WP 1 GRID BOTTLENECKS ASSESSMENT

Hydrobalance User meeting

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CONTEXT OF THE STUDY

WP 1: GRID BOTTLENECKS ASSESSMENT

- Context : Hydrobalance project aims at evaluating the potential of the hydropower generation in Norway to be used as a flexible resource to balance a Continental Europe system with a high share of renewable.

→ The results could be **strongly influenced by the level of development of transmission capacities** between the Nordic countries and Continental Europe.

- Objective of the deliverable:
  - Give quantitative results to find what will be **the most crucial transmission grid development necessary to evacuate the Norwegian surplus of energy**;
  - Context of a **development of hydro-based generation in Norway**, and **an increase of RES** capacities in Europe.
  - Current situation (2015) + mid-term (2030) and long-term (2050) horizon.
- How ? Review and synthesis of recent public studies:
  - ENTSO-E Ten Year Network Development Plan (**TYNDP**) 2014 and 2016 (draft) → *2030*
  - ENTSO-E Regional Investments Plans (RGIPs) 2015 → **2030**
  - **AGORA** study "Increased Integration of the Nordic and German Electricity Systems" → *2030*
  - ENTSO-E **E-Highway 2050** study 2012 – 2015 → *2050*

EXISTING GRID TRANSMISSION CAPACITIES AND MAIN BOTTLENECKS IN NORTHERN CONTINENTAL EUROPE AND SCANDINAVIA

RES development has increased the volatility of power flows

- Today, already strong connections between Nordic countries and Continental Europe (HVDC).
- Nordic countries often have a **surplus of energy** because of cheaper hydropower generation → **power flow pattern is mainly southbound**.
- The development of RES capacities has increased the **volatility** (daily / seasonal / yearly) **of power flows**, depending on the spread of prices between Nordic countries and Continental Europe.

→ **The increasing volatility caused by RES development implies a higher need for internal and cross-border capacities.**

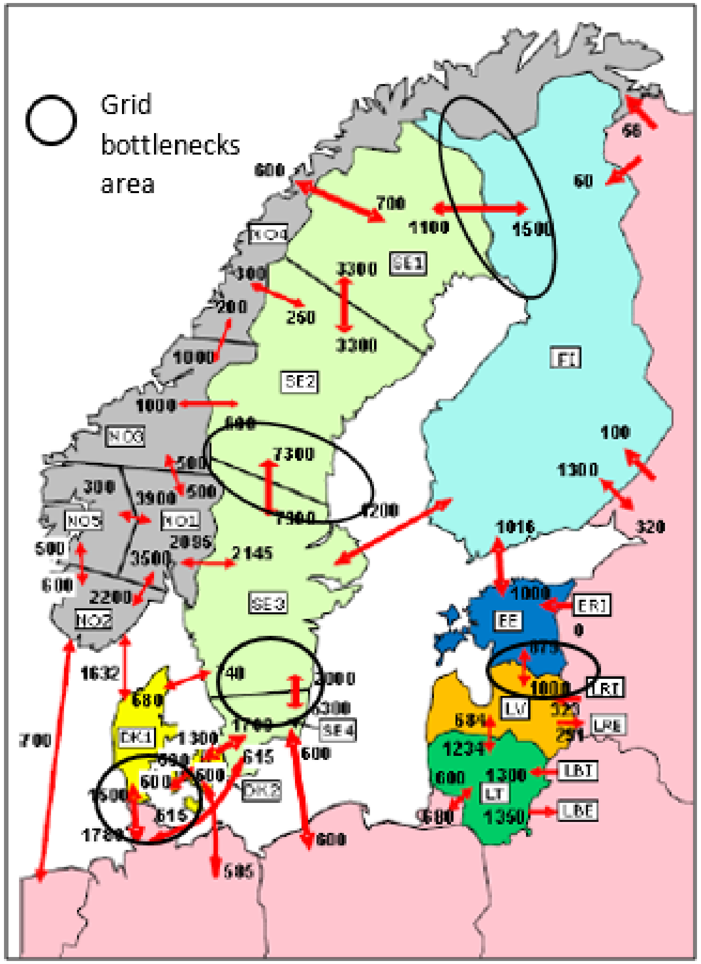
Physical energy flows 2015, ENTSO-E

Interchange with neighbouring countries [GWh]	2009	2010	2011	2012	2013	2014
Net imports from Sweden	688	-2,238	2,446	7,514	-1,001	1,011
Net imports from Norway	2,380	-2,597	1,187	4,781	-287	2,667
Net imports from Germany	-2,735	3,700	-2,315	-7,082	2,369	-823
Net imports in total	**334**	**-1,135**	**1,318**	**5,214**	**1,081**	**2,855**

Denmark interchange with neighbouring countries, Energinet.dk, 2015

INTERNAL BOTTLENECKS ARE A LIMITATION FOR EXPORTATION OF THE SURPLUS OF ENERGY

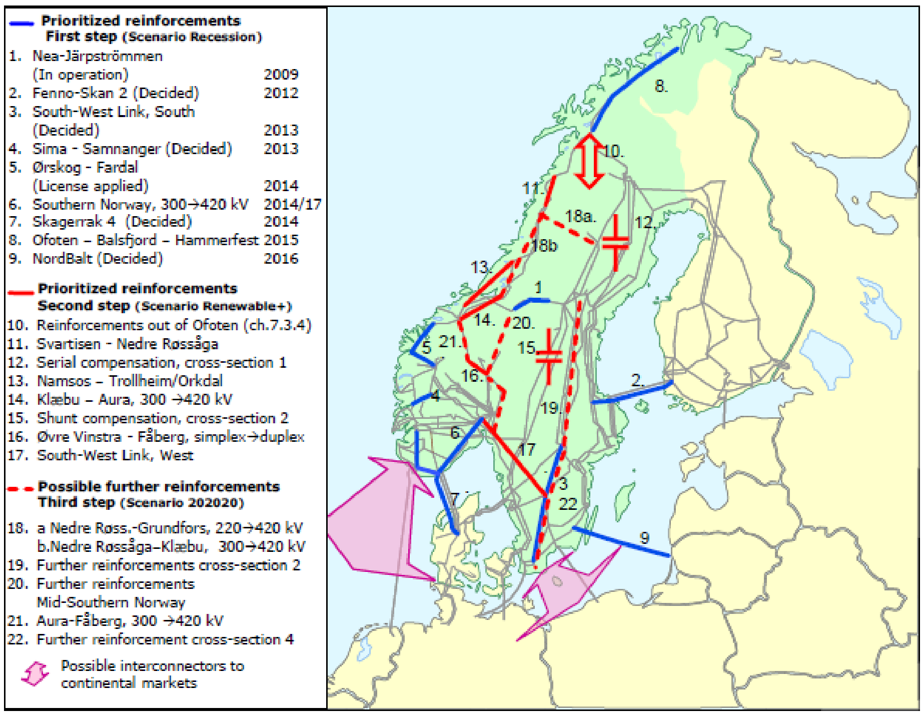
- Despite a couple of years of market integration in Nordic countries, power flows (and export of the surplus of energy) are currently limited due to a lack of transmission infrastructure:
  - **Internal and local bottlenecks in Norway and Sweden** → local surplus of production → price collapse or even hydro power spillage in Norway when the inflows are important or the reservoirs are full.
  - **Bottlenecks between northern and southern areas of Sweden** caused by a geographical imbalance between higher consumption area (south) and cheaper hydro-generation area (north). *The splitting of the Sweden market area in different bidding zones is a way for managing the congestions by limiting the internal transmission capacities.*
  - **Bottlenecks between northern Germany and Denmark** (see next slides)



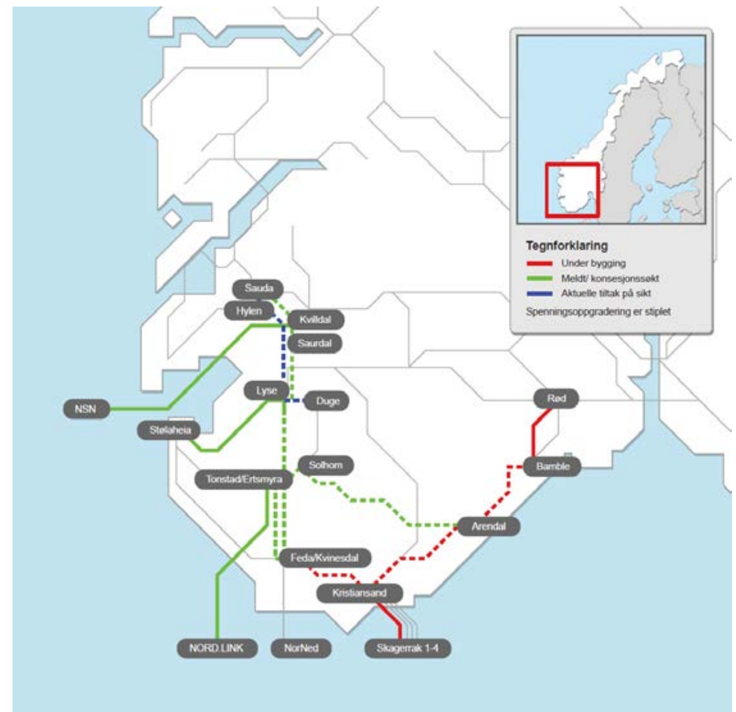
Net Transfer capacities (December 2014) and main grid constraints areas, ENTSOE-E

MAIN BARRIERS TO INTERNAL POWER EXCHANGES IN THE NORDIC

Statnett and Svenska Kraftnät joint study in 2010

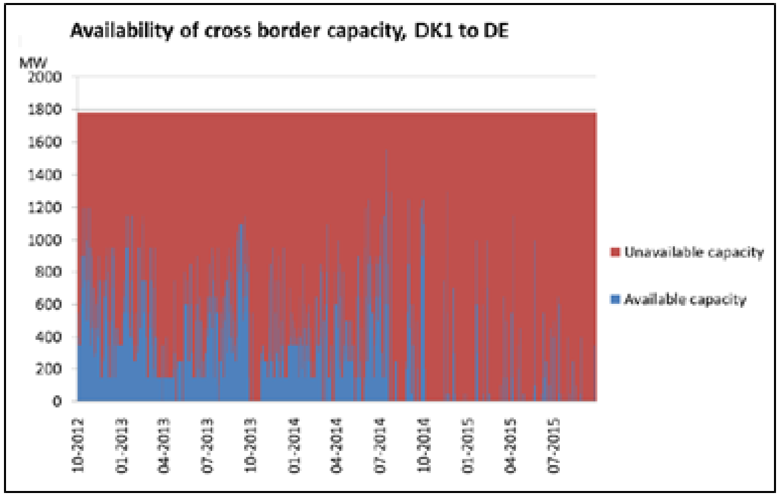


Statnett grid development plan

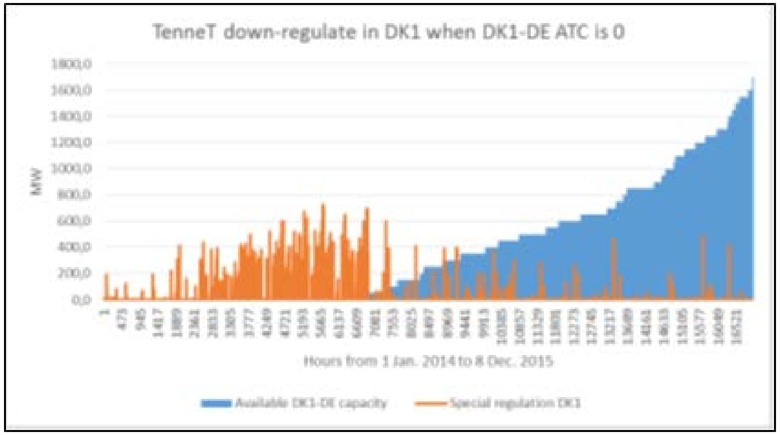


Curtailments of Danish – German capacities already limit Nordic exports

- Denmark West (DK1) ~ "hub" for cross-border power exchanges between the Nordic countries (hydro) and Germany (RES).
- Since 2014: **decrease of the cross-border transmission capacity between DK1 and Germany** (DE) despite the increasing need for power exchanges.
- Now NTC DK1→DE ~ 0 because of **massive curtailments of DK1-DE cross-border capacities** done by the German TSO TenneT in order to solve internal grid bottlenecks on the German grid.



Decrease of available cross border capacity between Denmark (DK1) and Germany (DE), source: Energinet.dk

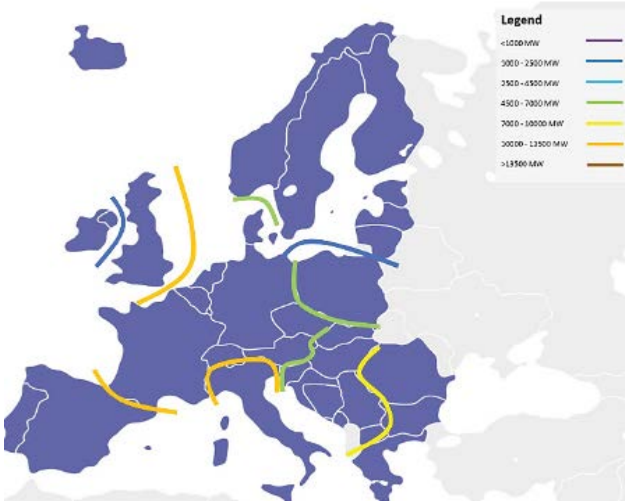


Counter-trading and redispatching in DK1, source: Nordpool, Energinet.dk

- **Consequence:** TenneT has to use some counter-trading and redispatching measures to compensate Danish (and Nordic) generation by German generation (up-regulation) because of the inability to trade → **discrimination between Nordic market participants and German competitors + loss of global economic welfare**.
- This situation shows **the importance of the need of internal grid investments for the exportation of Nordic generation to Europe**, not only in Nordic countries, but also inside Continental Europe.

A NEED FOR MID AND LONG TERM GRID INVESTMENTS

RES DEVELOPMENT IN CONTINENTAL EUROPE / UK TRIGGER THE NEED OF GRID INVESTMENTS IN NORDIC COUNTRIES

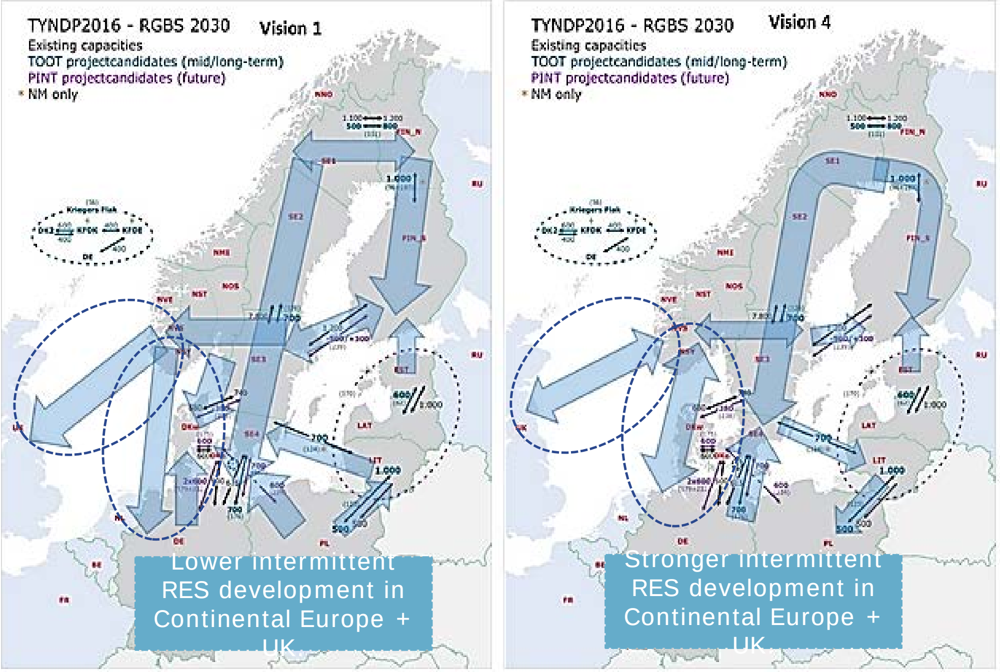


Target capacities 2030, Vision 4, TYNDP 2016

- TYNDP = synthesis of the main pan-European transmission grid investments and evaluation with a multi-criteria analysis through 4 prospective 2030 visions.
- **RES development = major driver in Europe for grid investments** (major shift of generation fleet in DE etc.).
- Target capacities indicates the “societal economic optimum” per border. Priorities: 1/ electric peninsulas (security of supply), 2/ connections with Nordic countries (economic interest increased by RES development).

- The **strong development of intermittent RES in Continental EU and UK** will be the main driver for integration of Nordic countries and may **trigger the need of new interconnection capacities**.

- The magnitude and the **volatility** of the power flows **increase as much as the contrasts between the areas** (Scandinavia vs. Continental EU + UK) and specifically the RES capacities increase → Nordic hydro power plants ~ flexible resource to balance the intermittent RES generation in UK and Continental EU.



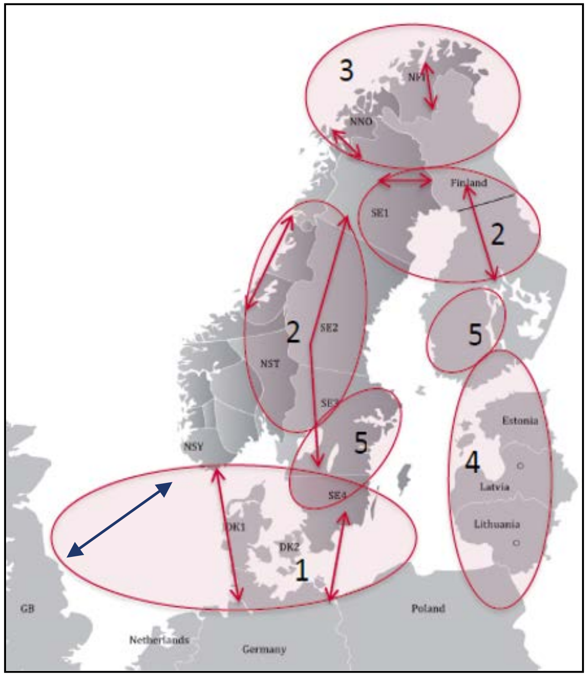
Comparison of main bulk power flows in V1 and V4, TYNDP 2016

TYNDP IDENTIFIES STRONG BENEFITS OF INTERCONNECTORS BETWEEN SCANDINAVIA AND CONTINENTAL EU + UK

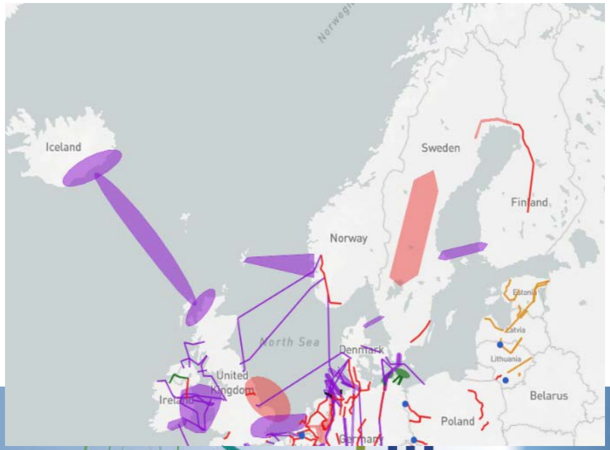
- **Area 1** *: integration of hydro-based Norwegian system with thermal / nuclear / wind based British and continental EU mix*:

Border	Name of project	Expected date	Capacity (MW)	Cost (M€)	Addition of economic social welfare (M€ / year)
UK - NO	NSN	2021	1400 DC	1850	+ [140 – 190]
	NorthConnect	2022	1400 DC	1613	
DE - NO	Nordlink	2020	1400 DC	1850	+ [70 – 120]
SE/DK2 – DE/PL	Hansa PowerBridge	2025	DC	660	~ + 40
	Kontek 2	2030	600 DC	360	~ + 10
DK1 / DE	Upgrade Kasso - Audorf	2020	AC	500	+ [10 – 20]
	New 400kV cable	2022	AC	210	~ + 10

- **Connections with UK are costly but the most interesting ones** (decrease spillage in UK when windy or hydro power spillage in NO when wet).
- Links between Norway and Germany also show high benefit thanks to hydro daily regulation with intermittent RES. Other projects are relevant between SE/DK and DE/PL, even if they bring less benefits.
- The spread of the annual social welfare amount between each visions with these projects can be explained by **the total volume of surplus in the Nordic countries**, the **increase of number of hours with more volatile prices**, **price spread**, and thus higher flows in both directions.



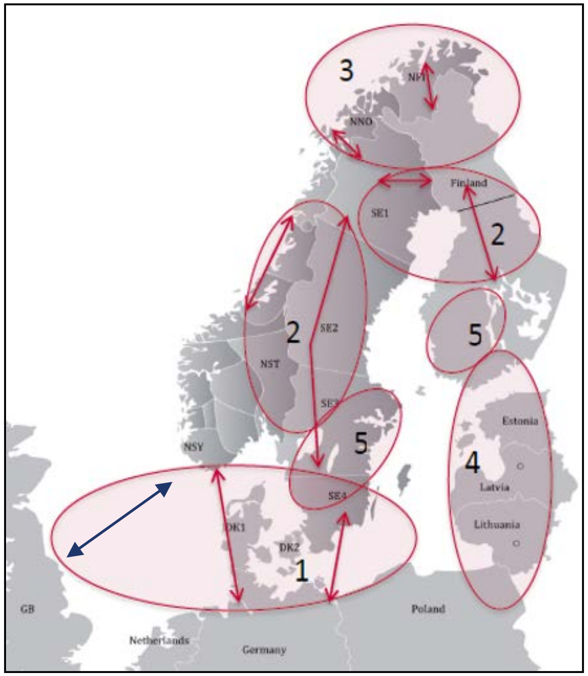
Focus areas for grid development in Scandinavia, RGiPs 2015



Planned investments in Europe, TYNDP 2016

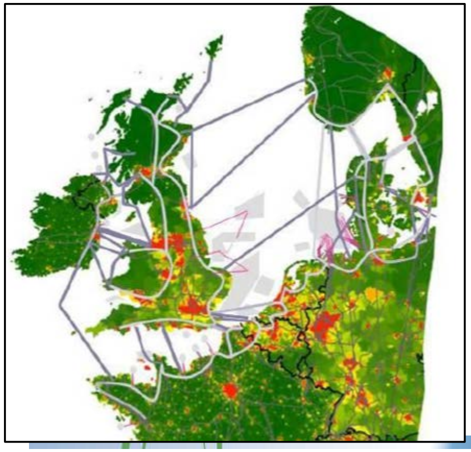
TYNDP: INTERNAL REINFORCEMENTS AND OFFSHORE GRIDS

- <u>**Area 2 / 5**</u> *: Internal reinforcements inside Nordic countries*
  - Related to projects in Area 1, the benefit to integrate Nordic countries with continental EU could be limited because of the bottlenecks beyond the borders. **Internal reinforcements in southern Norway / Sweden, and Germany will be indispensable** to further increase the rate of interconnections.
  - **Inside Sweden**: most of RES development are planned in north of Scandinavia → need of further reinforcements between SE1 / SE3. Prospective projects (2025, + 700 MW) with limited benefits (less than + 10 M€ / year) but help integrating 700 – 800 MW RES in northern NO / SE.



Focus areas for grid development in Scandinavia, RGiPs 2015

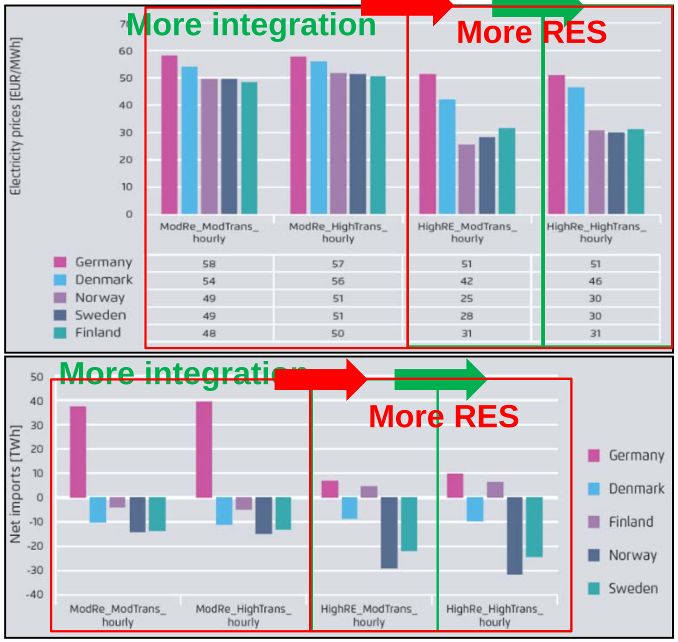
- <u>**Prospective North Sea offshore grid:**</u>
  - *TYNDP* : aggregation of 25 projects merging new assets and existing ones, put together in a scheme to maximise the global efficiency.
    - Most common design remains a point to point interconnection to connect countries, and dedicated AC or multiterminal DC offshore hubs are still rare because more expensive. **It is still cheaper to build and operate AC/DC converter stations onshore, instead of offshore.**
    - Total cost ~ 18 bn€. The increase of social welfare ~ [2 – 2,5] bn€/year in the different visions.
  - *NSCOGI studies:* compare "radial and meshed" designs
    - With a moderate development of RES capacities, both designs are similar ; **meshed designs bring more benefits with a strong development of RES** capacities due to saved infrastructure costs (lengths).



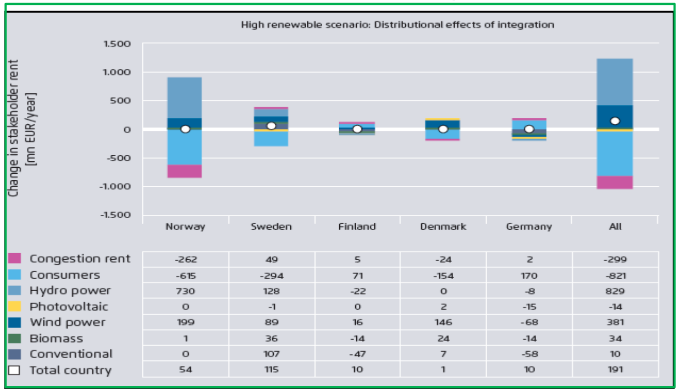
North Sea offshore grid infrastructure scheme, TYNDP 2014

INTEGRATION WITH HIGH RES DEVELOPMENT BRINGS BENEFITS TO NORWEGIAN HYDRO-POWER PRODUCERS

- <u>Context</u>:
  - Study published by AGORA Energiewende in June 2015. Evaluation of an increased integration of the Nordic and German electricity systems by 2030.
  - “Energiewende in Germany”: major transition toward a system with high share of intermittent RES → stronger need of flexibility and balancing → potential for using Nordic hydropower plants ?
- <u>Main results</u>: <u>in case of a strong development of renewables</u>:
  - the integration (addition of transmission capacities) slightly increases the prices in Norway but the decreasing price effect due to higher penetration of renewables is stronger → lower price in Scandinavia but **strong increase of the spread of prices between Scandinavia and DE → increase of export to Continental EU** → the value of the interconnectors between Scandinavia and Continental EU is much higher.
  - Integration mostly benefits to Sweden and Norway; **generators in Norway benefits both the increase of renewables and the integration**: hydro-power producers in Norway are those who catch the most important part of the surplus.



Main results from AGORA study, 2015: prices and net exchanges



Main results from AGORA study, 2015: consequences in case of the addition of transmission capacities in High Renewables scenario.

THE INCREASE OF NORDIC SURPLUS OF ENERGY BY 2050 TRIGGERS THE NEED FOR FURTHER GRID INVESTMENTS

- **E-Highway 2050:** project lead by ENTSO-E (2012-2015) which aims at identifying the major transmission needs in Europe to comply with the target of reduction of CO_2 emissions by 2050
- → 5 contrasted scenarios but showing possible developments of energy mix till 2050.

- In case of high penetration of RES and development of hydro-based capacities, Norway and Sweden are the major countries in surplus. **Without any further grid development** than those planned in TYNDP, **high volumes of RES or hydro spillage exist as Nordic countries have limited export possibilities to Continental Europe** because of grid bottlenecks.

  → optimization of transmission requirements.

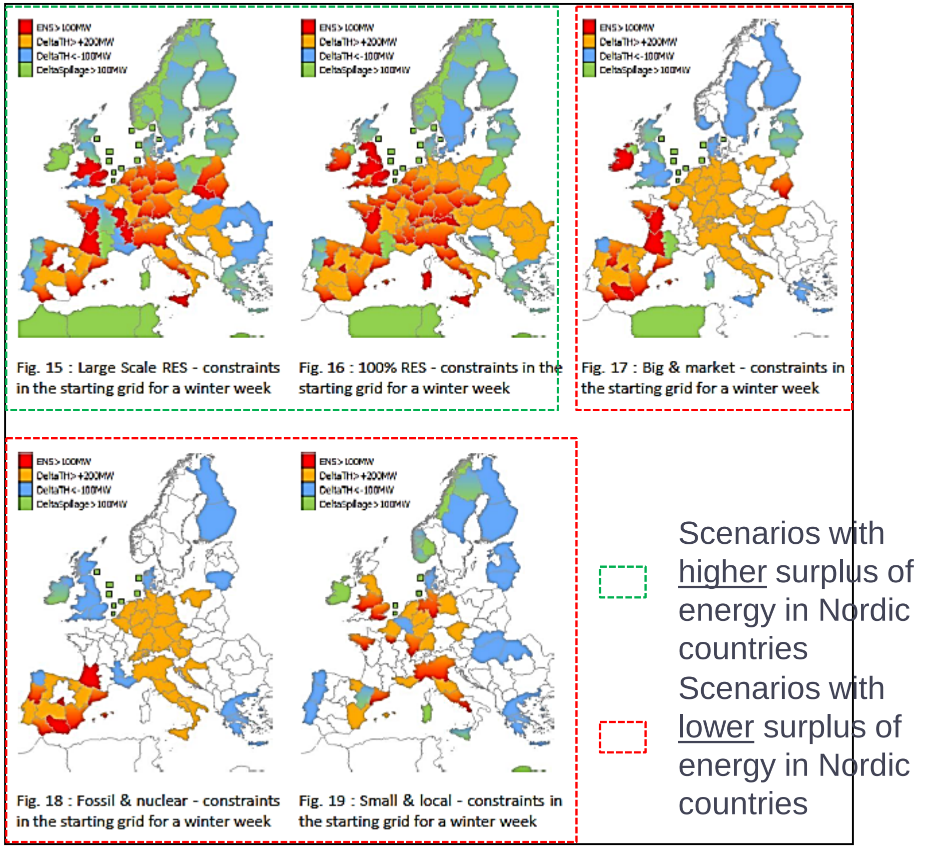


Fig. 15 : Large Scale RES - constraints in the starting grid for a winter week

Fig. 16 : 100% RES - constraints in the starting grid for a winter week

Fig. 17 : Big & market - constraints in the starting grid for a winter week

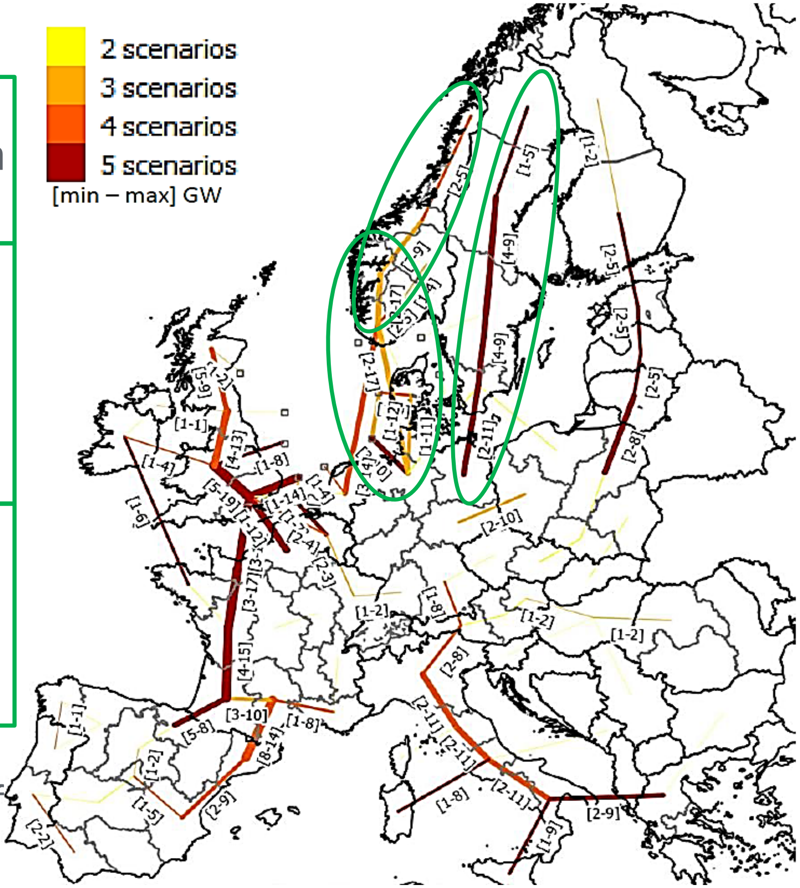
Fig. 18 : Fossil & nuclear - constraints in the starting grid for a winter week

Fig. 19 : Small & local - constraints in the starting grid for a winter week

Grid constraints in 2050 scenarios without further grid reinforcements beyond 2030 for a winter peak, e-Highway 2050

DESPITE HIGH COSTS, GRID REINFORCEMENTS ARE NEEDED AND MORE PROFITABLE IN CASE OF STRONG RES DEVELOPMENT

- **Main transmission requirements at the 2050 horizon**:
  - Whatever the scenarios, the **corridors in the North-South axis in Sweden need to be reinforced** between 4 and 9 GW on average.
  - The more hydro-power reservoirs are developed in Norway, the more **some reinforcements are necessary in northern Norway** (between 2 and 5 GW) **to bring down hydro generation or wind to the south of Norway** (higher consumption).
  - The **North-south axis from central Norway to Continental Europe** (Germany, Denmark and Netherlands) is **much reinforced in case of huge increase of wind and hydro capacities in Norway**.
  - Only in the case when the intermittent RES generation (and mainly PV) is important in UK, the reinforcement of the link between Norway and UK brings some benefits for the European system.

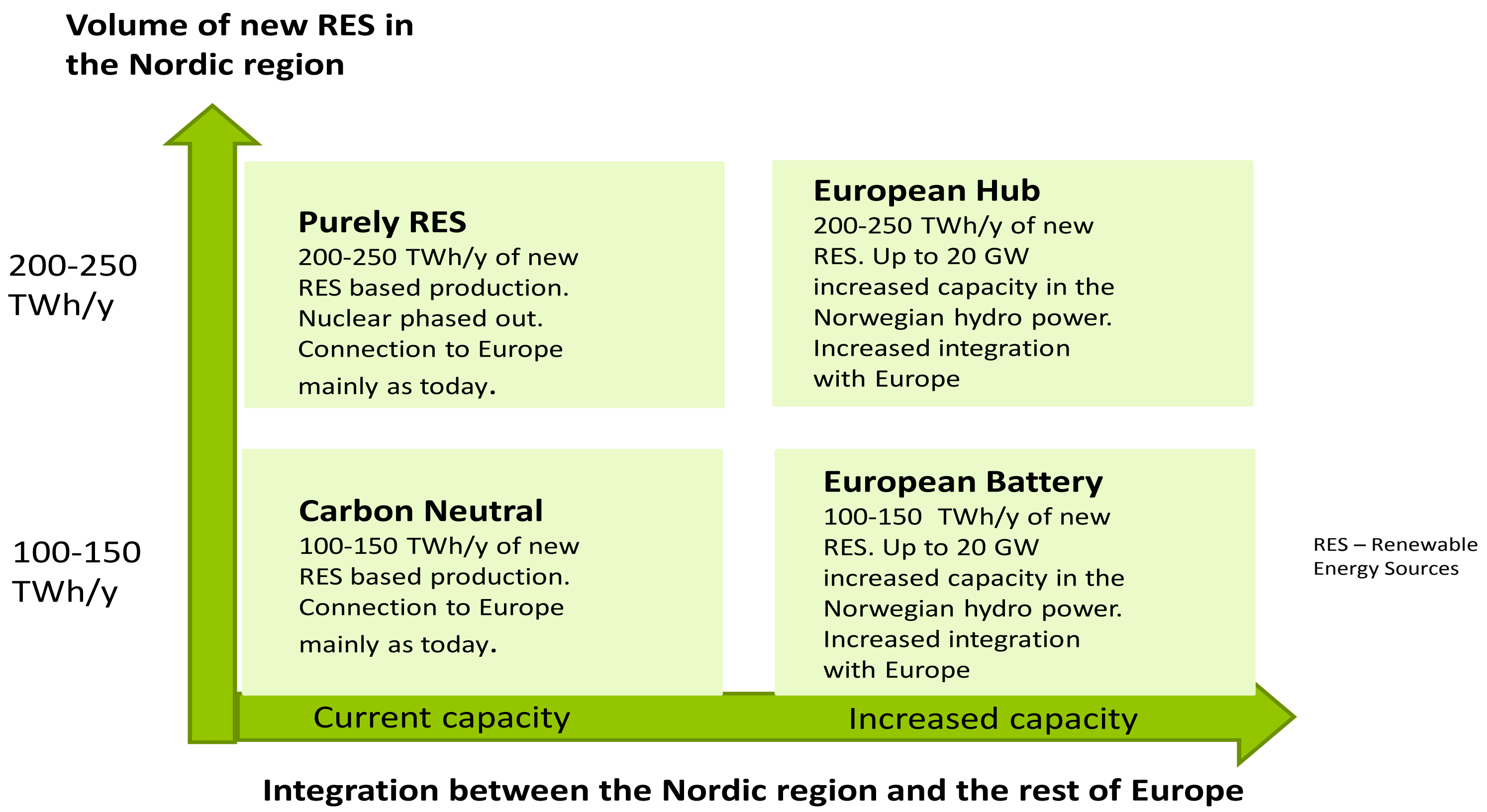


Transmission requirements between scenarios, e-Highway 2050

- **The investment cost is more or less doubled in case of a strong development of intermittent RES and hydro-based capacities, but the reinforcements are also more needed and much more profitable (benefits are three to nine times higher).**

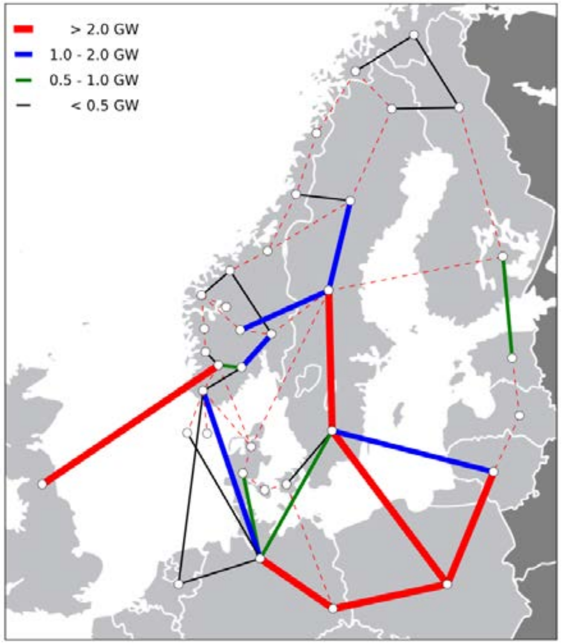
NORSTRAT PROJECT

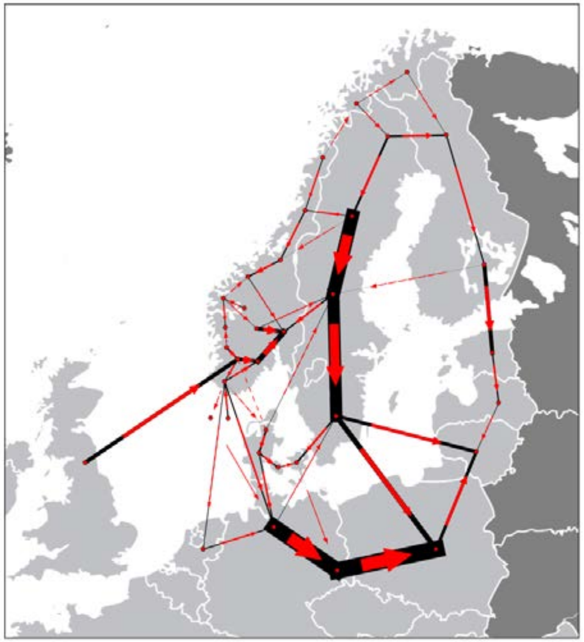
Scenarios for development RES in the Nordic System in 2050



Graabak, L. Warland, "A carbon neutral power system in the Nordic region in 2050 D3.1 in the NORSTRAT project", Report TR A7365, SINTEF Energy Research, March, 2014

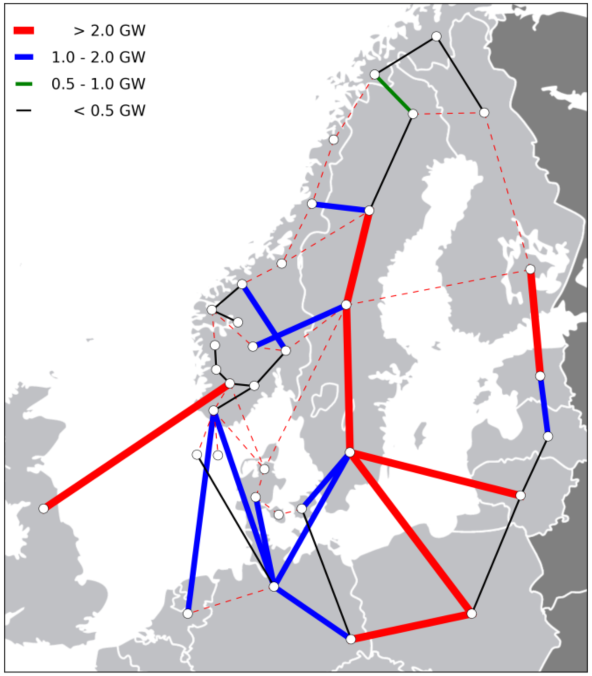
EUROPEAN BATTERY SCENARIO

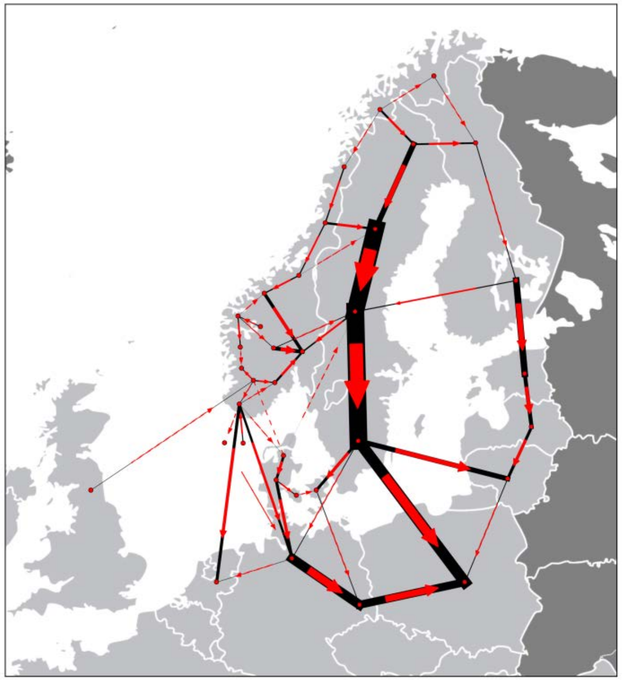




- Huge investments in transmission capacities (10 750 MW) in the Nordic countries
- Transmission capacity to continental Europe and Great Britain (12 200 MW).
- There net export from the Nordic region is limited to 36 TWh/year, including 122 TWh/year export and 86 TWh/year import

EUROPEAN HUB SCENARIO





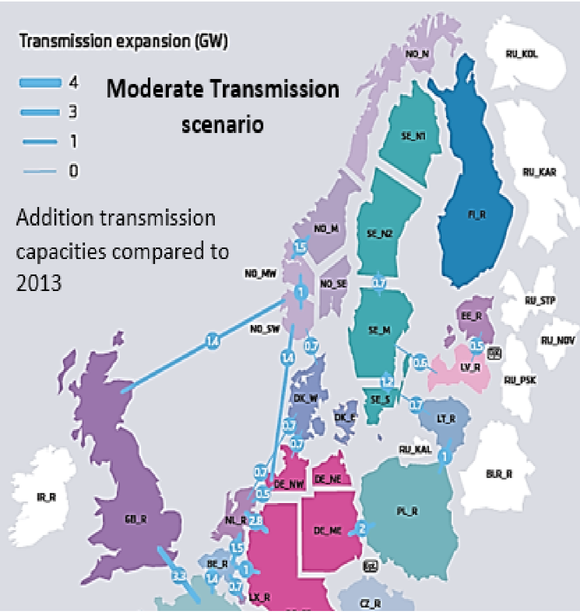
- Huge investments in transmission capacities (18 850 MW) in the Nordic countries
- Transmission capacity to continental Europe and Great Britain (19 200 MW).
- There net export from the Nordic region is limited to 110 TWh/year, including 197 TWh/year export and 87 TWh/year import

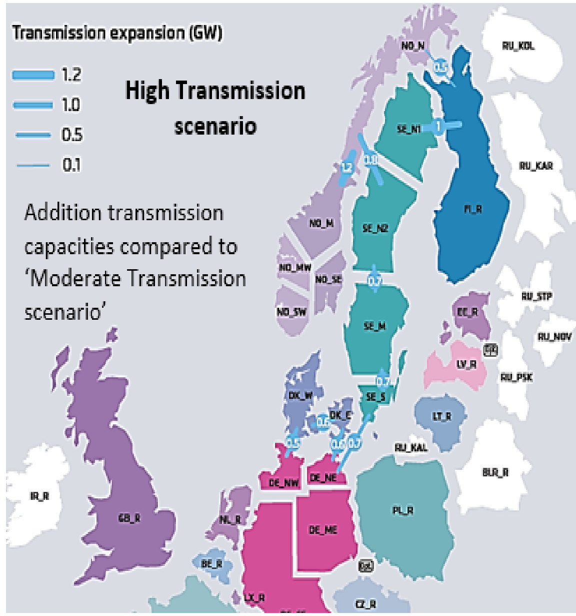
CONCLUSION

- With the most important hydro-based mix and an important potential for development of wind turbines, Norway (and Sweden) = the larger energy surplus area in Europe until 2050:
  - The power flows pattern should remain southbound to a large extent, considering that an important part of RES development is located in the northern areas of Scandinavia.
  - Probably **future larger and more volatile power flows between Scandinavia and Continental Europe**, because of the increasing penetration of intermittent RES in Continental EU → **Norway = electricity exporter to Continental EU**.
- <u>But</u> the benefits for exporting could be limited by grid bottlenecks:
  - Today, **some exports from Scandinavia to Germany already limited by curtailments** of the cross-border capacity between Denmark West and Germany.
  - **Huge reinforcements will be necessary not only inside Scandinavian countries, but also in Denmark and Germany.** <u>If the bottlenecks inside market areas are relieved</u>:
    - The more the intermittent RES generation is higher in UK, the more any reinforcement between Norway and UK increases the social welfare.
    - The level of penetration of intermittent RES capacities in Europe, and development of hydro-based generation in Norway will trigger the need for more interconnectors investments between Norway / Sweden and Germany / Denmark / Netherlands to relieve congestions.

Thank You

ANNEX: DETAILS ABOUT AGORA STUDY





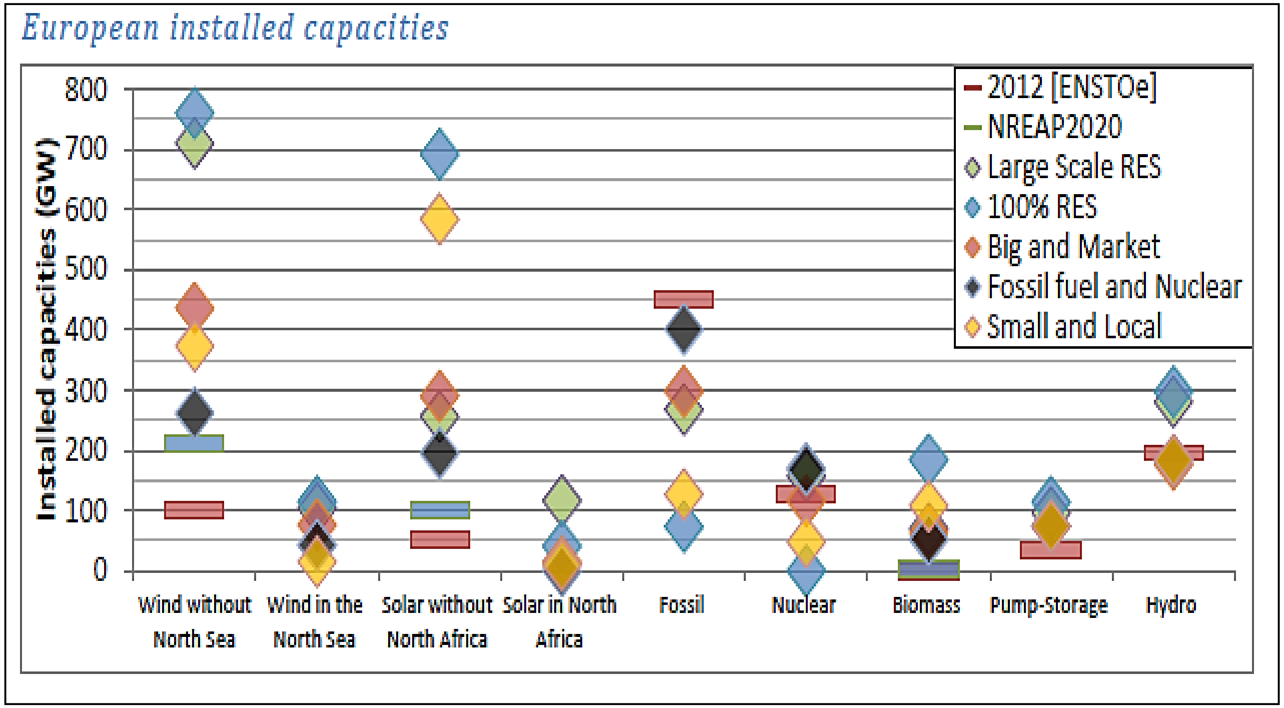
Project	From	To	Capacity (MW)	Year	Estimated Cost (€ millions)
Core Countries					
Westcoast	DK_W	DE_NW	500	2022	170–210
Hansa PowerBridge	SE_S	DE_NE	700	2025	200–400
3rd AC Finland-Sweden	SE_N1	FI_R	1,000	2025	64–120
Finland-Norway	NO_N	FI_R	500	2030	300–700
Norway-North Sweden	NO_N	SE_N2	750	2030	140–330
East Denmark-Germany	DK_E	DE_NE	600	2030	500–610
Sum of costs					1,374–2,370
Internal Reinforcements					
NordBalt Cable Phase 2	SE_S	SE_M	700	2023	170–270
Res in mid-Norway	NO_M	NO_N	1,200	2023	870–1,500
Great Belt II	DK_W	DK_E	600	2030	390–480
Sweden north-south	SE_M	SE_N2	700	2030	800–1,400
Sum of costs					2,230–3,650
Total cost of High Transmission scenario					**3,604–6,020**
Annual cost (4 % interest rate, 30 year lifetime)					**208–348**
Annual cost (5 % interest rate, 20 year lifetime)					**289–483**

Hypothesis of transmission capacities in AGORA scenario

Marginal value of transmission k€/MW							
From	**To**	**Capacity (Additional) MW**	**Cost k€/MW**	**ModRE ModTrans**	**ModRE HighTrans**	**HighRE ModTrans**	**HighRE HighTrans**
DK_W	DE_NW	2,500 (500)	20–24	32	17	74	42
SE_S	DE_NE	0 (700)	17–33	90	74	206	185
SE_N1	FI_R	1,300 (1,000)	4–7	8	1	45	21
NO_N	FI_R	0 (500)	35–81	–*	12	–*	53
NO_N	SE_N2	275 (750)	11–25	32	13	86	33
DK_E	DE_NE	600 (600)	48–59	48	17	110	44
SE_S	SE_M	4,850 (700)	14–22	3	3	5	8
NO_M	NO_N	600 (1,200)	42–72	20	5	42	10
DK_W	DK_E	600 (600)	38–46	18	1	39	4
SE_M	SE_N2	8,000 (700)	66–116	9	6	20	19

Marginal value of transmission capacities in the 4 scenarios of EGORA Energiewende study

ANNEX: DETAILS ABOUT E-HIGHWAY 2050



European installed capacities in the 5 different scenarios, e-Highway 2050

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