What is a realistic annual energy yield from very large wind farm clusters and energy islands?
Declarations setting ambitious political ambitions

THE ESBJERG DECLARATION
On the North Sea as a Green Power Plant of Europe

Energy security and the fight against climate change are crucial to the future of the European Union. Recalling the Versailles conclusions on energy, the European Commission’s communication on Joint European Action for more affordable, secure and sustainable energy, and the most recent IPCC report and taking note of the European Commissions III PowerEU announcement of 18 May, we aim to take urgent and immediate action. The recent geopolitical events will accelerate our efforts to reduce fossil fuel consumption and advance the deployment of renewable energy for more energy resilience in Europe.

Therefore, we will increasingly replace fossil fuels, including Russian oil, coal and gas, with European renewable energy from the North Sea, including offshore wind and green hydrogen, contributing to both EU climate neutrality and energy security.

To achieve this and to pave the way for the further expansion of offshore wind, we have decided to jointly develop The North Sea as a Green Power Plant of Europe, an offshore renewable energy system connecting Belgium, Denmark, Germany and the Netherlands and possibly other North Sea partners, including the members of the North Sea Energy Cooperation (NSEC). As Members of NSEC, we will build on the work already accomplished and will implement strategies to achieve our goals in close cooperation with the other regional countries and the European Commission, in doing so we will strive for a balanced consistency of offshore energy development projects and the development of offshore hydrogen infrastructure.

Together, we have set ambitious targets for offshore wind: 65 GW by 2030 and 150 GW by 2050. Based on the North Sea’s full potential, this means that we double our total capacity of offshore wind by 2030 and we need to reach our EU climate neutrality strategy targets.

This will contribute to the decarbonisation of Europe’s offshore production of green hydrogen. We have set combined targets of about 20 GW production capacity already by 2030, and 19.6 GW by 2030 to expand our production even further for 2050.

65 GW by 2030
150 GW by 2050

THE MARIELNBORG DECLARATION
The Baltic Sea Energy Security Summit

We are convinced that the Baltic Sea can be developed into a new energy crisis hub connecting Europe’s energy to the North Sea, unlocking its resources.

OSTEND DECLARATION OF ENERGY MINISTERS ON THE NORTH SEAS AS EUROPE’S GREEN POWER PLANT DELIVERING CROSS-BORDER PROJECTS AND ANCHORING THE RENEWABLE OFFSHORE INDUSTRY IN EUROPE

Recalling the declaration on the North Seas as a Green Power Plant of Europe in Esbjerg signed by the energy ministers of Belgium, Denmark, Germany and the Netherlands on 18 May 2022, we aim to strengthen our cooperation to ensure affordable, secure and sustainable energy, while at the same time, continuing our efforts to protect the marine ecosystem. In response to Russia’s aggression against Ukraine and strengthening of energy blockage against Europe we will accelerate our efforts to reduce fossil fuel consumption, as well as dependence on fossil fuel imports and promote the rapid expansion and deployment of renewable energy for an energy resilient Europe.

Further underlying that the goal of the development of infrastructure, production of offshore renewables and market design for the North Sea is to accelerate the energy transition and maximise the benefits for households, industry and society as a whole.

Together, we have set ambitious combined targets for offshore wind of about 120 GW by 2030 in the North Seas. Based on the North Sea as a Green Power Plant of Europe, we aim to more than double our total capacity of offshore wind to at least 300 GW by 2050.

We acknowledge the progress made since the last summit including through the conclusion of both bilateral agreements on offshore renewable generation and non-binding agreements to cooperate on goals for offshore renewable generation. In support of the North Sea, under the revised Framework for Transnational Cooperation in the North Sea (NITF-N). We fully support the ongoing work to accelerate the development of the offshore network and grid and offshore-grid connection.

In that respect, we also want to welcome a new group of countries that have joined the North Sea Declaration: Belgium, Denmark, Germany and the Netherlands.

This will contribute to the decarbonisation of Europe’s offshore production of green hydrogen. Germany has set combined hydrogen targets of about 500 GW by 2050.

120 GW by 2030
300 GW by 2050
Ambitions consistent with published data

From Ruiz Castello et al (2019),
- Calculate area available for wind installation
  - Installation capacity density 5 MW/km**2
  - Capacity factors from Global Wind Atlas (v1)

For the case of the Esbjerg Declaration countries,

...and inferring from Ruiz Castello et al (2019)

- Capacity range
  - DK 27-226 GW
  - DE 28-106 GW
  - NL 48-97 GW
  - BE 2-2 GW

- Total 105-431GW

How might this look?

This scale of wind energy deployment is completely new. No or limited experience of such development in the real world.

We need, and have models to guide us.
Farm efficiency... using WRF wind farm parameterization

Agora (2020):


12 MW turbine
Hub height 140 m
Rotor Diameter 200 m

20 colour coded wind farms
Total area is 7249 km²

5, 7.5, 10, 12.5, 20 MW/ km²

14 - 144 GW


Agora (2020):
• Efficiency drops for higher installed capacity densities (1)
• Efficiency also depends on wind farm location and climate. (2)
• Efficiency depends on farm size and proximity of large expanse of neighbouring wind farms (3)

Agora (2020)
Inferring results from Volker et al (2017) and Agora (2020) suggest Energy Island losses between 10 – 20%.

Dedicated Mesoscale simulations in van der Laan (2023) predict a wake loss between 9.3 - 10.1%.

Total area and capacity density:
6.4 * 10^3 km²
1.6 MW / km²

Research on wind farm modelling wakes

One object is to reduce grid choice dependency when using wind farm parameterizations

- using microscale models to provide thrust
- using anti-aliasing methods

Race Bank (UK)

Turbine 91 * 6 MW
Total Capacity 546 MW
Area 75 km²
Capacity density 7.3 MW / km²

Efficiency
Normalized Wake Area Size

0.73
5.1

0.76
3.1

dx = 1 km
3 km

See poster 4 for more details
Scaling-up within capacity density limits

Use Volker et al (2017) to guide capacity density as function of area available.

i.e. to keep large scale wind farm wake losses small (5 – 10 %)
limit aggregated installed capacity density to
- 2 MW/km² in Gulf of Suez
- 2 MW/km² for bottom-fixed in Red Sea
- 1 MW/km² for floating in Red Sea

A guiding estimate of capacity and production is
51.5 GW generating 176 TWh per year:

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Calculated wind farm power curves including farm efficiency

Useful for power time series studies...

Mesoscale wake (WRF ideal)

- Wind farm power curve derived for various sizes:
  - 4 x 4 (small) 0.24 GW
  - 8 x 8 (medium) 0.96 GW
  - 20 x 20 (large) 6 GW
  - 40 x 40 (x-large) 24 GW


Other studies

Maas and Raasch (2022):
LES study using,
Parallelized Large-eddy Simulation Model (PALM)

Turbine: 15 MW, D=240 m, z_h = 150 m
10.4 W/m² (efficiency down to 0.41)

• X-wakes project
  – Recent workshop 26/6/2023
  – Flight data, Lidar data, SAR scenes, flow modelling at different scales


Figure 10. Wind turbine efficiencies $\eta_{we}$ for all five cases (a–e) and overview of wind farm names (f).
Research on wind farm: broader environmental impacts

30-year worth wind and wave statistics

• Wind-Wake-Wave modelling

• waves affect the momentum transport into the ocean and thus mixing in the ocean.
  – mixing has important consequences for the ecosystem

Conclusions

My unofficial production estimate for 150 GW in North Sea is 507 – 570 TWh

• Capacity goals are ambitions and grounded in data

• Estimating yield for these installed capacities must consider wind farm wake impacts
  – different approaches have been presented

• Uncertainty estimation is needed
  – Validation is a challenge given the scale of installations does not yet exist

• Modelling approaches show promise
  – Broader impacts on environment can also to be assessed

Thank you for your attention

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