



Nicolaos A. Cutululis  
**Energy Islands**

# Agenda

- Offshore wind in Europe
- Grid connection concepts for offshore wind
- Energy hubs/islands
- Wind turbines/plants for energy islands
- Bornholm as a test centre for energy island technologies

# Offshore wind in Europe

# Offshore wind in Europe in 2021

## Offshore Wind in Europe

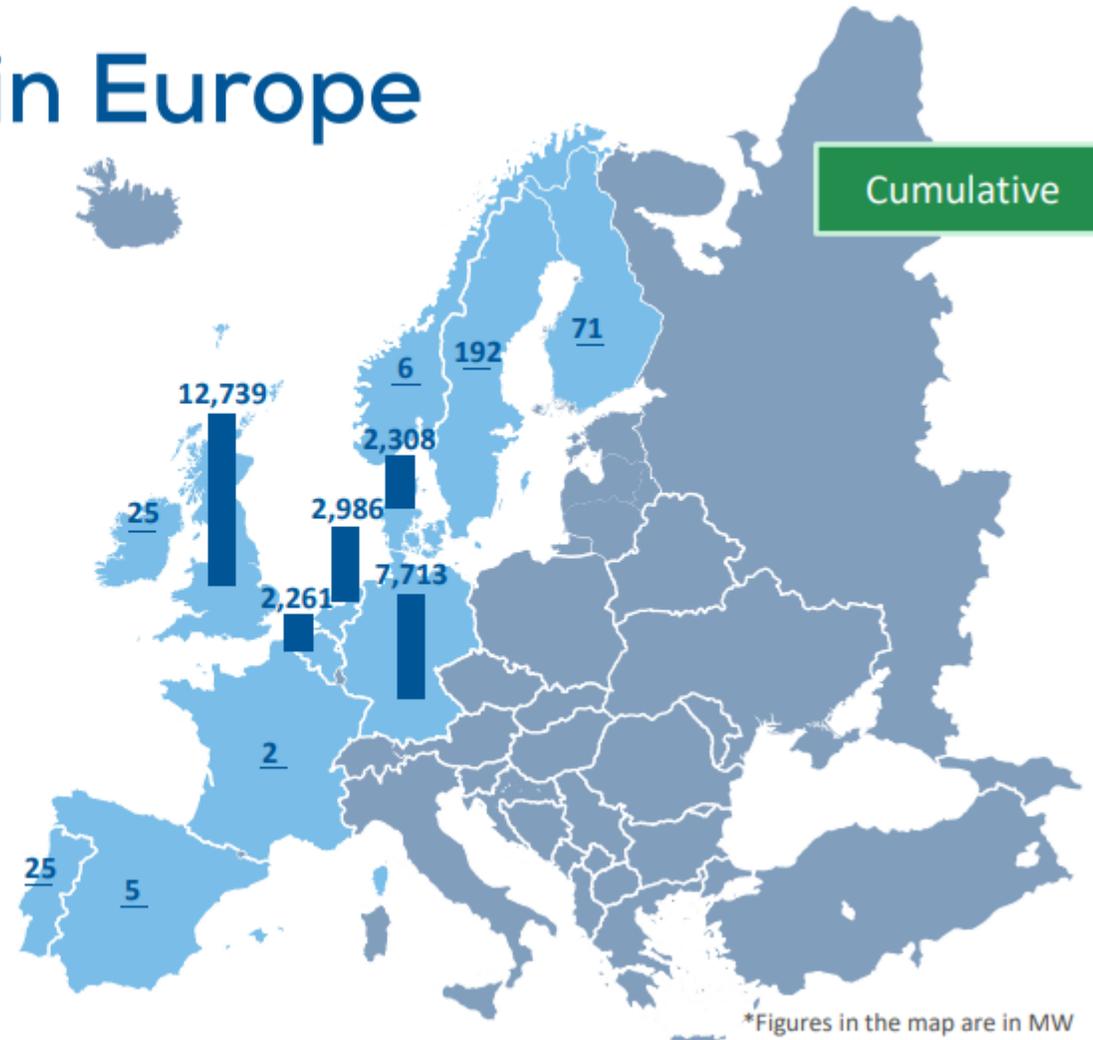
28,333 MW  
Connected to the grid

12 Countries

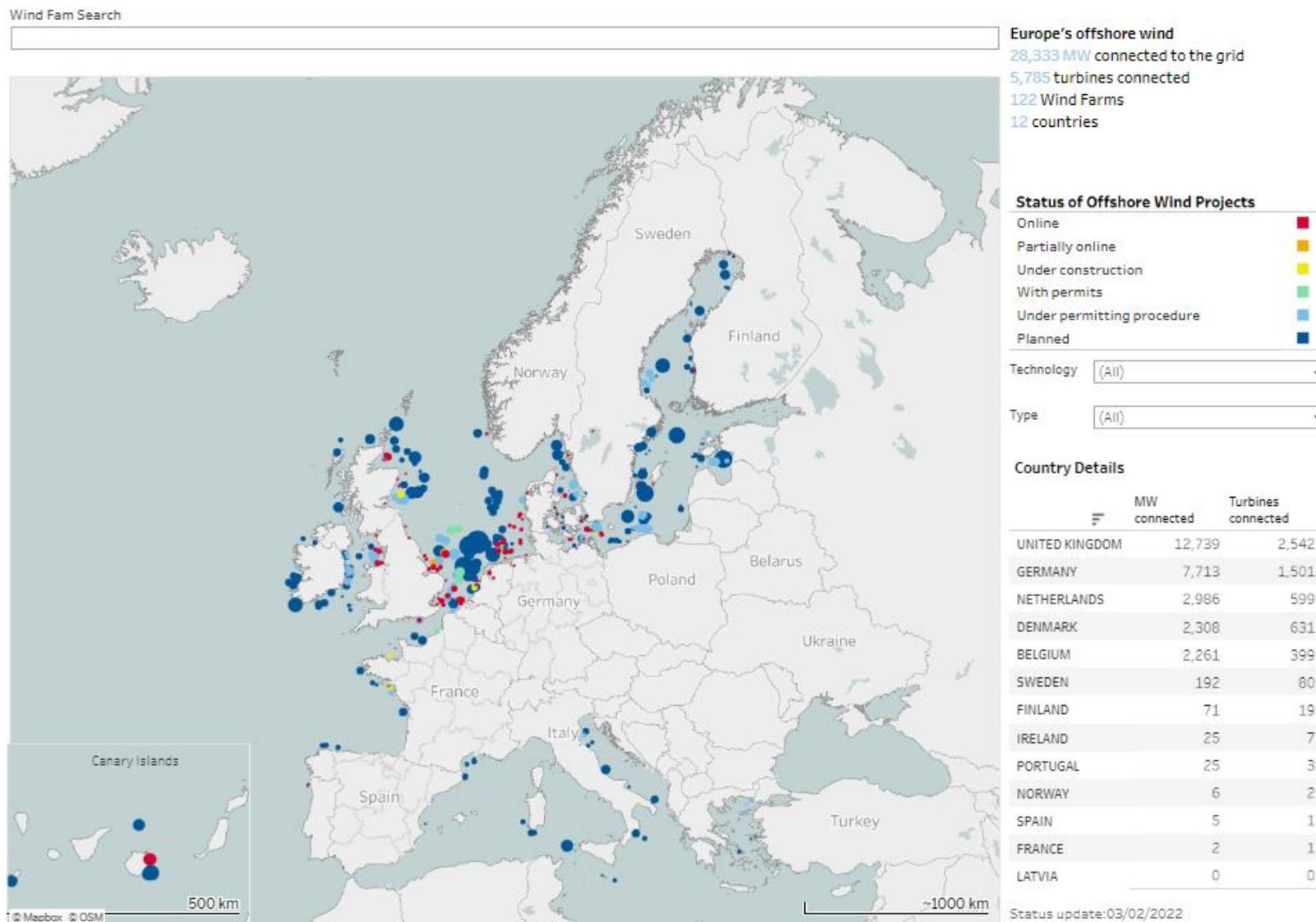
5,785 Turbines

122 Wind Farms

Wind  
EUROPE



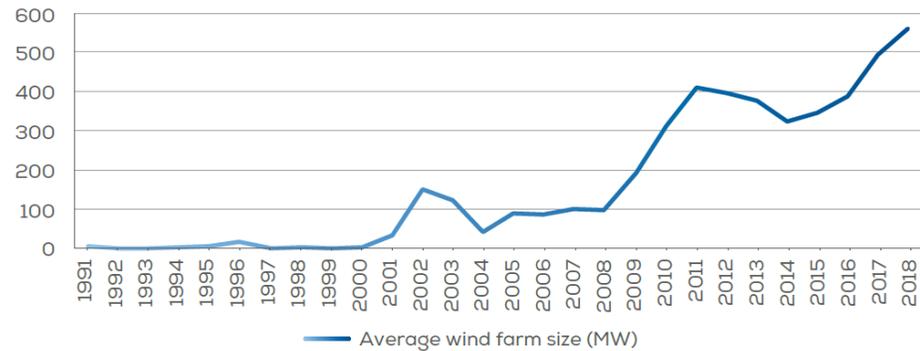
# Offshore wind farms map



# Offshore wind farms – large & far

**FIGURE 8**

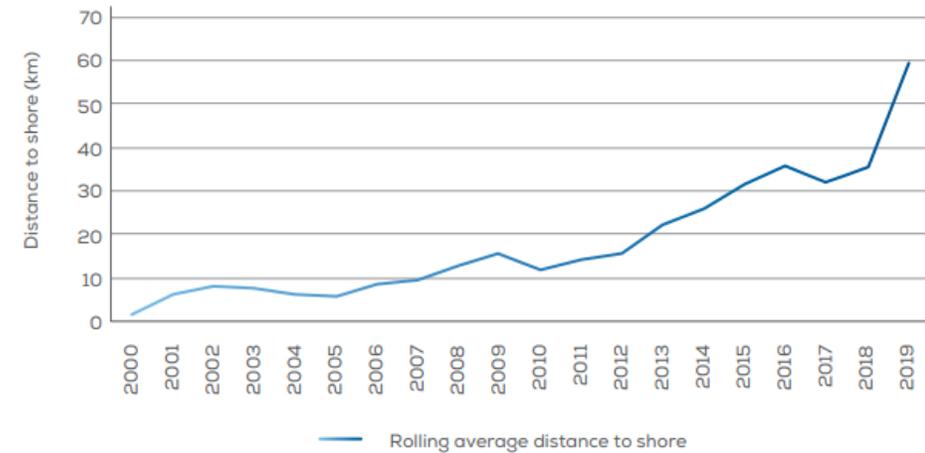
Average size of commercial offshore wind farms in construction and grid-connected in the given year



Source: WindEurope

**FIGURE 10**

Rolling average distance to shore of online offshore wind farms



Source: WindEurope

# North Sea Summit – Esbjerg, May 18

## North Sea Summit

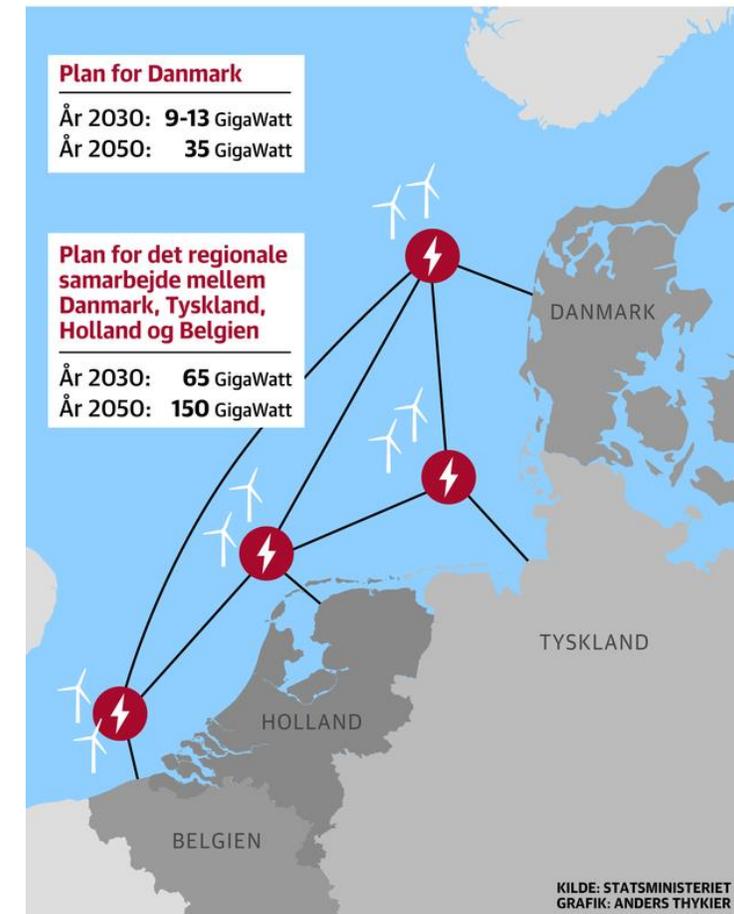
- President of the EC Ursula von der Leyen
- German Chancellor Olaf Scholz
- Dutch Prime Minister Mark Rutte
- Belgium Prime Minister Alexander De Croo
- Denmark Prime Minister Mette Frederiksen

**150 GW by 2050**

(+ UK 100GW and NO 40GW)

## Havvindsatsning i Nordsøen

I forbindelse med et topmøde om havvind underskriver regeringslederne fra Danmark, Tyskland, Holland og Belgien en erklæring om at sætte turbo på udbygningen af havvindmøller i Nordsøen og udbygge mindst 150 GW i 2050.



# North Sea Summit 12/9/2022

- Belgium, Ireland, Denmark, France, Germany, Luxembourg, the Netherlands, Norway and Sweden
- The 9 countries pledged to build at least **260 GW** of offshore wind by **2050**, with intermediate targets of **193 GW** by **2040** and **76 GW** of offshore wind by **2030**.

North Seas Summit focuses on how to deliver ambitious new offshore wind targets



Ministers and top officials from the 9 "North Seas" countries and the EU Commission met in Dublin today. That's Belgium, Ireland, Denmark, France, Germany, Luxembourg, the Netherlands, Norway and Sweden. They adopted a declaration with ambitious new volumes for the expansion of offshore wind. They discussed how exactly to deliver those volumes, with a special focus on how to strengthen Europe's offshore wind supply chain.

Source: [windeurope.org](https://windeurope.org)

# The Baltic Sea Energy Security Summit Bornholm, August 2022

- Denmark and its neighbours around the Baltic Sea, Sweden, Finland, Germany, Poland, Latvia, Lithuania and Estonia, signed a declaration on 30 August that aims to rapidly expand their offshore wind power capacity.
- The ambition is to have **19.6 GW** of offshore wind capacity by **2030** – a sevenfold increase compared to the current 2.8 GW.
- The substantial potential for offshore wind power in the Baltic Sea basin, reaching up to **93 GW**

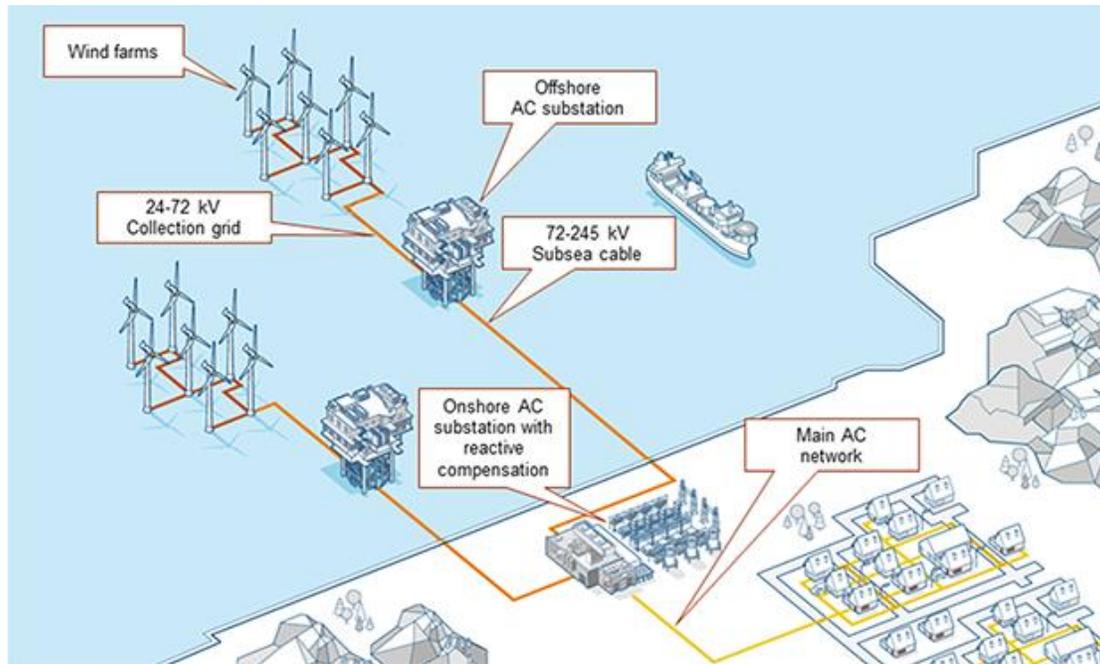


Source: State of Green

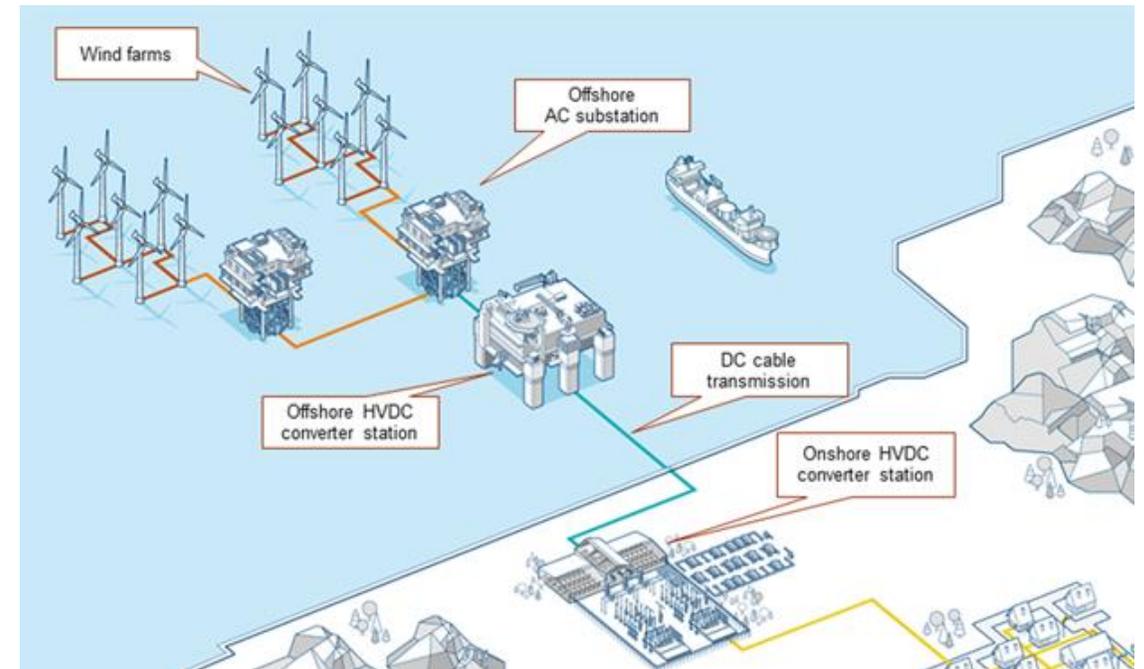
# Grid connection concepts

# Grid connection system

## HVAC



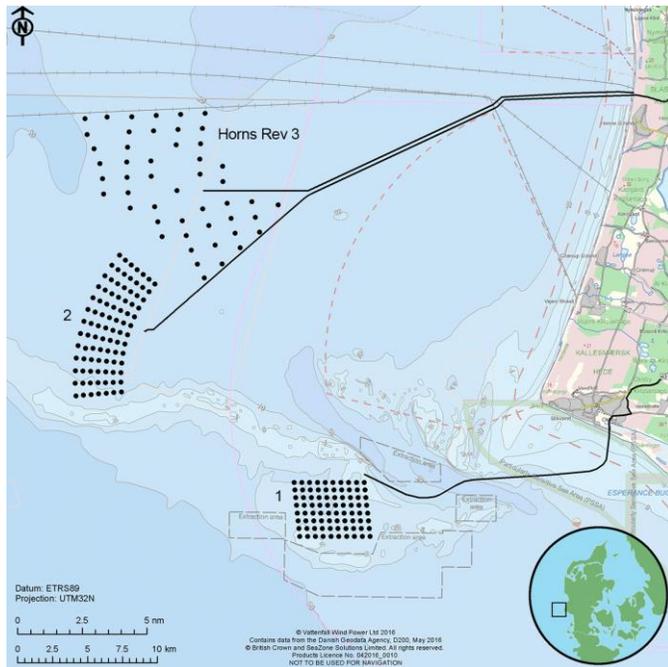
## HVDC



Source: ABB

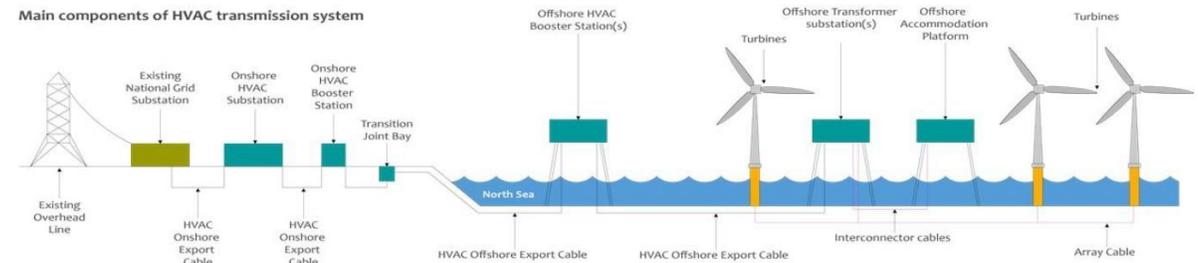
# Grid connection HVAC

## HVAC



## HVAC with compensation

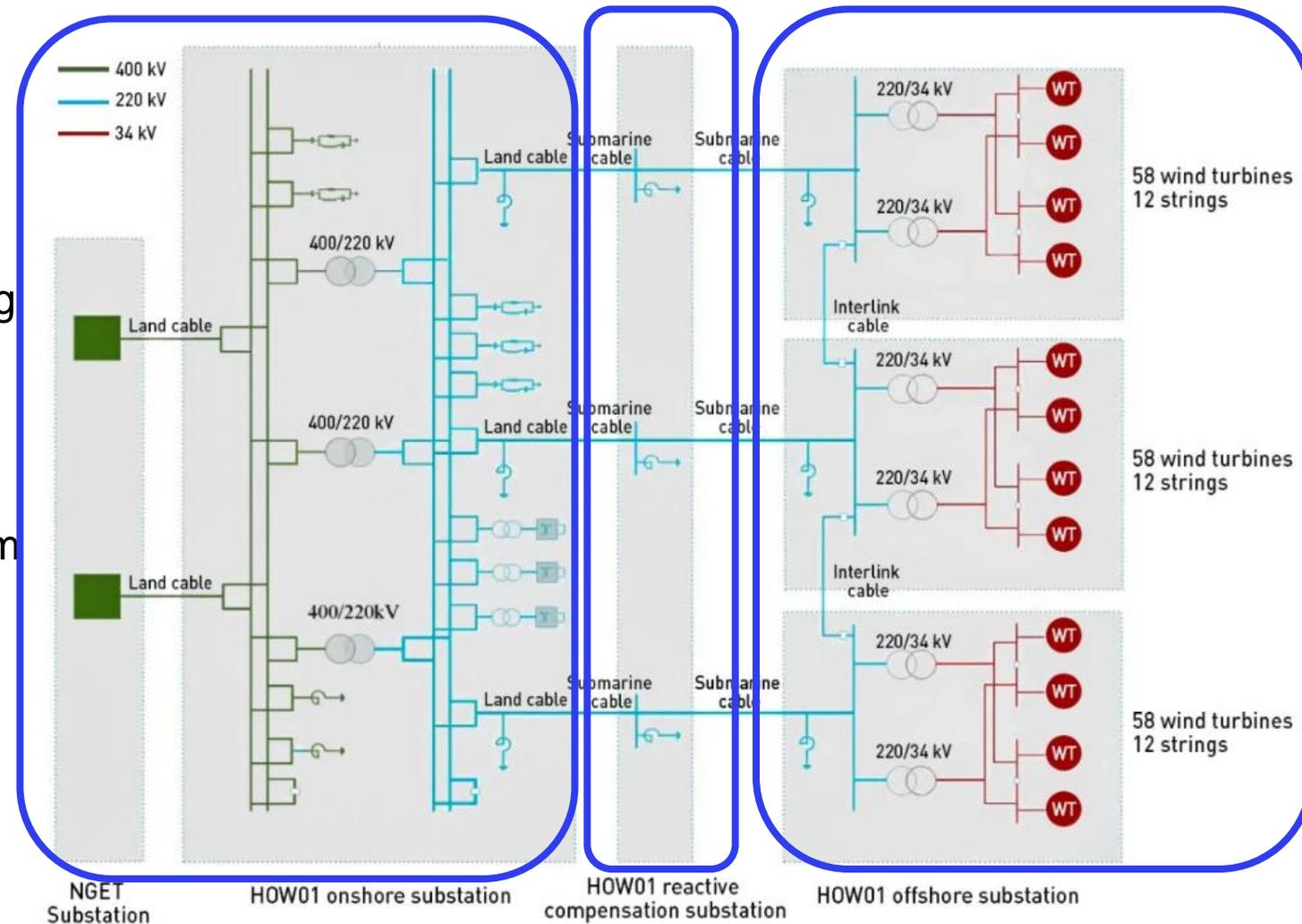
Main components of HVAC transmission system



# HVAC with compensation

## Hornsea ONE WPP:

- 174 WTs X 7.0 MW → 1.218 MW
- Three clusters (58 WTs each, 12 strings)
- Export cables of app. 170-190 km
- Interlink cables
- Mid-point compensation (extra platform)
- Compensation units:
  - Passive - shunt reactors
  - Active – STATCOM
- Filters: C-type



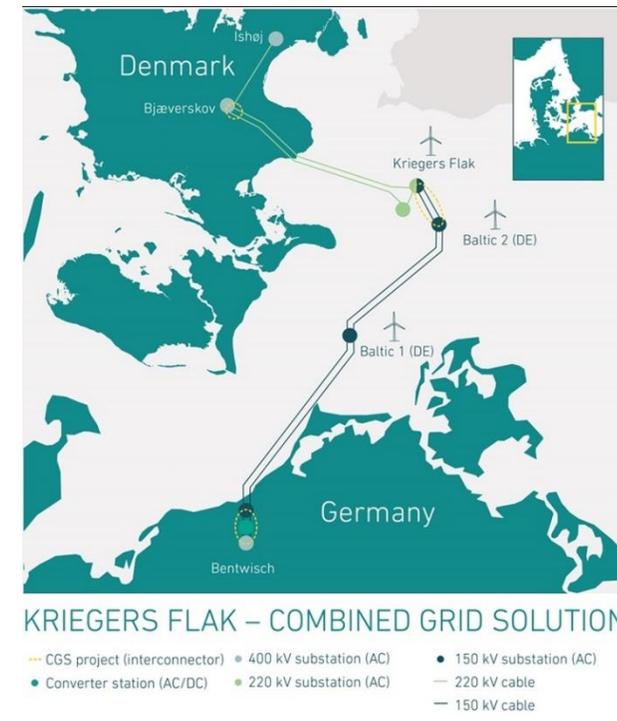
Source: Active Filtering in a Large-Scale STATCOM for the Integration of Offshore Wind Power - Lehmann et al

# Grid connection HVDC

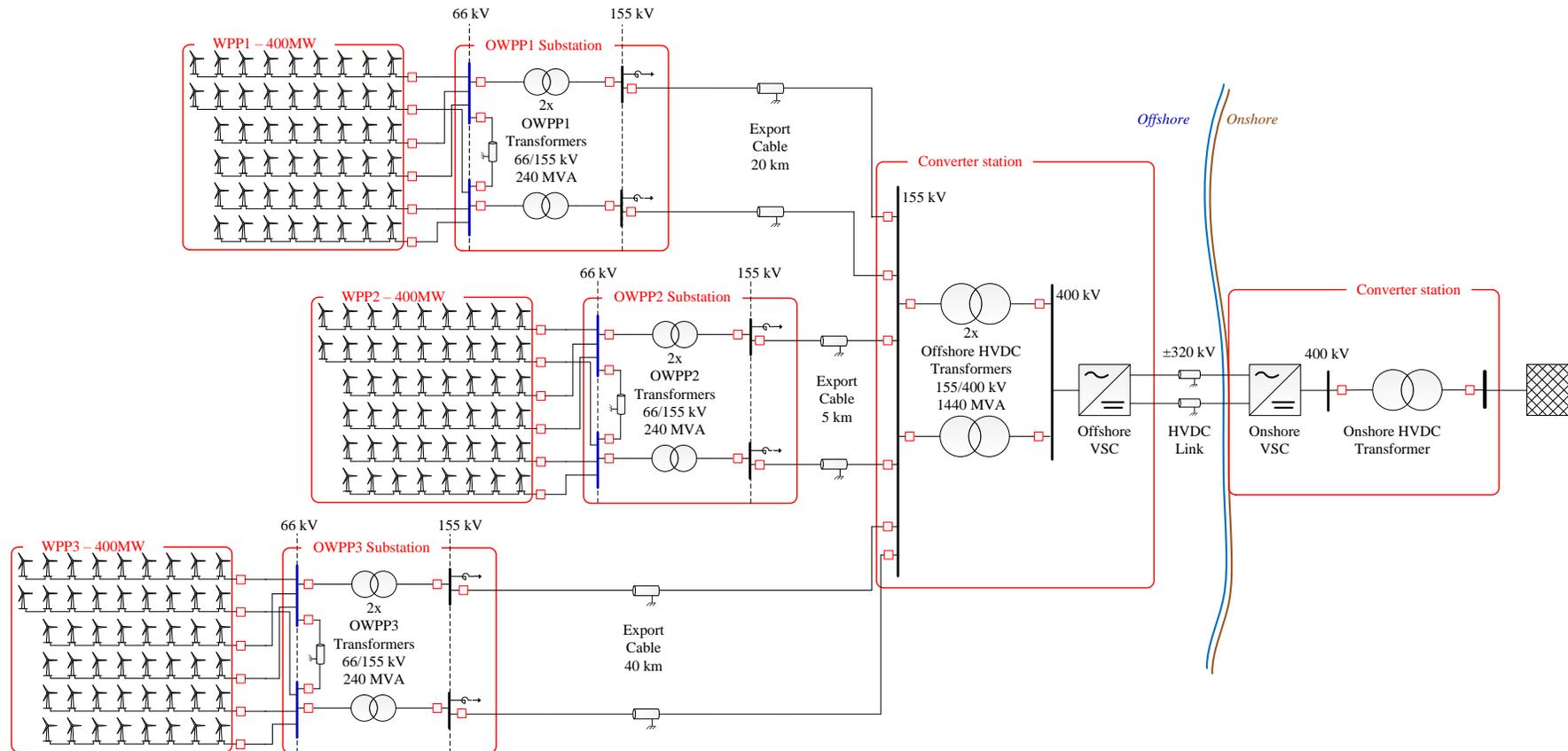
## HVDC



## Hybrid



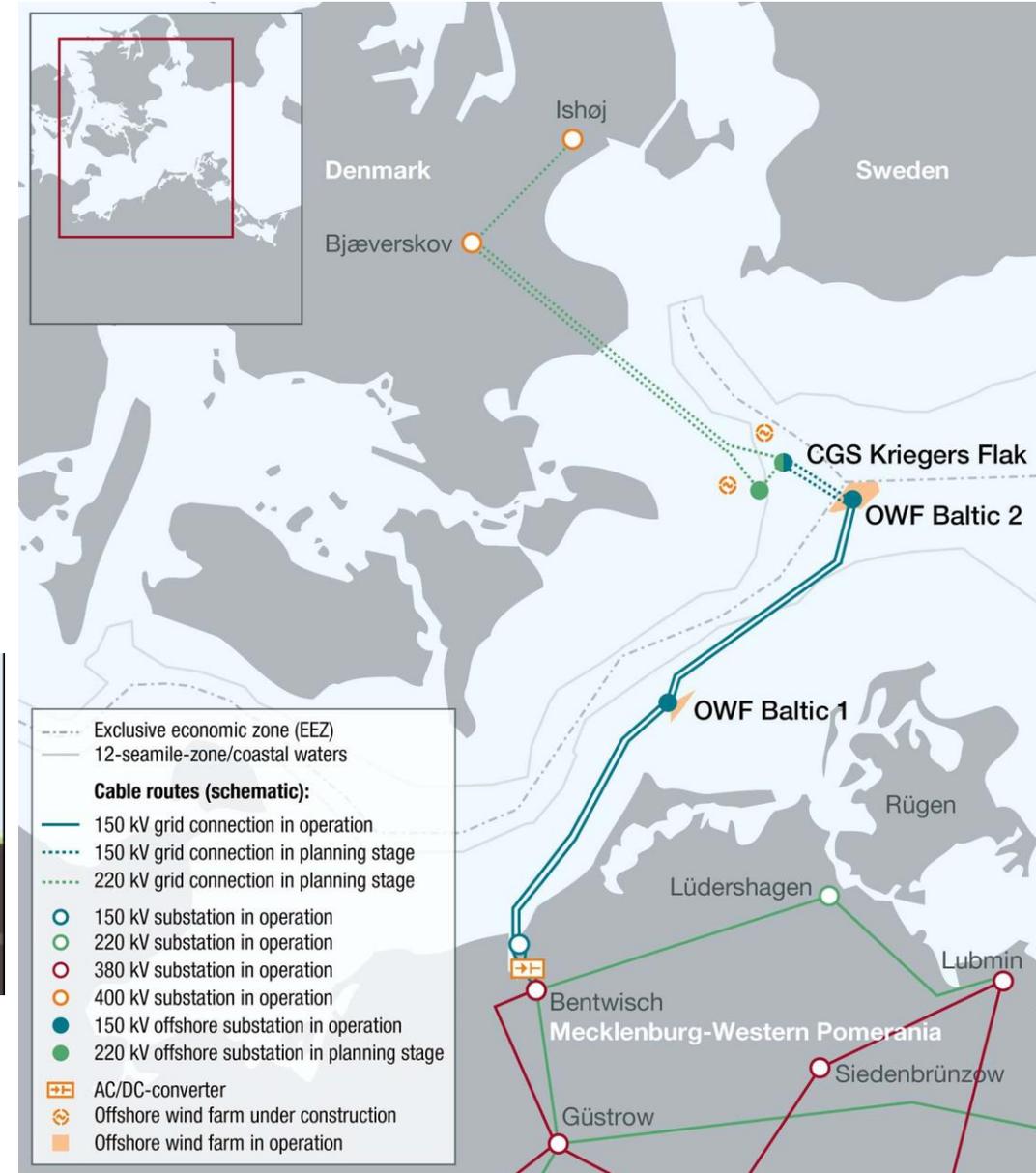
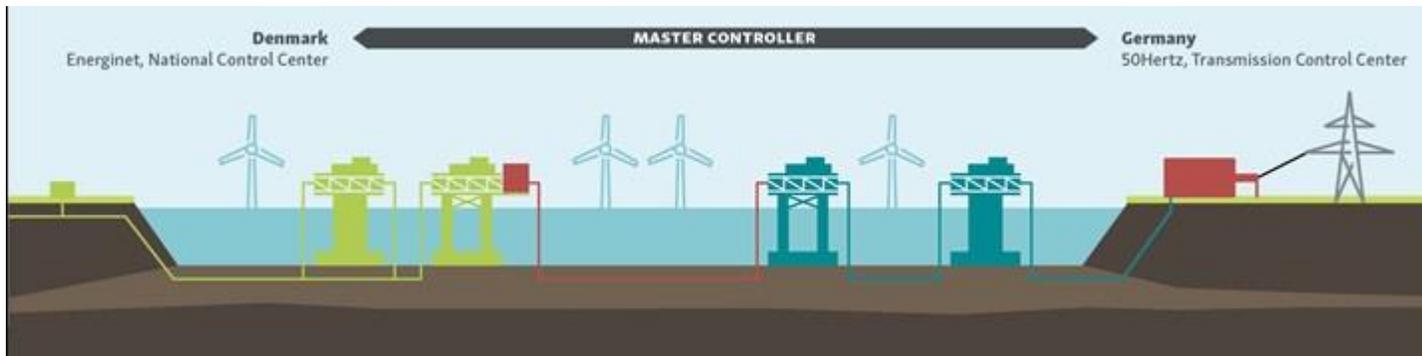
# VSC HVDC transmission



# Grid connection - Hybrid

Kriegers Flak - Combined grid solution:

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



# Offshore grids/islands/hubs

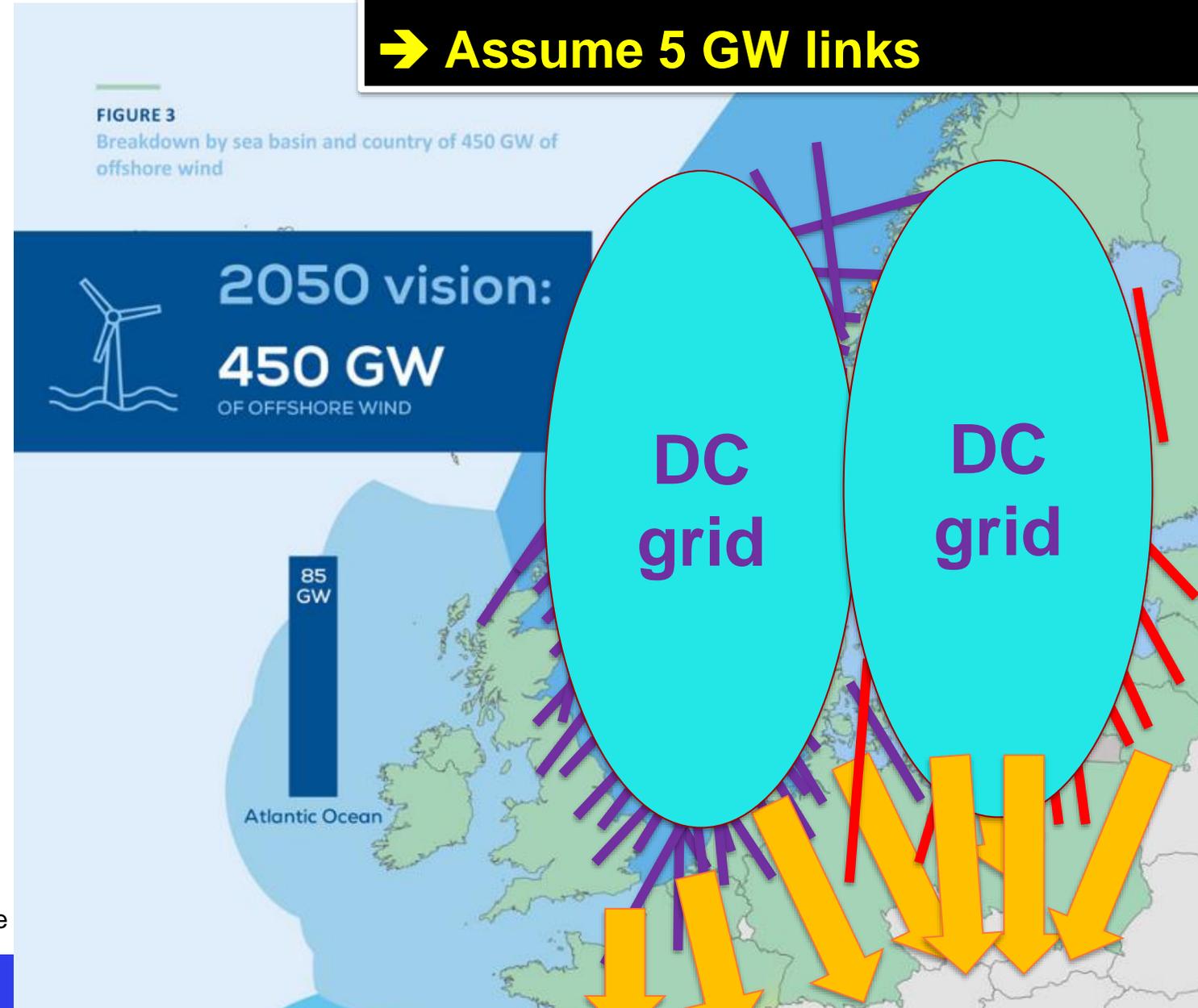
# Where do we need to go?

**We need to connect 200 GW from the north sea**

**→ Assume 5 GW links**

## Ambitious goals

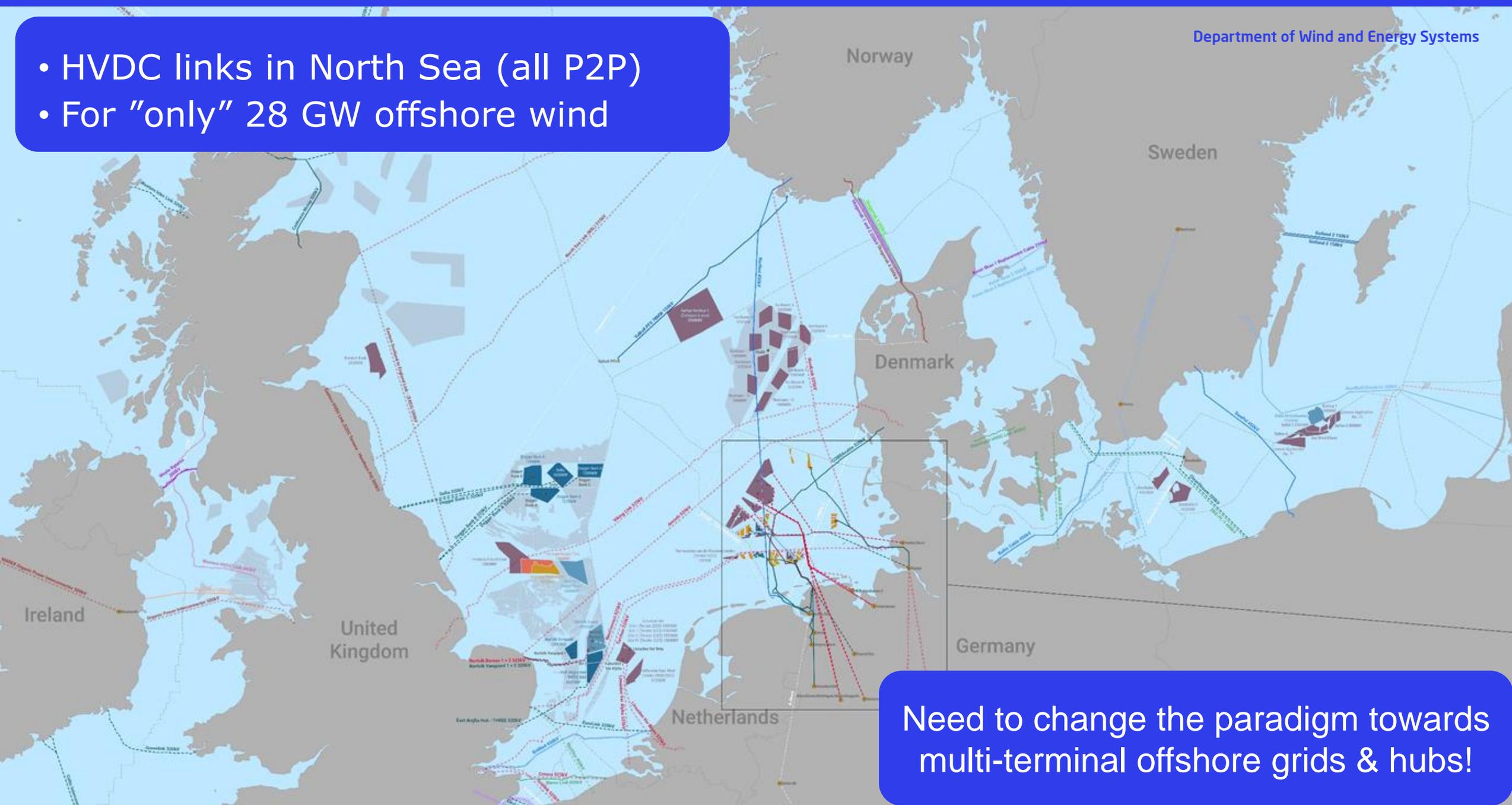
- 300-> 450 GW of offshore wind by 2050
  - +/- 35 GW of wind offshore installed to date (2/3 in Europe)
  - ±100 GW by 2030
  - North Sea: 200 GW by 2050
  - Solar will see similar developments
- Offshore requires massive investments (EC: 2/3<sup>rd</sup> of 800 Billion by 2050)
- Meshed HVDC grids are the only realistic option:
  - Connections are increasingly further from shore
  - Needs to be integrated in the existing system (hybrid AC/DC)
  - Towards new backbone grid



Source: Prof. Van Hertem

Figure: WindEurope

- HVDC links in North Sea (all P2P)
- For "only" 28 GW offshore wind



Need to change the paradigm towards multi-terminal offshore grids & hubs!

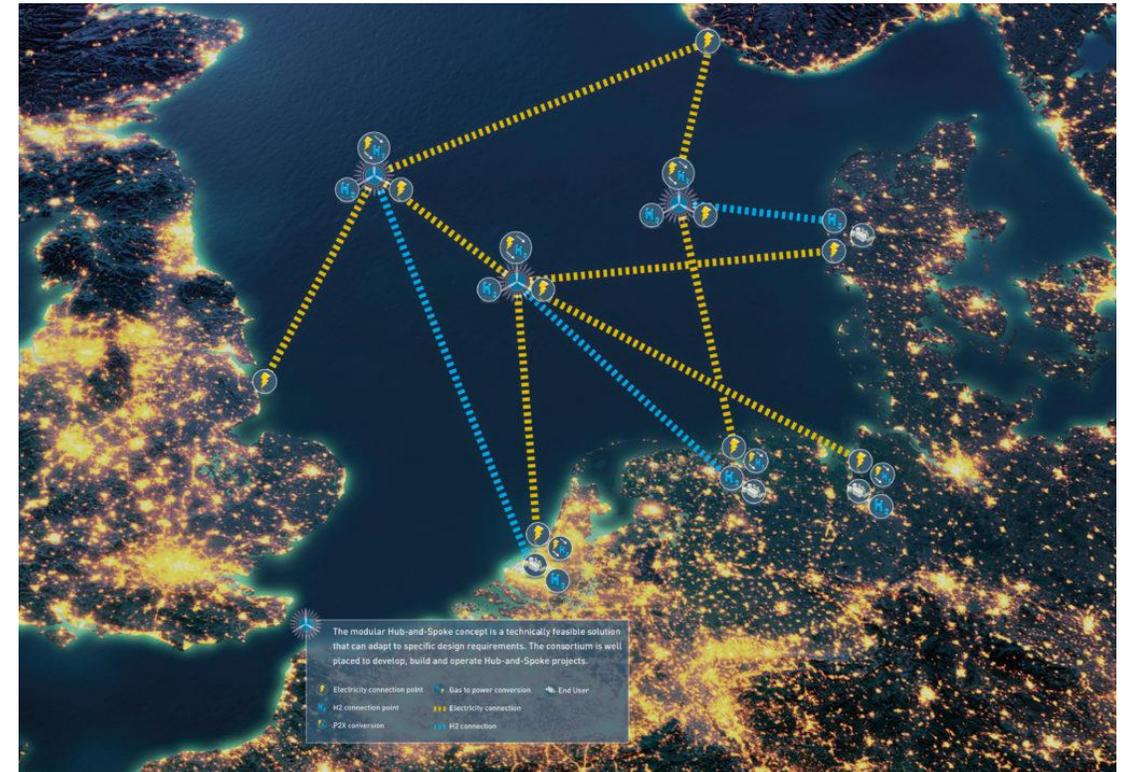
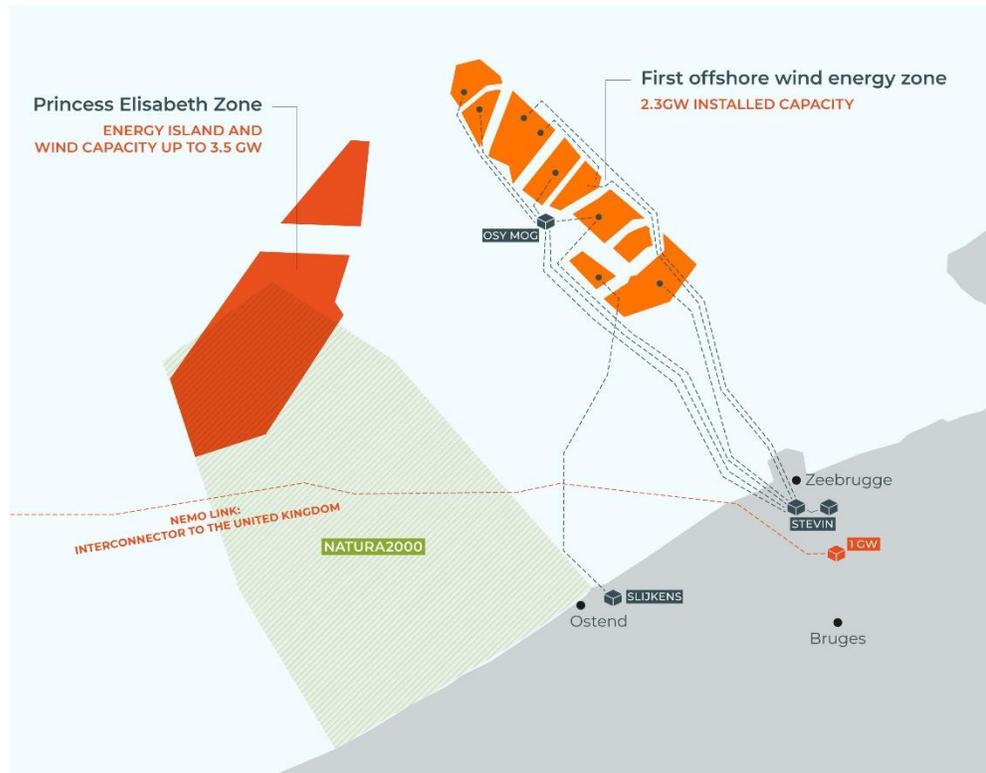
# Wind on energy islands



- **Baltic Sea – on the existing island of Bornholm**
- **North Sea – app. 80 km from the west coast of Denmark**

North Sea Energy Island – 10 GW

# Energy islands



# Optimized wind turbines/plants for energy islands

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- Grid codes for wind parks
  - Requirements imposed by the power system operator that ensure **stable operation of the power system**
    - Based on power system characteristics



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  - Requirements imposed by the power system operator that ensure **stable operation of the power system**
    - Based on power system characteristics
  - Require **additional equipment** and controls
  - Every wind park has to comply
  - Results in higher cost and/or nonoptimal operation



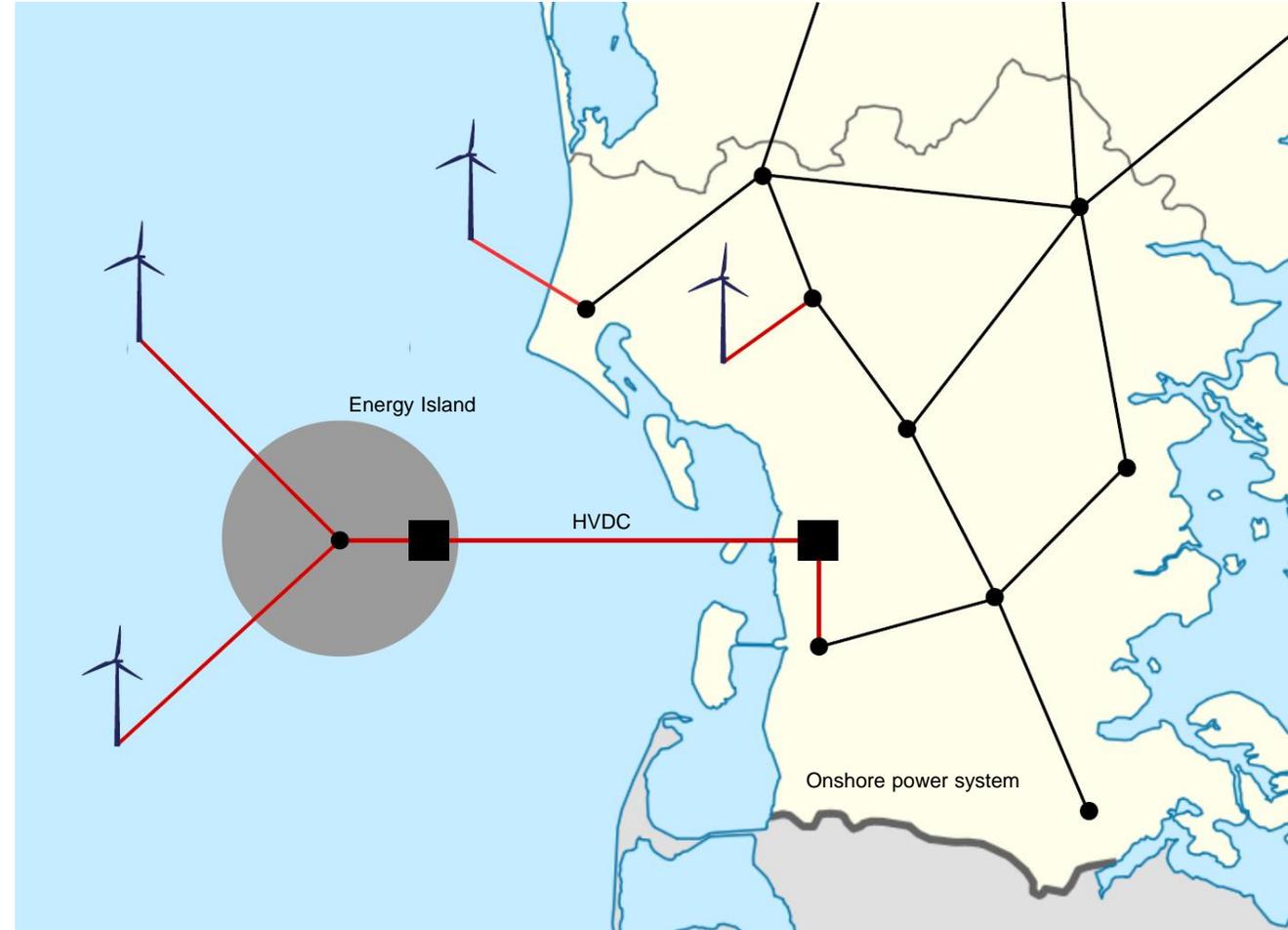
# Optimize wind turbines/plants for energy islands

- Grid codes for wind parks
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  - Require **additional equipment** and controls
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  - Results in higher cost and/or nonoptimal operation
- Currently in DK:
  - **All wind parks, on- and offshore, are directly connected to the onshore power system**



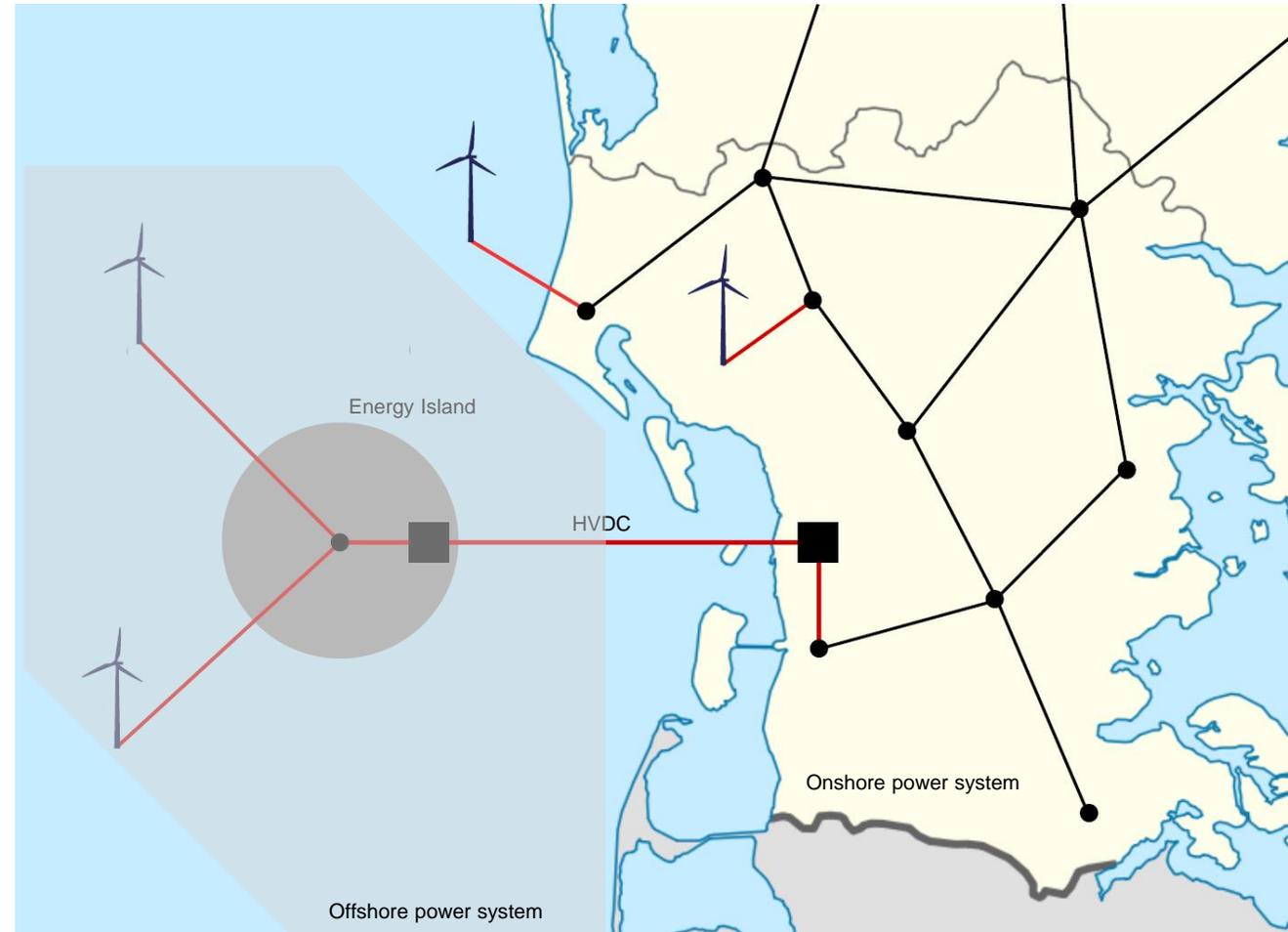
# Optimize wind turbines/plants for energy islands

- Energy Island:



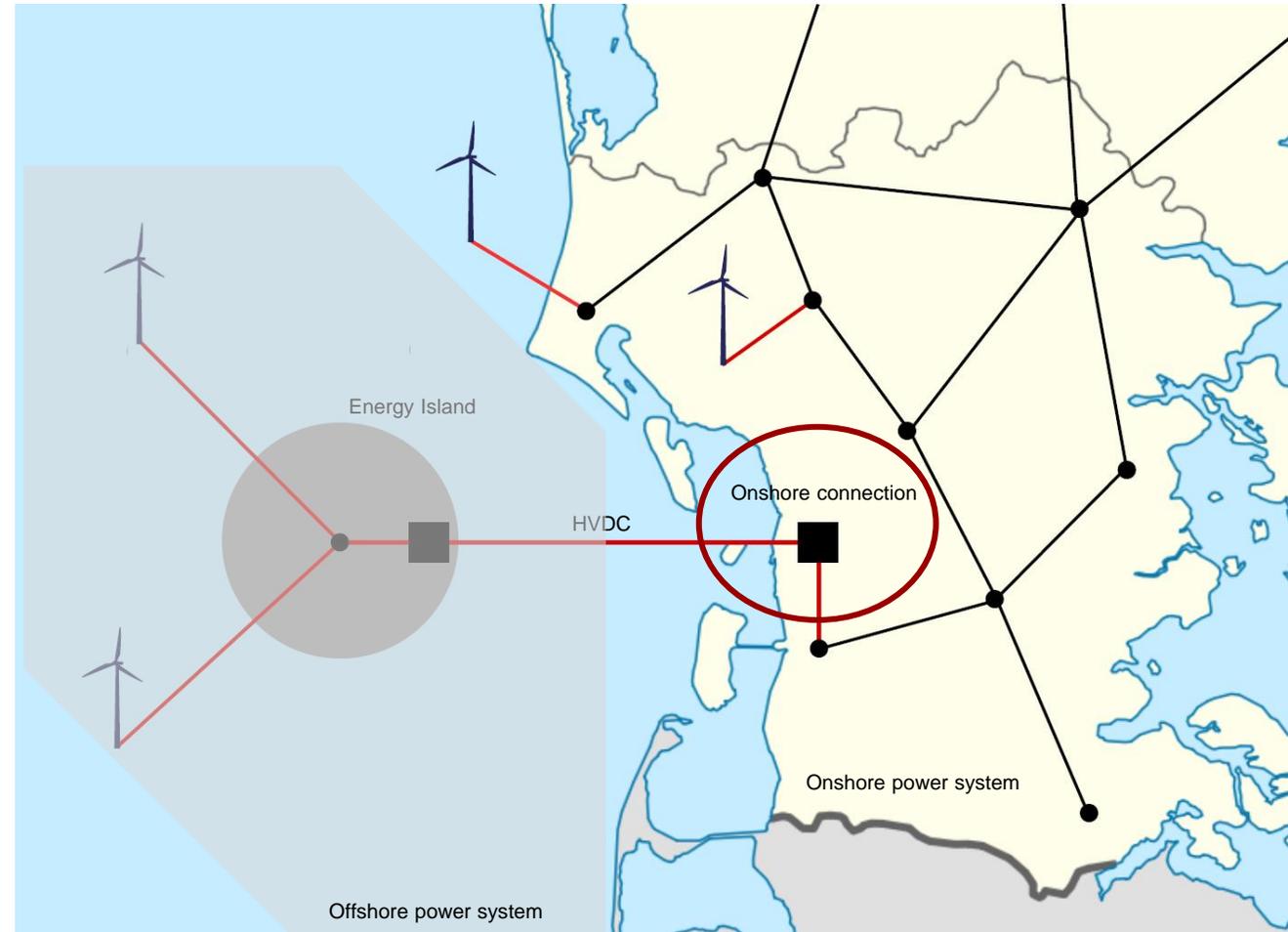
# Optimize wind turbines/plants for energy islands

- Energy Island:
  - HVDC decouples the offshore from the onshore system



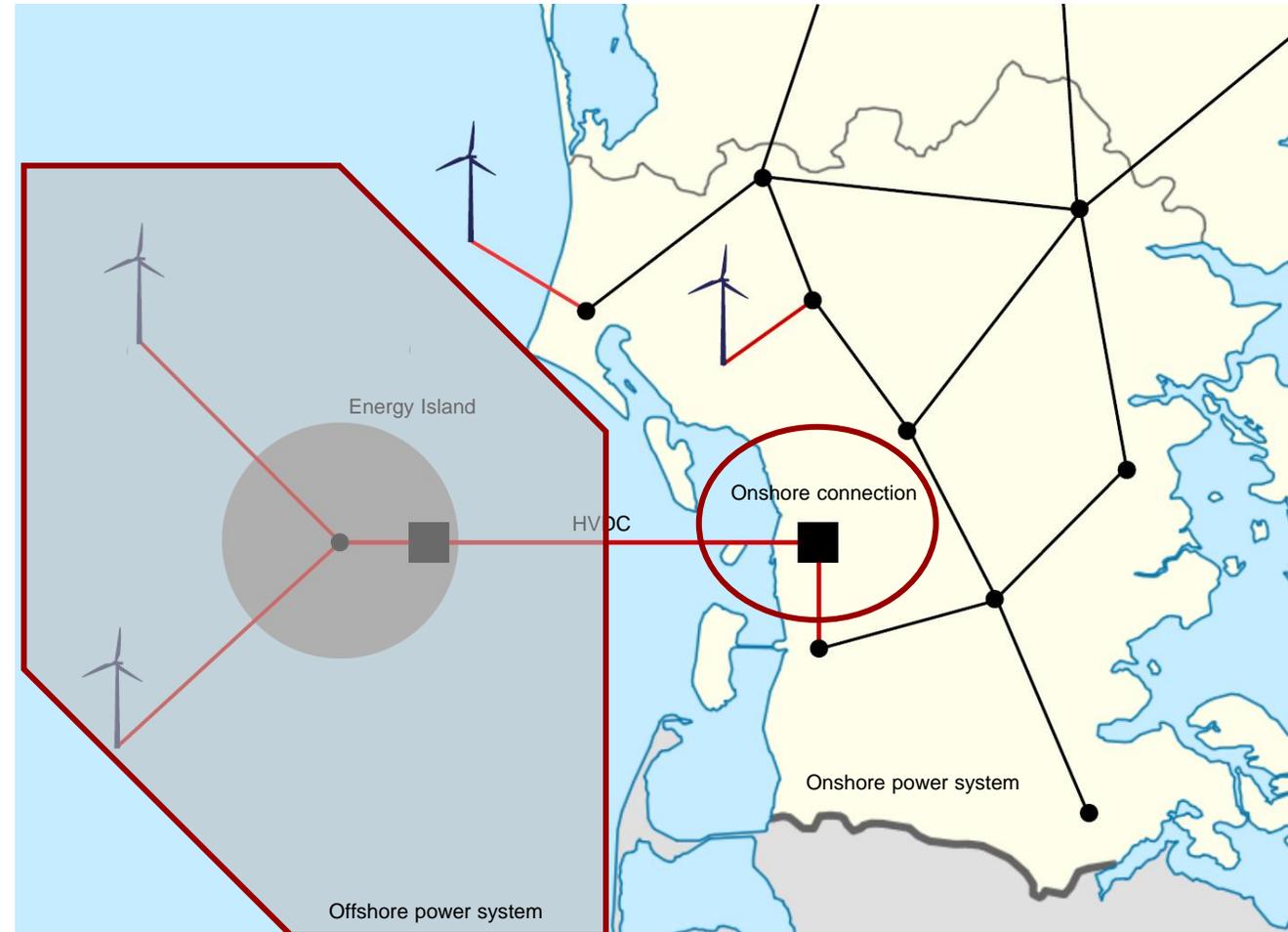
# Optimize wind turbines/plants for energy islands

- Energy Island:
  - HVDC decouples the offshore from the onshore system
  - Onshore HVDC converter establishes the connection to the power system
    - Responsible for grid code compliance



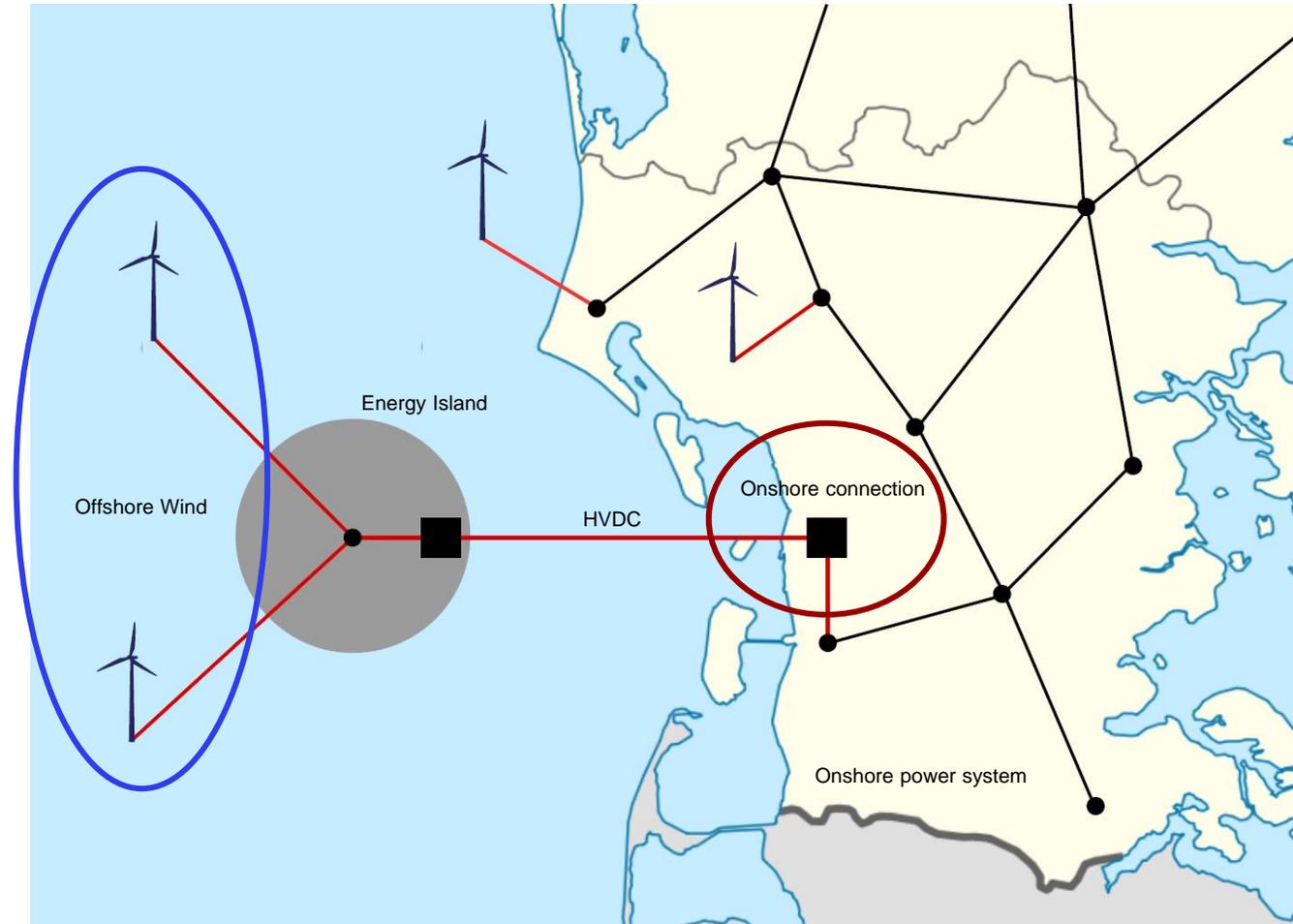
# Optimize wind turbines/plants for energy islands

- Energy Island:
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    - Responsible for grid code compliance
  - Offshore system has different characteristics and different needs



# Optimize wind turbines/plants for energy islands

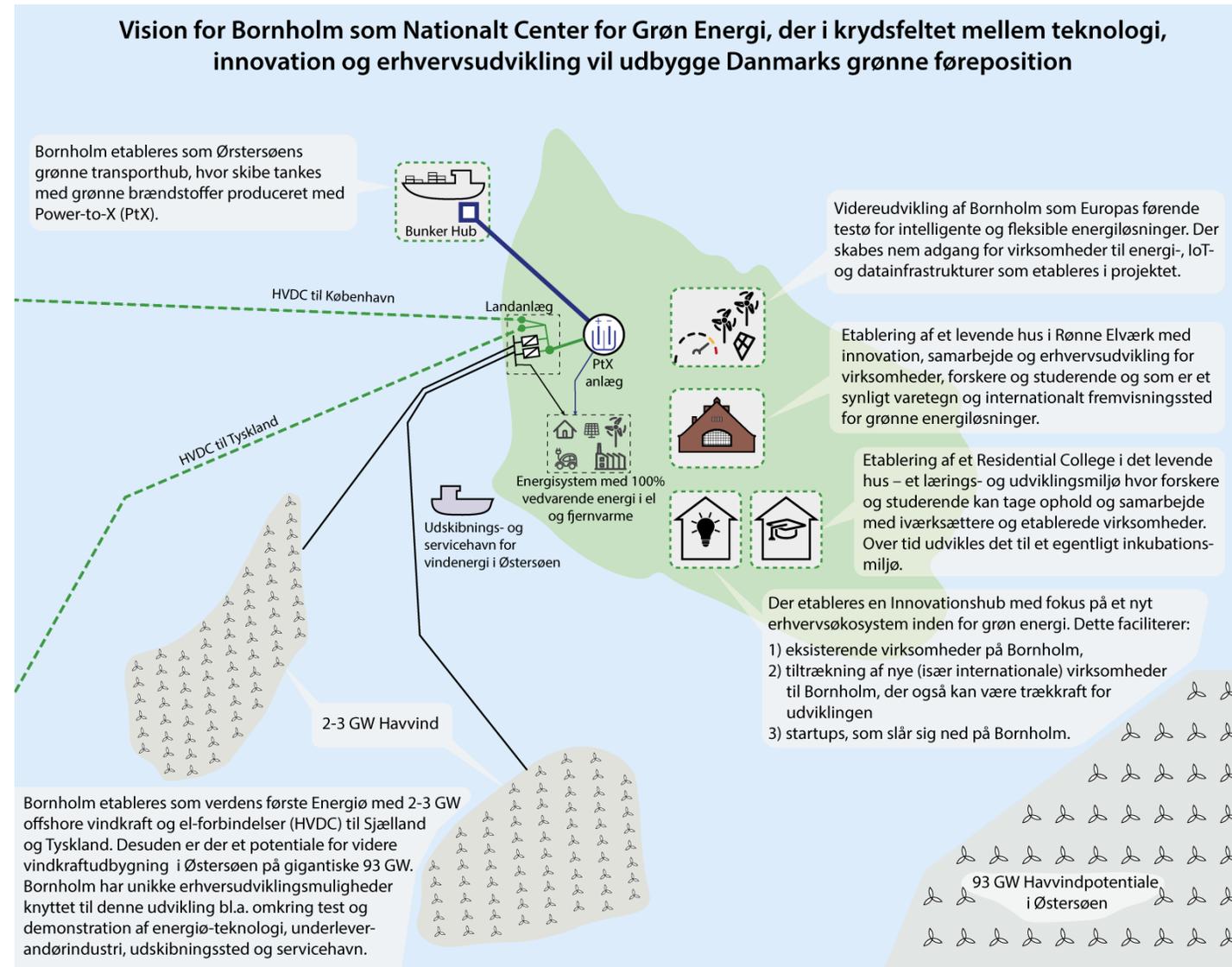
- Energy Island:
  - HVDC decouples the offshore from the onshore system
  - Onshore HVDC converter establishes the connection to the power system
    - Responsible for grid code compliance
  - Offshore system has different characteristics and different needs
  - Task: Define new grid code requirements for wind parks connected to energy islands
  - Potential for **cost savings** due to reduced equipment and optimized operation



# Bornholm as a test centre for energy island technologies

# Bornholm as a test centre for energy island technologies

- Energy Island Bornholm:
  - Bornholm will be the first ever energy island
  - Inhabited island with existing infrastructure
    - Airport, ferry, port, etc.
  - Accessibility derisks testing of new solutions
  - Local power system part of the energy island



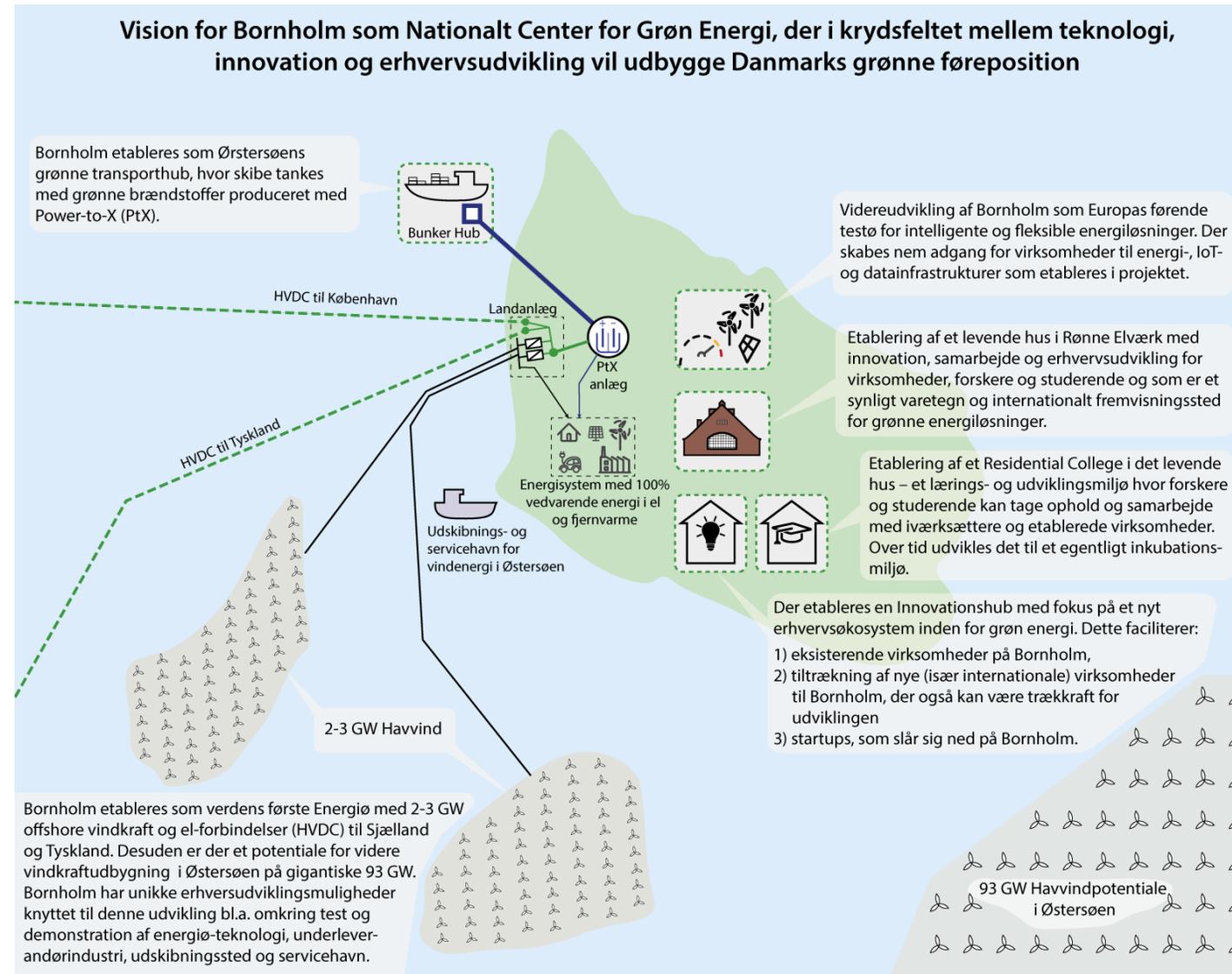
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## Bornholm as a test centre:

1. Technologies can and will be tested due to Bornholm being the first of its kind
2. Development of a dedicated test centre



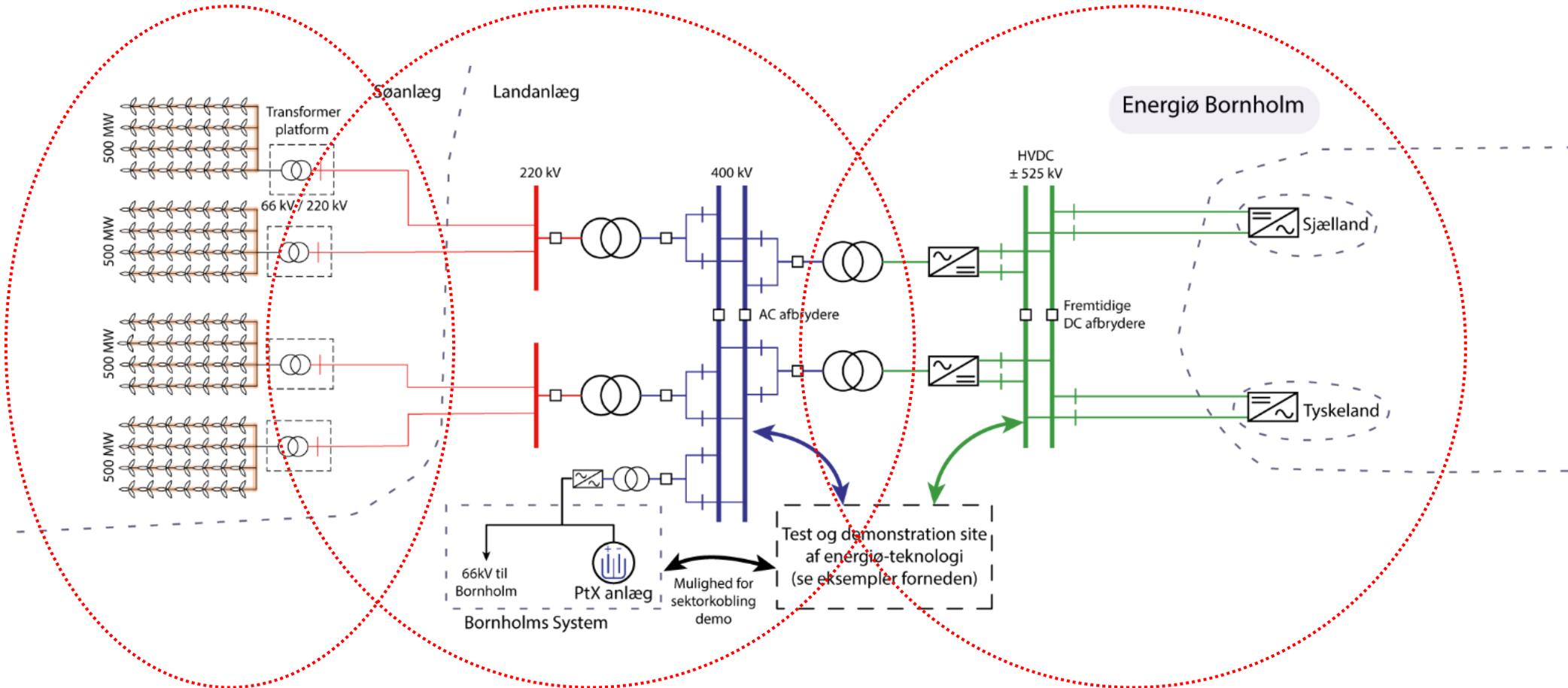
Slide: Daniel Müller, DTU embedded in the energy island infrastructure

# Electrical infrastructure of the energy island Bornholm

Offshore Wind

Offshore &amp; Island AC system

HVDC connections to shore

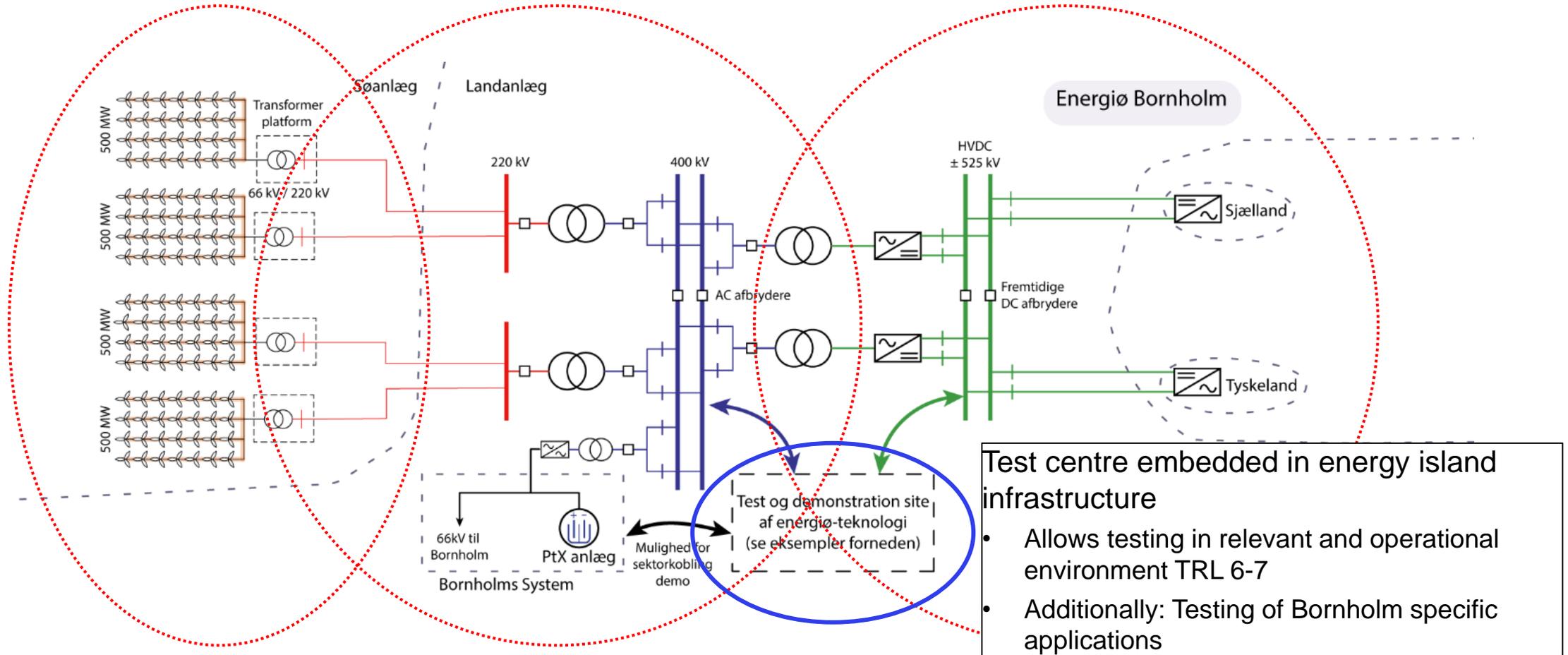


# Test centre embedded in energy island

Offshore Wind

Offshore &amp; Island AC system

HVDC connections to shore



# Main takeaways

- Offshore wind ambitions in Europe are very high & moving towards very large projects
- HVDC technology is quickly ramping up and is very closely related to offshore wind (for now)
- “Old” paradigms of P2P connections not good anymore, need to move to more centralized infrastructure like energy islands and multi-terminal HVDC offshore grids
- Opportunities for “energy island” wind turbines/plants & test centers

DTU

