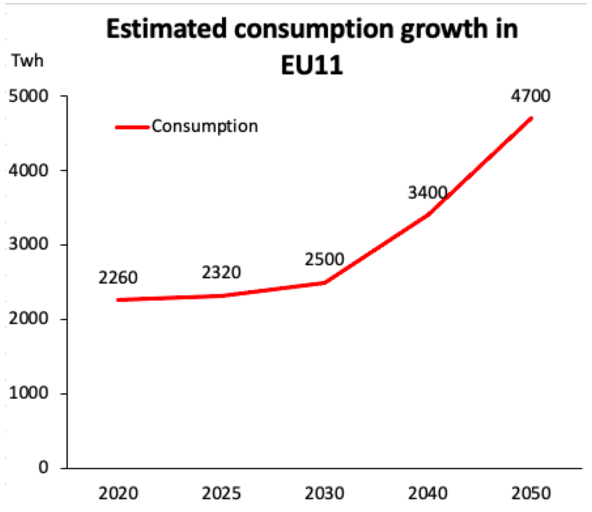
Offshore wind and its effect on the Nordic power market

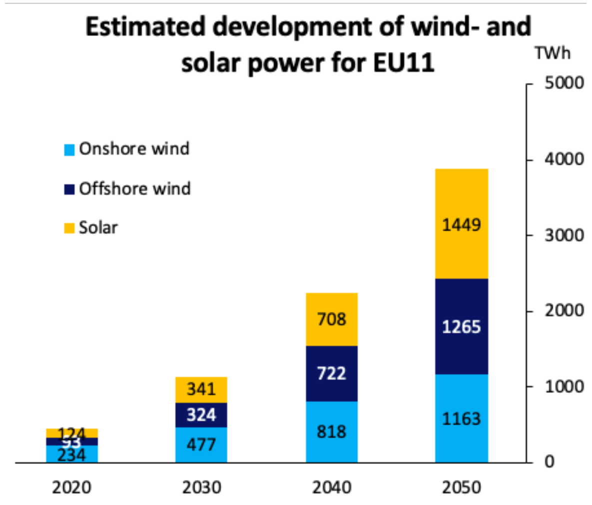
A master thesis presentation by Elise Tomt and Martine Utgård

Agenda

- Introduction to offshore wind
- Research question
- Research approach
- Simulation results
- Q&A

Offshore wind





Source: Statnett's Long-term market analysis 2020-2050

Changing electricity markets and the importance of renewable energy sources

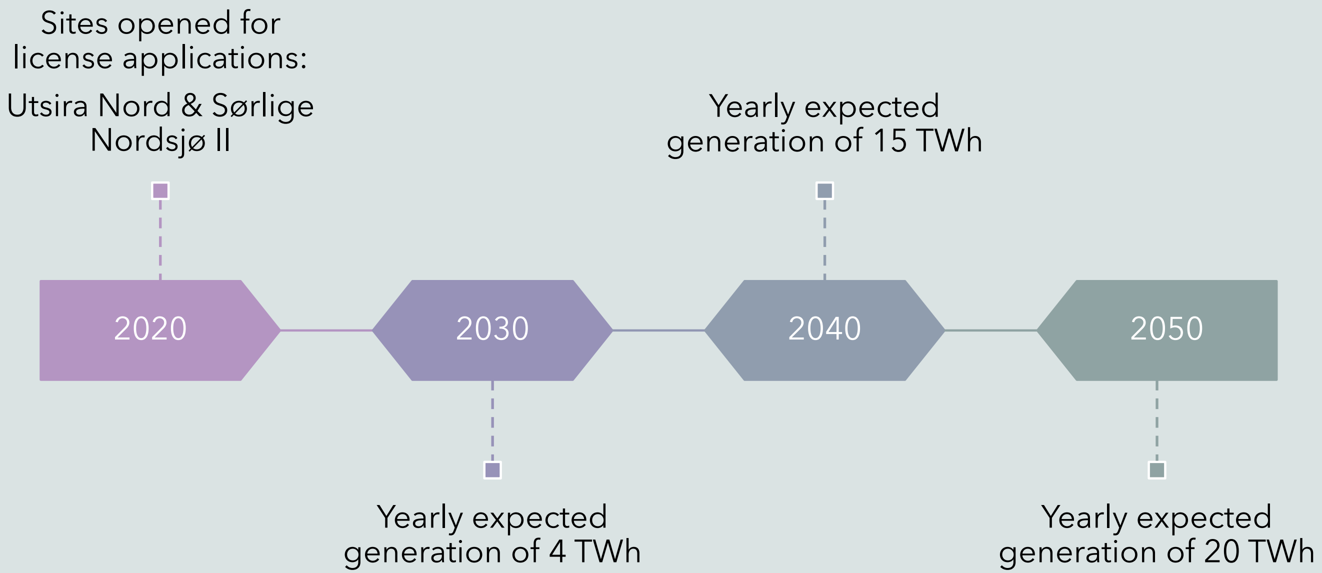
Main trends:

- Decarbonization of the energy secto
- Increasing demand for electricity

In the transition towards low-carbon energy supply, there is a substantial need for integrating more renewable energy sources in the upcoming years.

- Statnett predicts that current generation of wind- and solar power will tenfold within 2050, with wind power accounting for the highest share.
- They also predict that offshore wind will account for more than 50% of total wind power generation.

Offshore wind in Norway



With a long coastline and good wind resources, Norway has the prerequisites for deploying offshore wind.

The main limitation resulting in current deployment of offshore wind sites taking place in other countries is the challenging water depths and wave heights on the Norwegian coast.

However, with a rapidly evolving offshore wind market, decreasing costs and Norway's expertise in offshore activities, offshore wind can pose great opportunities.

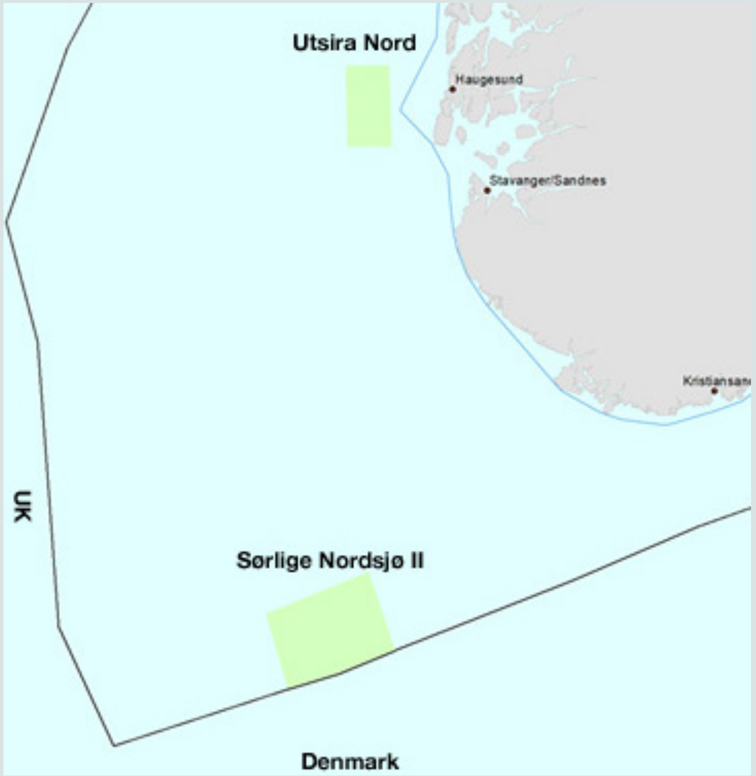
As a result, Norway's two first offshore wind sites have been opened for license applications as of 2021.

Source: Statnett's Long-term market analysis 2020-2050; Norwegian Ministry of Petroleum and Energy (2020)

Offshore wind in Norway: Sørlige Nordsjø II and Utsira Nord

Sørlige Nordsjø II is located 140 kilometers from shore and borders the Danish part of the North Sea.

Utsira Nord is located 22 kilometers from shore outside of Haugesund.



	Small deployment	Large deployment
Sørlige Nordsjø II	1008 MW	3000 MW
Utsira Nord	504 MW	1512 MW

Table 5.3: Estimated deployments for Sørlige Nordsjø II and Utsira Nord (NVE, 2012).

Source: NVE (2012) .

Integration of offshore wind

- Wind power depend on weather conditions rather than demand conditions and there will not always be optimal wind conditions to generate power in line with installed capacity.
- The need for grid developments and increased storage capacity to potentially decrease price sensitivity towards weather conditions will as a result be of importance.
- The main generation source in Norway is hydropower, which can be stored in hydropower reservoirs.
  - As such, the flexible hydropower generation plays an important role in the Nordic power market.

Source: NVE (2012); Charmasson et al. (2018); Statkraft (2020)

Research question

How will offshore wind deployment, connected to the hydropower dominated Norwegian mainland grid, impact the Nordic power market?

Research approach

Operating hours

- The hydrological situation in Norway plays a crucial part in determining power prices, both in Norway and in the Nordic power market.
- How much of the water in the reservoirs that is utilized to generate electrical energy depends on the water value – the alternative cost of utilizing the water today.
- The water values depends on expectations of future consumption and participation patterns, as well as the level of water in the reservoirs.
- To minimize the effects of future consumption and participation pattern, the chosen operating hours are at the same time of day and at the same time of year – 28th of September between 08 and 09 am.
- 28th of September is characterized by its high water levels compared to other seasons.

Norway's largest hydropower reservoir, Storglomvatnet.

Years	Min.	1st Qu.	Median	Mean	3rd Qu.	Max
2000-2019	62.25 %	77.92 %	82.52 %	82.31 %	89.16 %	93.96 %
2014-2019	76.82 %	79.38 %	82.73 %	83.27 %	85.45 %	92.72 %

Table 1: Descriptive statistics of water reservoir levels in week 39.

Water levels in the reservoirs	
Low seasonal water level (28/09/2018)	76.82%
Average seasonal water level (28/09/2017)	83.12%
High seasonal water level (28/09/2015)	92.72%

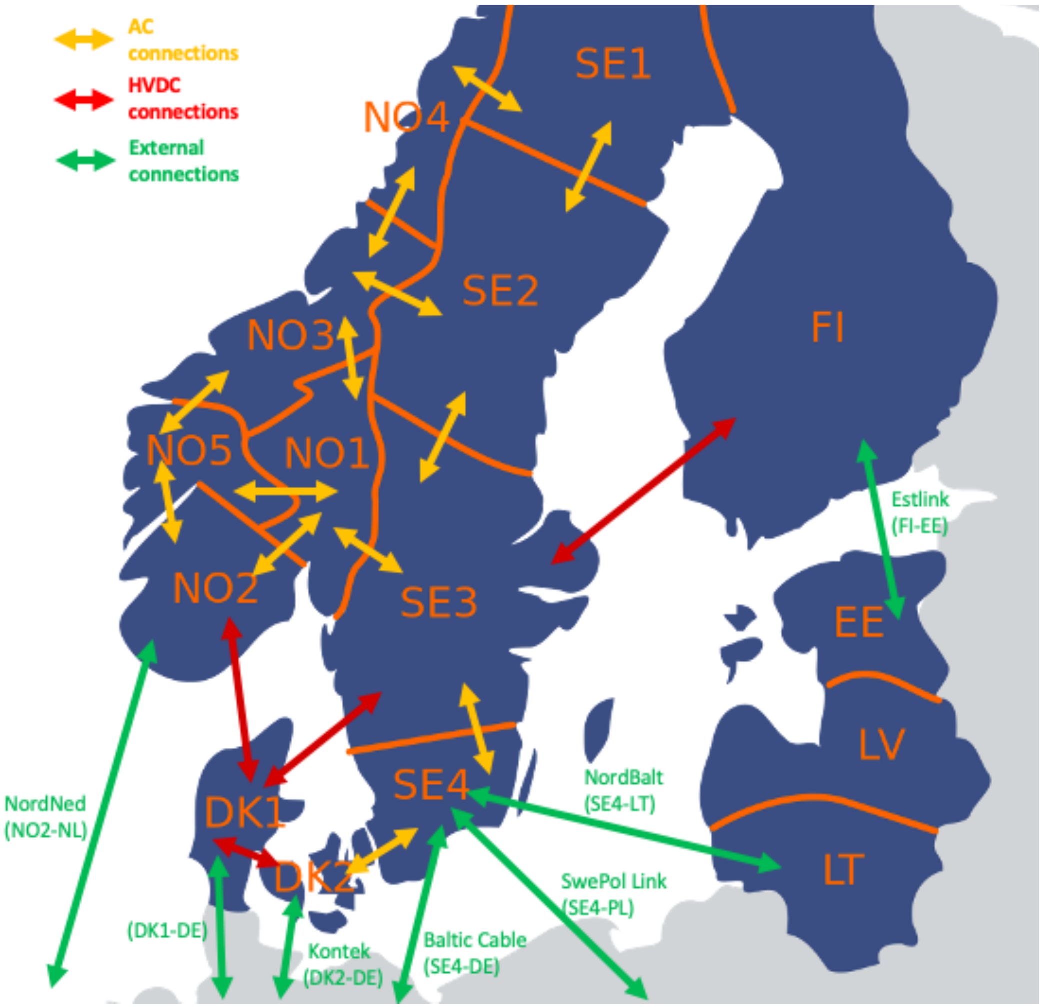
Table 2: Water levels in the reservoirs on the chosen operating hours.

Source: NVE (2020)

Data sources and implementation

To simulate the day-ahead power prices in the Nordic bidding areas we used data from Nord Pool on power exchange limits between bidding areas and aggregated supply and demand bids.

Bidding areas and power flows



Data sources and implementation

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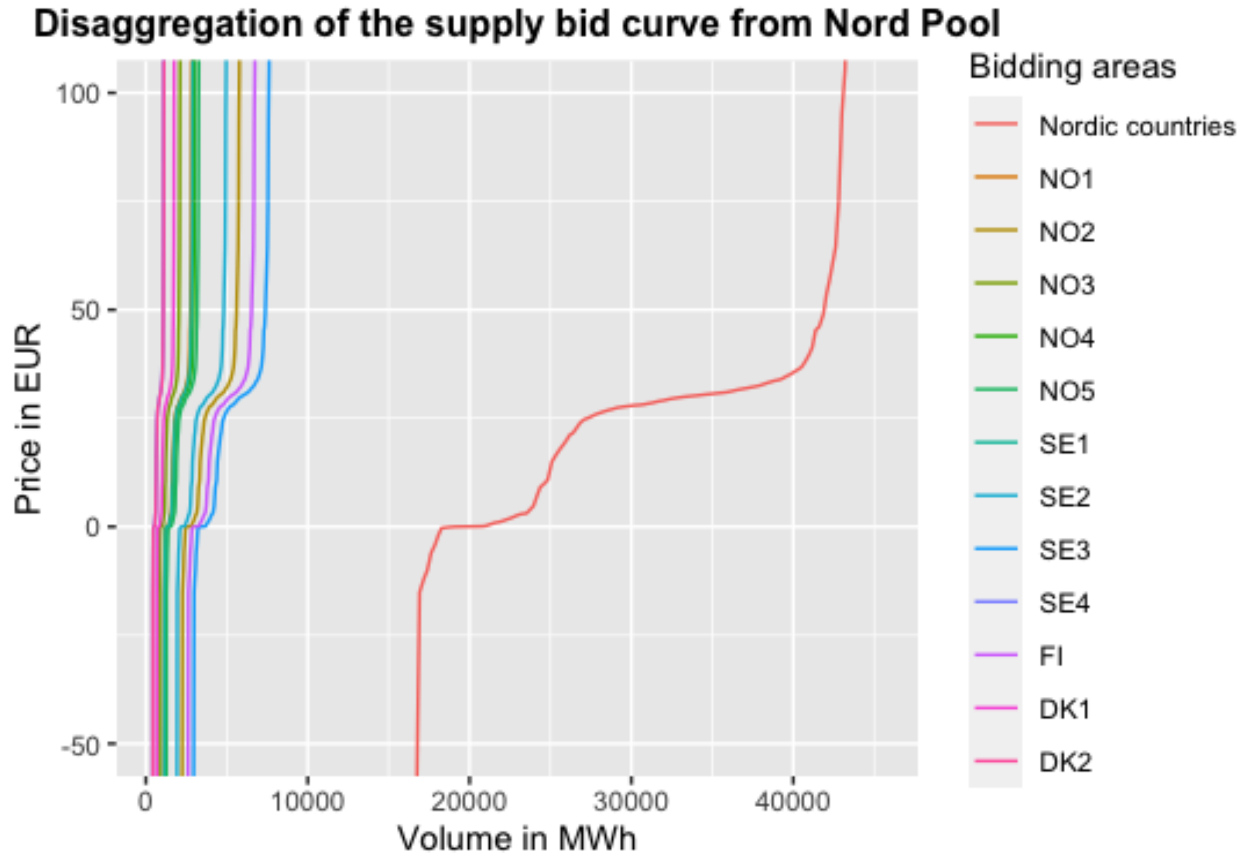
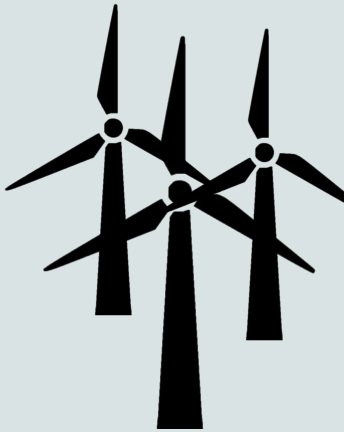
Disaggregation of bid curves

- The bid curves from Nord Pool is on a Nord Pool area level (the Nordic and Baltic countries).
- We used production and consumption shares for each bidding area in the respective operating hour to disaggregate the bid curves.



Offshore wind in the model

- The generation from Sørlige Nordsjø II and from Utsira Nord is added to the supply bid curves in NO2 and NO5, respectively, at a marginal cost of zero.
- This implies that we have assumed that the two sites are directly connected to the mainline grid in Norway and potential negative bids due to subsidies are not taken into account.
- Estimates from NVE on small and large deployment at both sites were used as the basis for the added offshore wind capacities. We also modelled scenarios where only half of the installed wind power is utilized.
    - Small deployment at both sites implied capacities of 8.4%, 10.0% and 11.1% of initial bids in Norway for the three operating hours.
    - Large deployment at both sites implied capacities of 25.0%, 29.9% and 33.3% of initial bids in Norway for the three operating hours.



Simulation results

Baseline scenarios

- The three chosen baseline scenarios illustrate the within season variation in water reservoir level and its effect on power prices
- The model does fairly well simulate the Elspot prices
- In alignment with Buhler and Muller-Merbach (2009), the correlation between the deviation from the median seasonal water level and the baseline prices in hydrodominant bidding areas, shows a strong negative relationship exists

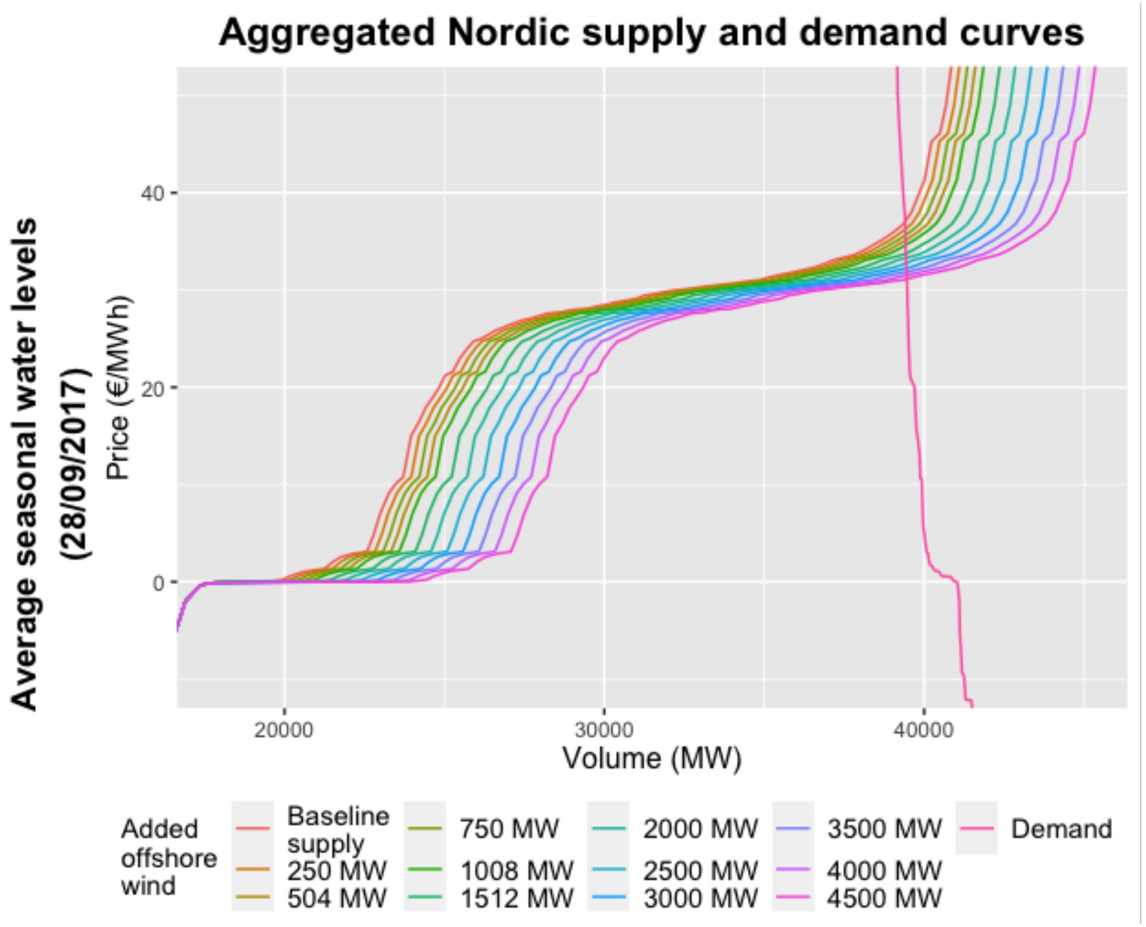
	Low water level (28/09/2018)		Average water level (28/09/2017)		High water level (28/09/2015)	
	Elspot prices	Baseline prices	Elspot prices	Baseline prices	Elspot prices	Baseline prices
DK1	44.44	44.55	34.61	35.48	53.33	54.80
DK2	44.44	44.55	49.21	49.57	53.33	54.80
FI	70.47	70.63	45.96	46.76	58.02	59.75
NO1	44.44	44.55	30.57	31.56	15.12	15.46
NO2	44.44	44.55	30.57	31.56	15.12	15.46
NO3	44.44	44.55	34.61	35.48	20.71	20.93
NO4	44.44	44.55	31.13	35.48	20.71	20.93
NO5	44.44	44.55	30.57	31.56	15.12	15.46
SE1	44.44	44.55	34.61	35.48	20.71	20.93
SE2	44.44	44.55	34.61	35.48	20.71	20.93
SE3	44.44	44.55	34.61	35.48	20.71	20.93
SE4	44.44	44.55	34.61	35.48	20.71	20.93

Table 6.1: Elspot prices and simulated baseline prices (in €/MWh).

- The low seasonal water level scenario is characterized by a high price convergence between bidding areas
- Both the high and average seasonal water levels have baseline prices that vary to a large degree between bidding areas – caused by limitations in the transmission capacities between bidding areas

A descending price trend: Merit order effect

- Throughout all scenarios with added offshore wind we see that power prices decline.



Deployment at Sørlige Nordsjø II

- For the low seasonal water level scenario prices in all bidding areas except for Finland decline by 1.14€/MWh in the case of 50% utilization of small deployment
- With increasing levels of offshore wind power, the prices in DK1, NO1, NO2 and NO5 are to a larger degree affected and decline more than the other bidding areas
- The price decline in DK1, NO1, NO2 and NO5 to 25.01€/MWh represent a price decline of 43.85%

Low seasonal water level (28/09/2018) - Sørlige Nordsjø II					
		Small deployment (1008 MW)		Large deployment (3000 MW)	
	Baseline prices	50% utilization	Installed capacity	50% utilization	Installed capacity
DK1	44.55	43.41	41.29	38.91	25.01
DK2	44.55	43.41	42.77	42.77	42.77
FI	70.63	70.63	70.63	70.63	70.63
NO1	44.55	43.41	41.29	38.91	25.01
NO2	44.55	43.41	41.29	38.91	25.01
NO3	44.55	43.41	42.77	42.77	42.77
NO4	44.55	43.41	42.77	42.77	42.77
NO5	44.55	43.41	41.29	38.91	25.01
SE1	44.55	43.41	42.77	42.77	42.77
SE2	44.55	43.41	42.77	42.77	42.77
SE3	44.55	43.41	42.77	42.77	42.77
SE4	44.55	43.41	42.77	42.77	42.77

Table 6.2: Simulated prices (in €/MWh) for low seasonal water level on 28/09/2018 07-08 AM with capacities added from Sørlige Nordsjø II to NO2.

Deployment at Sørlige Nordsjø II

- Only NO1, NO2 and NO5 are affected by the offshore wind generation from Sørlige Nordsjø II on the average and high seasonal water level scenarios
- Adding the same volumes of offshore wind generation do not necessarily imply a higher absolute price decline when fewer bidding areas are affected
- 50% utilization of small deployment: price decline of 1.01 €/MWh on the average seasonal water level and on 1.14 €/MWh on the low seasonal water level scenario where all bidding areas expect Finland are affected
- Relative price change with large deployment:

  Average: -40.33% *High: -84.15%*

Average seasonal water level (28/09/2017) - Sørlige Nordsjø II					
		Small deployment (1008 MW)		Large deployment (3000 MW)	
	Baseline prices	50% utilization	Installed capacity	50% utilization	Installed capacity
NO1	31.56	30.55	29.76	28.42	18.83
NO2	31.56	30.55	29.76	28.42	18.83
NO5	31.56	30.55	29.76	28.42	18.83

Table 6.3: Simulated prices (in €/MWh) for average seasonal water level on 28/09/2017 07-08 AM with capacities added from Sørlige Nordsjø II to NO2.

High seasonal water level (28/09/2015) - Sørlige Nordsjø II					
		Small deployment (1008 MW)		Large deployment (3000 MW)	
	Baseline prices	50% utilization	Installed capacity	50% utilization	Installed capacity
NO1	15.46	13.71	11.79	9.85	2.45
NO2	15.46	13.71	11.79	9.85	2.45
NO5	15.46	13.71	11.79	9.85	2.45

Table 6.4: Simulated prices (in €/MWh) for high seasonal water level on 28/09/2015 07-08 AM with capacities added from Sørlige Nordsjø II to NO2.

Deployment at Utsira Nord

Low seasonal water level (28/09/2018) - Utsira Nord					
		Small deployment (504 MW)		Large deployment (1512 MW)	
	Baseline prices	50% utilization	Installed capacity	50% utilization	Installed capacity
DK1	44.55	44.13	43.41	42.78	38.91
DK2	44.55	44.13	43.41	42.78	42.77
FI	70.63	70.63	70.63	70.63	70.63
NO1	44.55	44.13	43.41	42.78	38.91
NO2	44.55	44.13	43.41	42.78	38.91
NO3	44.55	44.13	43.41	42.78	42.77
NO4	44.55	44.13	43.41	42.78	42.77
NO5	44.55	44.13	43.41	42.78	38.91
SE1	44.55	44.13	43.41	42.78	42.77
SE2	44.55	44.13	43.41	42.78	42.77
SE3	44.55	44.13	43.41	42.78	42.77
SE4	44.55	44.13	43.41	42.78	42.77

Table 6.5: Simulated prices (in €/MWh) for low seasonal water level on 28/09/2018 07-08 AM with capacities added from Utsira Nord to NO5.

- All bidding areas expect for Finland are affected with the same price decline up to added offshore wind of 750 MW, representing 50% utilization of large deployment
- Full utilization of large deployment at Utsira Nord gives a price reduction of 5.64 €/MWh in DK1, NO1, NO2 and NO5, representing a relative price decline of 12.66% from the baseline prices
- For added offhore wind generation up to 1512 MW, the results show identical price changes regardless of whether the added generation comes from Utsira Nord or Sørlige Nordsjø II for the low seasonal water level scenario

Average seasonal water level (28/09/2017) - Utsira Nord					
		Small deployment (504 MW)		Large deployment (1512 MW)	
	Baseline prices	50% utilization	Installed capacity	50% utilization	Installed capacity
NO1	31.56	30.91	30.55	30.17	28.42
NO2	31.56	30.91	30.55	30.17	28.42
NO5	31.56	30.91	30.55	30.17	28.42

Table 6.6: Simulated prices (in €/MWh) for average seasonal water level on 28/09/2017 07-08 AM with capacities added from Utsira Nord to NO5.

High seasonal water level (28/09/2015) - Utsira Nord					
		Small deployment (504 MW)		Large deployment (1512 MW)	
	Baseline prices	50% utilization	Installed capacity	50% utilization	Installed capacity
NO1	15.46	14.67	13.71	12.76	9.85
NO2	15.46	14.67	13.71	12.76	9.85
NO5	15.46	14.67	13.71	12.76	9.85

Table 6.7: Simulated prices (in €/MWh) for high seasonal water level on 28/09/2015 07-08 AM with capacities added from Utsira Nord to NO5.

Deployment at Utsira Nord

- On both the average and high seasonal water level scenarios, only NO1, NO2 and NO5 are affected by adding offshore wind
- Relative price change with large deployment:

Average: -9.93% *High: -36.27%*

Relative price changes

- The figure shows the relative price change from the baseline price in the bidding area where the offshore wind is added
- Up to 2000 MW of offshore wind added, the price changes is similar regardless of whether the offshore wind is added to NO2 or NO5
- Although we established an almost perfectly negative relationship between the deviation from the median seasonal water level and the baseline prices, there do not seem to be a clear explanation for why the relative price changes differs between the seasonal water levels

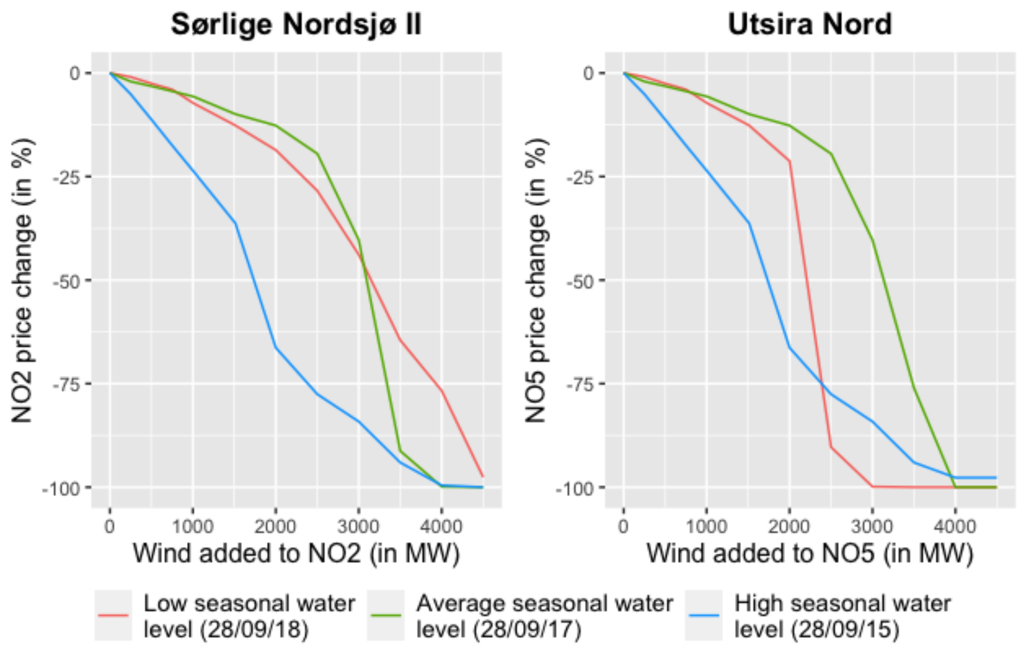


Figure 6.2: Relative price changes when adding offshore wind capacities from Sørlige Nordsjø II and Utsira Nord to NO2 and NO5 on 28/09/2017 07-08 AM.

Generation

- One common feature we find throughout all scenarios is that generation increases in the bidding are where offshore wind capacity is added, whereas it decreases in other bidding areas with a descending price trend.

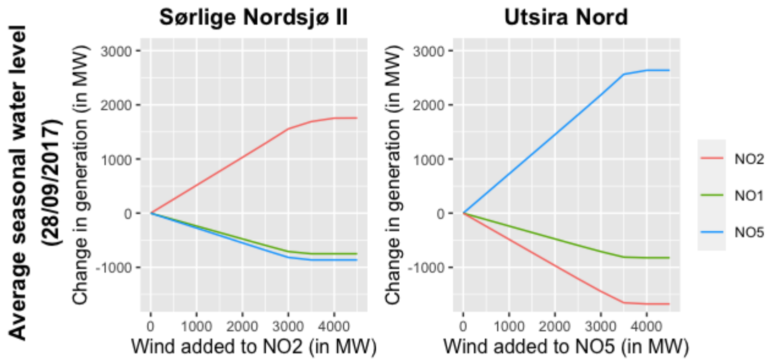


Figure 6.3: Changes in generation when adding offshore wind on 28/09/2017 07-08 AM.

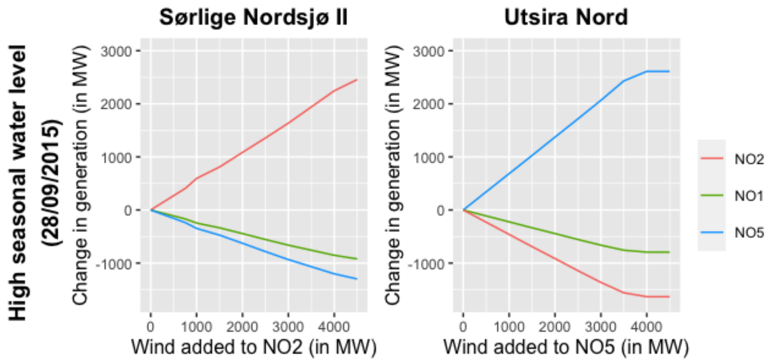


Figure 6.4: Changes in generation when adding offshore wind on 28/09/2015 07-08 AM.

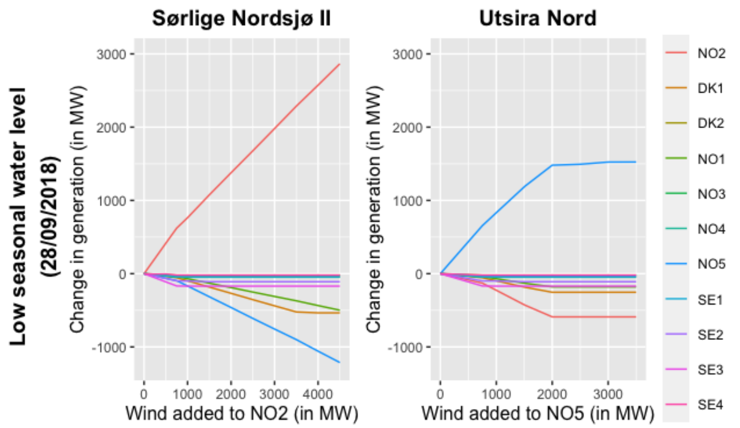
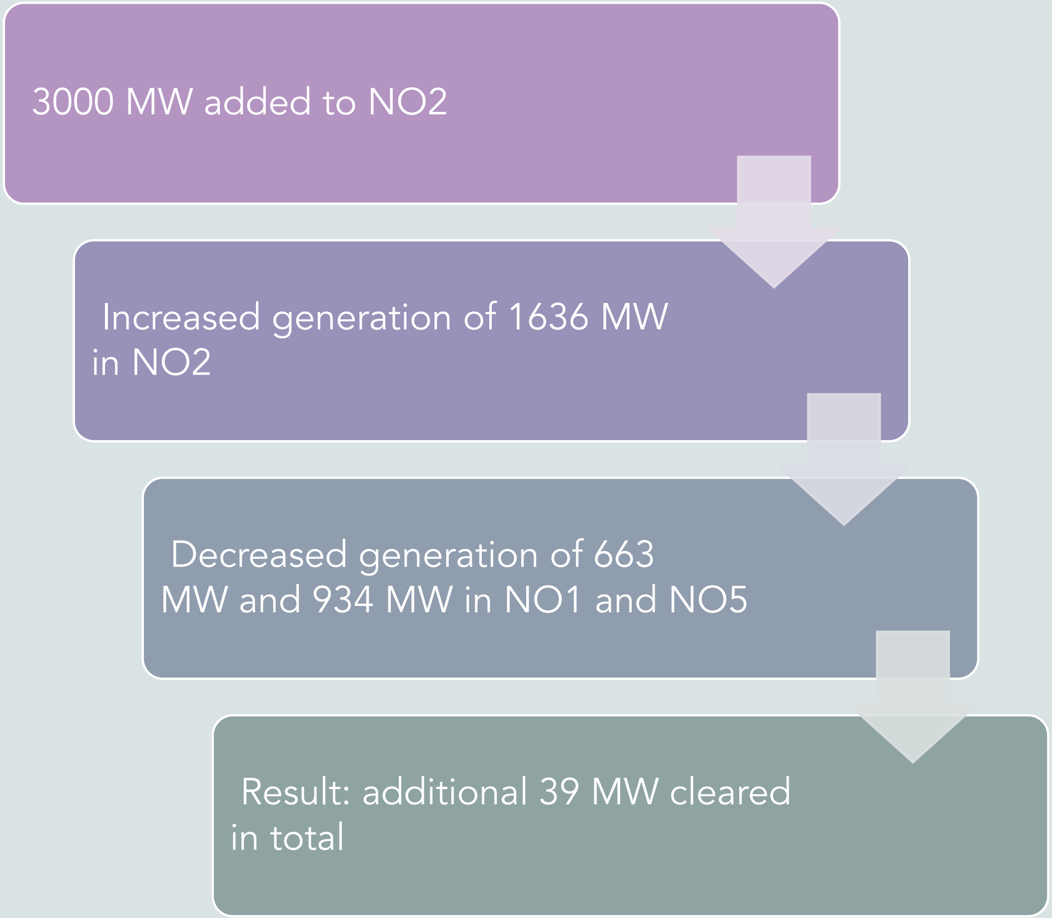


Figure 6.5: Changes in generation when adding offshore wind on 28/09/2018 07-08 AM.

Generation

In all scenarios, we find that the aggregate net change in generation in the Nordics appear to be smaller than the added offshore wind capacity.

This feature is caused by the inelasticity of demand and the merit order effect.



Conclusion

- We find a descending price trend throughout all scenarios.
- The price impacts varies with added capacities from offshore wind and depend on seasonal water level and initial level of congestion in the grid.
  - The larger the number of bidding areas affected does not neccesarily imply lower impact on price and vice versa.
  - The results show no clear pattern between relative price change and seasonal water level
- Results show a pattern of increasing generation in the bidding area where the offshore wind capacity is added and decreasing generation in other bidding areas affected.