A look at North Sea area scenarios developed in the NSON-DK project

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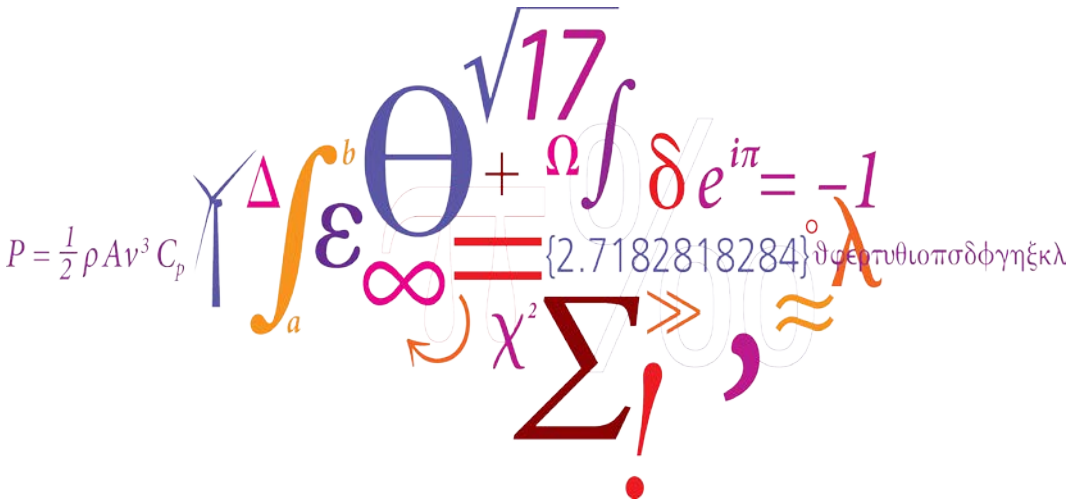
May 23rd, 2018



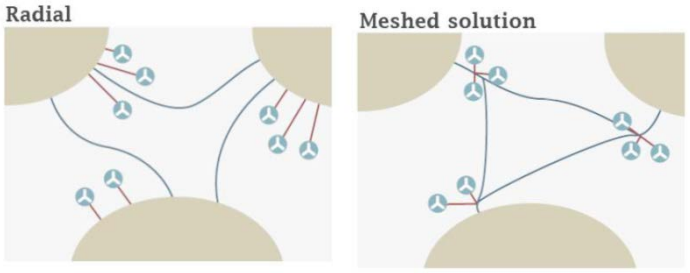
DTU Wind Energy
Department of Wind Energy

Topics to be covered

1) About the NSON-DK project
2) Background and assumptions taken in the NSON-DK scenarios
3) Briefly about the Balmorel energy system model
4) The Radial scenario towards 2050
5) Challenges in modelling the meshed case
6) Preliminary results for the Meshed scenario

About the NSON-DK project

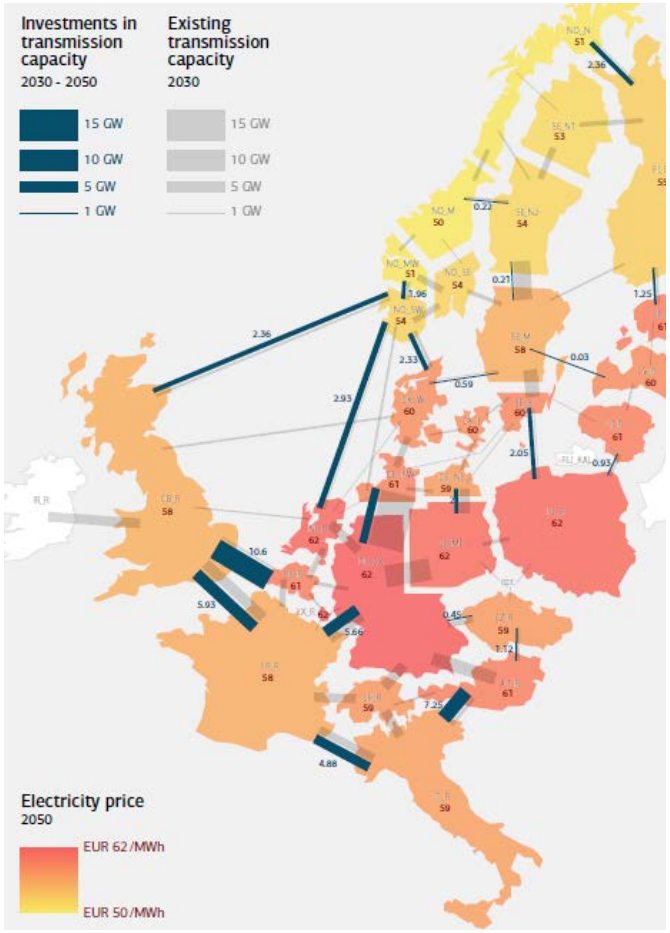
- How the future **massive offshore wind power** and the **associated offshore grid development** will affect the Danish power system in the transition towards a future sustainable energy system?
  - Scenarios until 2050
  - Both radial and meshed grid structures
- Partners:
  - DTU Wind Energy
  - DTU Management Engineering
  - EA Energy Analyses
- Topics include:
  - **Scenario modelling considering both radial and meshed cases**
  - Balancing and need for reserves in the Danish power system
  - Market analyses
  - Power system adequacy (Danish system)
  - Regulation and policy



Figures from the Study of the benefits of a meshed offshore grid in northern seas region report: https://ec.europa.eu/energy/sites/ener/files/documents/2014_nsog_report.pdf

Background for the NSON-DK scenarios

- The scenarios are based on the Nordic Energy Technology Perspectives (NETP) 2016 scenario
  - www.nordicenergy.org/project/nordic-energy-technology-perspectives/
- NETP specifies a radial scenario until 2050
  - Includes generation capacity investments, region-to-region transmission line investments…
- The scenarios are built using the **Balmorel tool**
- Main **reasons for updating the NETP** scenario
  - Update generation cost assumptions (mainly offshore wind and solar PV lower)
  - Does not include any meshed grid case



Some assumptions, and updates to NETP

- **4 representative weeks** selected for the energy system optimization
- Countries with investment optimization are shown on the right
  - Neighbouring countries take part in electricity trading
- **Wind and solar PV investment costs** are updated
- Meshed offshore grid related costs added
- CO2 price as in NETP (significant increase assumed)
- **Resource grades** modelled for onshore wind and solar PV investments
  - Different regions have different amounts of investable GWs with different capacity factors
  - As not all investable GWs are the same
- **Offshore wind power plants** divided to AC and DC connectable GWs
  - In the meshed case, also to hub-connectable GWs

The Balmorel energy system model

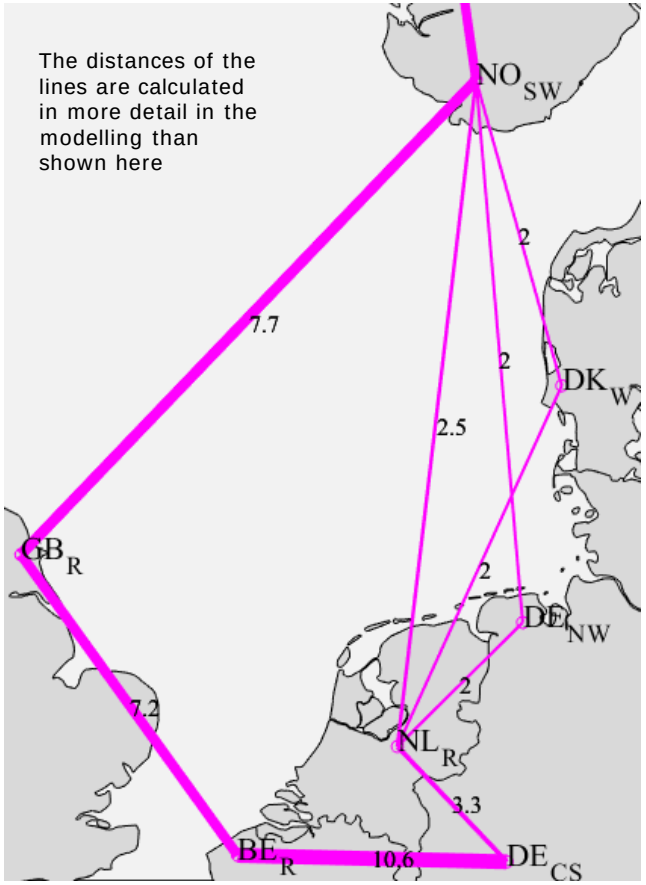
- Electricity and district heat sectors
- Deterministic
- Partial Equilibrium
- **Bottom-up approach**
- **Mainly linear optimization** → All costs are specific (i.e. €/MW)
  - Advantage: Large problems can be solved
  - Disadvantage: Economies of scale are more difficult to model
- Also available: **Mixed Integer Programming**
  - Better representation of economies of scale
  - Important in the modelling of the meshed case
- Latest version BB4 used
  - **Models scenario years progressing in time**
  - Not just optimizing a single year
- www.balmorel.com
- Frauke Wiese et al., “Balmorel open source energy system model”, *Energy Strategy Reviews*, vol. 20, April 2018, pp. 26-34 (doi.org/10.1016/j.esr.2018.01.003)

The Radial scenario

- About transmission investments:
  - **Norway (with hydro) connected** increasingly to all countries, especially UK
  - **UK connected to Germany** (here via Belgium)
- About generation investments:
  - Note: Solar PV has about 2-5 times lower capacity factor than wind
  - In this scenario, Germany imports energy

Total wind and solar PV generation investments (GW) by 2050

	Onshore wind	Offshore wind			Solar PV
		Nearshore	AC connected	DC connected	
Belgium	7	0	4	0	18
Denmark	4	0	6	0	7
Germany	17	0	9	3	50
UK	26	0	18	11	54
Netherlands	5	0	15	2	27
Norway	4	0	4	4	0
Total	64	1	56	21	156
Share of GWs	22 %	26 %			52 %

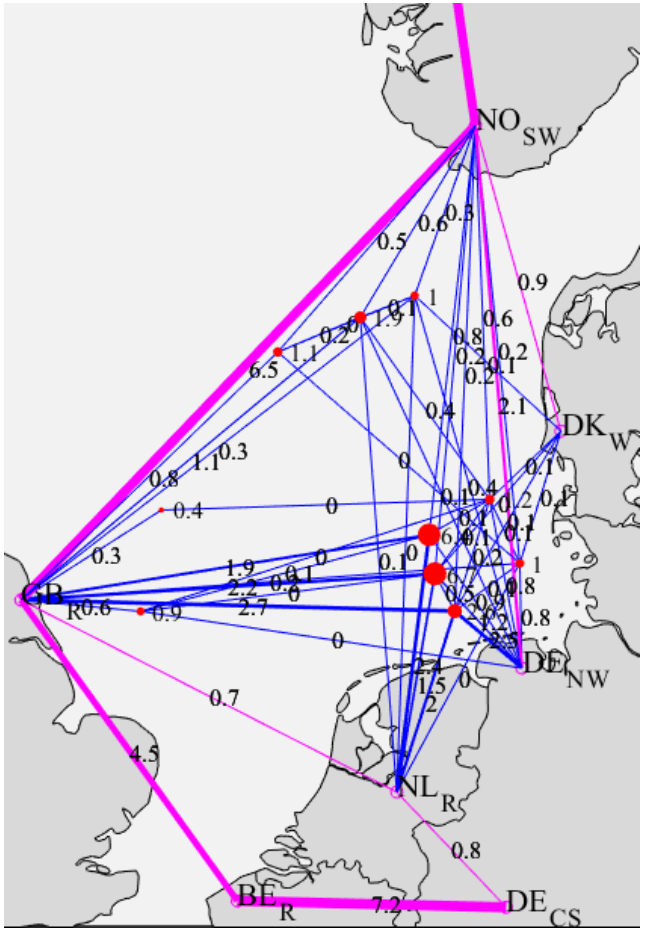


Total transmission investments (GW) by 2050

For all investments, the starting point is 2020 (with an assumed fixed scenario from today until 2020)

Challenges in modelling the meshed case

- On the right: Result using linear programming (LP) with a fixed €/MW cost for each line
  - Clearly unfeasible
  - **Many lines are too small**
- Mixed integer programming (MIP) work is ongoing
  - Requires **significant simplifications** to the model
  - E.g., less hours, some lines left out, onshore system frozen (based on linear programming results)
  - Even with such simplifications, **calculation time is several days**
- After the MIP results, final runs will be optimized so that both the Radial and Meshed scenarios are comparable



Preliminary Meshed scenario results

- Note: these are **results from the LP run**, including unfeasibly small lines
- Hub-connected generation is listed under AC connected in the table below
  - As connection to hub is AC
- Total **offshore wind generation increases by 5 GW compared to the Radial scenario** (by 2050)
- UK shows very little hub-connected offshore wind generation

Total wind and solar PV generation investments (GW) by 2050

	Onshore wind	Offshore wind			Solar PV
		Nearshore	AC connected	DC connected	
Belgium	7	0	4	0	16
Denmark	4	0	6	0	8
Germany	15	0	25	0	62
UK	26	0	19	5	55
Netherlands	0	0	15	0	11
Norway	4	0	7	0	0
Total	57	1	77	5	152
Share of GWs	20 %	29 %			52 %

Total wind generation investments to hubs (GW) by 2050

BorWin	DE	7
DolWin	DE	3
HelWin	DE	1
NorWin	DE	0
SylWin	DE	1
WeiWin	DE	7
UK-NL_UK	UK	0
DoggerBank	UK	0
DoggerBank	UK	0
HornSea	UK	0
HornSea	UK	1
UK-NL_NL	NL	0
NO_c	NO	2
NO_e	NO	1
NO_w	NO	1

For all investments, the starting point is 2020 (with an assumed fixed scenario from today until 2020)

Considering a “limited onshore wind” case: Limited Meshed scenario (early results)

- Why UK showed only 1 GW of hub-connected offshore wind in the Meshed scenario?
  - Partly because the model sees a lot of investable onshore wind generation in UK with high capacity factors
- But is a lot of **onshore wind politically feasible**?
- To test a case where investable onshore wind might be limited, “limited onshore wind” scenarios were created
- In the **Limited Meshed scenario, UK hubs increase significantly** compared to the non-limited scenario

Total wind and solar PV generation investments (GW) by 2050

	Onshore wind	Offshore wind			Solar PV
		Nearshore	AC connected	DC connected	
Belgium	3	0	4	0	18
Denmark	2	0	6	0	8
Germany	17	0	27	0	61
UK	8	0	25	6	55
Netherlands	0	0	15	0	11
Norway	4	0	8	0	0
Total	35	1	86	6	152
Share of GWs	12 %	33 %			54 %

Total wind generation investments to hubs (GW) by 2050

BorWin	DE	7
DolWin	DE	3
HelWin	DE	1
NorWin	DE	0
SylWin	DE	1
WeiWin	DE	7
UK-NL_UK	UK	0
DoggerBank	UK	0
DoggerBank	UK	1
HornSea	UK	2
HornSea	UK	3
UK-NL_NL	NL	0
NO_c	NO	2
NO_e	NO	1
NO_w	NO	1

For all investments, the starting point is 2020 (with an assumed fixed scenario from today until 2020)