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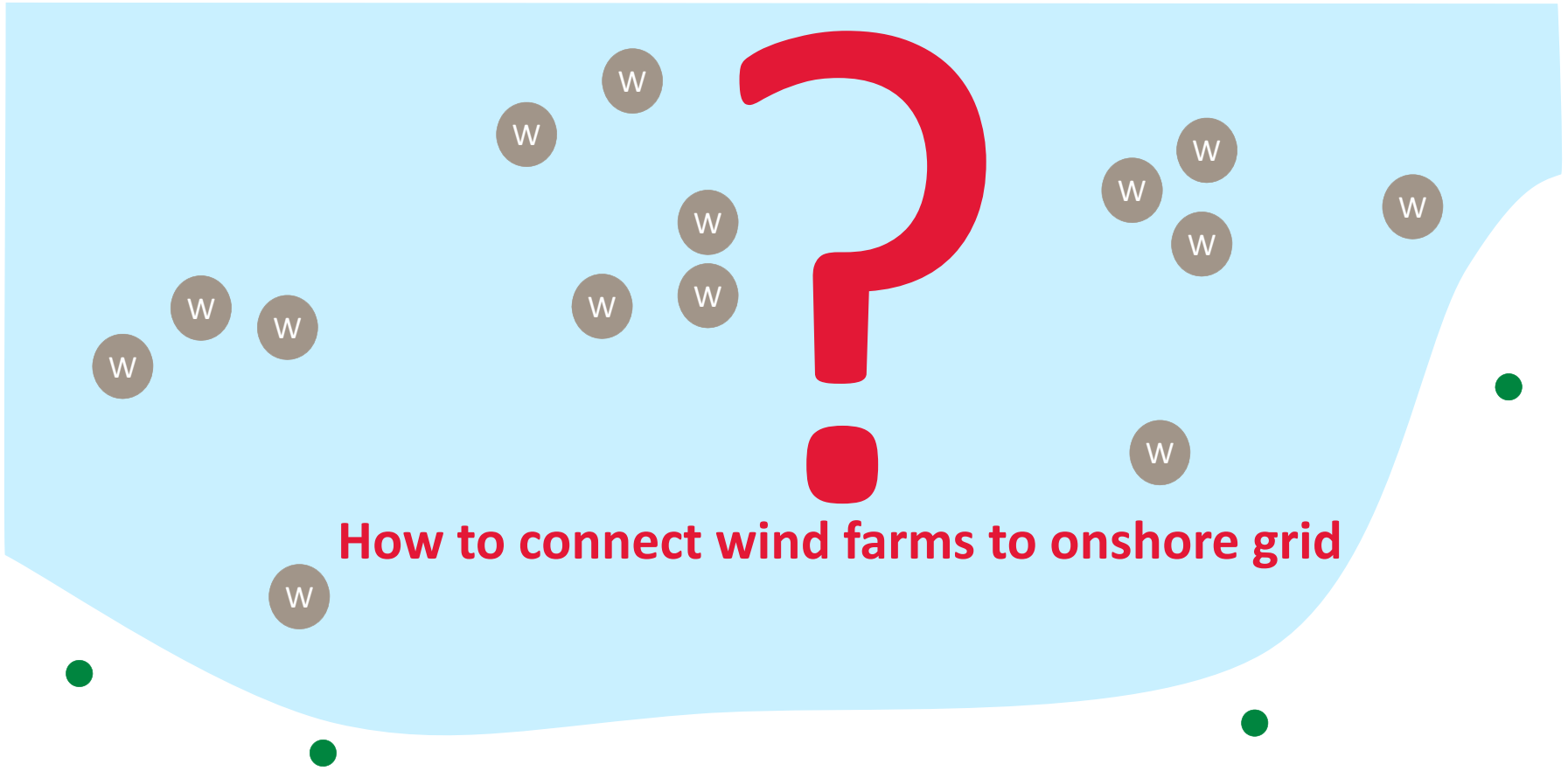
Planning Tool for Clustering and Optimised Grid Connection of Offshore Wind Farms

- Background
- The Net-Op DTOC tool
- Example: Kriegers Flak area
- Conclusions

The problem

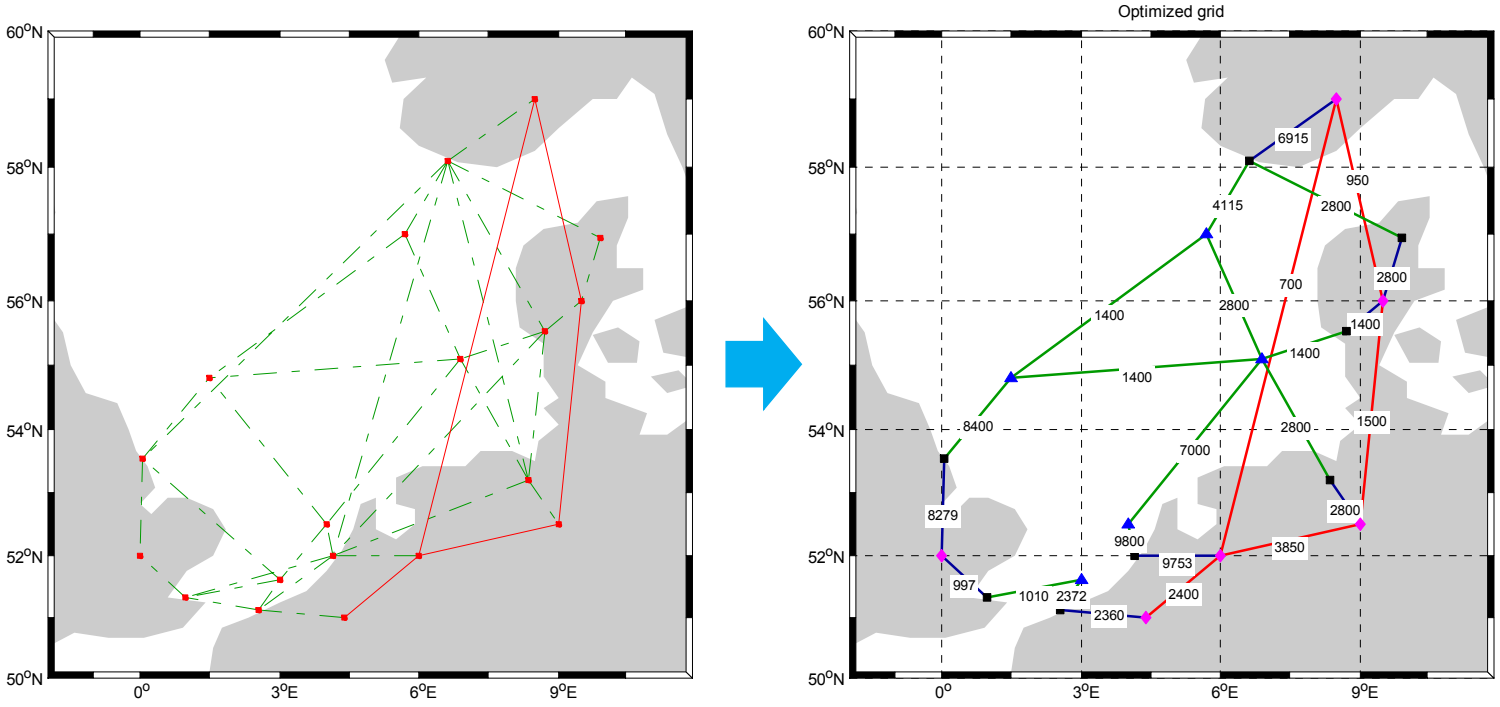

W = wind farm
= onshore node
How to connect wind farms to onshore grid

Background

- NOWITECH – Norwegian Research Centre for Offshore Wind Technology
  - Has supported development of Net-Op → Applied on North Sea offshore grid analyses
  - www.nowitech.no
- EERA-DTOC – EU FP7 project
  - Aims to establish and integrated Design Tool for Offshore wind farm Clusters, including electrical grid design
  - www.eera-dtoc.eu

Net-Op

- Offshore grid expansion optimisation (planning tool)
  - **Input**: allowable connections + cost parameters + time series for wind power, demand and power prices
  - **Output**: Optimal design (number + capacity of cables)
  - Ref: *Trötscher & Korpås*, dx.doi.org/10.1002/we.461



Net-Op approach

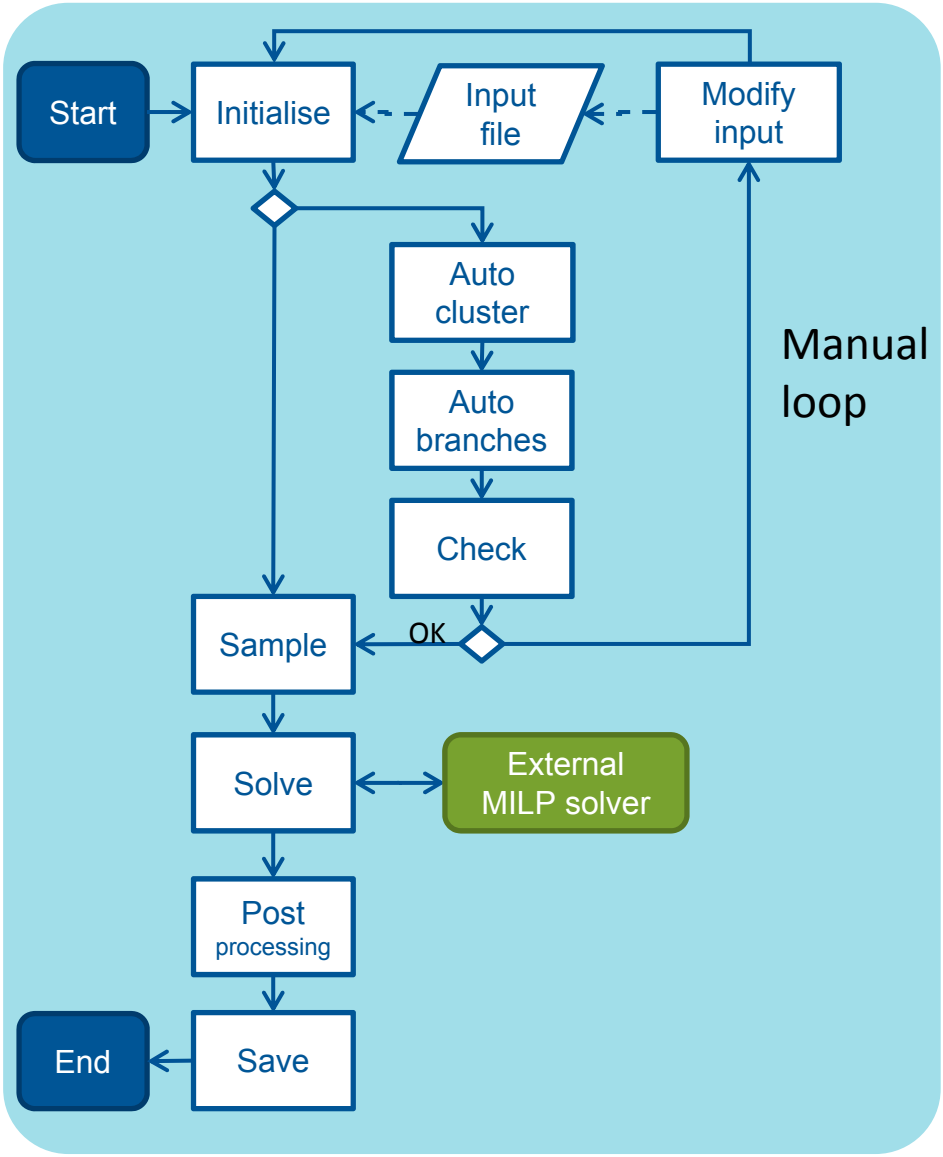
- Optimisation
  - Mixed integer linear programming (MILP) problem formulation
  - Cost function = cost of investment + operational costs (net present value)
    - Cost = fixed cost + cost per MW × rating
    - 'fixed cost' may be distance dependent
- Sampling of operational states to account for variable wind, demand and prices
- Need to limit number of allowable connections
- MATLAB implementation

$$\text{possible combinations of } B \text{ branches} = 2^B$$
$$\text{possible connections of } N \text{ nodes, } B = \frac{1}{2}N(N-1)$$

Applicable to wind farm cluster level?

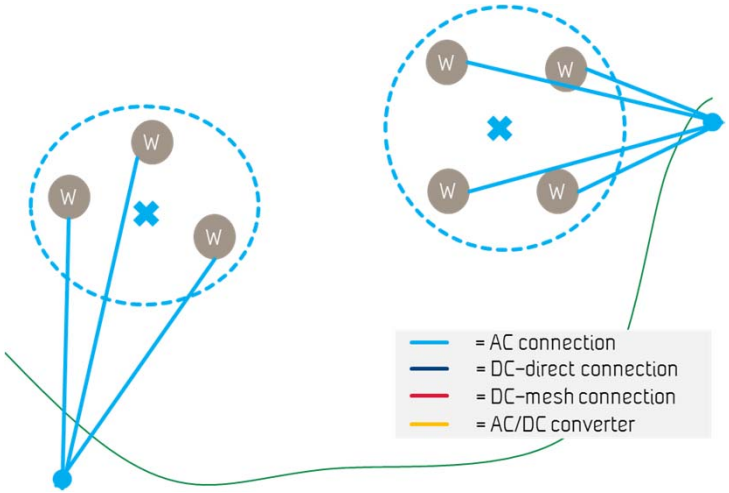
Net-Op DTOC – an upgraded version

- Modifications
  - Multiple cable types (AC, DC)
  - Pre optimisation processing
    - Clustering algorithm
    - Automatic generation of allowable connections
  - Interface to external MILP solvers
  - Result export to PSSE, Google Earth plot (KML)
  - Command-line tool

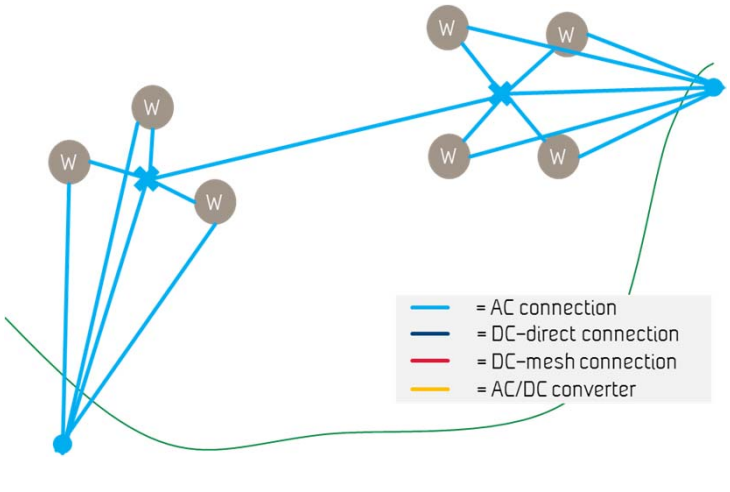


Pre-processing: Generate allowable set of connections

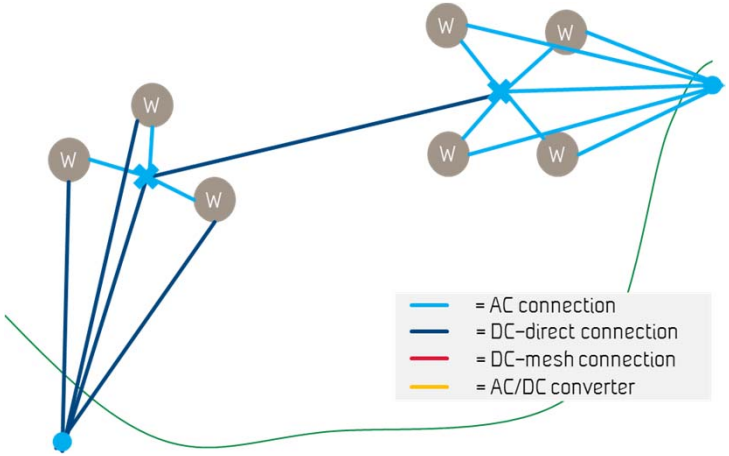
1: Clustering



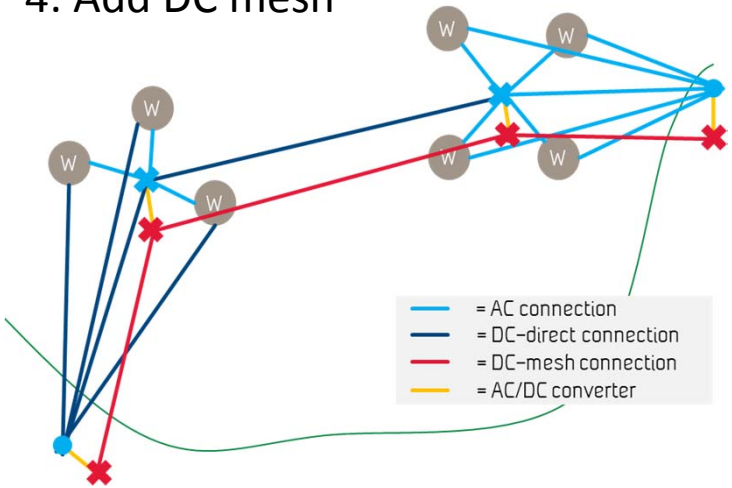
2: Add cluster branches



3: Replace AC by DC

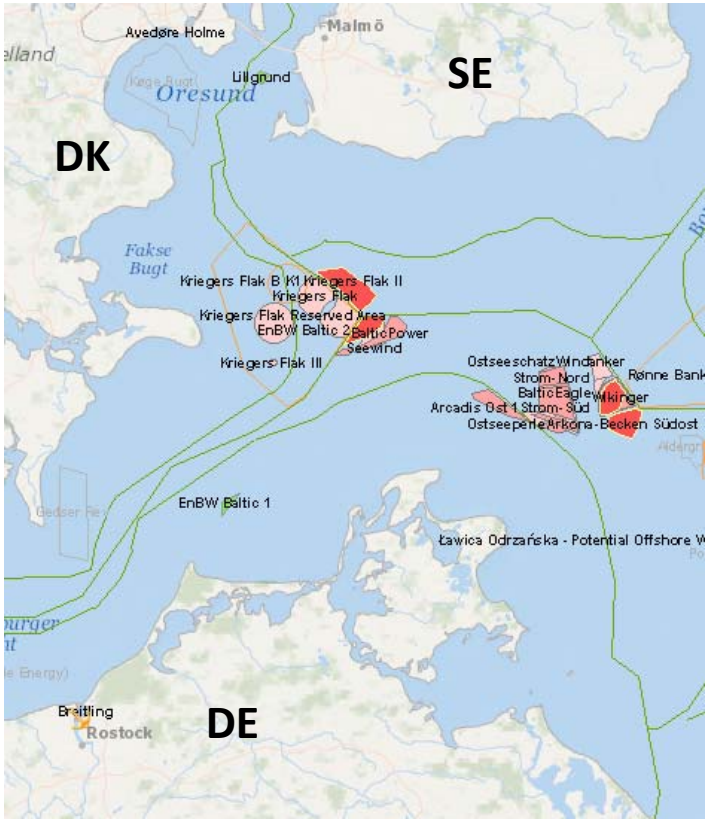


4: Add DC mesh



Case study: Kriegers Flak

- Wind farms:
  - Kriegers Flak (DK+DE+SE), Baltic 1 (DE), Ventotec (DE)
- Cost parameters
  - Based on Windspeed project (D2.2 – Garrad Hassan)
- Time series
  - 2010 hourly values for
    - wind production (from DTU's CorWind model – N. Cutululis)
    - demand (daily and seasonal profile as used in TradeWind & OffshoreGrid projects)
    - area prices (from Nordpool & EEX)



Input data

Wind farms:

P	Name	Country
640	Kriegers Flak	SE
288	Baltic 2	DE
600	Kriegers Flak III	DK
48	Baltic 1	DE
500	Baltic Power	DE
400	Wikinger	DE
480	Arkona Becken Südost	DE

Cost data (branches):

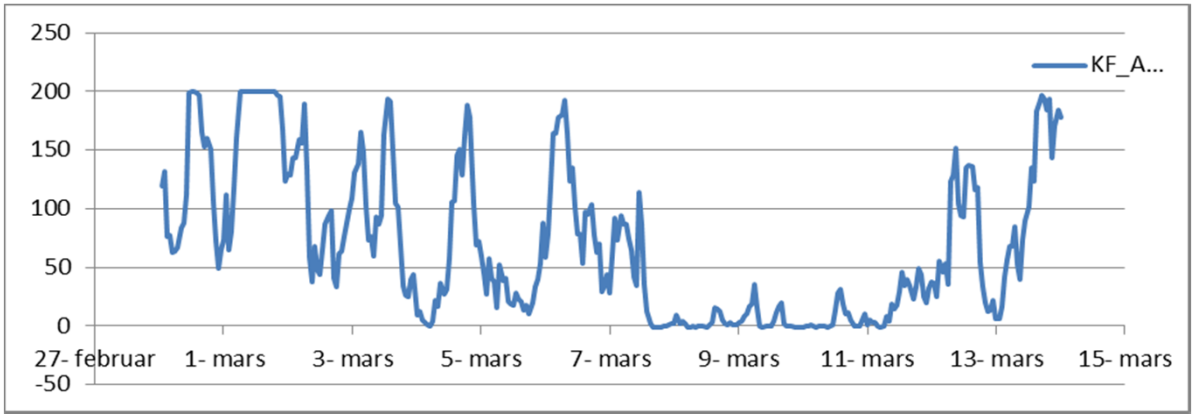
	Cost per branch			Cost per branch endpoint			
Type	B_d k€/km	B_{dp} k€/kmMW	B k€	C^L_p k€/MW	C^L k€	C^S_p k€/MW	C^S_p k€
AC	0	4.1	5,000	11.8	0	11.8	0
DC-direct	0	1.27	5,000	221.8	0	221.8	27,600
DC-mesh	0	1.27	5,000	70.0	0	70.0	0
converter	0	0	0	105.0	0	105.0	27,600

Branch limits and losses

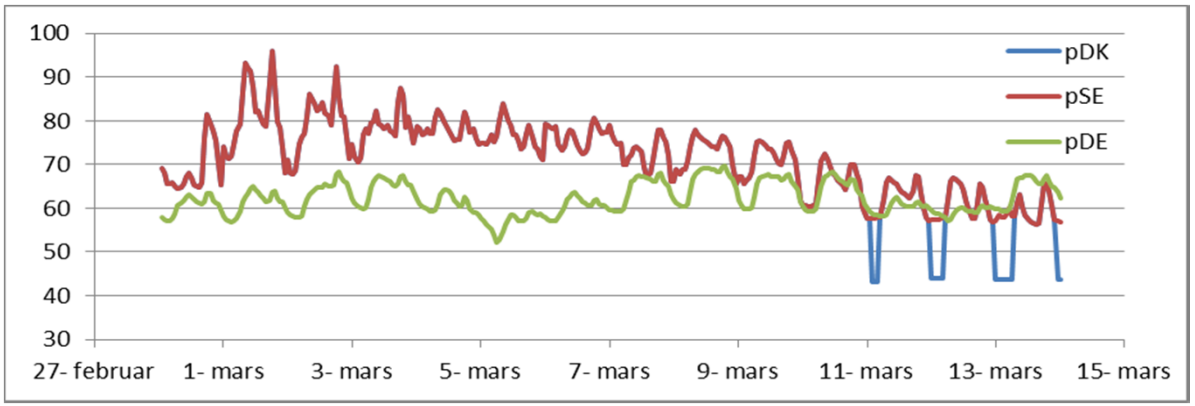
Branch type	Max distance	Max power	power loss constant	slope
AC	70 km	700 MW	0	0.005 %
DC-direct		1200 MW	3.2 %	0.003 %
DC-mesh		1200 MW	0	0.003 %
converter		1200 MW	1.6 %	0

Extract showing two weeks

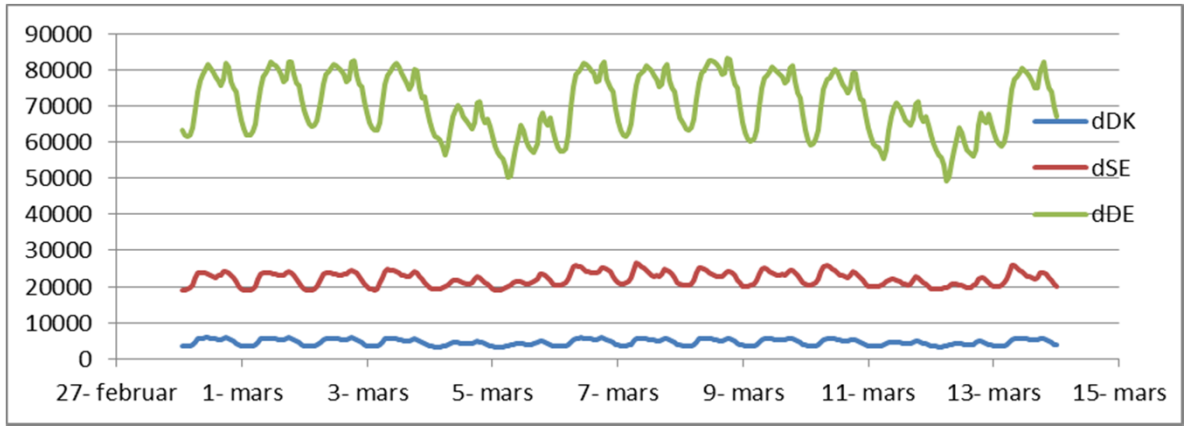
Wind power



Power prices

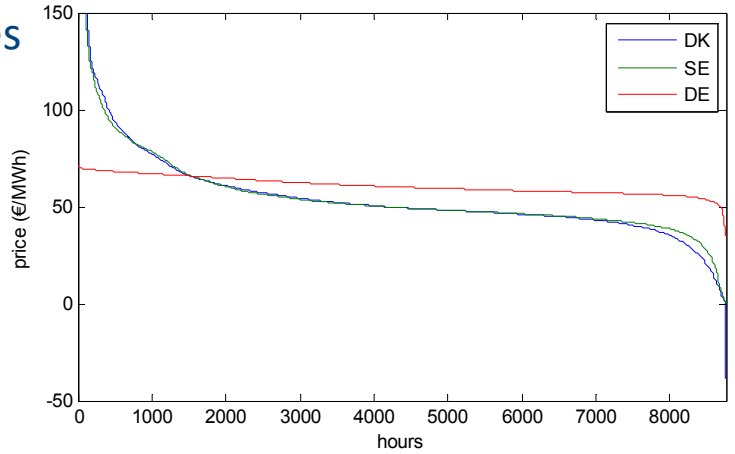


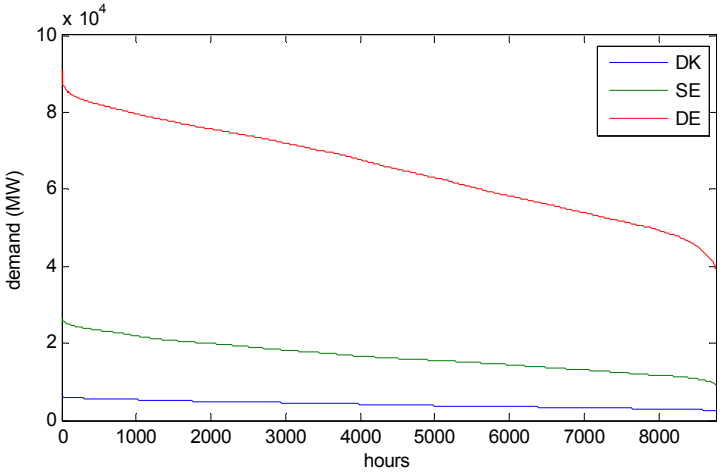
Power demand



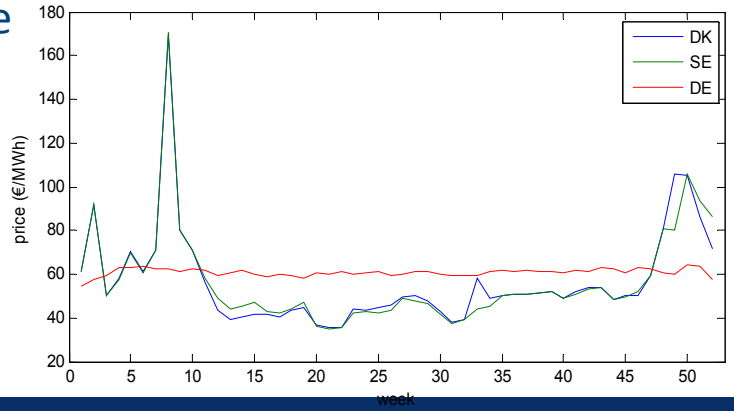
2010 power prices power demand

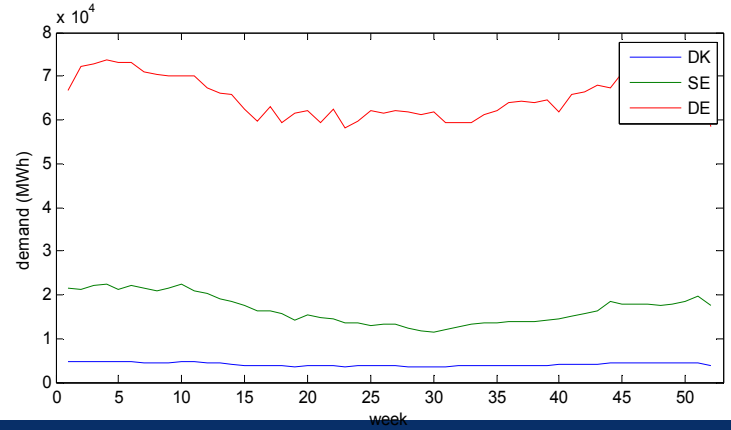
- Duration curves



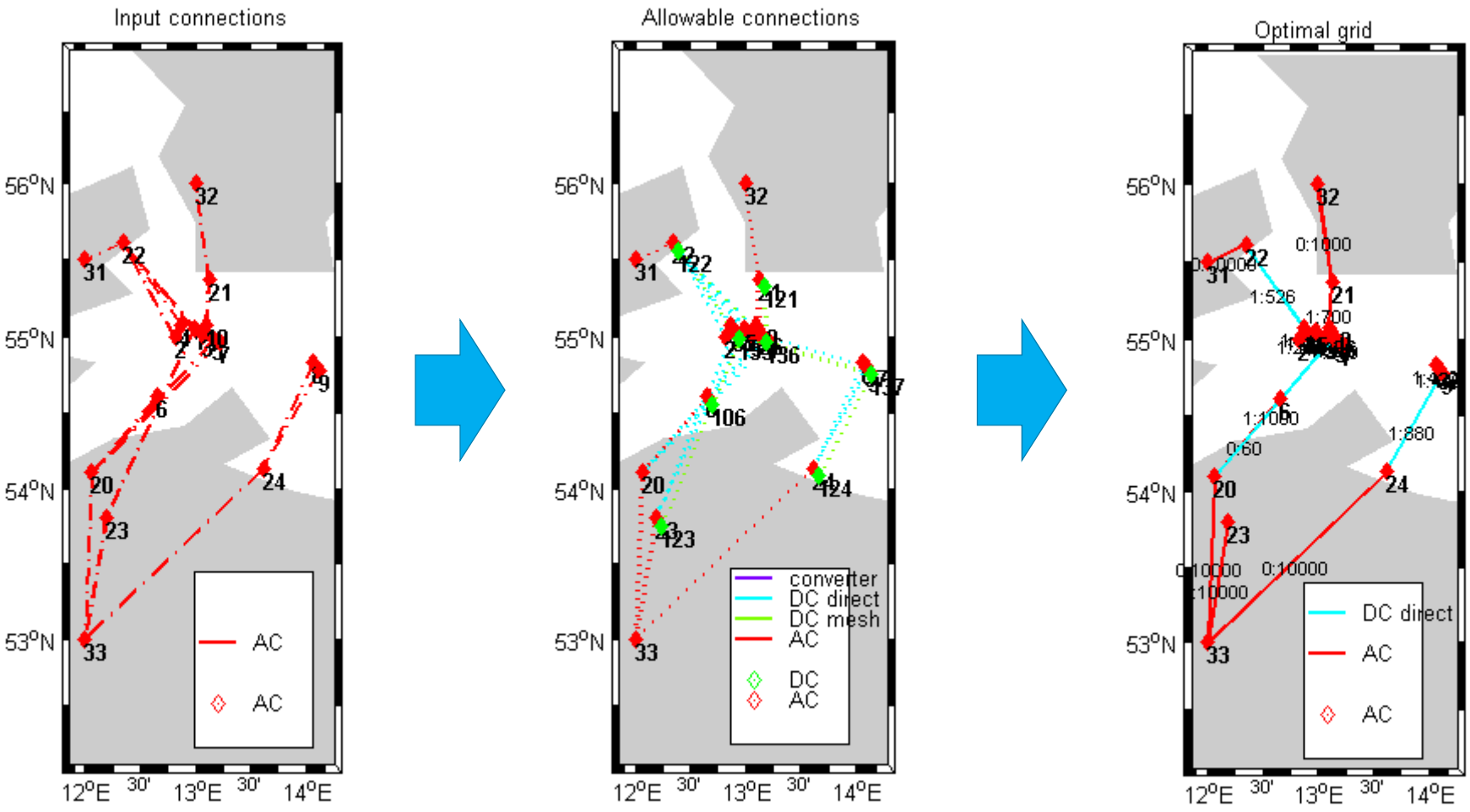


- Weekly average

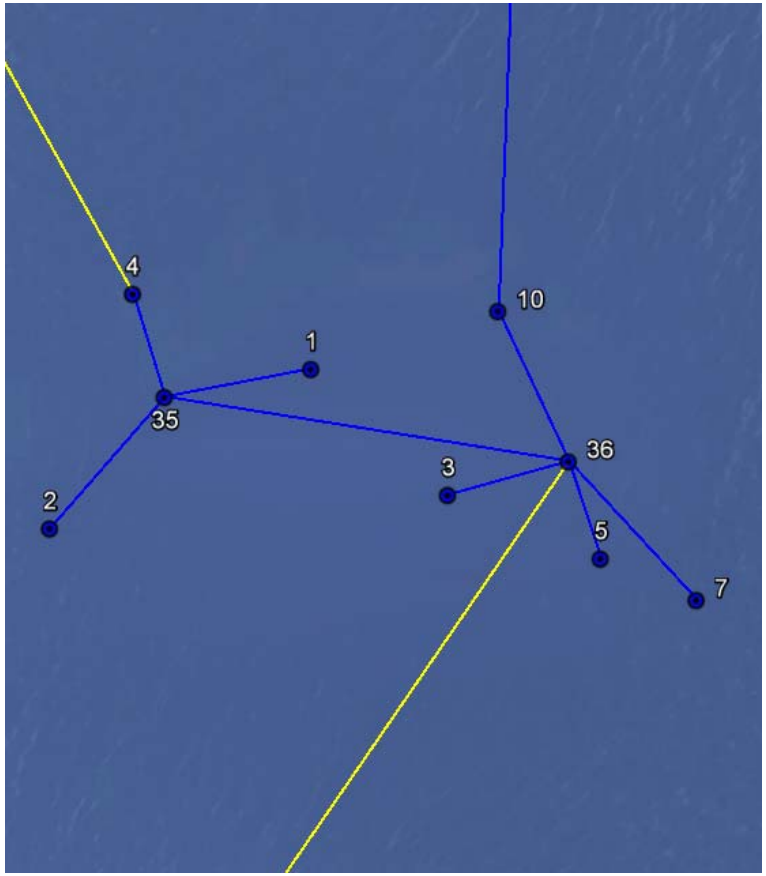




Net-Op DTOC processing



Result: Optimal grid



Additional output

- E.g. branch flow

from	to	cable type	loss fraction	distance	new cables	total capacity	cost (M€)	mean flow 1->2	mean flow 2->1
4	22	3	3.406 %	68.5	1	526	829	291.9	113.2
6	20	1	0.340 %	68.0	0	60	0	20.4	0.0
9	24	3	3.437 %	79.1	1	880	1138	380.2	0.1
10	21	1	0.169 %	33.9	1	700	348	350.6	164.7
20	33	1	0.001 %	123.0	0	10,000	0	724.8	64.2
21	32	1	0.001 %	70.1	0	1,000	0	350.0	164.7
22	31	1	0.001 %	25.3	0	10,000	0	282.0	113.2
23	33	1	0.001 %	90.3	0	10,000	0	0.0	0.0
24	33	1	0.001 %	165.6	0	10,000	0	367.1	0.1
1	35	1	0.029 %	5.9	1	200	48	92.8	0.0
2	35	1	0.034 %	6.9	1	200	55	90.2	0.0
3	36	1	0.025 %	5.0	1	200	41	92.4	0.0
4	35	1	0.021 %	4.3	1	522	53	129.8	220.5
5	36	1	0.020 %	4.0	1	288	39	134.6	0.0
7	36	1	0.037 %	7.4	1	500	79	234.7	0.1
8	37	1	0.019 %	3.7	1	400	42	196.8	0.1
9	37	1	0.015 %	3.0	1	400	36	0.1	196.8
10	36	1	0.033 %	6.6	1	700	84	257.8	142.3
36	35	1	0.081 %	16.2	1	515	156	92.1	184.2
36	20	3	3.570 %	123.3	1	1,000	1558	732.7	66.3

Conclusion

- Net-Op DTOC is a tool for clustering and grid connection optimisation of offshore wind farms
- High-level automated offshore grid planning, taking into account
  - Investment costs
  - Variability of wind/demand/power prices
  - Benefit of power trade between countries/price areas
- The tool will be integrated in the DTOC framework (www.eera-dtoc.eu)

Technology for a better society