

DTU



Oscar Saborío-Romano

# Grid Connection of Offshore Wind Energy

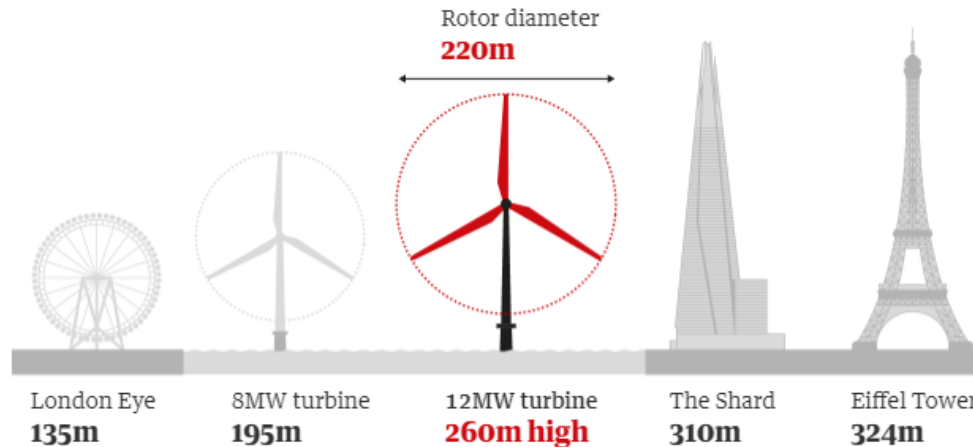
# Offshore wind – how big is big?

## Ørsted to Use GE Haliade-X 12 MW on US Offshore Wind Farms

Ørsted has selected GE Renewable Energy as the preferred turbine supplier for two of its US offshore wind farms which marks the world's first commercial deployment of GE's Haliade-X 12 MW offshore wind turbine.



### How big is the world's largest offshore wind turbine?



Guardian graphic. Source: GE Renewable Energy

**Berlingske Business**  
**Vindeby vindmølle**  
 Mandag d. 08. februar 2016, kl. 19.58

**Vindeby vindmølle**  
**0,45 MW**

**Burbo Bank Extension**  
**8 MW**

**MOLLEN:** Bonus Energy - det nuværende Siemens Wind Power - leverede verdens første havvindmølle til Vindeby, ingeniørerne hos Bonus i Brande sørgede blandt andet for, at der altid var tert inde i møllen for at undgå erosion. Desuden blev møllerne malet med den samme maling, som bruges til boreplatforme i Nordsøen.

**FUNDAMENTET:** Vindmøllerne står på et såkaldt gravitationsfundament. Det er kort fortalt en meget stor betonkuboid, som står havbunden. Fundamenterne blev i sin tid støbt på land og sejlet ud på bølgerne, hvor de så blev sænket ned. De er relativt simple at få op igen. Man kan løfte dem op, og så sender man en dykker ned med en have- og ordner sandbunden. Eneste udfordring er at finde et skib, der har kræfter nok til at løfte de meget tunge fundamenter.

**MOLLEN:** Vestas har i mange år været lillebroderen inden for havvindmøller, hvor Siemens er løbet med de fleste ordrer. Gennem samarbejdet med Mitsubishi i MHI Vestas er det dog lykkedes for den danske producent at få en stor ordre til Burbo Bank Extension på sin otte megawattmølle. Møllen hedder V164 med reference til rotordiameteren på 164 meter.

**FUNDAMENTET:** Ifølge DONG Energy's hjemmeside vil der på det britiske Burbo Bank Extension-projekt blive brugt tre forskellige fundamenttyper. En af disse er de såkaldte monopæle, som har været brugt i stor stil gennem de senere års vindmølle-eldorado i DONG. Disse pæle bankes ned i havbunden og holder møllen på plads. Monopælene er forholdsvis nye, så der går mange år, inden de skal tage op for første gang, men besværet med den proces bliver formentlig større end med Vindeby-fundamenterne.

**Turbine: Bonus**  
Byggeår: 1991

**Turbine: Vestas**

**En blåhval er 35 meter lang** | **Vindeby havvindmølle park er sammenlagt på 4,95MW.** | **Hele Burbo Bank Extension er på 258 MW.** | **DONG har annonceret, at man vil bygge Hornsø 1, der er på 1.200 MW.**

TEKST / MICHAEL KORSGAARD MØLLEN | BERLINGSKE GRUPPENS WINDSEKTOR/DONG

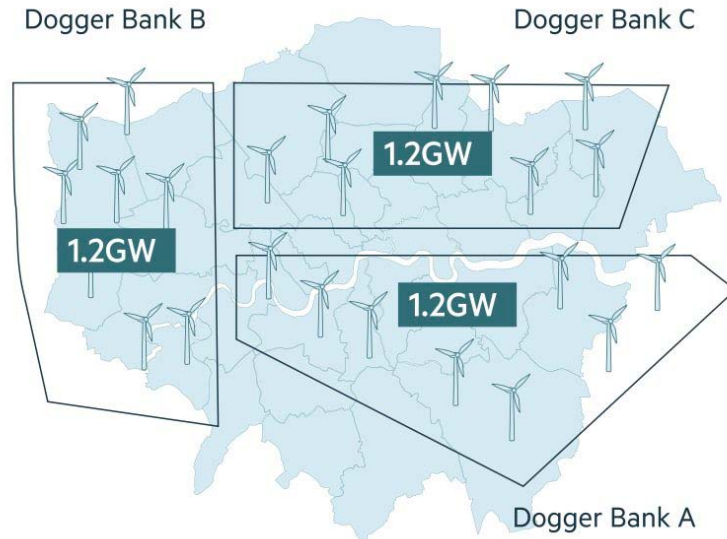
# Offshore wind – how large is large?

## Area of Dogger Bank offshore wind farm compared to Greater London

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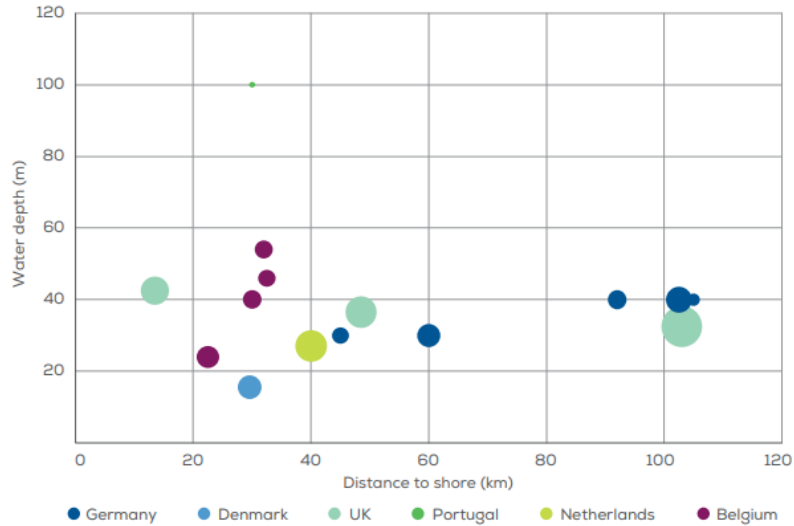
Dogger Bank covers 1,700km<sup>2</sup>, an area larger than Greater London

### GREATER LONDON



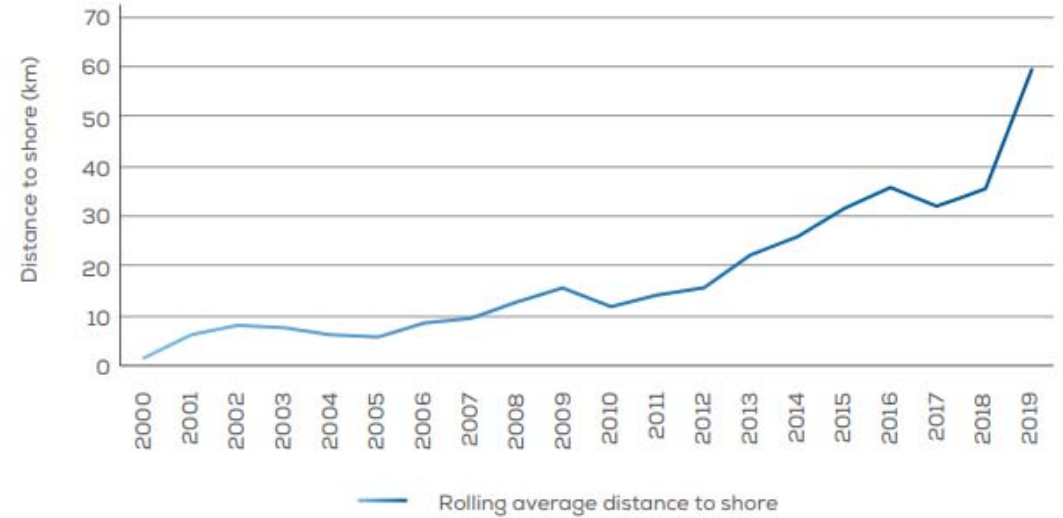
# Offshore wind – how far is far?

**FIGURE 8**  
Average water depth and distance to shore of offshore wind farms under construction during 2019. The size of the bubble indicates the capacity of the site



Source: WindEurope

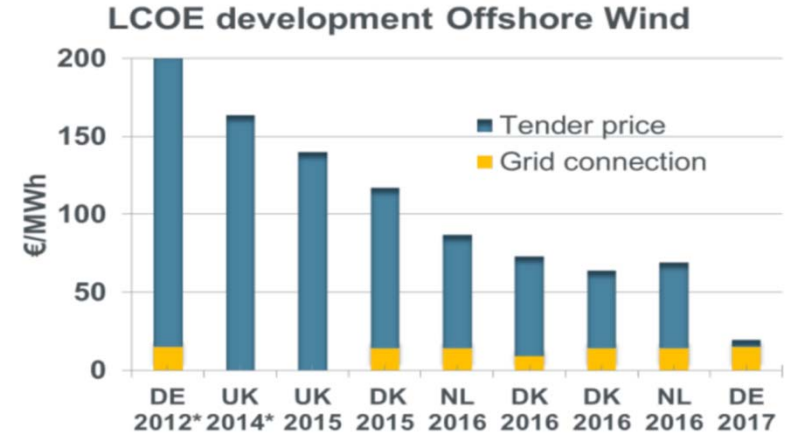
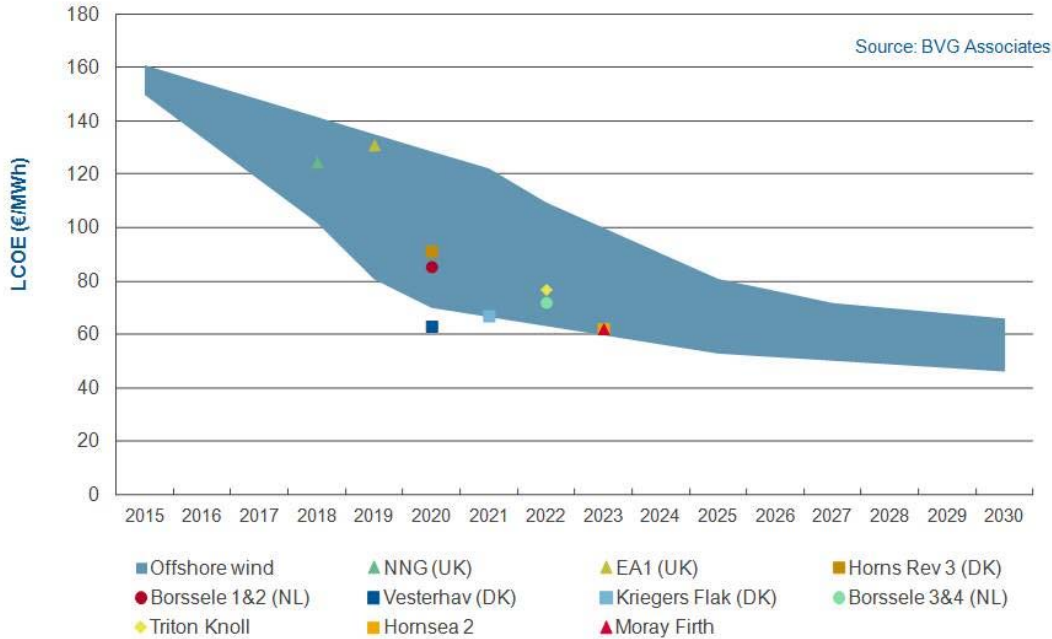
**FIGURE 10**  
Rolling average distance to shore of online offshore wind farms



Source: WindEurope

# Offshore wind cost reduction

....but



- Limited cost reduction in grid connections.
- Longer offshore connections lead to increase in cost

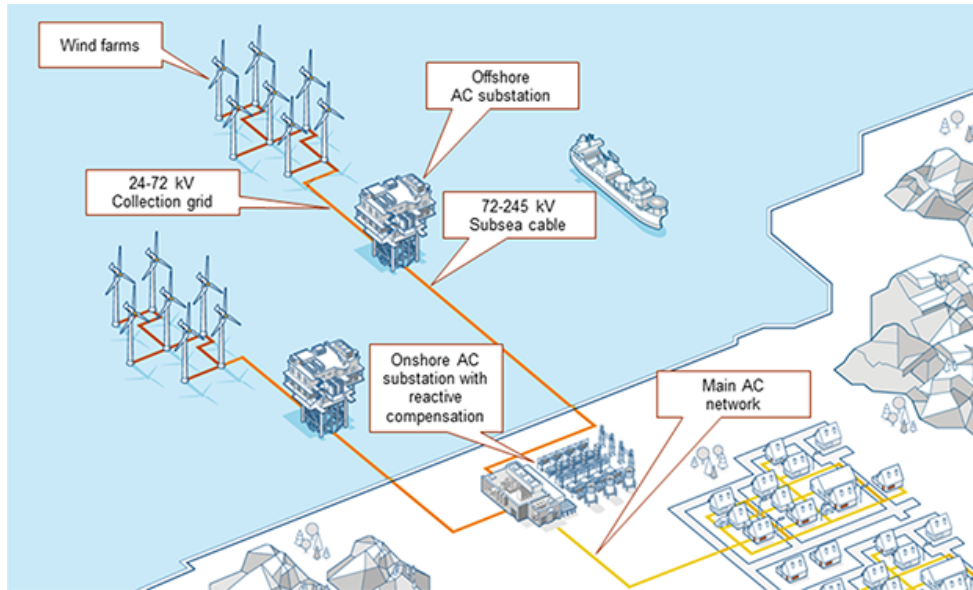
Source: North Sea Energy Infrastructure: Status and outlook, TenneT, Deepwind 2019

[...] this is mainly from technology innovations in turbines and installation, and reductions in financing costs [...]

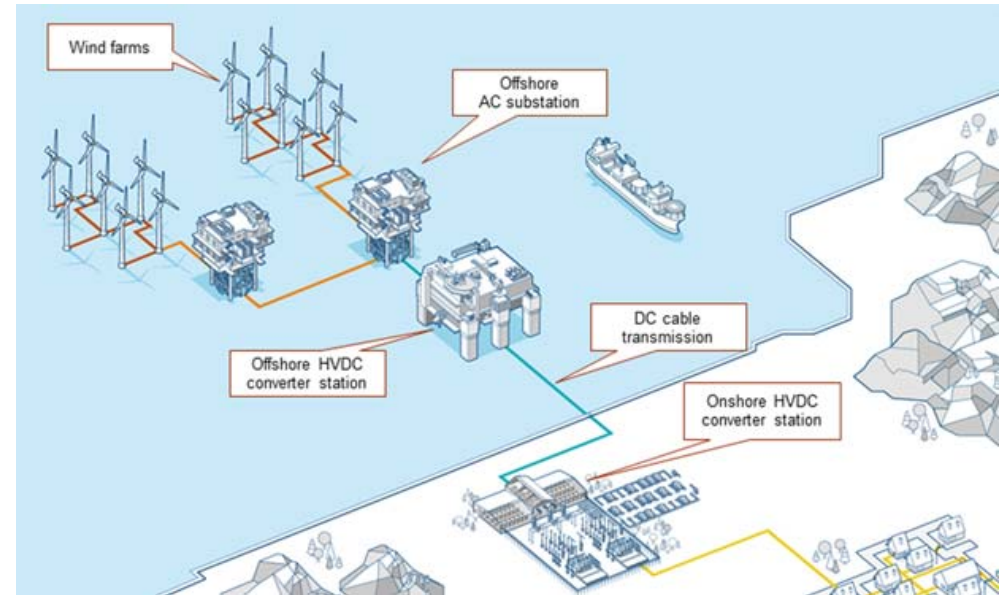
WindEurope

# Grid connection – main components

## High-Voltage Alternating Current (HVAC) Transmission



## High-Voltage Direct Current (HVDC) Transmission

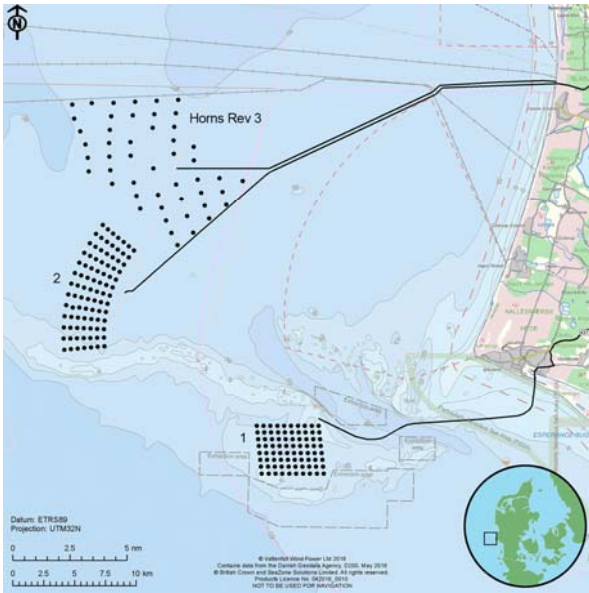


Source: ABB



# Grid connection concepts

## HVAC



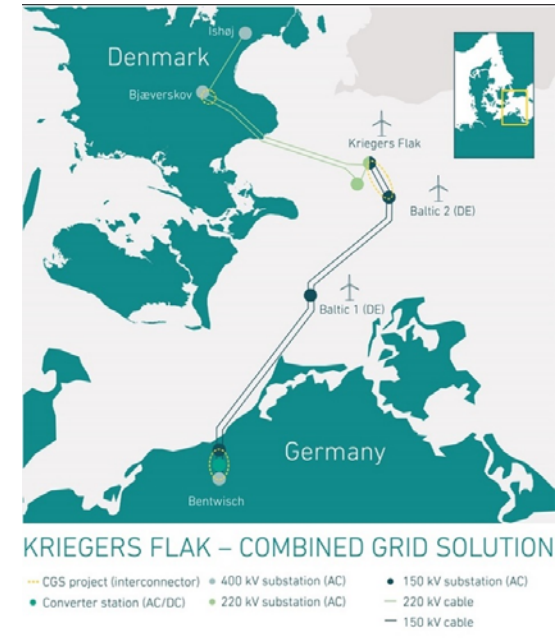
## HVDC

HVDC offshore wind farm connections in the North Sea



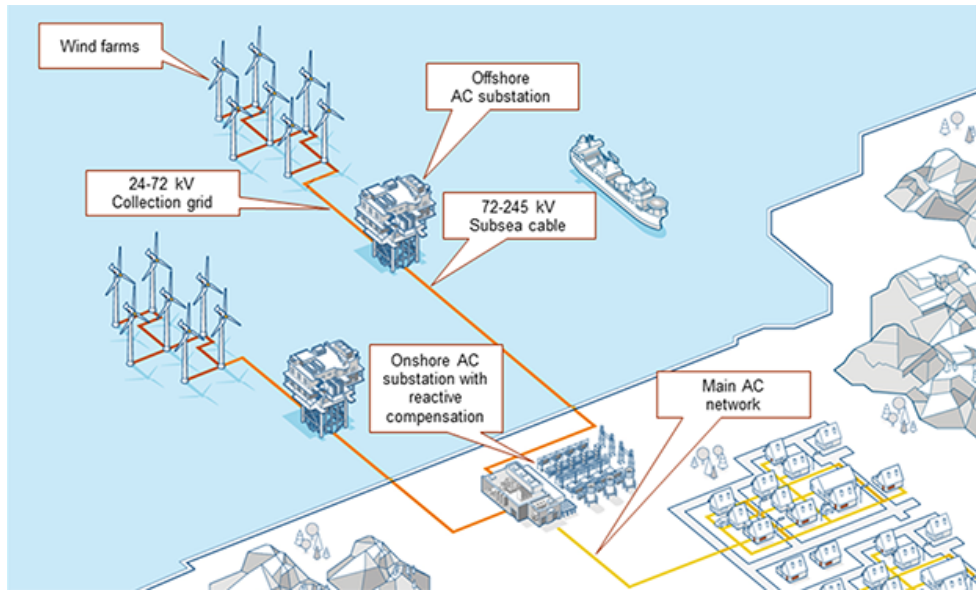
Source: TenneT

## Hybrid

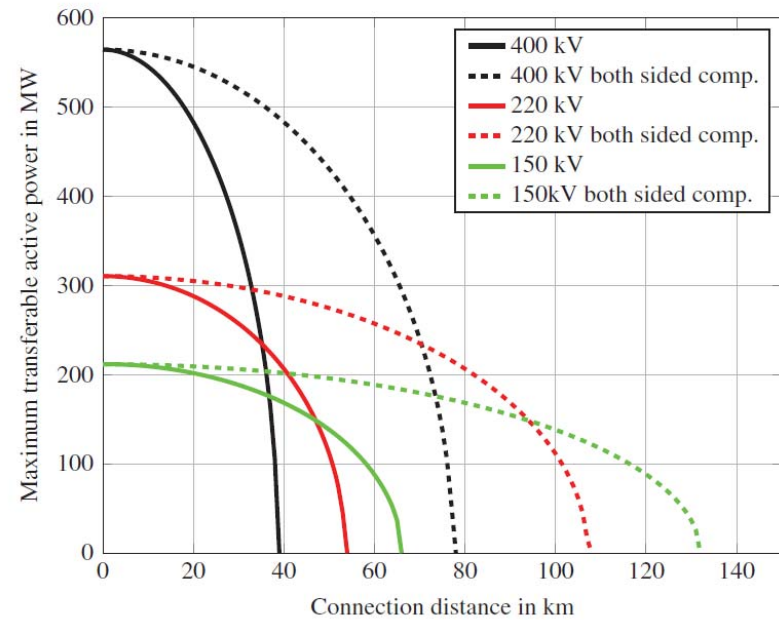




# HVAC transmission

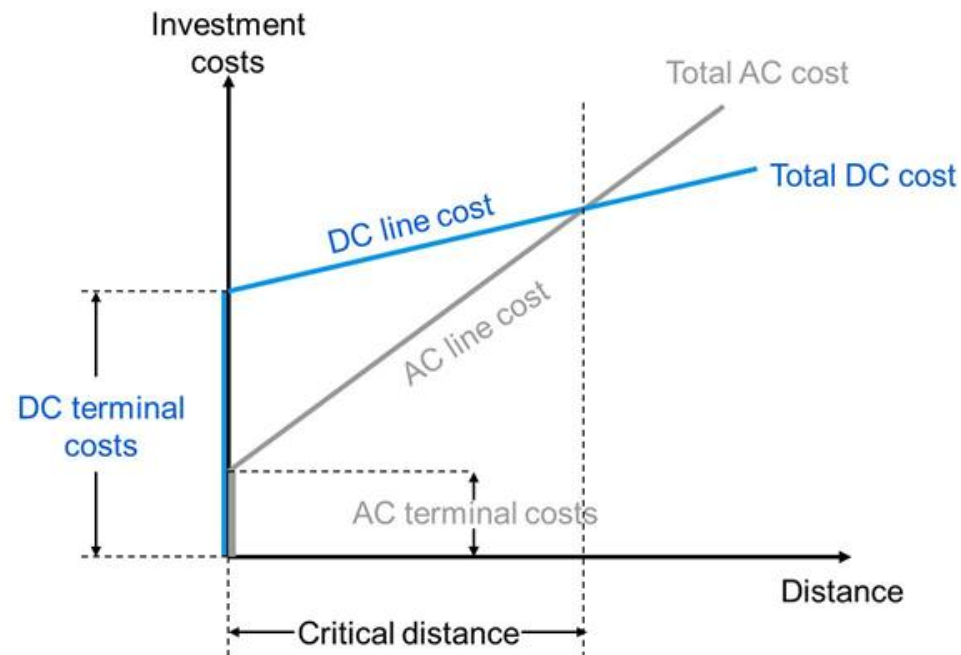
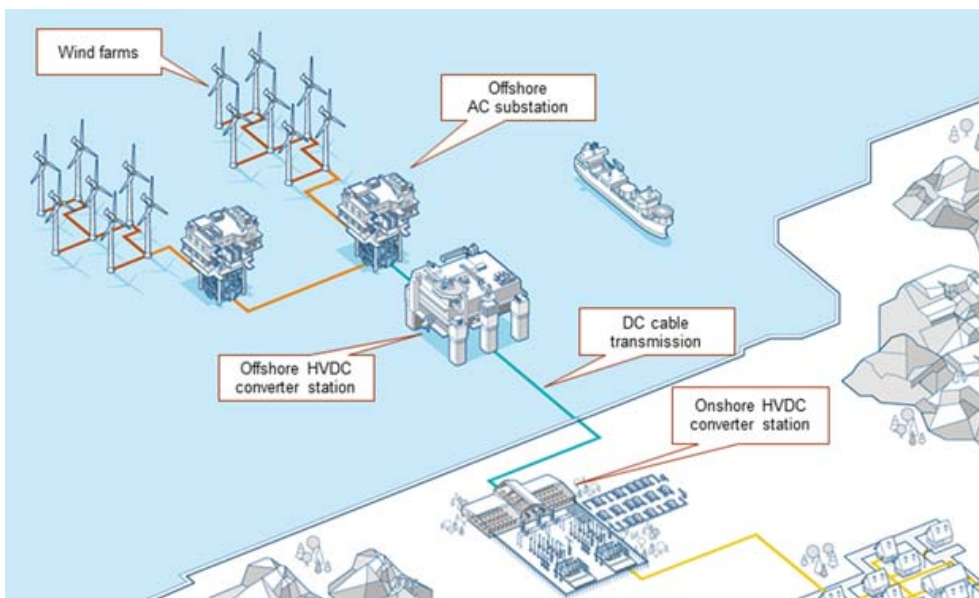


Main limitation:  
capacitive current (function of distance)



# HVDC transmission

Distance to shore is the most important factor

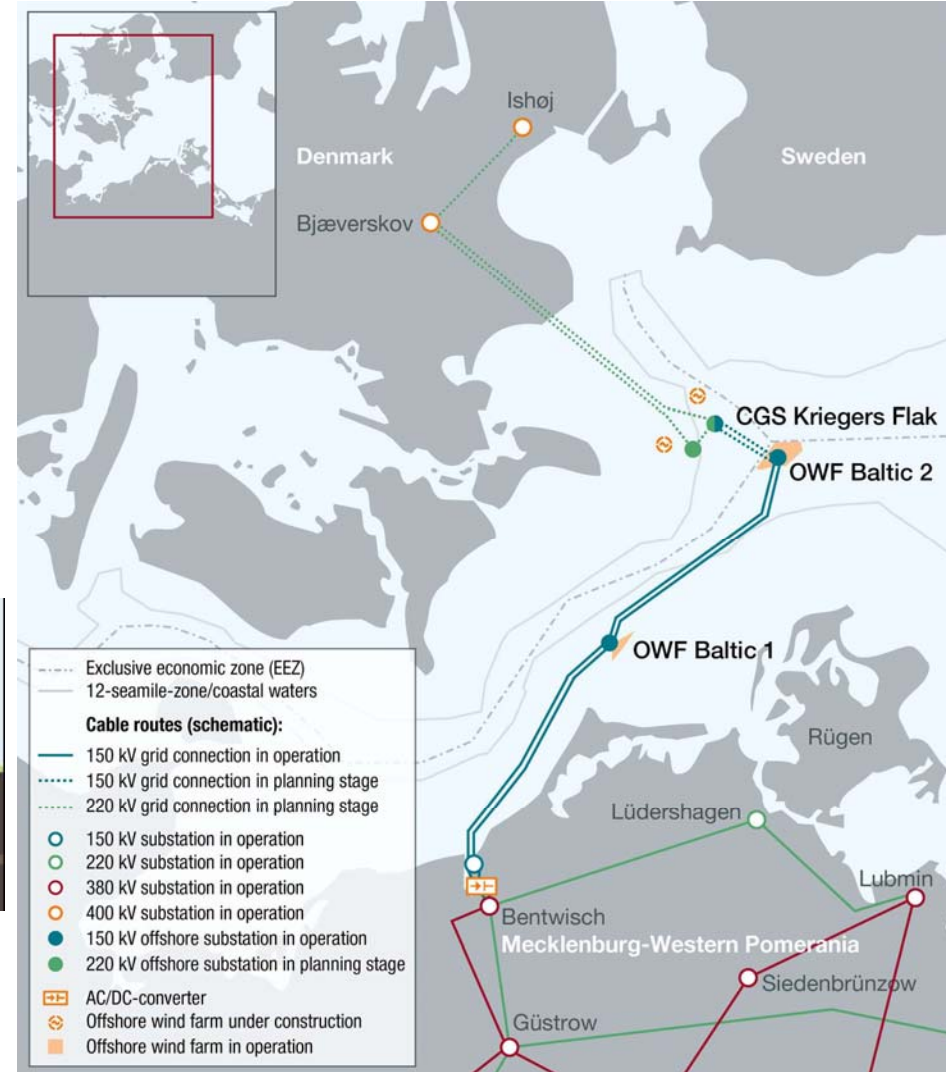
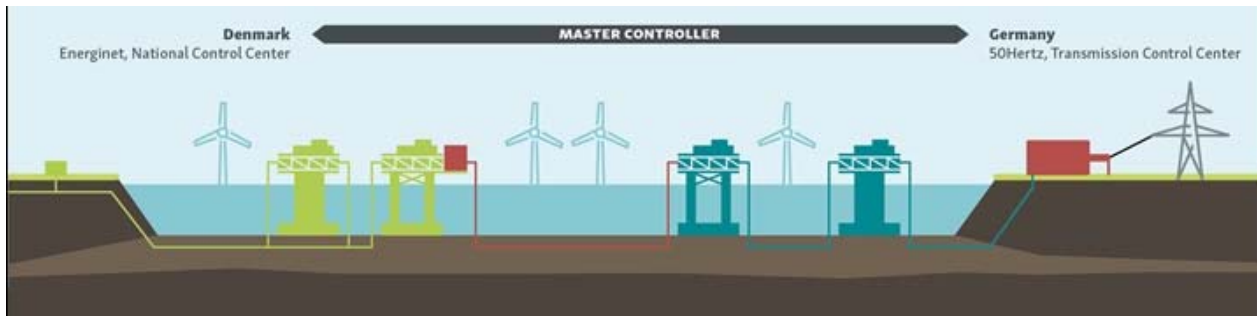


Break-even distance: 50-100 km

# Hybrid

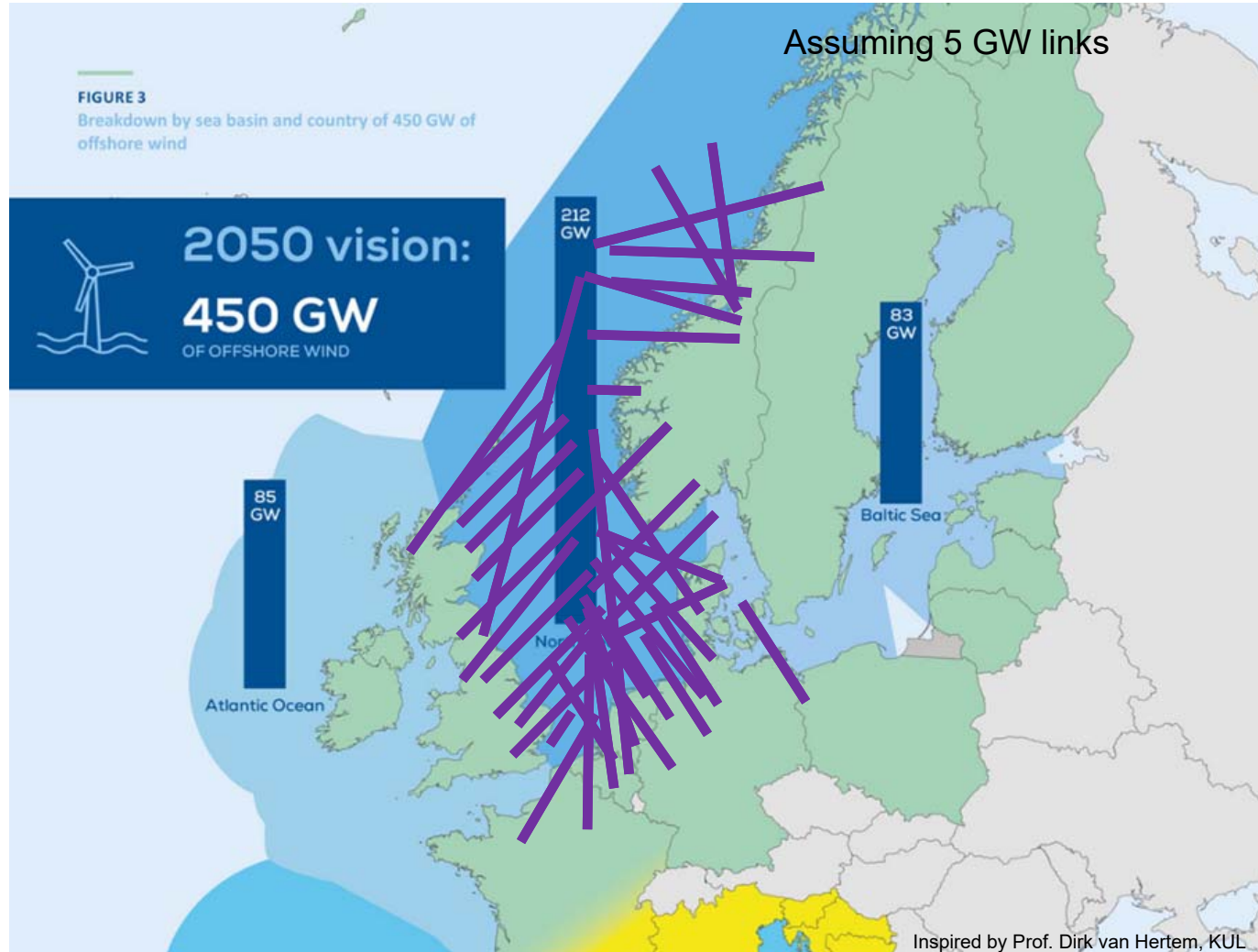
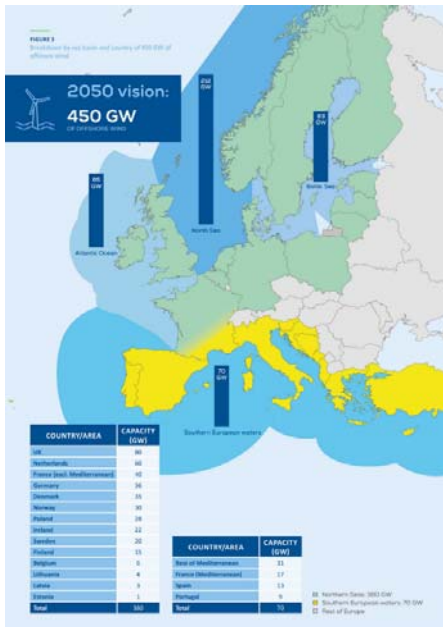
Kriegers Flak - Combined grid solution:

- Connecting offshore wind to the shore
- Connecting two countries
- Connecting two markets
- Connecting two synchronous areas



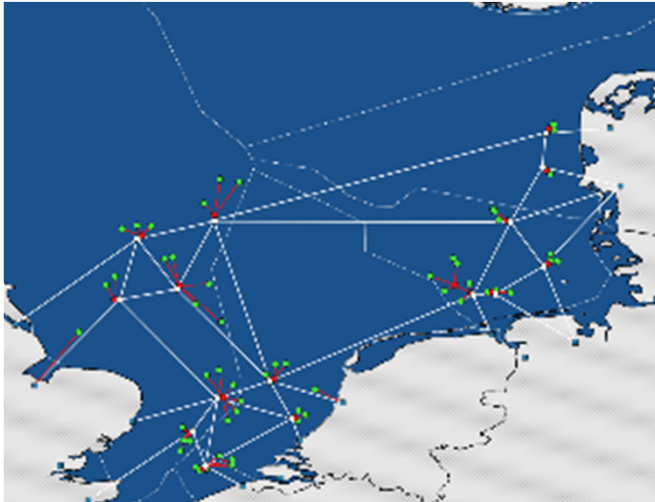
# Very high ambitions

- Around 22 GW installed today
- Expectations for 100 GW by 2030 and 200 GW by 2050



Inspired by Prof. Dirk van Hertem, KUL

# Meshed offshore HVDC grids...



- Critical components like DC circuit-breakers
- Higher voltages, better capacity, better redundancy
- Fully interoperable systems
- Further developments in technology (diode-rectifiers, DC collection grids, ...)
- Hybrid transmission and fully interconnected systems

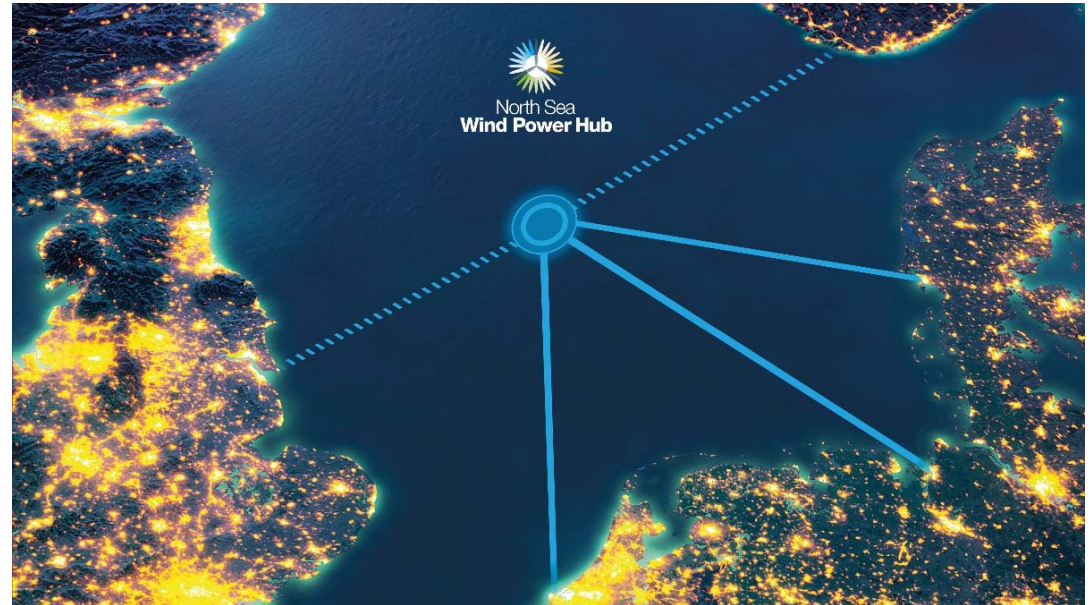




# Energy islands/hubs

- North Sea Wind Power Hub Consortium
  - TenneT (NL-GE) - TSO
  - Energinet (DK) - TSO
  - Gasunie (NL) – Natural gas
- Launched the initial concept of an energy island
- Proposing “Modular Hub-and-Spoke concept”
- Produced a number of studies

<https://northseawindpowerhub.eu/category/studies/>



# Danish Energy Islands/Hubs

- In June 2020, Danish parliament decided [...] the construction of two energy islands in Denmark – in the North Sea and in the Baltic Sea. The energy island on Bornholm will have a capacity of 2 GW, while the one in the North Sea will have a capacity of 3 GW in 2030, and 10 GW in the longer term.

North Sea – 3 GW by 2030, aim for 10 GW by 2050

Bornholm island – 2 GW





# North Sea Energy Island

## VindØ consortium

- Electrical infrastructure:
  - HVDC converter stations
- Living quarters
- Energy storage
- Power-2-X facilities



Rendering launched recently:

<https://www.youtube.com/watch?v=0MO9pdZTEzc>

# Bornholm Energy Island

Ørsted:

- Placed on an existing island
- Mainly for electrical infrastructure



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