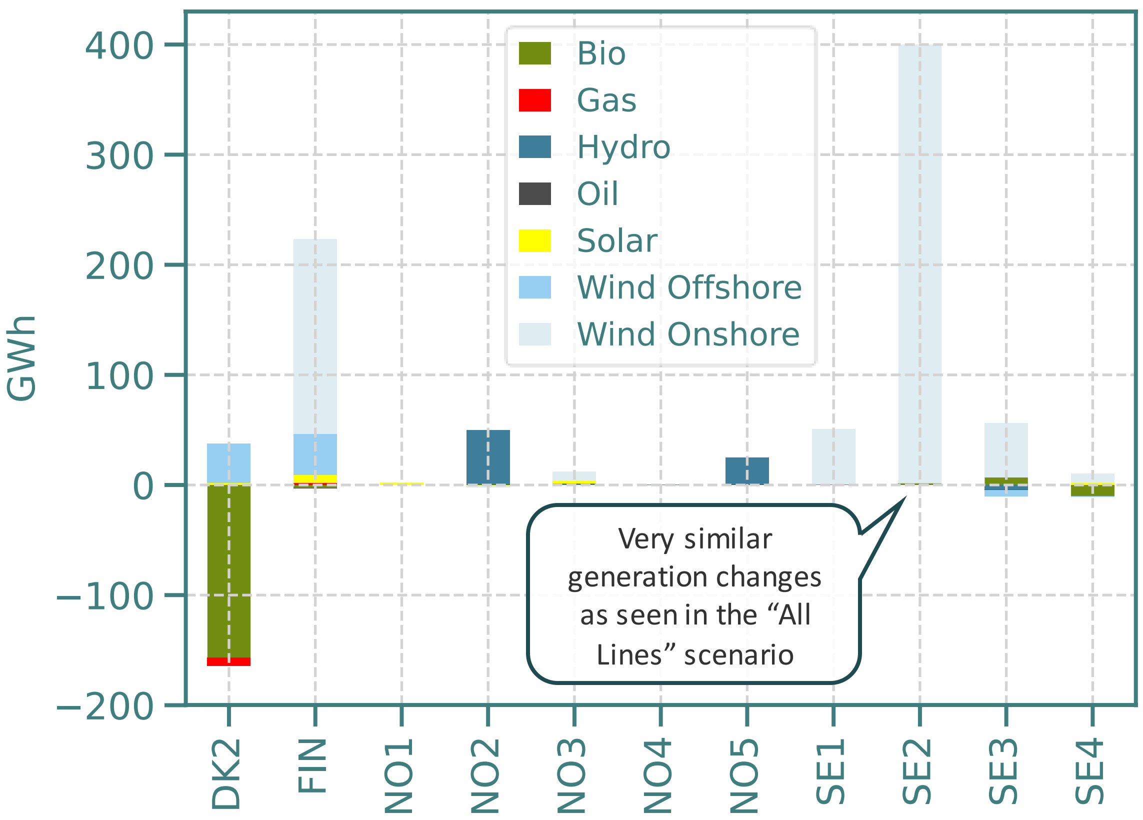
Also smaller changes in available capacity or on selected lines have a significant effect

Below a comparison for the case in which line capacity is increased by 10% or increased by 25% on selected lines

Generation Change [GWh] – (10% Scenario – Base)



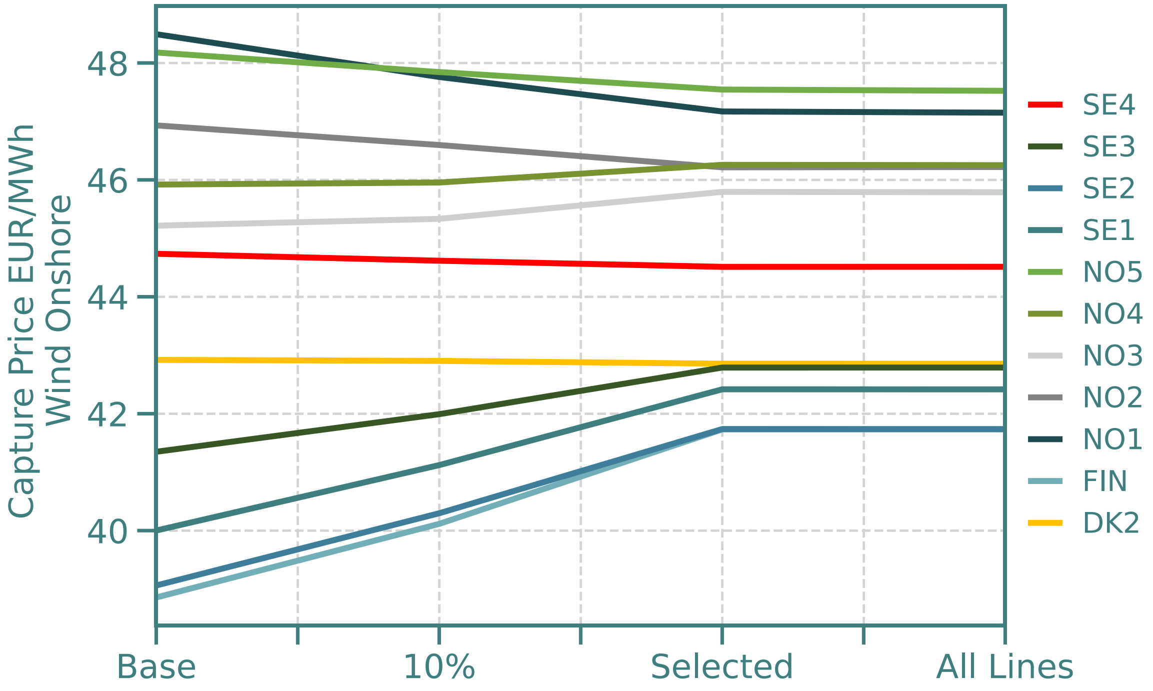
Generation Change [GWh] – (Selected Lined – Base)



Increased transmission capacities can incentivise new RES investments

Increase in capture prices resulting from increased transmission capacity makes investments more attractive

Onshore wind capture prices across scenarios



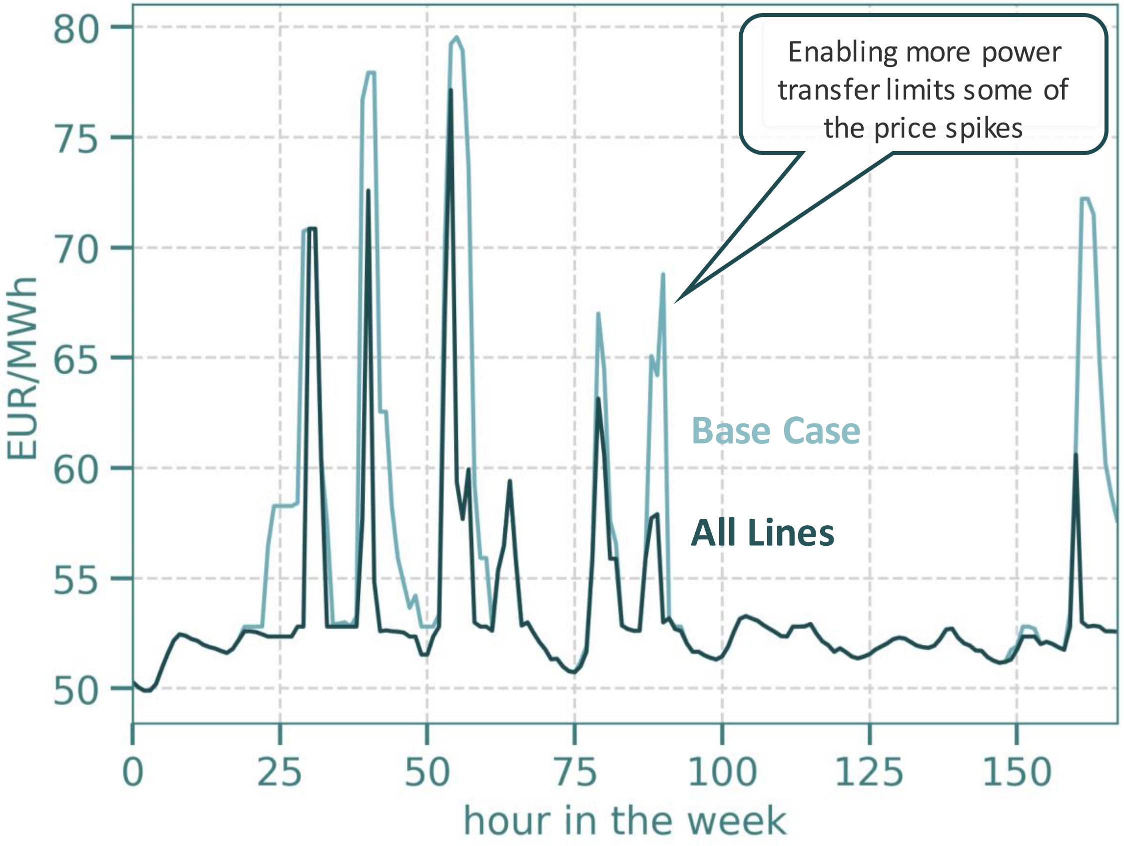
Commentary

- The areas with high onshore wind production, such as SE1, and SE2, receive higher capture prices as a result of increased transmission capacities.
- This can incentivise new investments in wind generation (or other intermittent sources), contributing to an even stronger generation increase in the long term (i.e. when considering the effect on investment).
- Note: In some areas, like NO5, wind revenues and capture prices can decrease somewhat. But in this case, the onshore build-out is limited due to political and regulatory limitations. So here, the commercial aspects are often not the limiting factor for wind build-out.

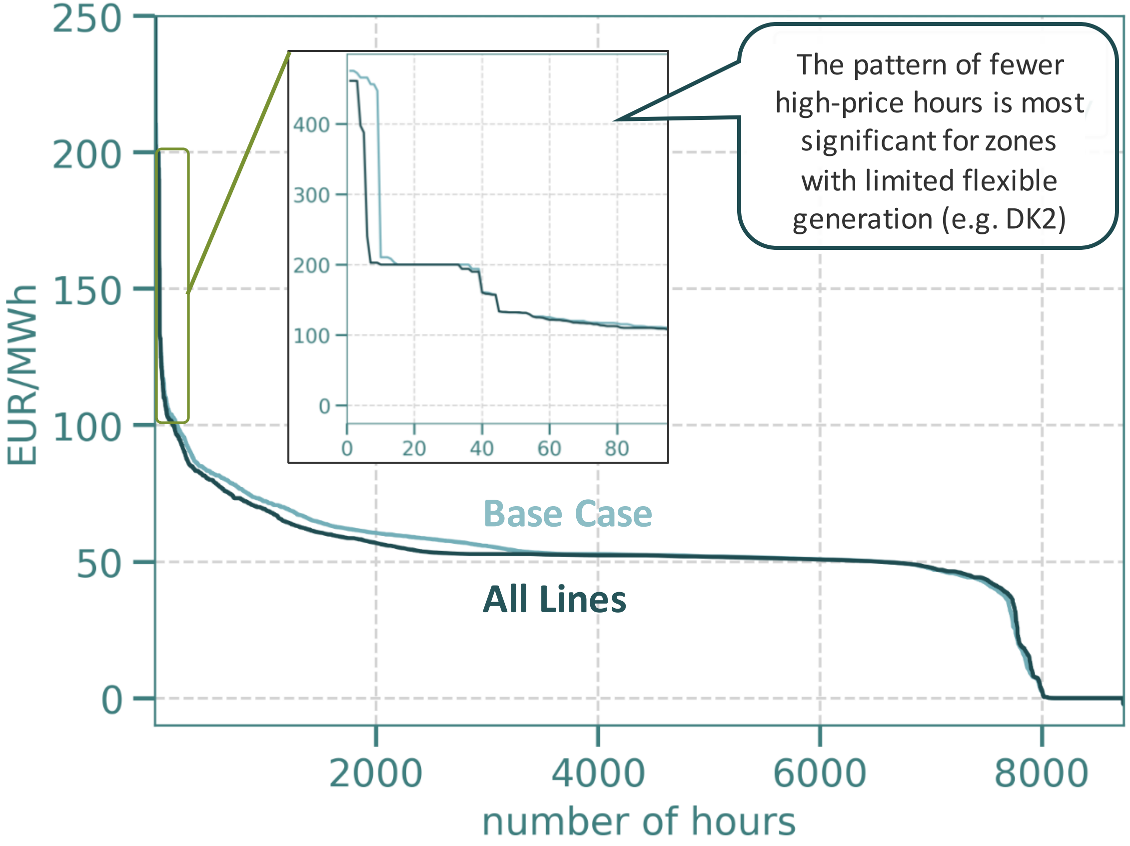
In markets incurring higher price levels, price spikes can be significantly reduced

This indicates that also security of supply is increased through an increase in grid capacities

DK2 hourly prices for Week 42

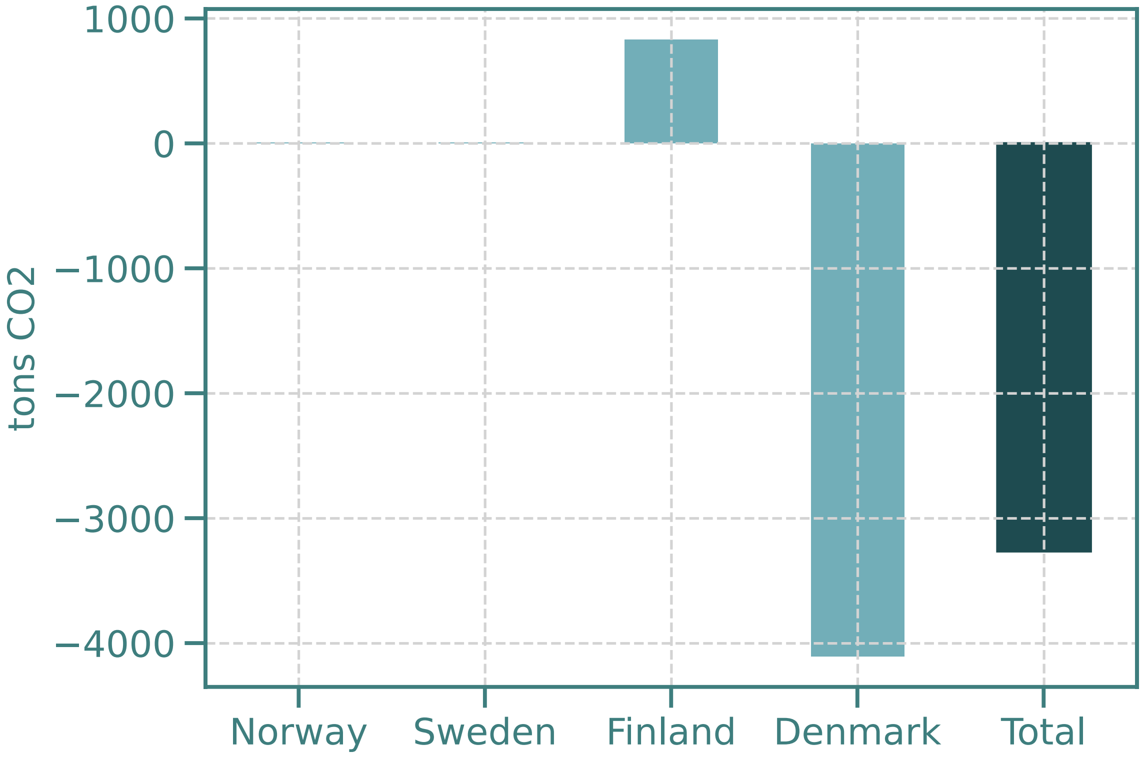


DK2 hourly price duration curve: Increased transmission reduces the number of hours with very high prices



The increased renewable production replaces some thermal generation – and thereby reduces emissions in the Nordics

Within the Nordics, increased transmission reduces emissions, particularly in DK2 - Results for All Lines versus Base Case



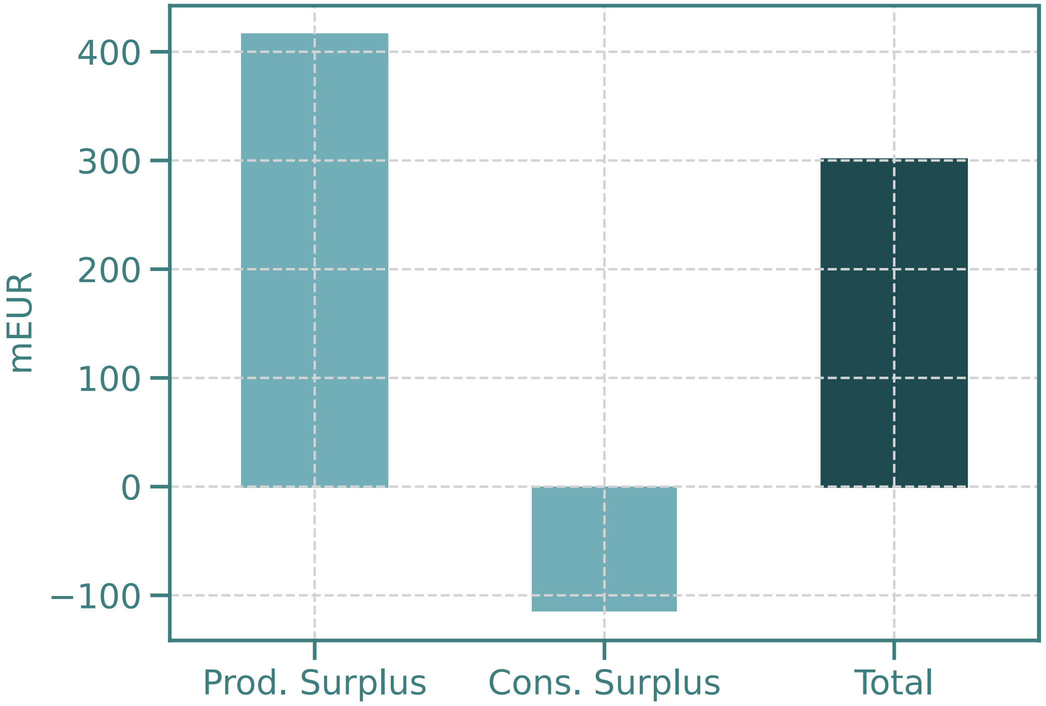
Commentary

- The increase of renewable production reduces some thermal generation within the Nordics, leading to a decrease in emissions of about 3.000 tons of CO_2, particularly in Denmark.
- However, as the overall output from RES increases, more power is available for export outside the Nordic market.
- The overall increase in renewable generation amounts for around 0.85 TWh in the All Lines scenario (compared to the Base case). If we assume that this generation replaces marginal gas generation in Europe, which has a carbon intensity of around 0.35 tons CO_2/MWh, the emission reduction would be around 300.000 tons CO_2.

An increase in transmission is likely to result in an overall welfare increase

Increased transmission within the Nordics provides more value to local renewable producers

Welfare change between the All Lines and Base Scenario (annual values)



Commentary

- The change in prices within the different zones, and the increase in renewable generation leads to changes in consumer and producer surplus.
- Overall, the higher prices experienced in areas with high RES output lead to a higher welfare gain for producers of up to 400 mEUR within the Nordics.
- In the case of consumers, the increase in prices in some regions leads to some decrease in consumer surplus. The effect is, however, much more modest, and does not offset the gains for producers.
- The net effect is in the magnitude of EUR 300 million per annum.
- Note: We have, due to methodological challenges related to calculation congestion rents in a FBMC setup, not included changes in congestion rent for TSOs. This may change the results somewhat. Please also note that any increase in welfare would need to be calculated against costs for investing in increasing transmission capacity. Such calculations were outside the scope of the assignment.

THEMA
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