Optimal offshore grid developments in the North Sea towards 2030

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Deep Wind 2013 – Strategic Outlook Session

25th January 2013

SINTEF

NOWITECH
Norwegian Research Centre for Offshore Wind Technology

Twenties
Transmitting wind

SEVENTH FRAMEWORK PROGRAMME

EUROPEAN COMMISSION

OffshoreGrid

INTELLIGENT ENERGY EUROPE

Motivation: Strategic Outlook – 2030

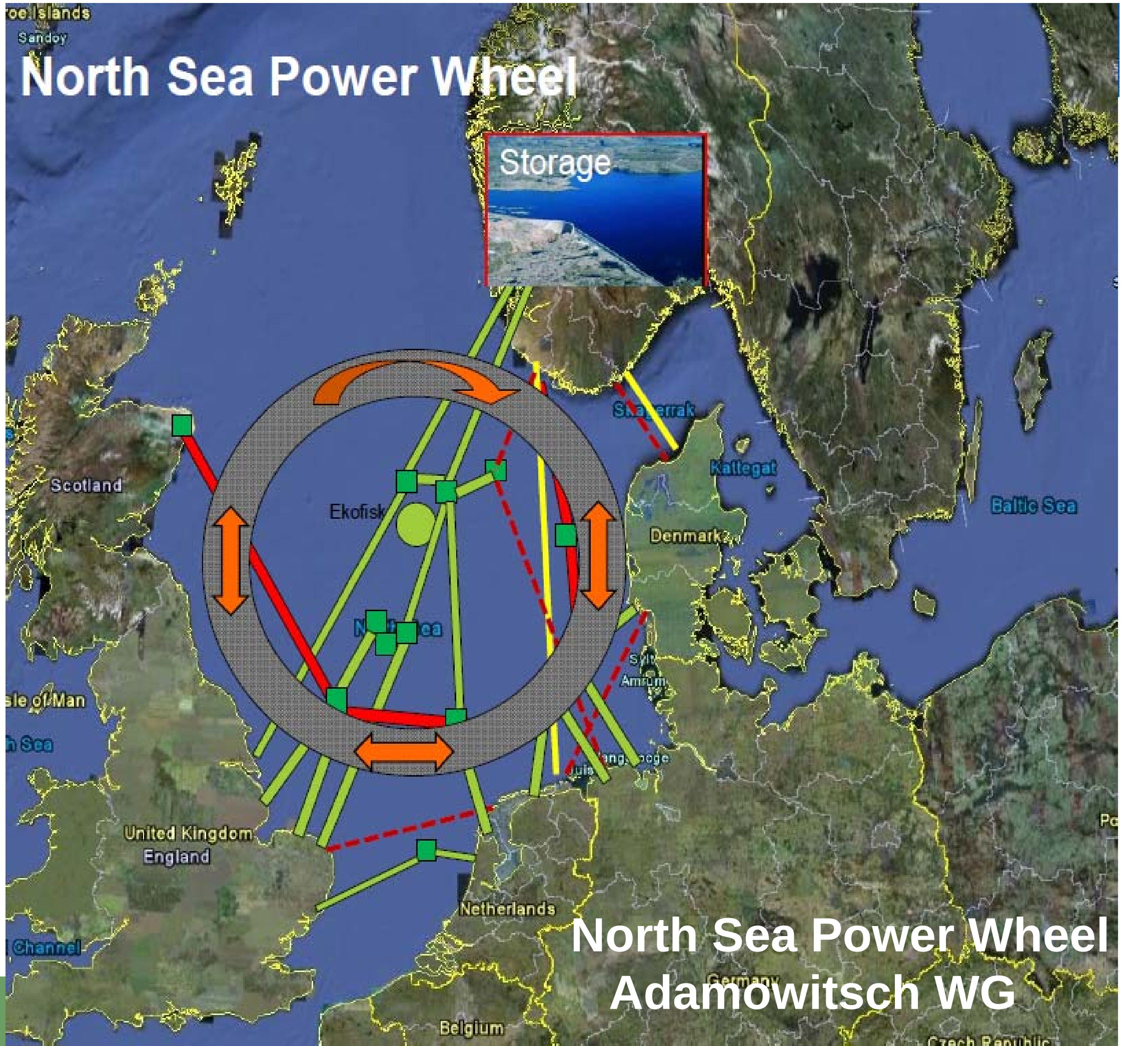
Hydro power

(Flexibility, Storage, Balancing)

Grid

Offshore wind

(Penetration, Variability)



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Motivation: Strategic Outlook – 2030

- What is the **Strategy** to reach this Vision?
- How to define a **robust development path** to deploy our **Strategy**?

Motivation: Strategic Outlook – 2030

- **Strategy:**

"An interconnected offshore grid in the North Sea in 2030"

- Can be highly beneficial from an economic perspective
- Contributes to reaching the European 20-20-20 targets and beyond
- Will increase the security of supply
- Is a step towards an integrated electricity market
- Helps to smooth fluctuations and integrate RES
- Connects northern storage capacities to the power system

(Conclusions of IEE-EU project OffshoreGrid)

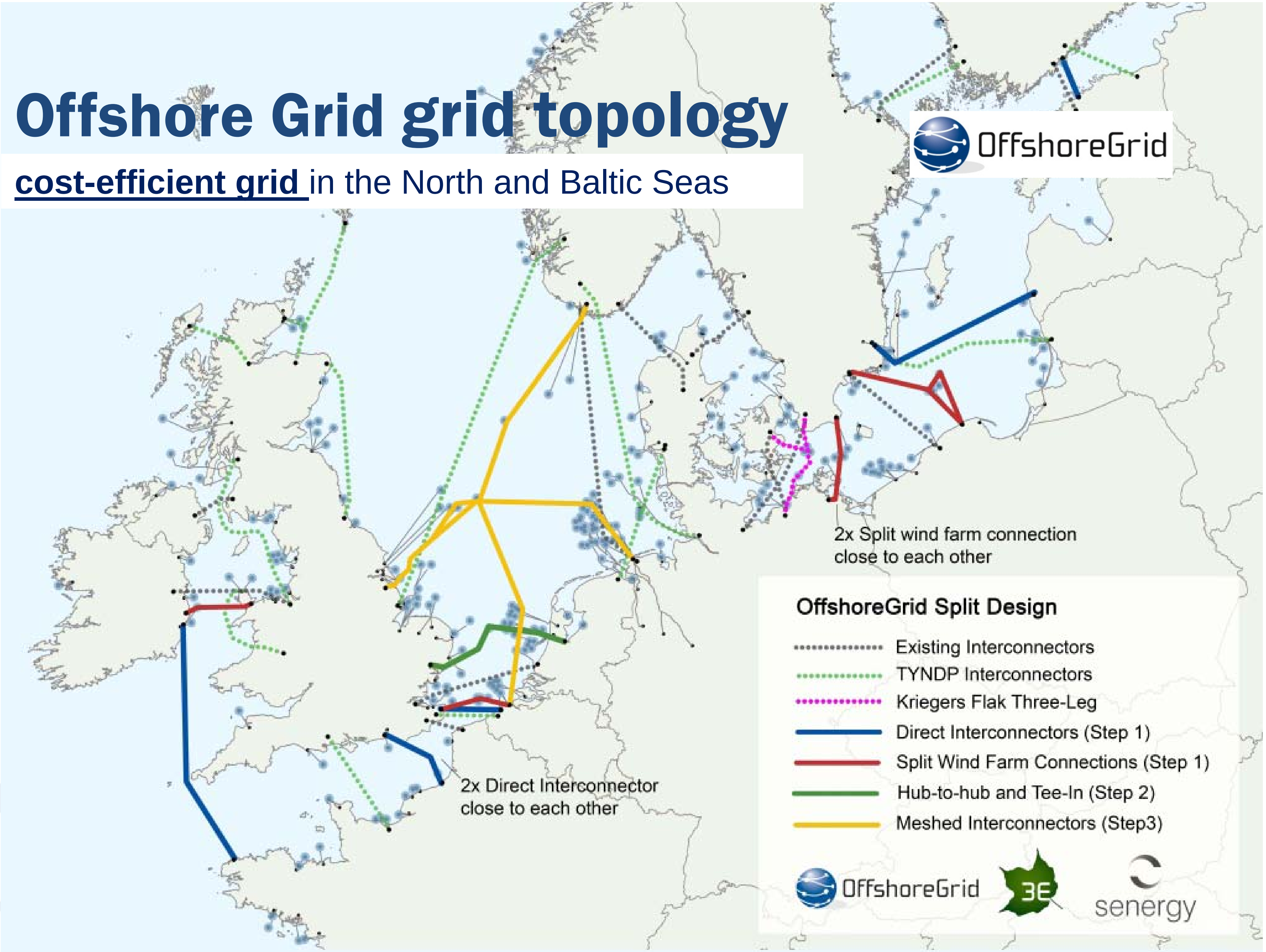
OffshoreGrid

IEE OffshoreGrid

- Techno-economic study
- Cost-benefit analysis of different design options
- First in-depth analysis of how to build a cost-efficient grid in the North and Baltic Seas
- Coordinator 3E, 8 partners, consultancy & applied research
- SINTEF : Harald Svendsen, Leif Warland, Magnus Korpås, DHH

Offshore Grid grid topology

<u>cost-efficient grid</u> in the North and Baltic Seas



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Intelligent Energy Europe

Sensitivity Analysis & Robustness

Main Aspects considered

- ✓ Potential for **large scale offshore wind deployment**.
- ✓ Potential for **flexible generation** – increased **hydro power potential** in Norway.
- ✓ Analysis of **onshore grid reinforcement strategies** for **offshore grid topologies**
- ✓ **SINTEF**: Hossein Farahmand, Stefan Jaehnert, DHH

European Interconnected Network (2030)

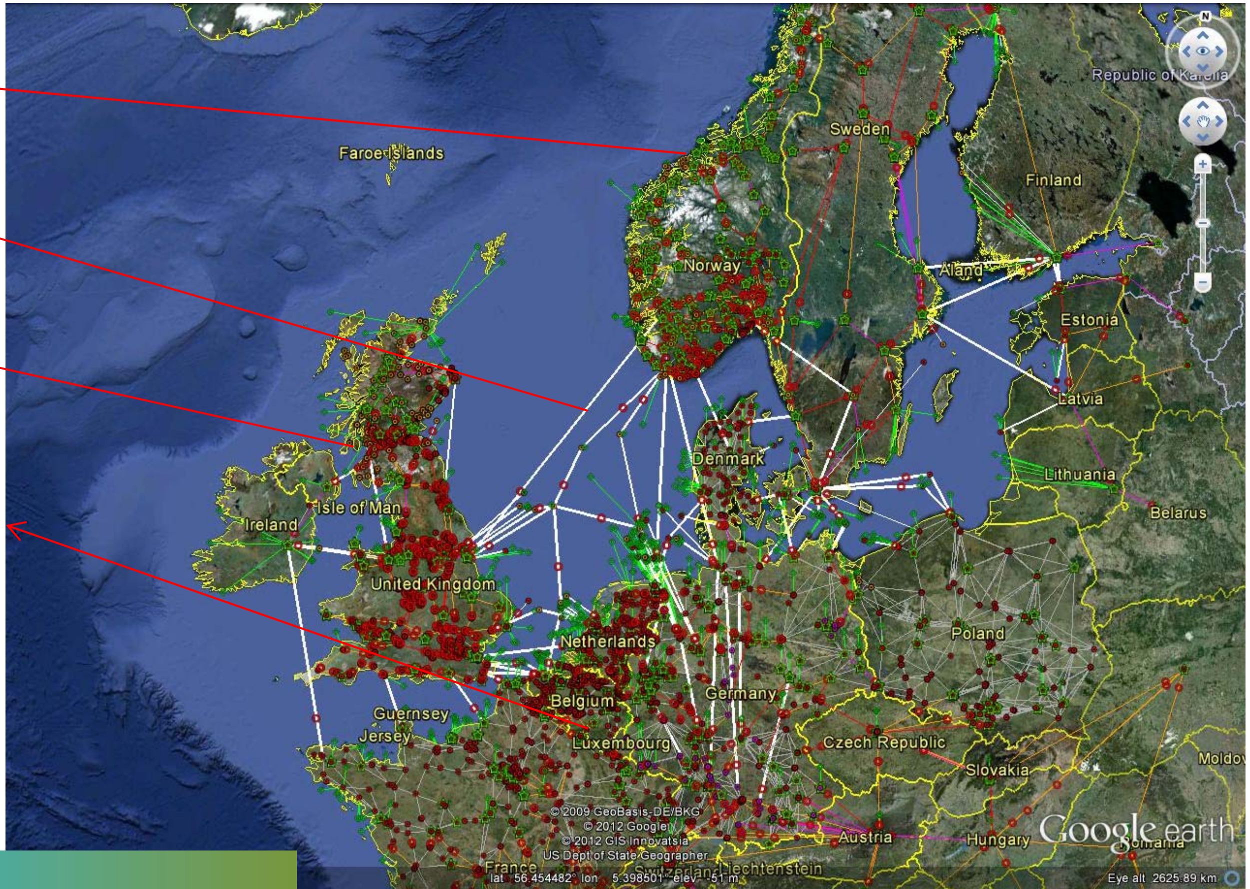
Tool: Power System Simulation Tool (PSST) – DC Power Flow

Detail model of Norway

Offshore Grid

Detail model of the UK

Detail model of ENTSO-E



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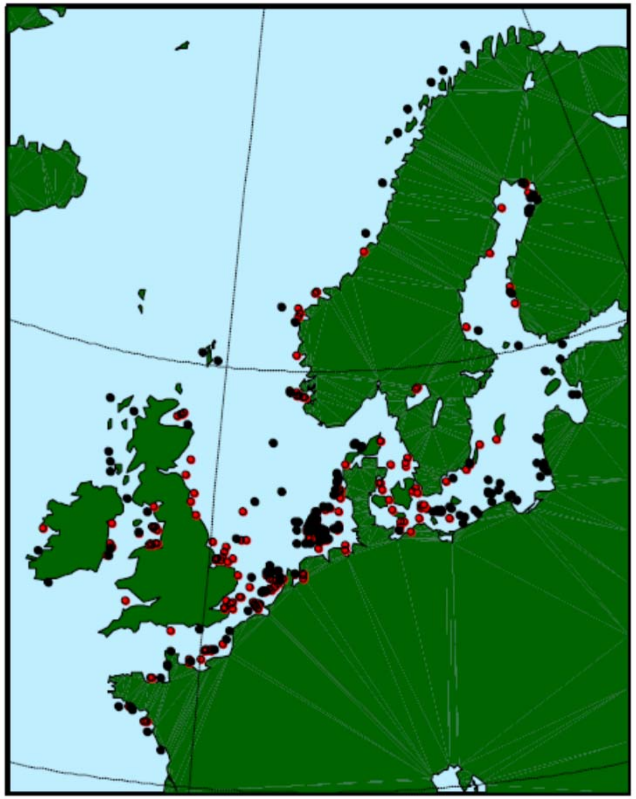
Wind Power Scenarios in Northern EU

Country	2020				2030			
	Total installed Capacity (GW)		Offshore wind power (GW)		Total installed Capacity (GW)		Offshore wind power (GW)	
	Base	High	Base	High	Base	High	Base	High
Belgium	4.26	4.66	2.16	2.16	6.72	7.01	3.96	3.96
Germany	49.8	55	8.81	13	78.01	92.01	24.06	32.38
Denmark	6.51	7.21	2.81	3.21	9.48	11.19	4.61	5.81
Estonia	0	0	0	0	1.7	1.7	1.7	1.7
Finland	2.35	2.95	0.85	1.45	5.58	7.34	3.61	5.16
France	22.93	23.94	3.94	3.94	30.65	34.67	5.65	7.04
UK	30.06	37.68	16.31	22.78	54.29	71.77	36.2	51.77
Ireland	6.37	7.48	2.12	2.38	8.81	10.66	3.22	4.48
Lithuania	0	0	0	0	1	1	1	1
Latvia	0	0	0	0	1.10	1.10	1.10	1.10
Netherlands	8.8	10.3	5.3	6.80	17.40	22.38	12.79	17.29
Norway	3.6	5.14	0.42	1.02	9.49	12.27	5.31	7.64
Poland	10.5	12.5	0.5	0.5	18.46	19.84	5.30	5.30
Sweden	9.08	11.13	3.08	3.13	14.76	16.94	6.87	8.22
	154.26	**177.99**	**46.3**	**60.37**	**257.45**	**309.88**	**115.38**	**152.85**

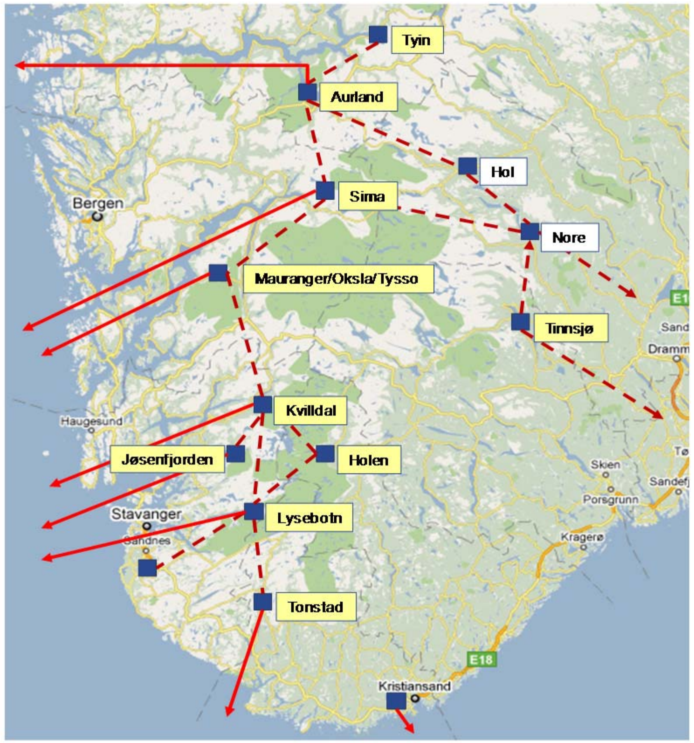
Offshore wind farms in 2020 (red) and 2030 (red+black)



Technical University of Denmark DTU

Scenario Analysis of Hydro Power Potential (D16.2 & CEDREN SINTEF Report http://www.cedren.no)

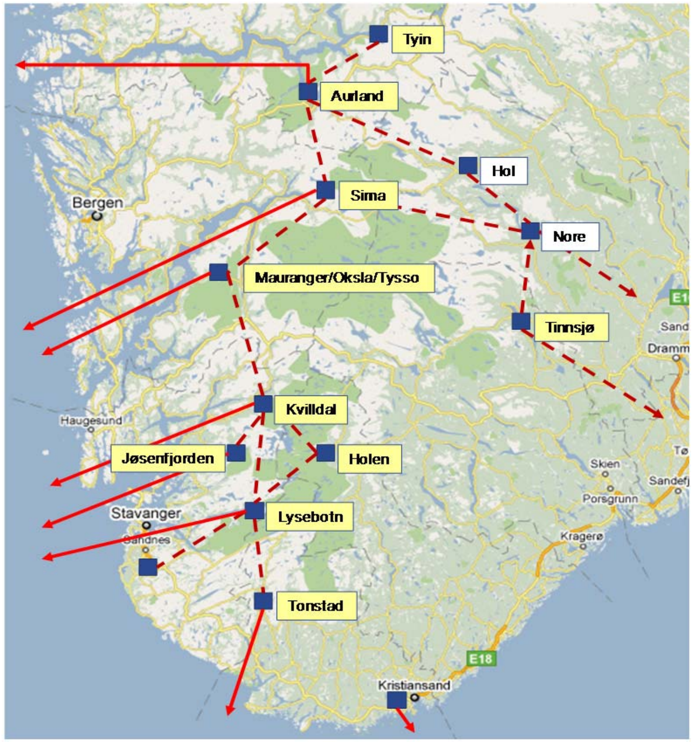
Plant	2020 (MW)	2030 (MW)
Pump Storage Plant Tonstad	1400	1400
Pump Storage Plant Holen	700	1000
Pump Storage Plant Kvilldal	1400	2400
Power Plant Jøsenfjord	1400	2400
Pump Storage Plant Tinnsjø	1000	2000
Pump Storage Plant Tinnsjø	1400	2400
Power Plant Lysebotn	400	1800
Power Plant Mauranger	-	400
Power Plant Oksla	700	700
Pump Storage Plant Tysso	700	1000
Power Plant Sy-Sima	700	1000
Power Plant Aurland	700	700
Power Plant Tyin	700	1000
Amount of new power capacity	**11200**	**18200**

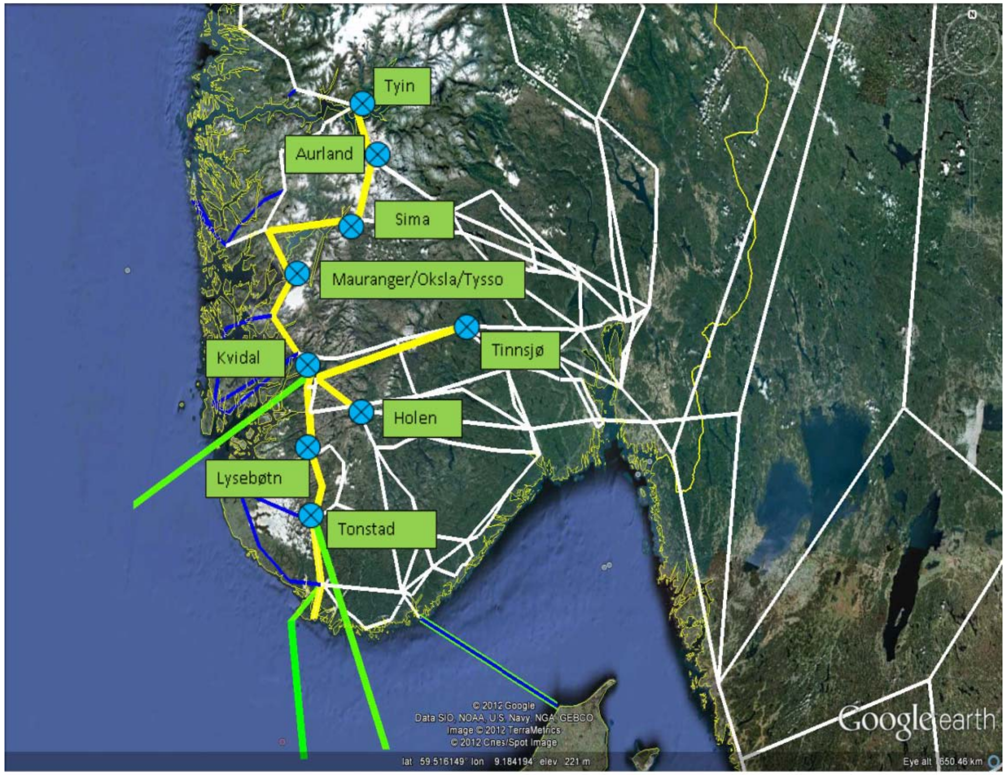


E. Solvang, A. Harby, Å. Killingtveit, "Increasing balance power capacity in Norwegian hydroelectric power stations (A preliminary study of specific cases in Southern Norway)," SINTEF Energy Research, CEDREN Project, Project No. 12X757, 2012

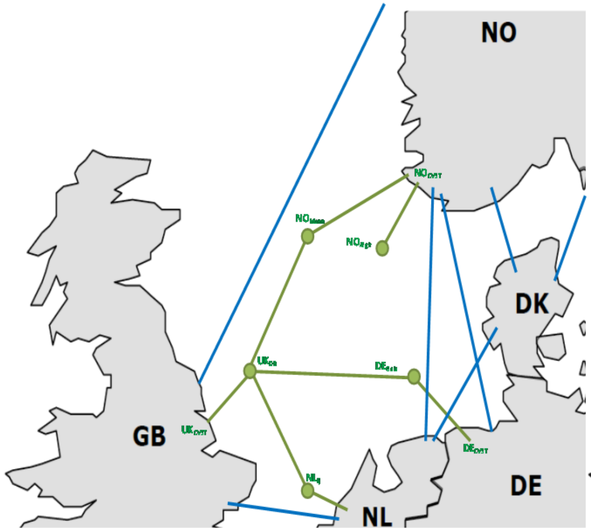
Grid Implications of Hydro Power Flexibility in Norway

- Grid reinforcement in Norway according to Statnett grid development plans
- Special attention is paid to the corridor where the hydro production capacity expansion is proposed (highlighted in yellow)

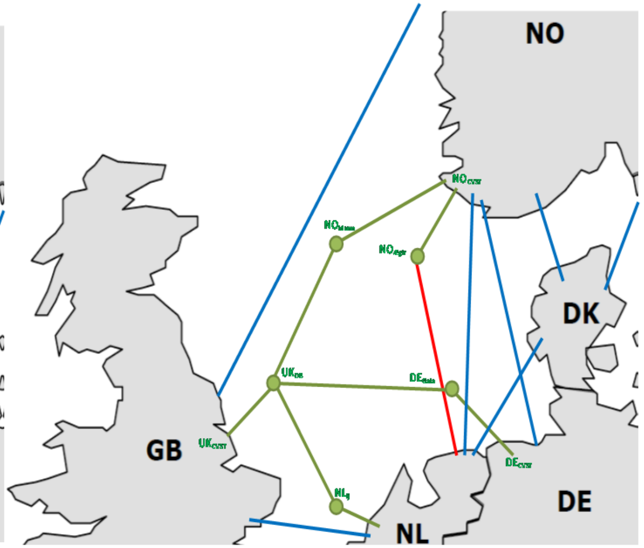




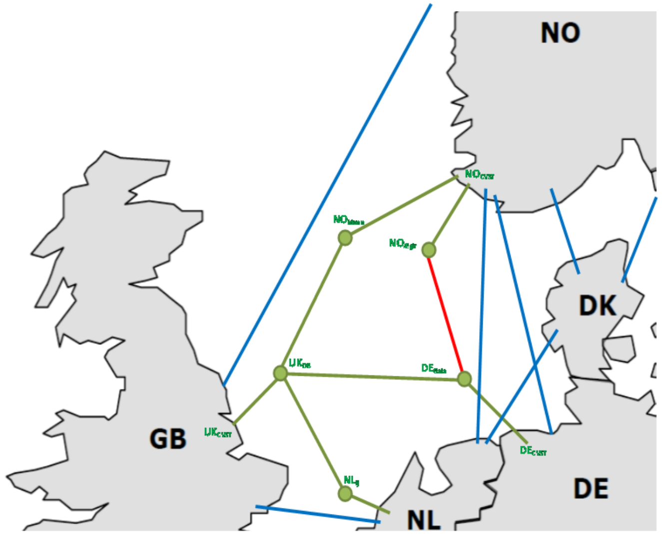
Offshore Grid Alternatives



Case A



Case B

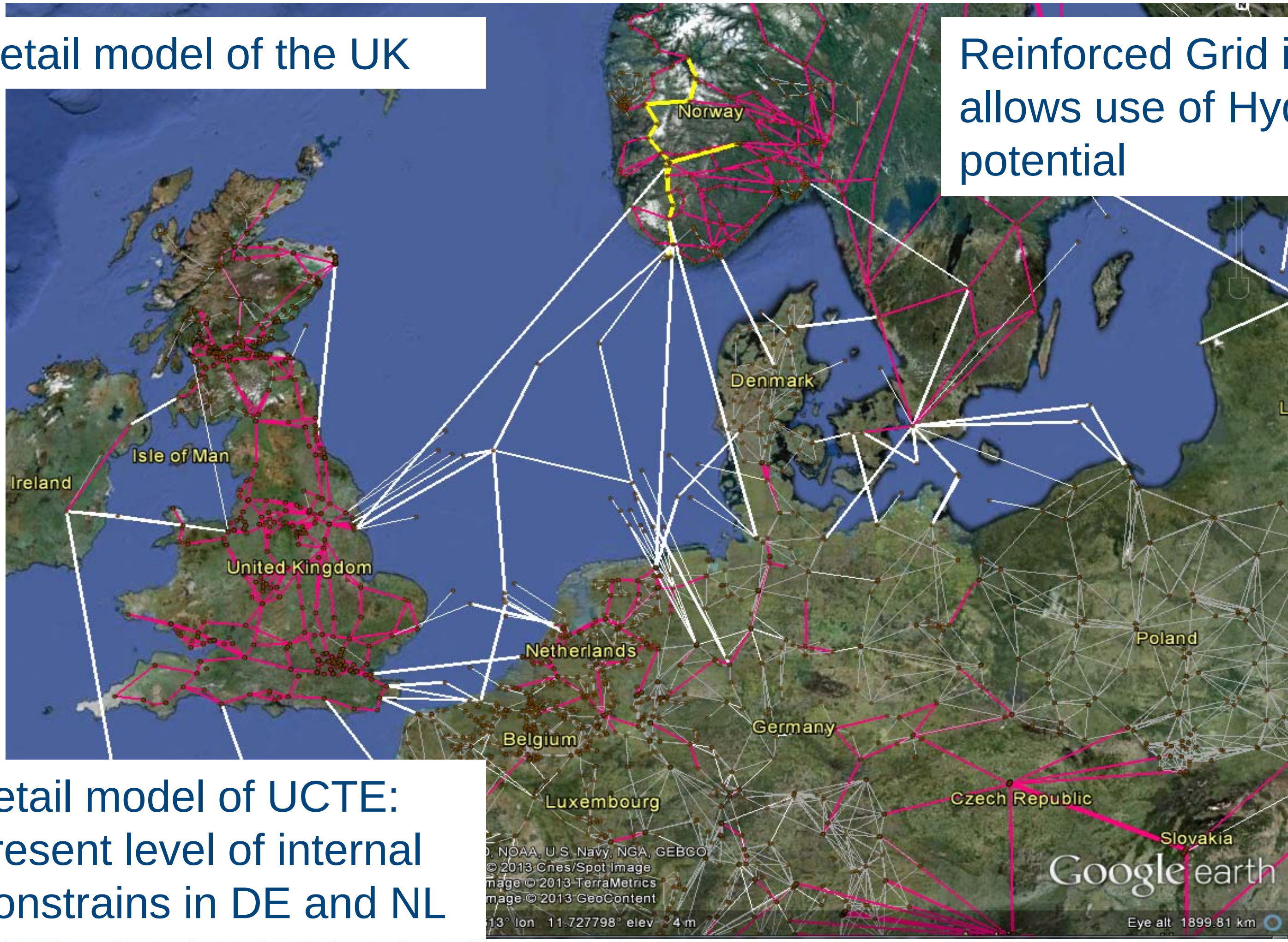


Case C

Internal Constraints

Detail model of the UK

Reinforced Grid in Norway – allows use of Hydro flexibility potential

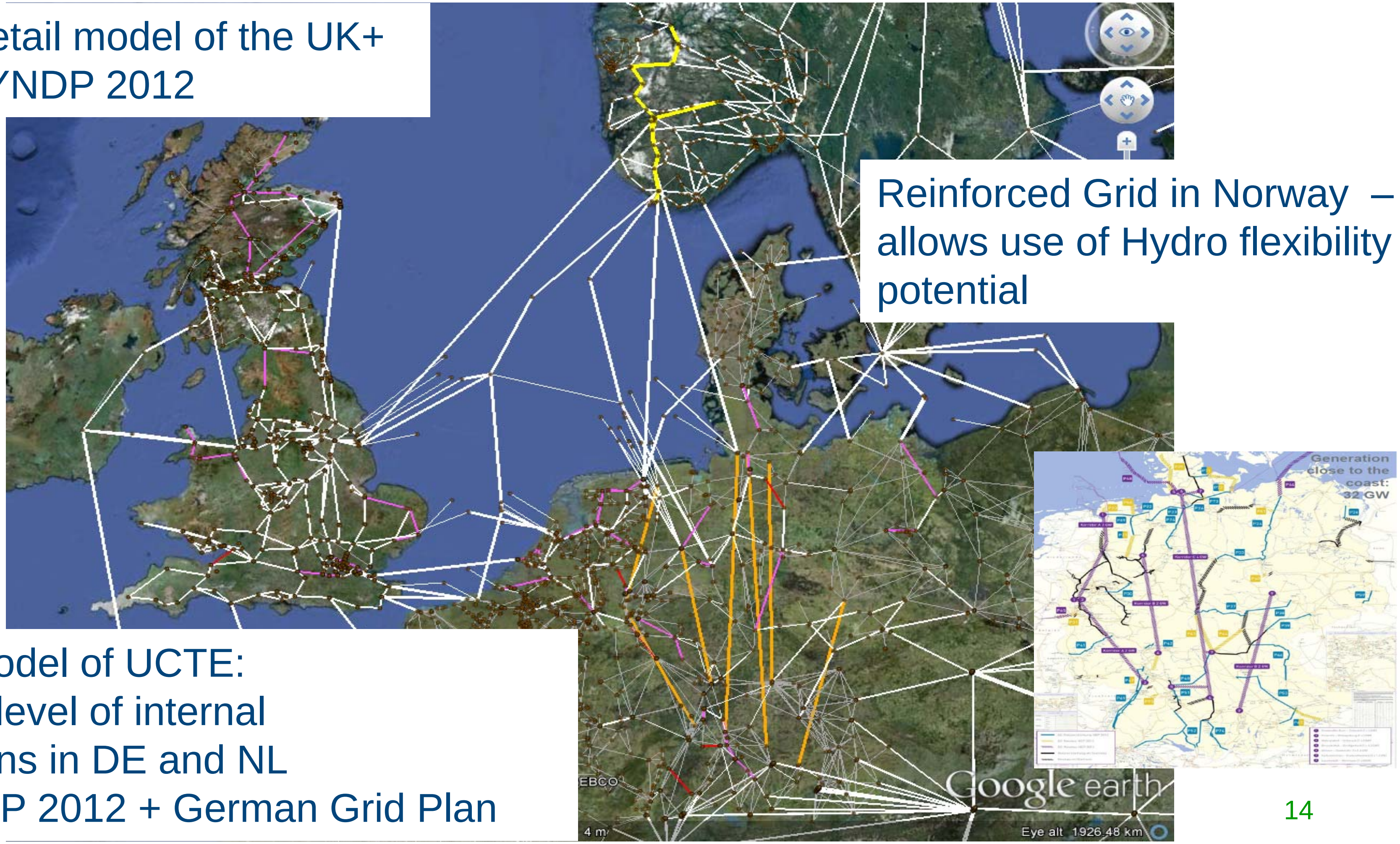


Detail model of UCTE:
Present level of internal Constrains in DE and NL

Internal Constraints + Expansion

Detail model of the UK+
TYNDP 2012

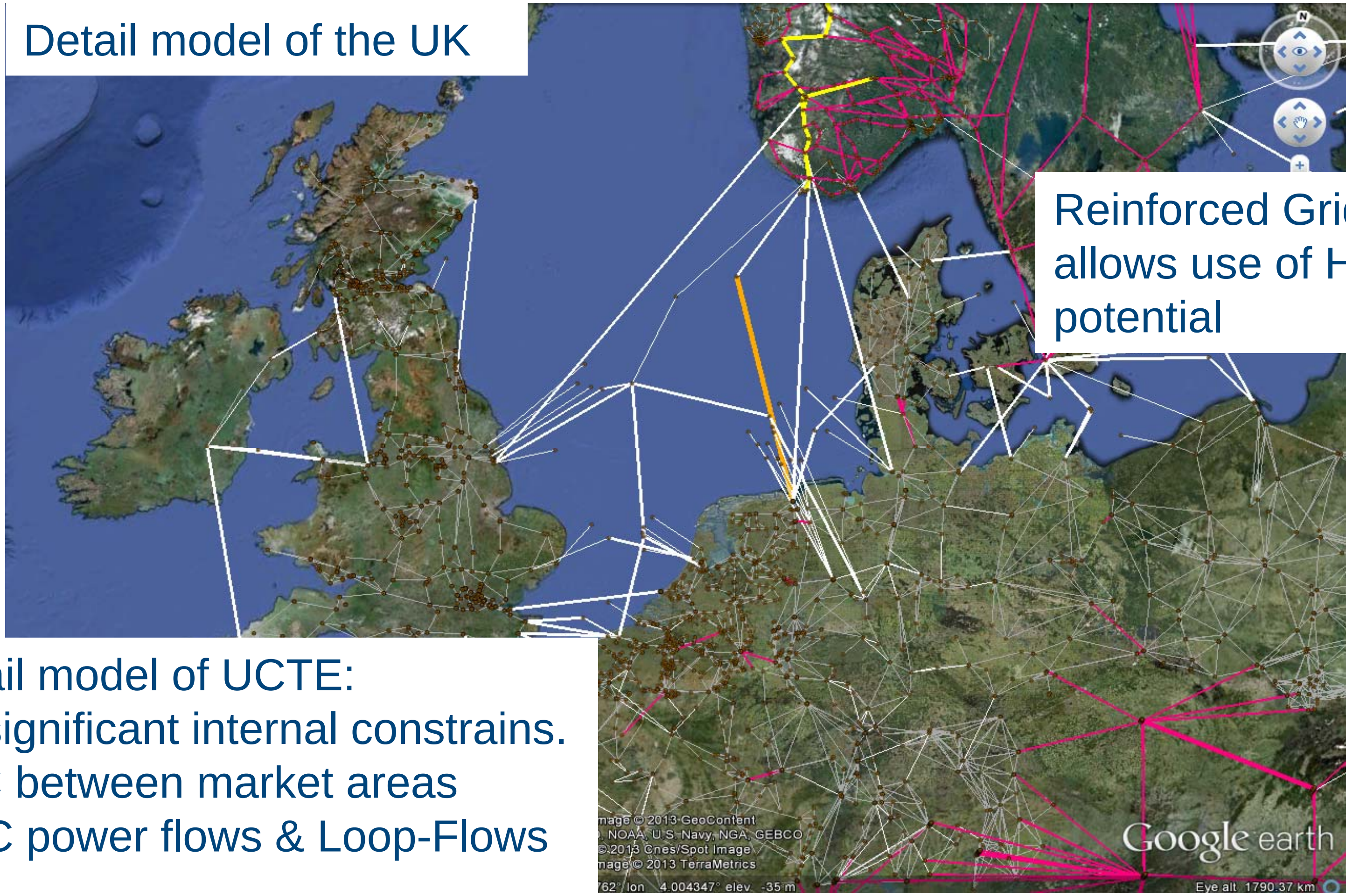
Reinforced Grid in Norway – allows use of Hydro flexibility potential



Detail model of UCTE:
Present level of internal
Constrains in DE and NL
+ TYNDP 2012 + German Grid Plan

No-Internal Constraints

Detail model of the UK

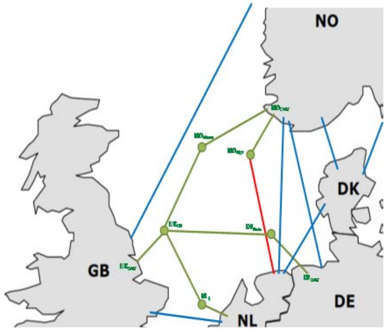


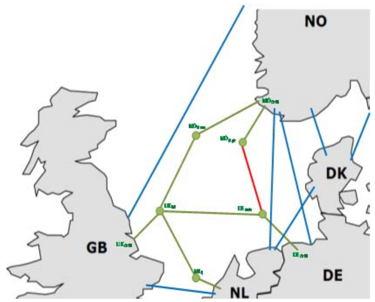
Reinforced Grid in Norway – allows use of Hydro flexibility potential

Detail model of UCTE:
No significant internal constrains.
NTC between market areas
+ DC power flows & Loop-Flows

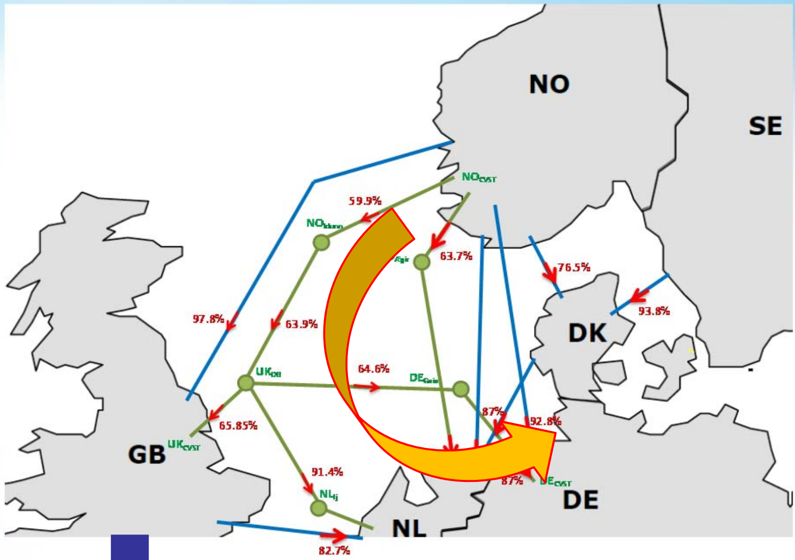
Operating costs

Onshore Grid Constraints in the ENTSO-E and the UK	Offshore grid Cases	Cost (Milliard EUR/a)
1.No constraint	Case A	92.8462
	Case B	92.7498
	Case C	92.7665
2. Internal Constraint	Case A	95.5779
	Case B	95.5273
	Case C	95.517
3.Internal Constraint with Expansion	Case A	92.9928
	Case B	92.9288
	Case C	92.9274



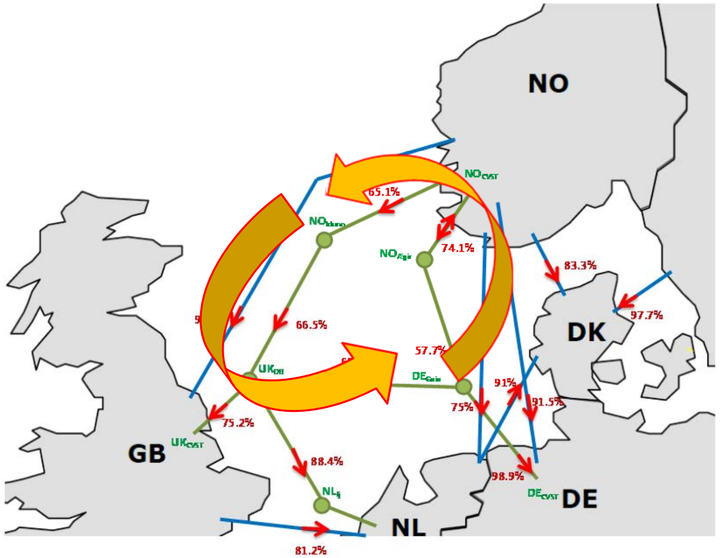


1-Case B, No internal Constrains

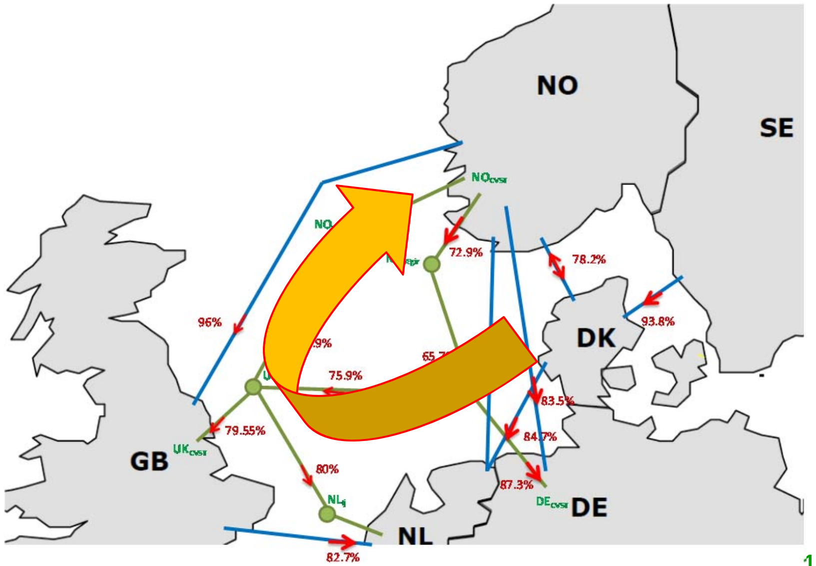


The Impact of Internal Onshore Constraints (average annual exchange)

2- Case C, Internal Constrains + Expansion

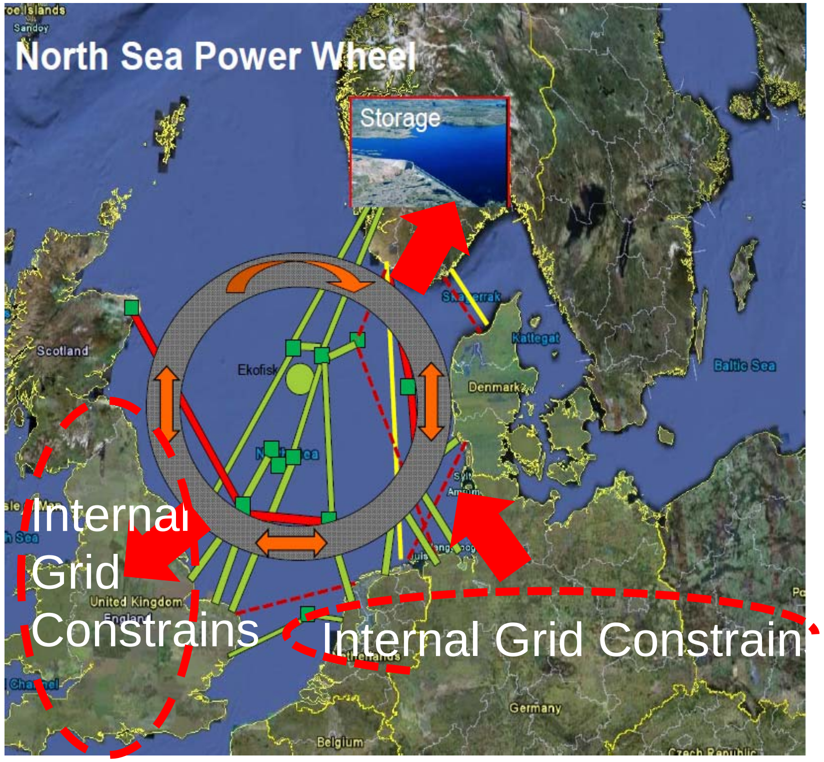


3- Case C, Internal Constrains



The Impact of Internal Onshore Constraint

Onshore grid constraints *inland* strongly influence the optimal use of wind and hydro resources; Limitations to transfer the power inland hence increase the operating cost significantly.

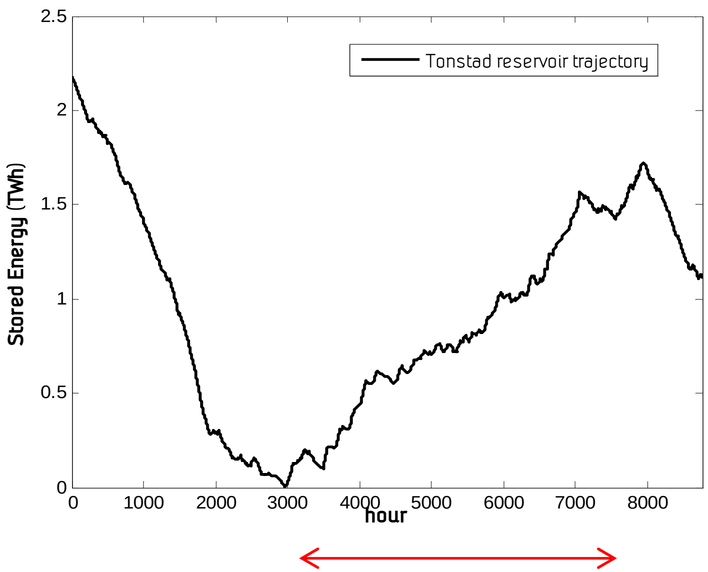


North Sea Power Wheel
Mr. G.W. Adamowitsch

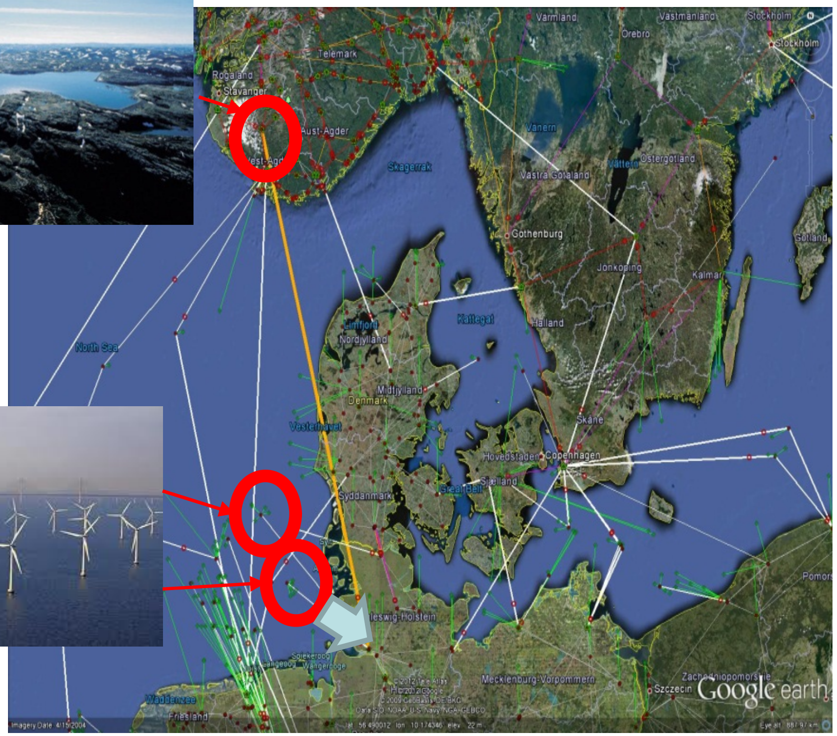
This work has performed a detailed techno-economic study to quantified this effect.

Pumping Strategies

Specific Case (Tonstad & NorGer HVDC cable)



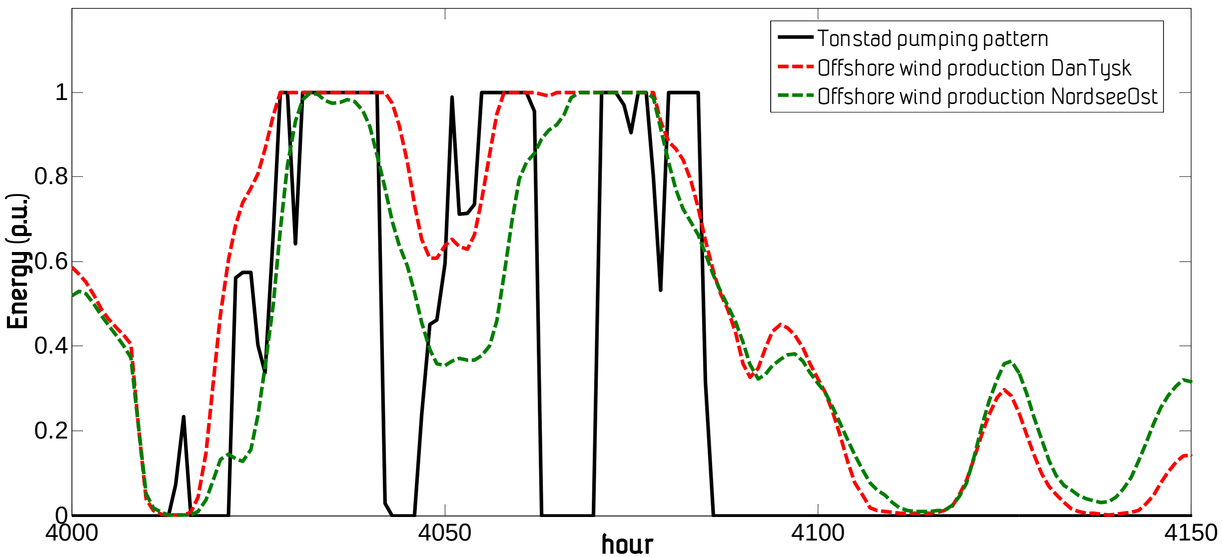
Tonstad Reservoir in Norway



Pumping Strategies

Specific Case (Tonstad & NorGer HVDC cable)

- The reservoir is drained very fast during winter time until hour 3000
- From hour 3000 to 6000 there is a filling season with high natural inflow to reservoir
- During the above period, small fluctuations have been observed
- The small fluctuations are assumed to be the effect of wind production variability



Summary

- Work done in IEE-EU OffshoreGrid, FP7- TWENTIES, FME NOWITECH have performed detailed **techno-economic** studies of:
  - In-depth analysis of how to build a **cost-efficient grid** in the North and Baltic Seas
  - Identification of **required transmission** capacity between the Nordic region and Northern Continental Europe for **optimal** use of hydro power and wind power generation.
  - Sensitivity analysis on effect of **onshore grid constrains**

Main conclusions

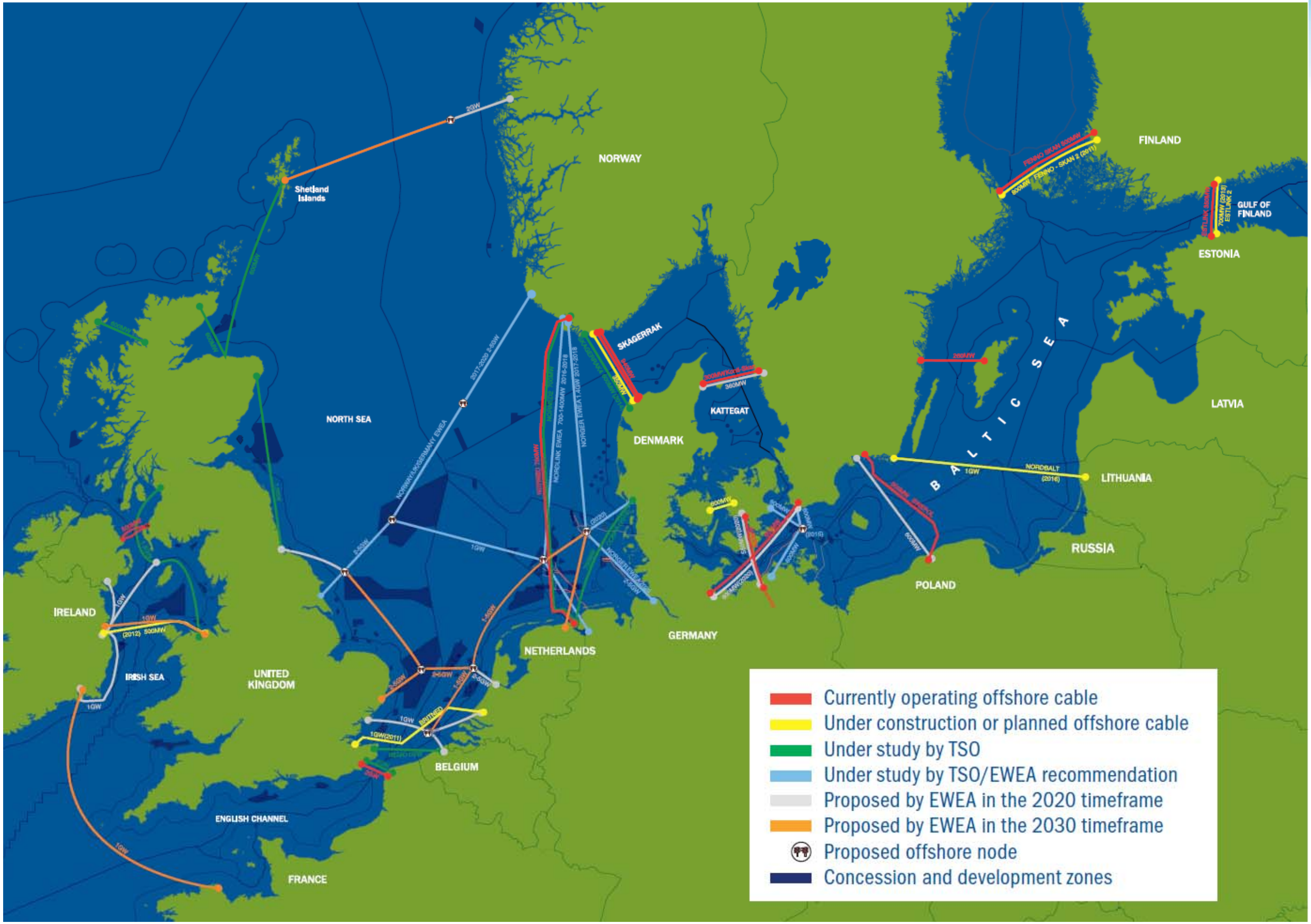
- **Onshore grid** constraints <u>strongly influence</u> the flows across a **meshed offshore grid**, therefore affecting the optimal use of wind and hydro

- **Long term strategies** for the development of **offshore grids** and **onshore grid expansion** <u>must be done in a coordinated way</u> to ensure **optimal developments**.

- The analysis demonstrates the **correlation** between the pumping strategies in the Norwegian system and the onshore and offshore wind variations around the North Sea

Thank You !!

BACK-UP SLIDES



NORWAY
FINLAND
GULF OF FINLAND
ESTONIA
Shetland Islands
SKAGERRAK
KATTEGAT
NORTH SEA
DENMARK
LATVIA
BALTIC SEA
LITHUANIA
NORDBALT (2016)
RUSSIA
POLAND
GERMANY
NETHERLANDS
IRELAND
IRISH SEA
UNITED KINGDOM
BELGIUM
ENGLISH CHANNEL
FRANCE
Currently operating offshore cable
Under construction or planned offshore cable
Under study by TSO
Under study by TSO/EWEA recommendation
Proposed by EWEA in the 2020 timeframe
Proposed by EWEA in the 2030 timeframe
Proposed offshore node
Concession and development zones

Motivation: Strategic Outlook – 2030

- How to define a **robust development path** to reach this **Vision?**

- Research can contribute to this task by:

  - Considering different **Scenarios** including different configurations of offshore grids in the North Sea.

  - Perfoming sensitivity analysis of the considered configuration(s) on different important **key parameter & assumptions**

- The main focus of a such analysis is to gain knowledge about the key relationships and driving forces so better decisions can be made (today), about the best strategy to reach our **Vision.**

Grid Implication Studies: Northern Europe

- **Tool**

  Power System Simulation Tool (PSST) – DC Power Flow

- **Generation portfolio and demand:**

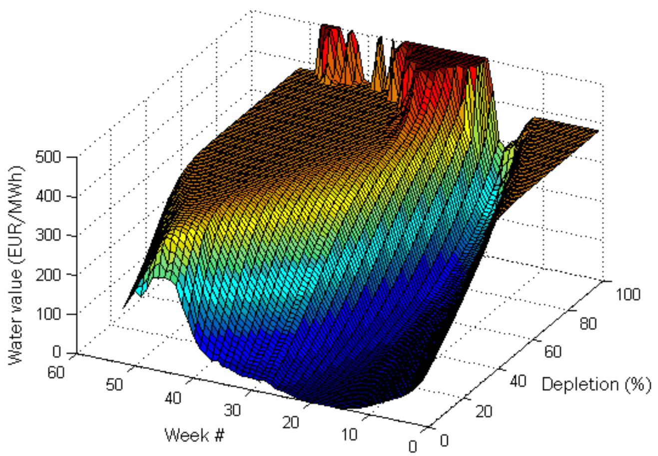
  The scenarios and data are consistent with Market Model

- **Grid Model**
  - ✓ ENTSO-E UCTE Study Model (winter 2008)
  - ✓ British (National Grid-Seven Year Statement)
  - ✓ Nordic and Eastern Europe data (SINTEF-NVE & TradeWind)

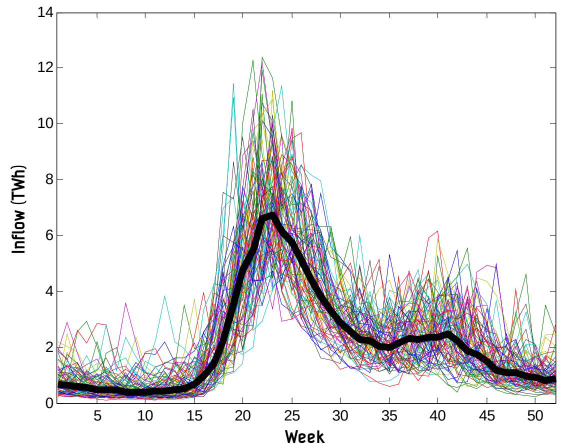
- **Modelling Development**
  - ✓ 5651 buses, 2410 generators, 9611 branches
  - ✓ 2020, 2030 Scenarios

Hydro modelling

- Since there is a limited amount of water storage in hydro reservoirs, its long-term utilisation is essential to be optimised
- The water values reflect the expected future value of the other types of production that the hydro generators substitute
- The water values are imported from the market model (EMPS) and used as exogenous input to the next model (PSST)



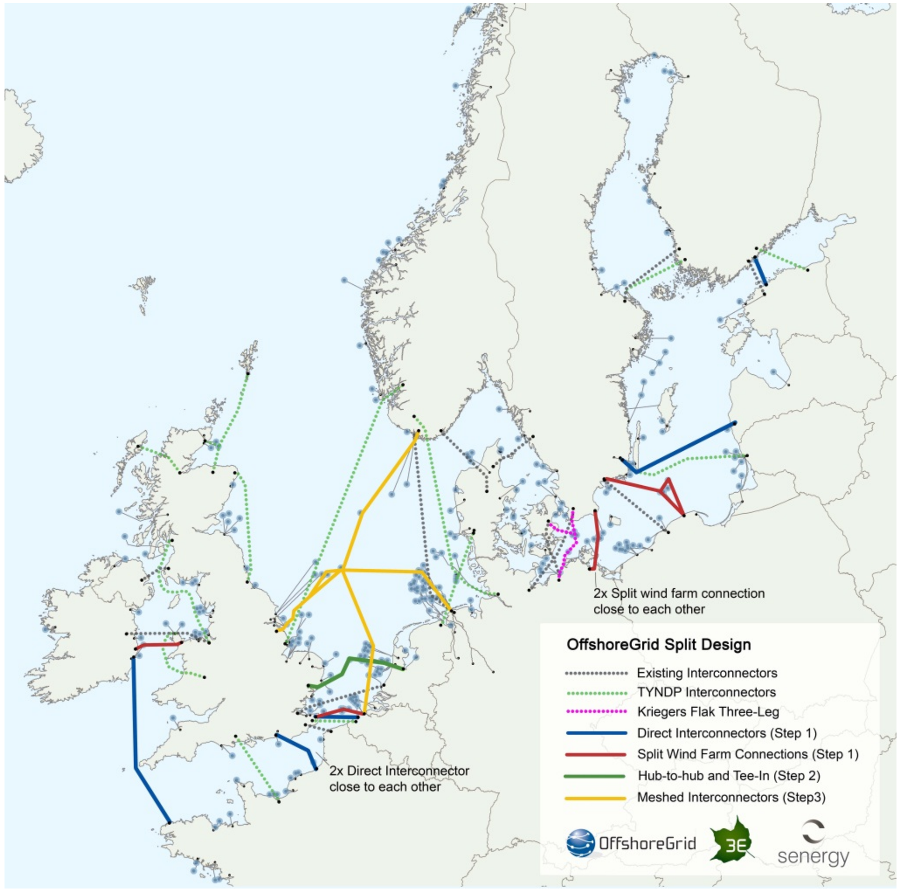
Calculated Water Values For a Reservoir in Southern Norway

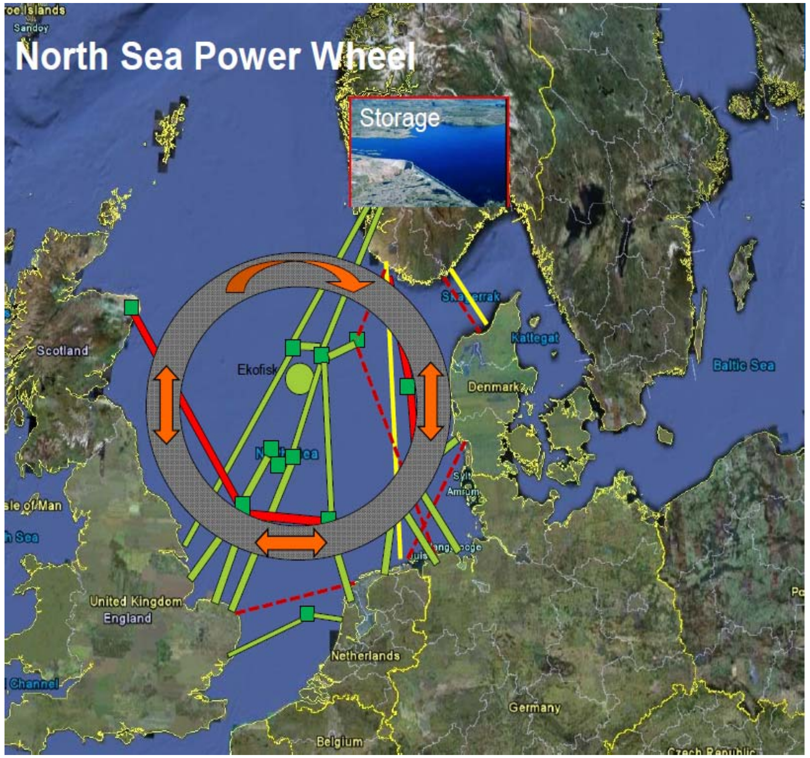


Inflow Scenarios in the Norwegian Power System

European Interconnected Network (2030)

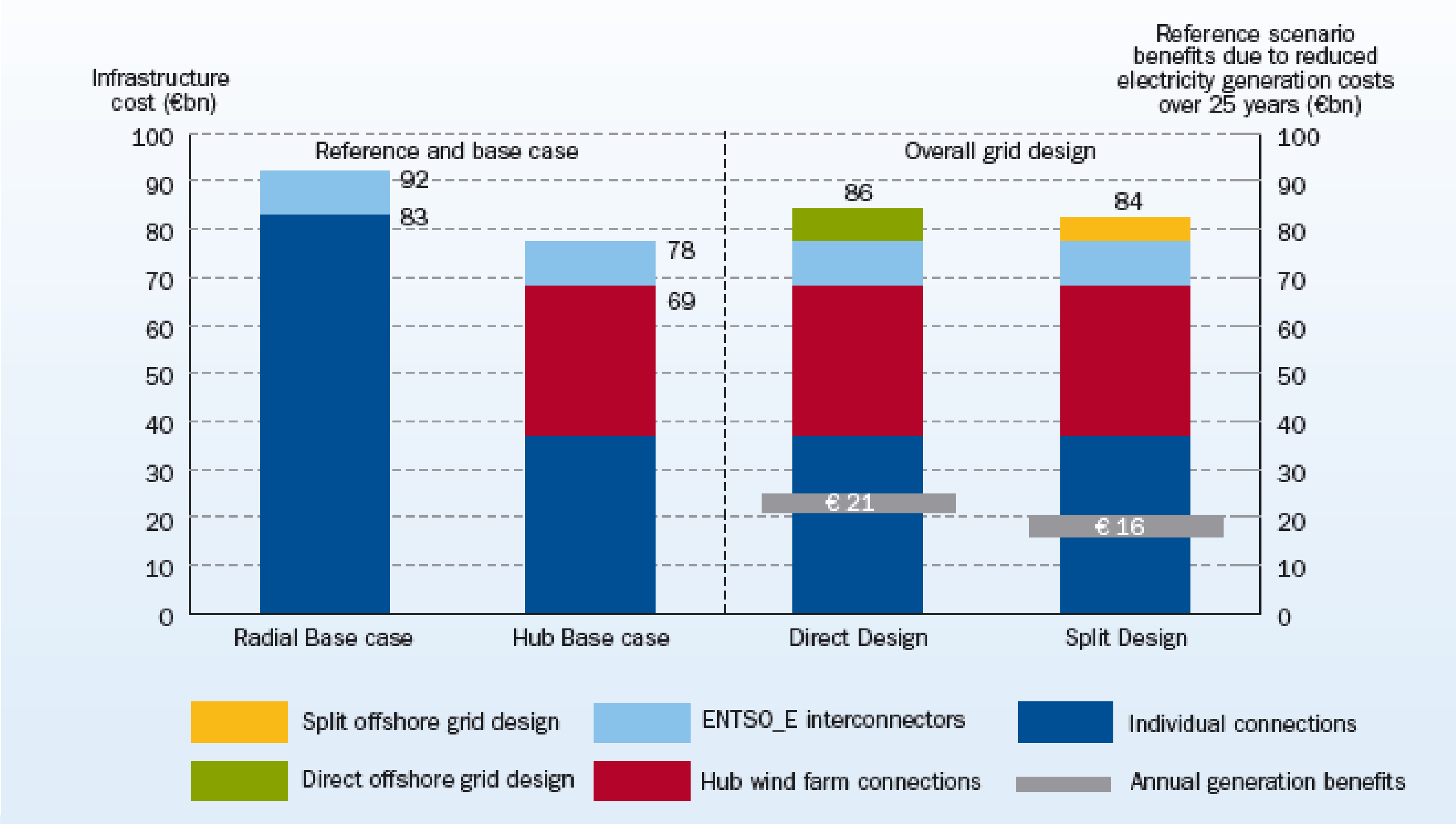
PSST + Offshore Meshed Grid (IEE-EU OffshoreGrid Project)





North Sea Power Wheel
Mr. G.W. Adamowitsch

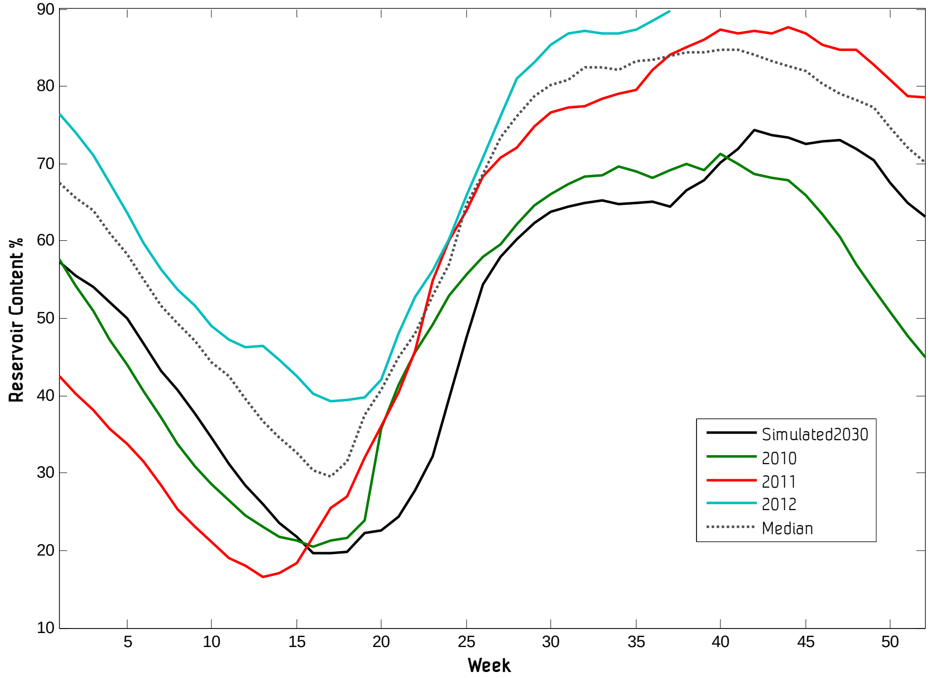
Main Results in a Nutshell – Total costs



- Hub connection saves €14 bn .
- Additional interconnections costs €5-8bn and bring benefits €bn 16-21
- The financial numbers speak clearly for an offshore grid.

Reservoir Trajectory in Norway in 2030

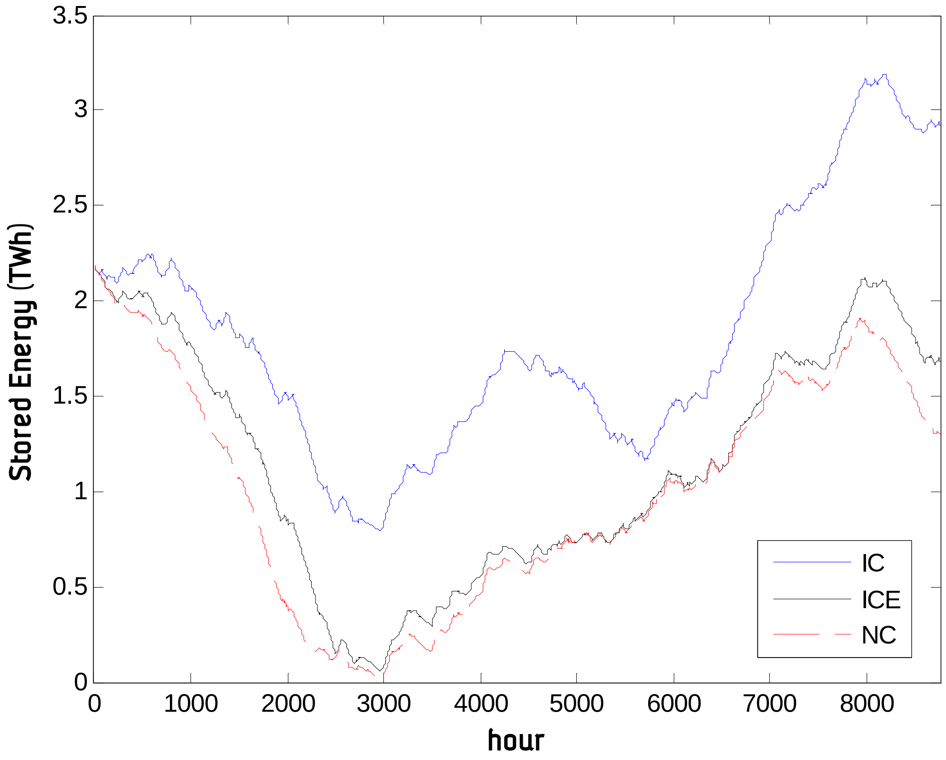
The simulated reservoir (black curve) follows the seasonal variation



Average Normal Hydrological Year

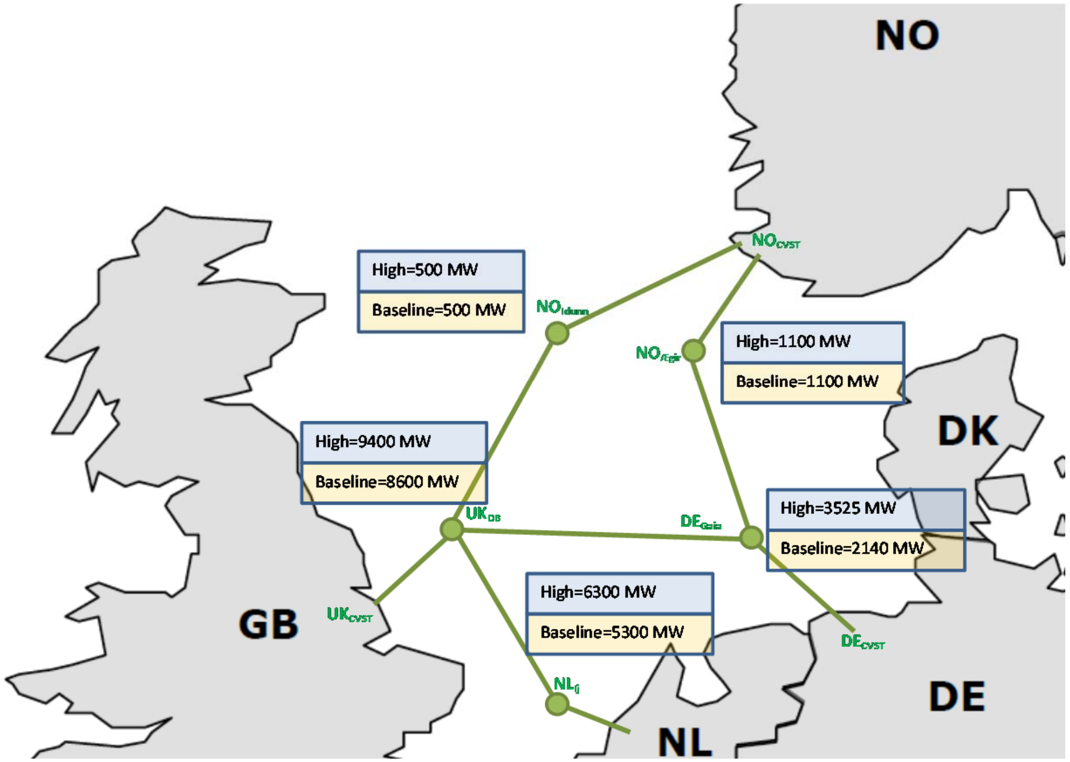
Comparing Tonstad Simulated Reservoir Trajectory

- IC: Present Internal constraint
- ICE: Expanded transmission according to TYNDP2012+ German Grid Plan
- NC: No internal constrains – NTC limited



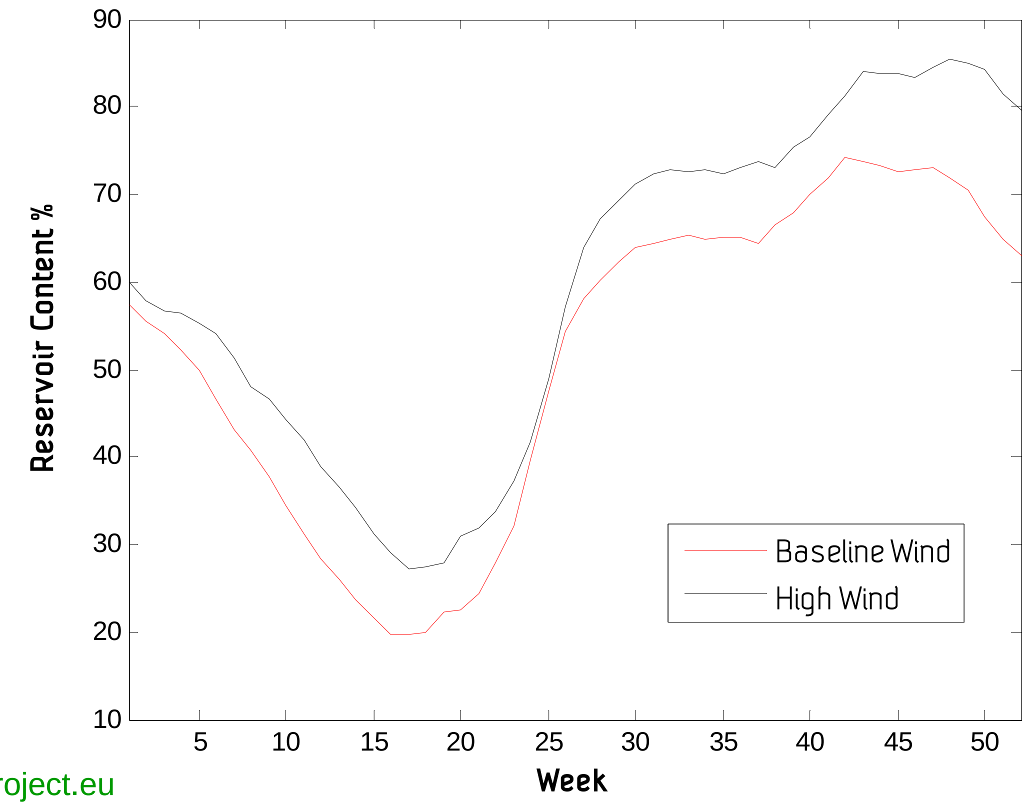
High Wind Scenarios

Increase of WPP up to 63 GW



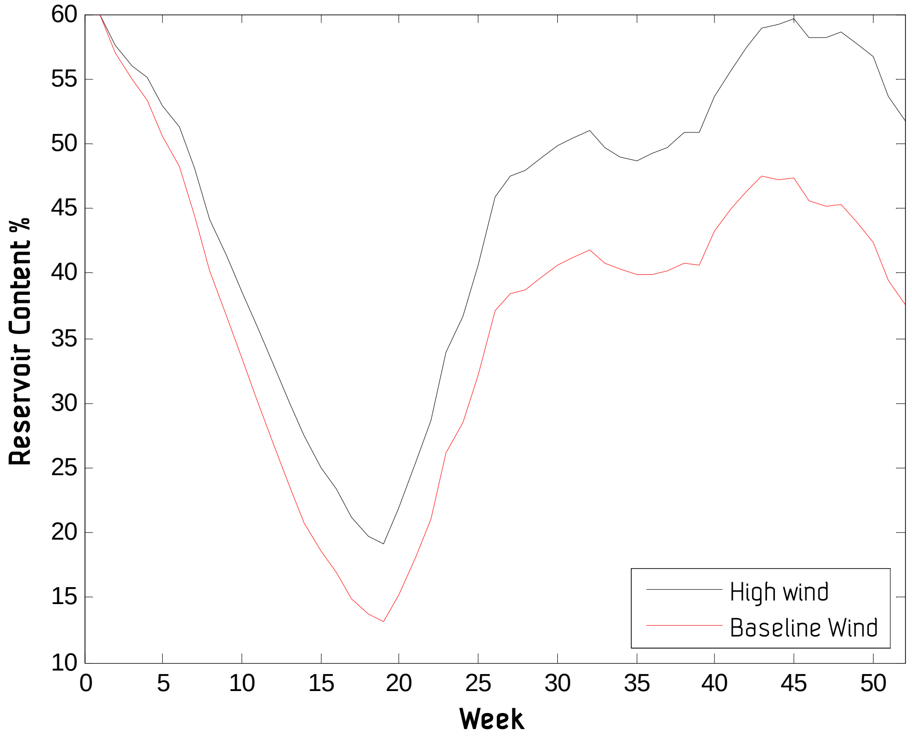
Reservoir Trajectory in Norway

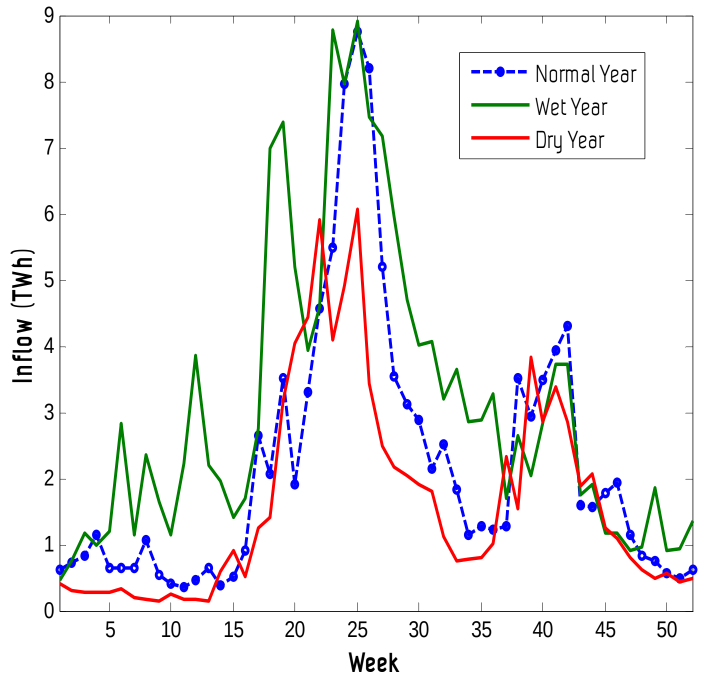
The wind energy surplus is stored in the Norwegian hydro reservoir by pumping the water from low to high altitude reservoirs



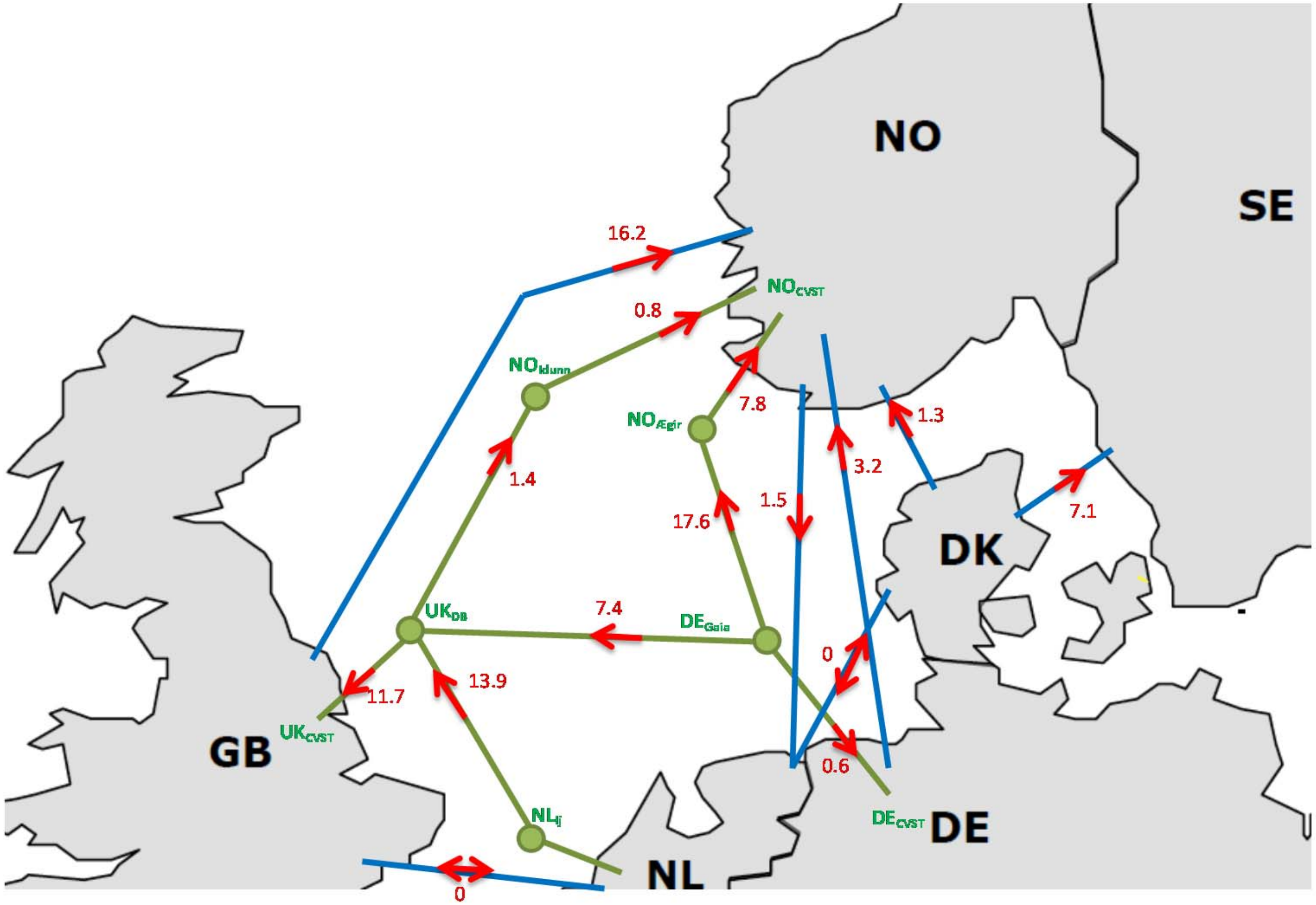
Dry Year and High Wind Scenario

Wind energy is stored in the Norwegian reservoir helping the Norwegian power system to cover the load in depletion season and fill up the reservoir in the filling season





Exchange Variation (high and baseline wind-dry year)



Material shown IEE-EU OffshoreGrid project (Leif and Harald)
TWENTIES (Hossein Farahmand, Stefan Jaehnert)

Cross-border capacities

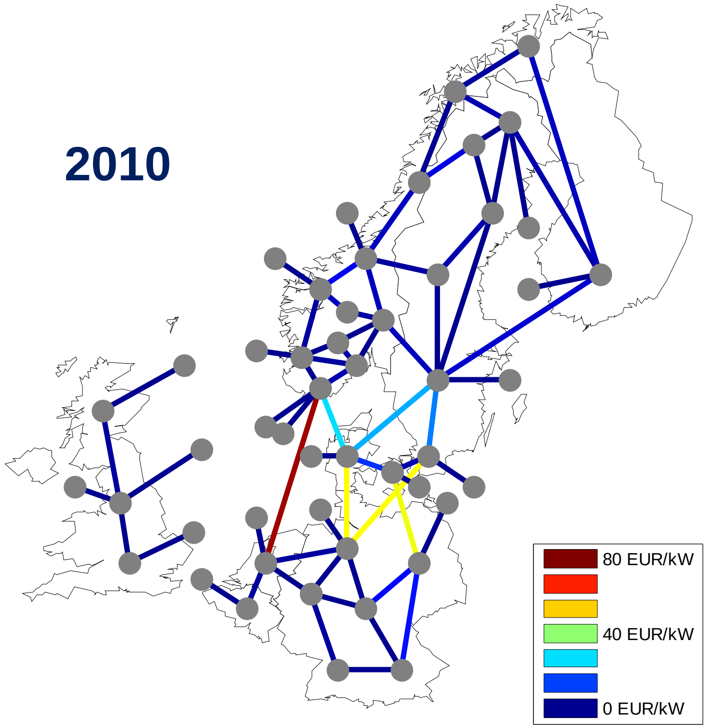
- Significant expansion of cross-border transmission capacities

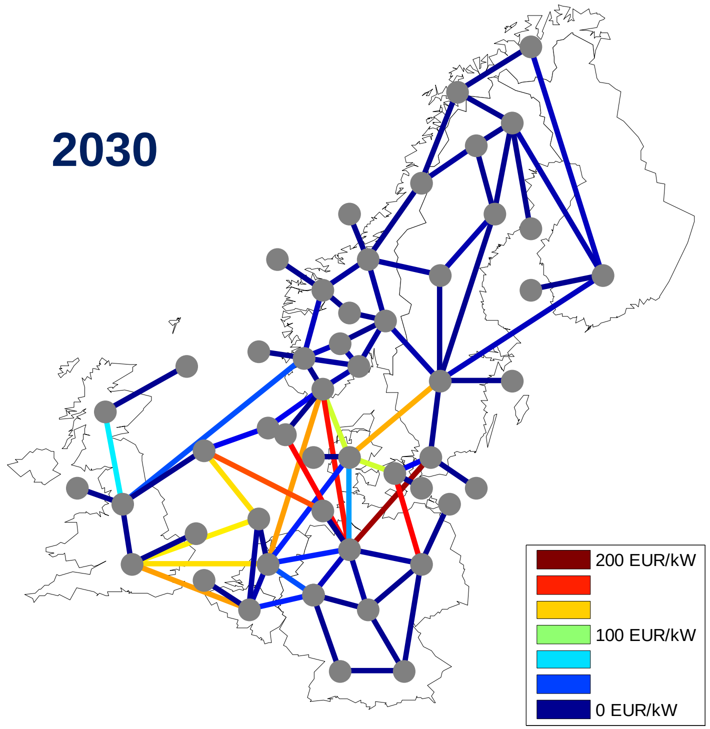
NorNed	Nordlink	Cobra	BritNed	Skagerrak	Storbælt	Konti-Skan	Kontek	Baltic
700	-	-	-	900	500	720	550	525
1400	700	700	1000	1600	500	720	600	600

SwePol	Fenno-Skan	Nemo	NorBrit		DK-DE	DE-NL	DE-BE	NL-BE
450	550	-	-		1400	4000	-	1400
450	1100	1000	1400		2400	6300	1600	2400

Marginal profit

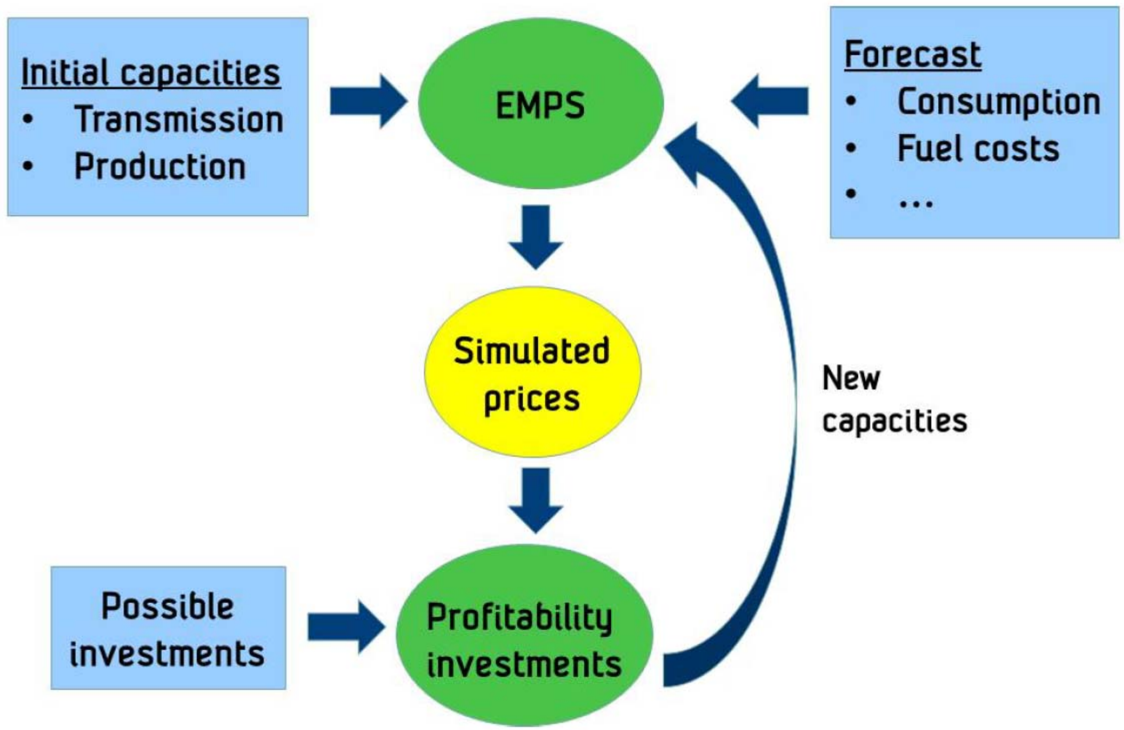
High marginal transmission profit on corridors crossing the North and Baltic Sea in 2030 (due to price differences) => arbitrage / investment potential





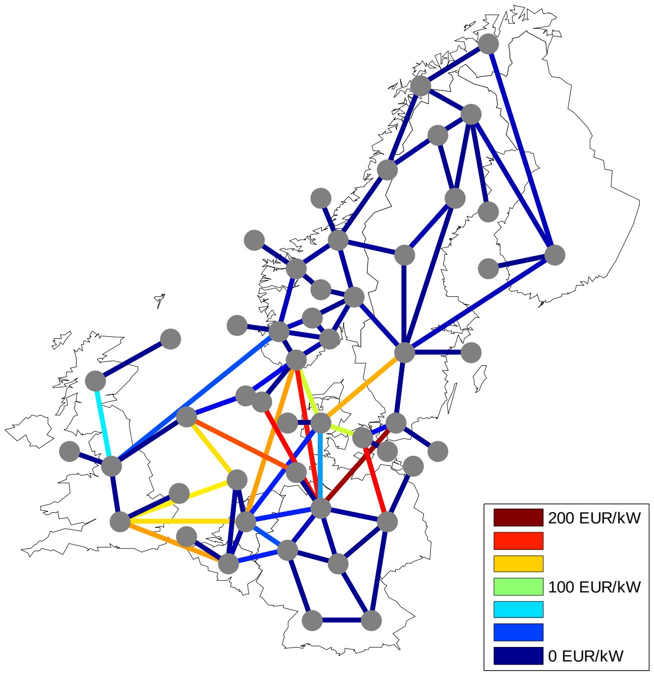
Transmission Expansion - Investment algorithm

- **Two-step methodology:**
  1. **Detailed power market simulation**
  2. **Investment decision based on outcome of power market simulation**
- **Impact of investments on electricity price is taken into account**
- **Investment based on marginal profit**

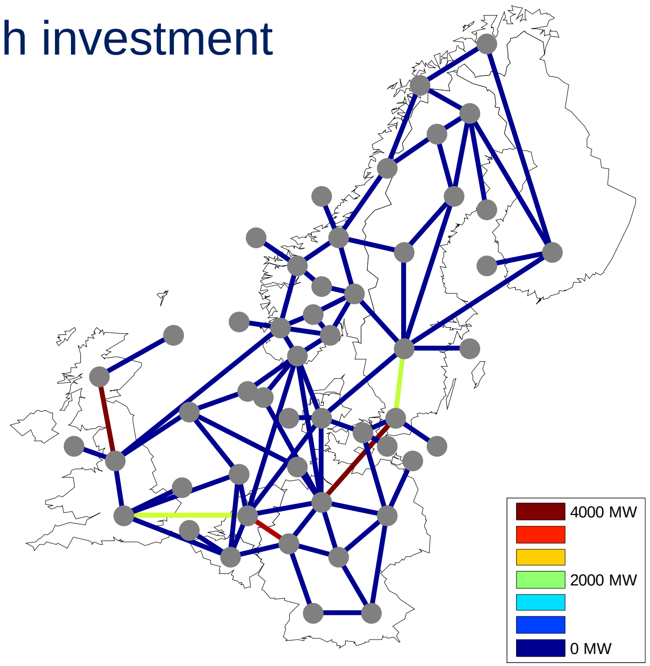


Transmission expansion

- Although marginal profits Main expansion only occurs around the North Sea



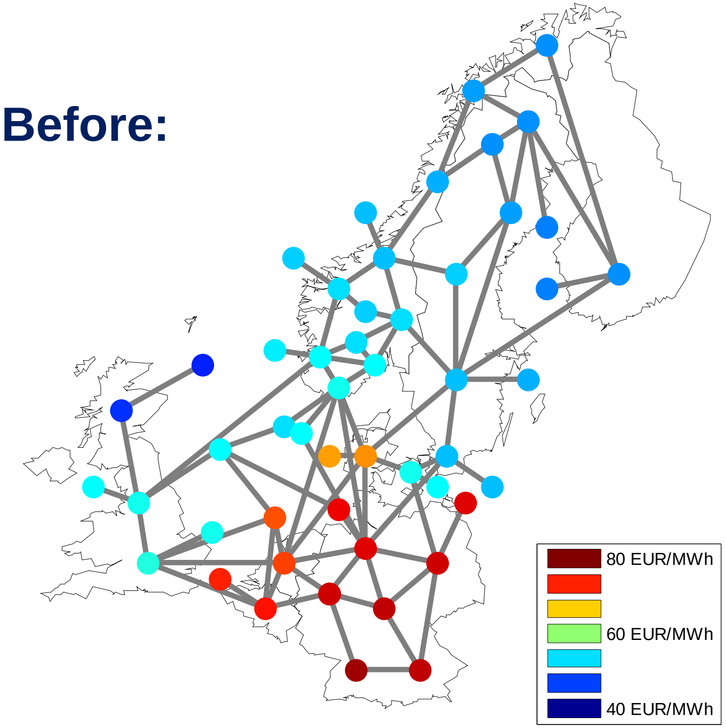
- Increasing the capability of transmitting energy from renewable energy sources (Sweden, Scotland) to load centres (Southern Germany, Southern UK)
- No expansion within the North Sea due to high investment



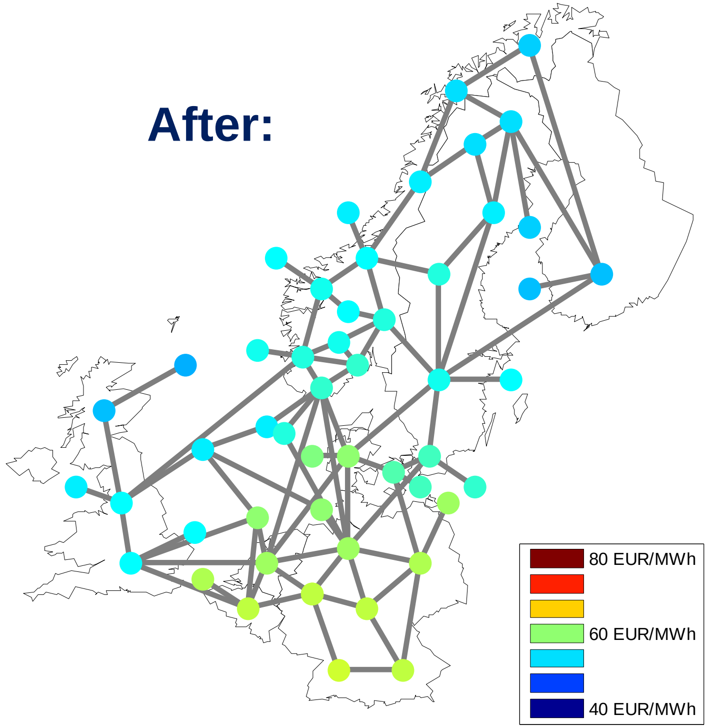
Electricity prices – before and after transmission expansion

Alignment of prices in the Nordic region, Great Britain and continental Europe

Before:



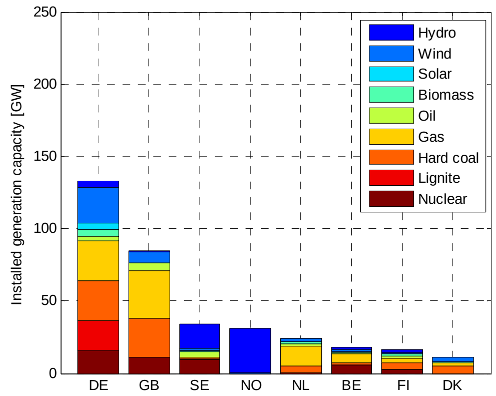
After:

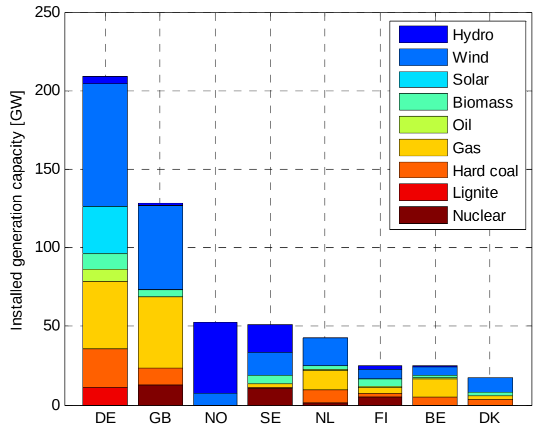


Generation portfolio / Mix

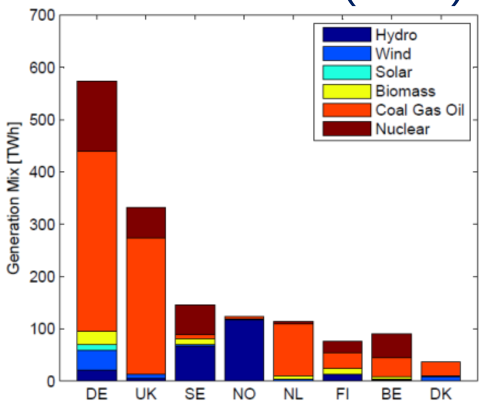
- Increase of WPP up to 191 GW
- Decommissioning of

nuclear / lignite power plants

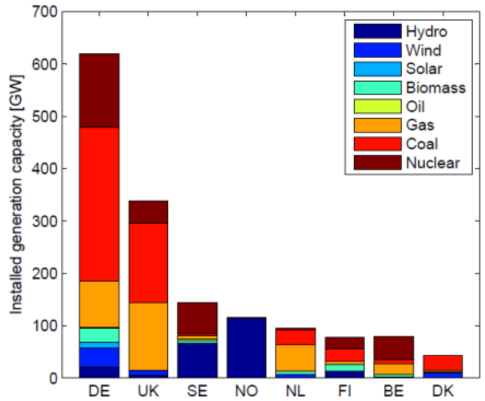




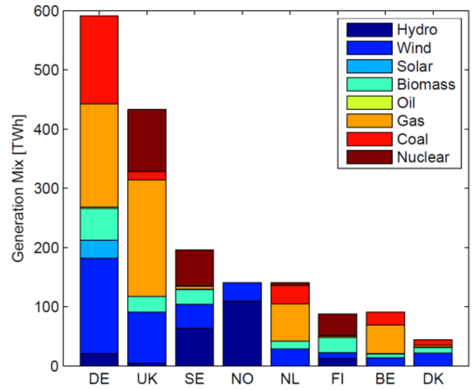
ENTSO-e (2010)



2010



2030



2010 scenario calibrated to generation mix reported by ENTSO-e
Significant shift of generation sources up to 2030

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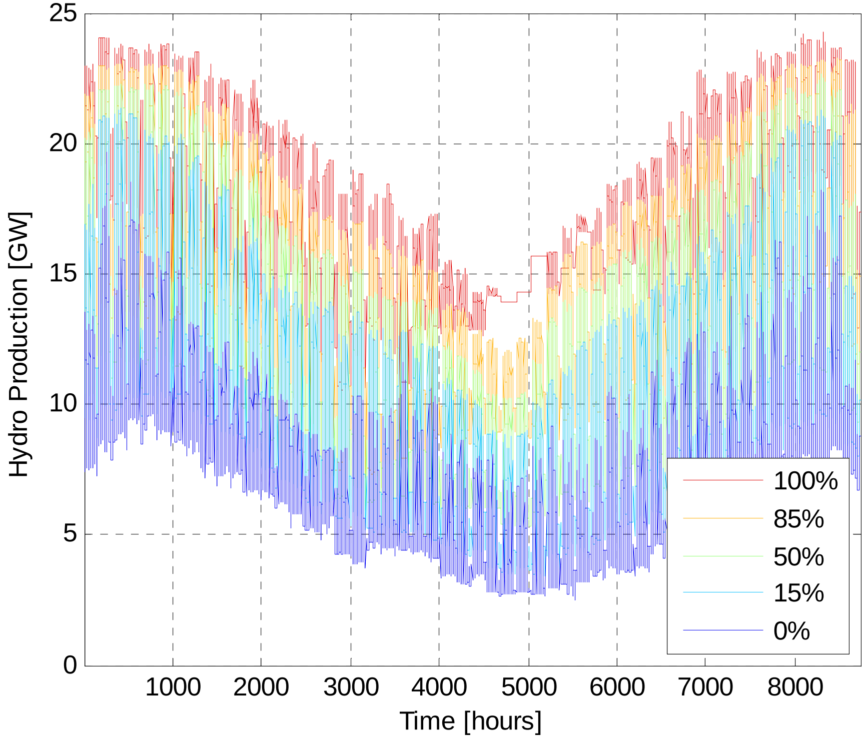
Twenties
Transmitting wind

SEVENTH FRAMEWORK PROGRAMME

EUROPEAN COMMISSION

Hydro power production (Norway)

- **Increased production variability due to balancing of WPP**
- **2010**



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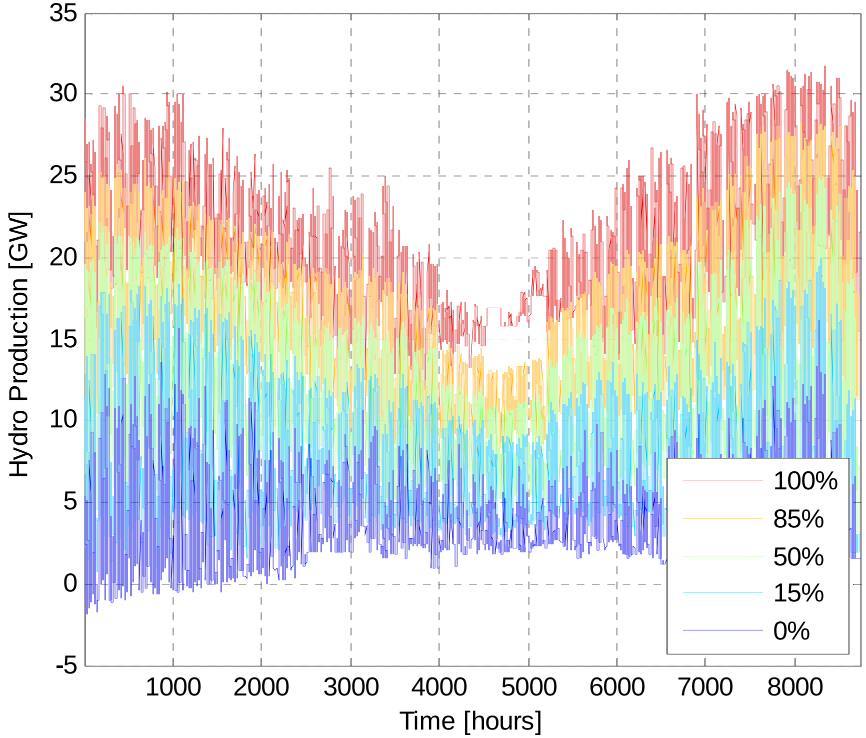

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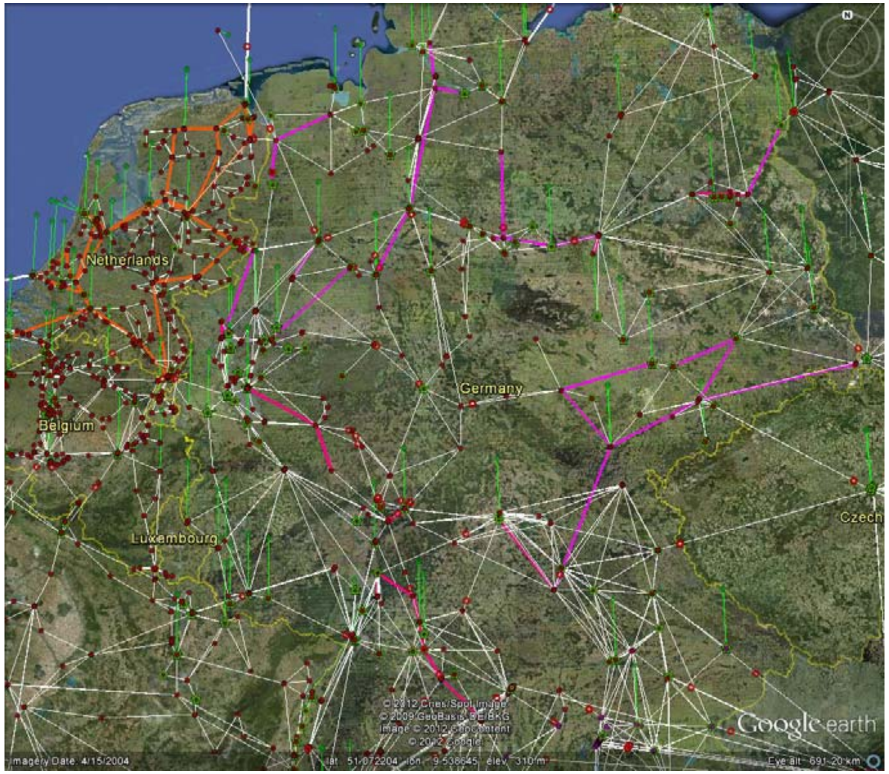
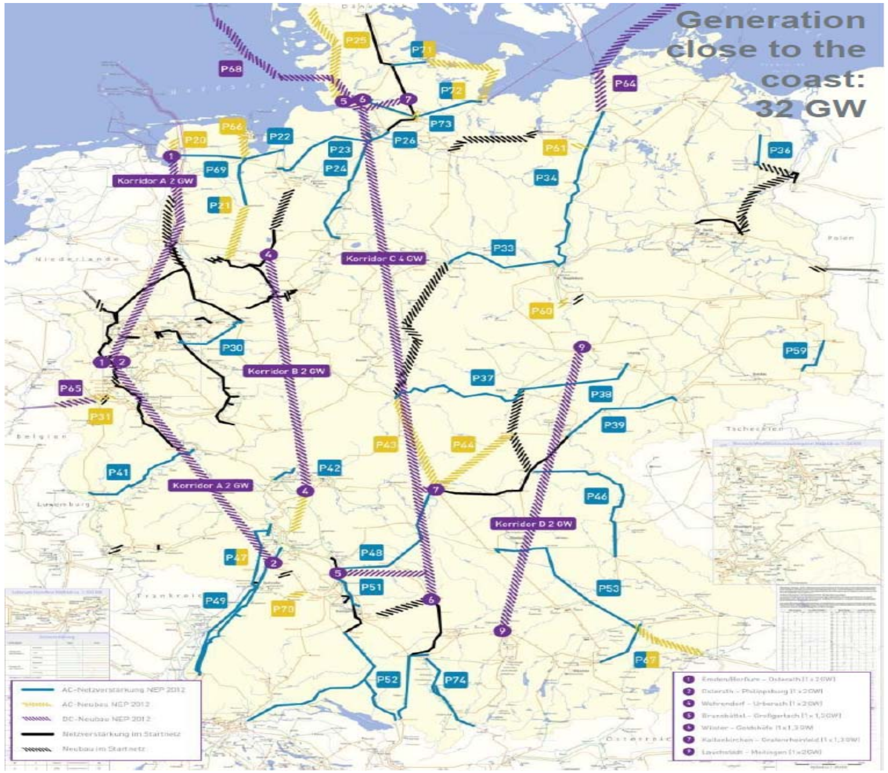
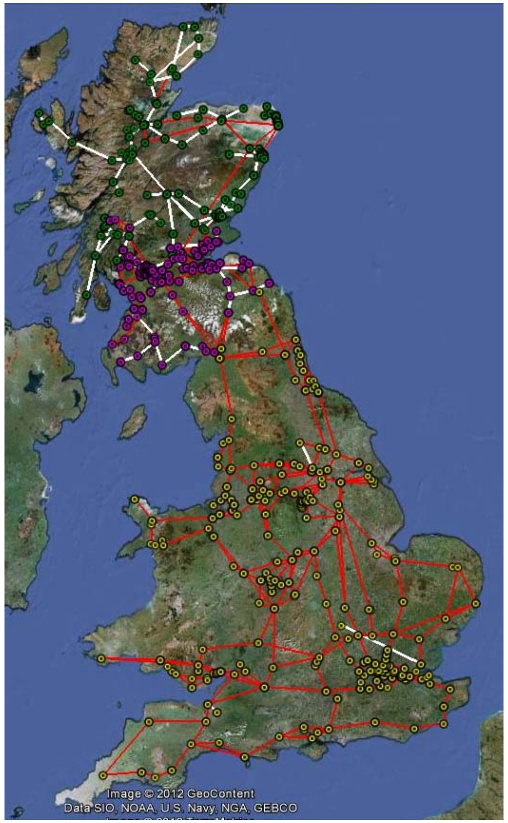
The Grid Expansion in the German Power System





DE and NL + TYNDP 2012 + German Grid Plan

The Grid Expansion in the British Power System



The UK+ TYNDP 2012

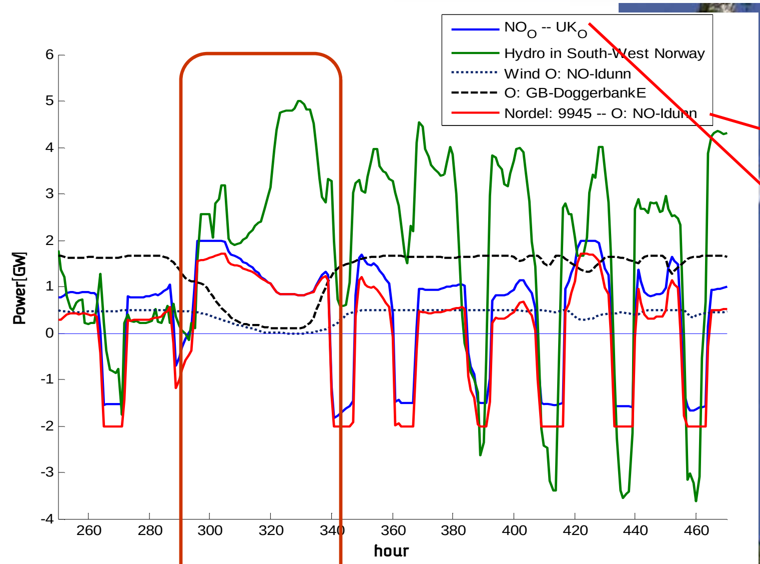
Some "*hints*" of the North Sea Power Wheel

Twenties
Transmitting wind

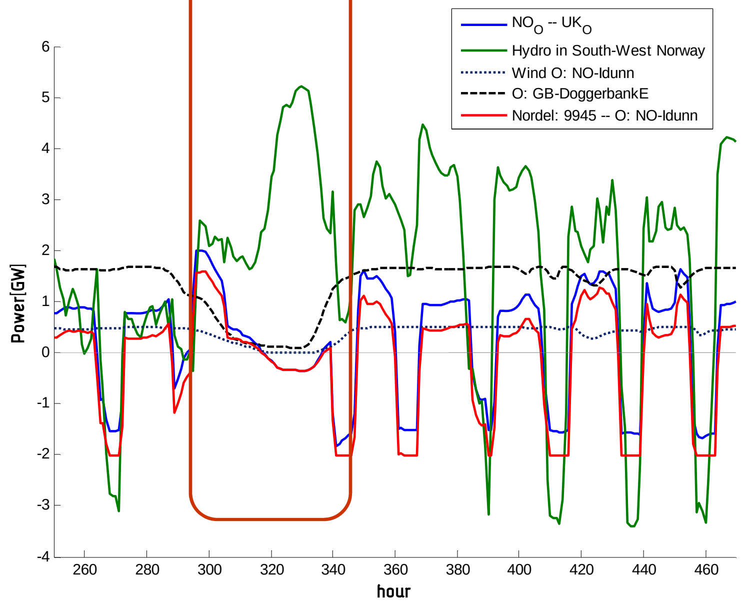
SEVENTH FRAMEWORK PROGRAMME

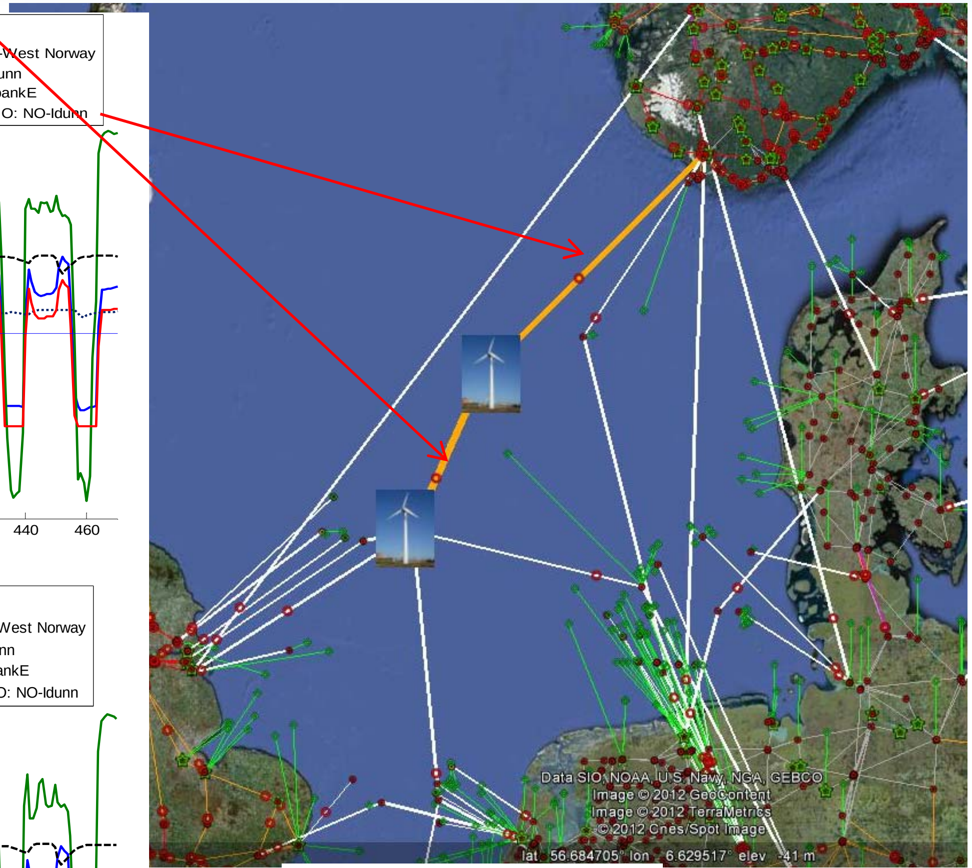
EUROPEAN COMMISSION

Without Expansion



With Expansion





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