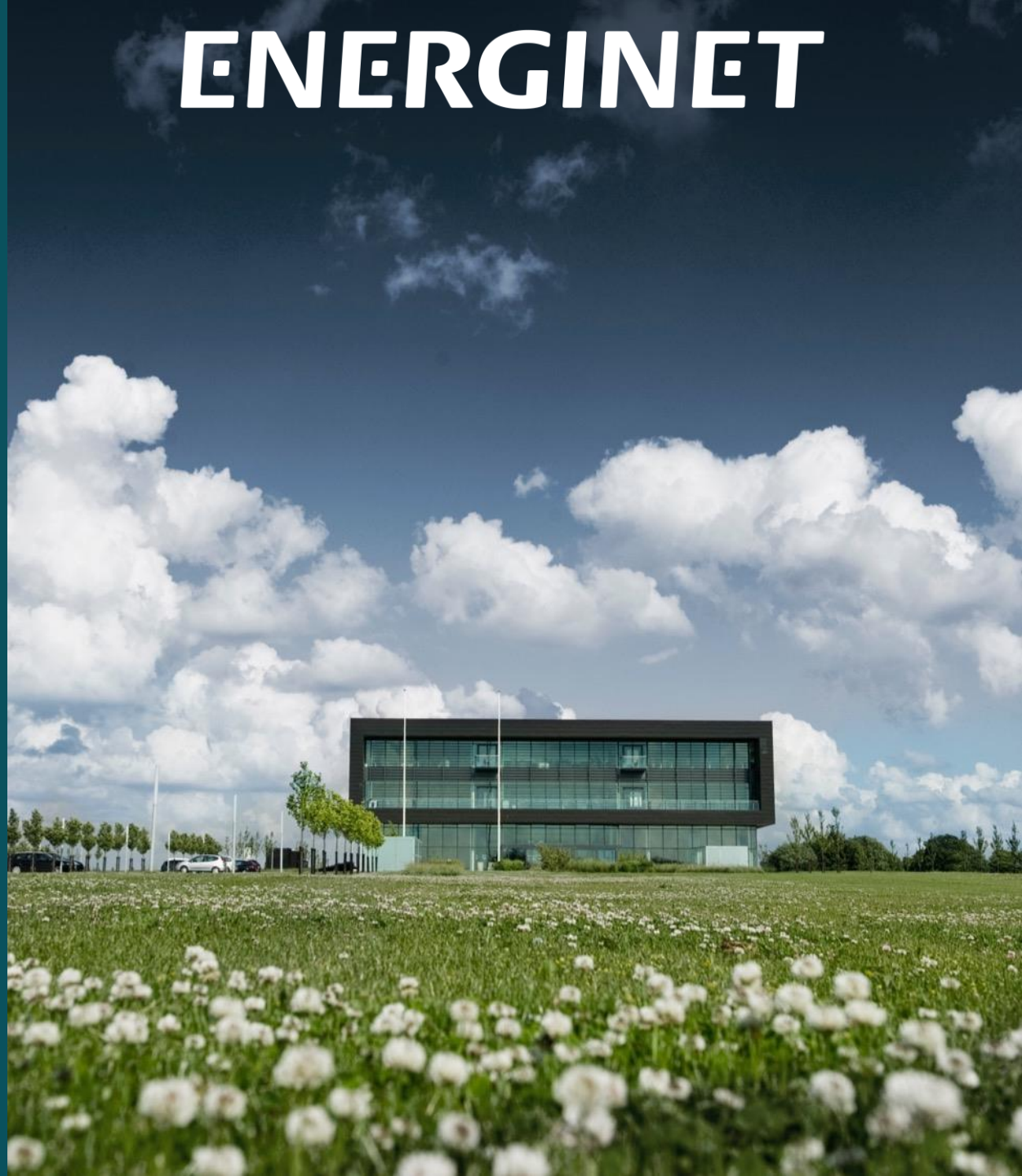
OFFSHORE WIND GRID CONNECTION – THE DANISH EXPERIENCE

June 2023

Peter Markussen, Senior Director, International Relations, Energinet

GLOBAL PST CONSORTIUM
Founding TSO



ENERGINET

THE ENERGY BACKBONE

We operate and develop the transmission grids and gas pipelines in Denmark.

ENSURE BALANCE

We have the day-to-day and long-term responsibility for the overall electricity and gas system in Denmark.

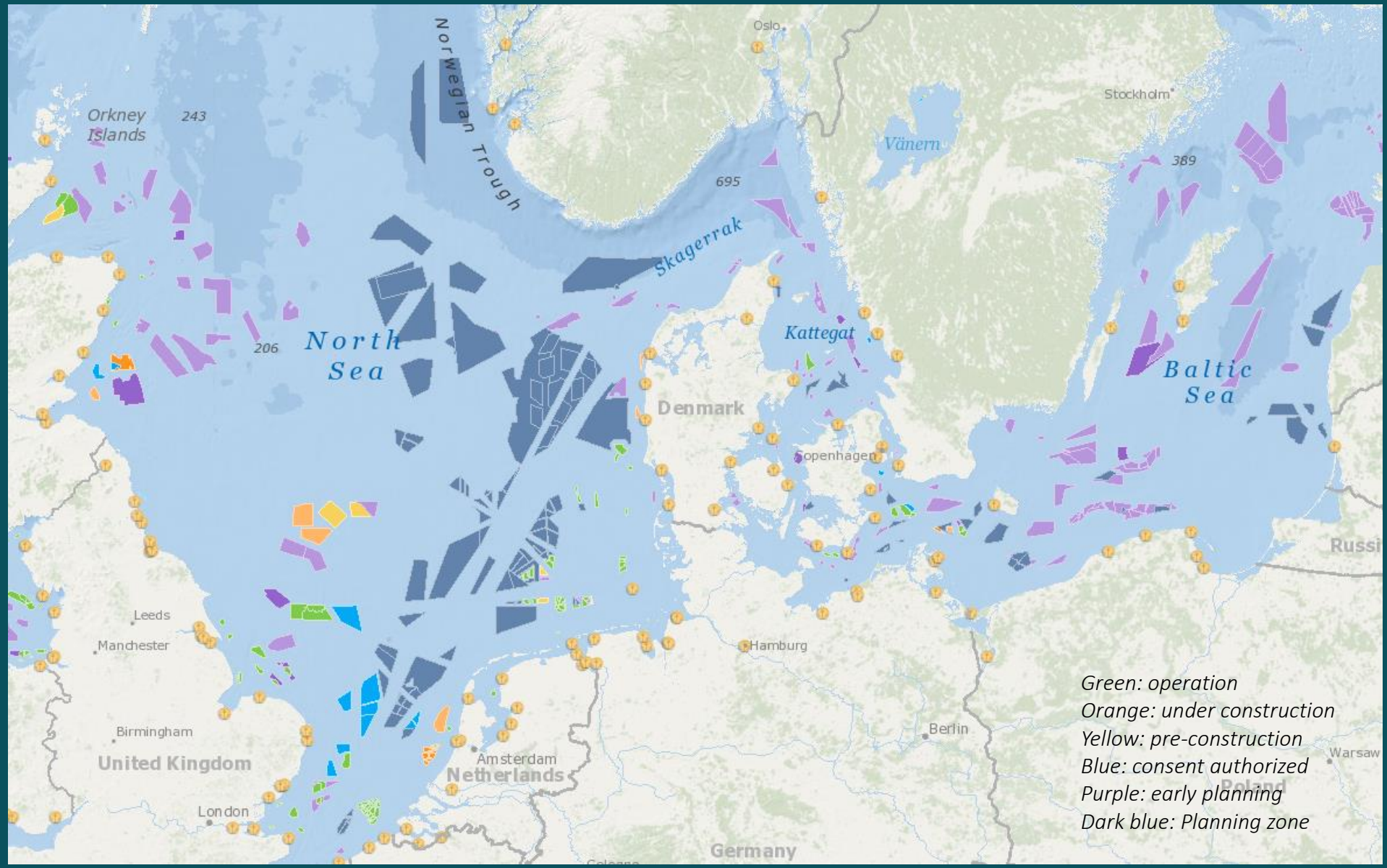
WORKING FOR THE SOCIETY

Owned by the Danish Ministry of Climate, Energy and Utilities we safeguard society's interests as we move to a 100% green energy system.

Appr. 1800 Employees

Energy island location, OSW and connections only illustrative

LARGE OFFSHORE WIND POTENTIAL IN NORTH SEA AND BALTIC SEA



Global Offshore Renewable Map | 4C Offshore

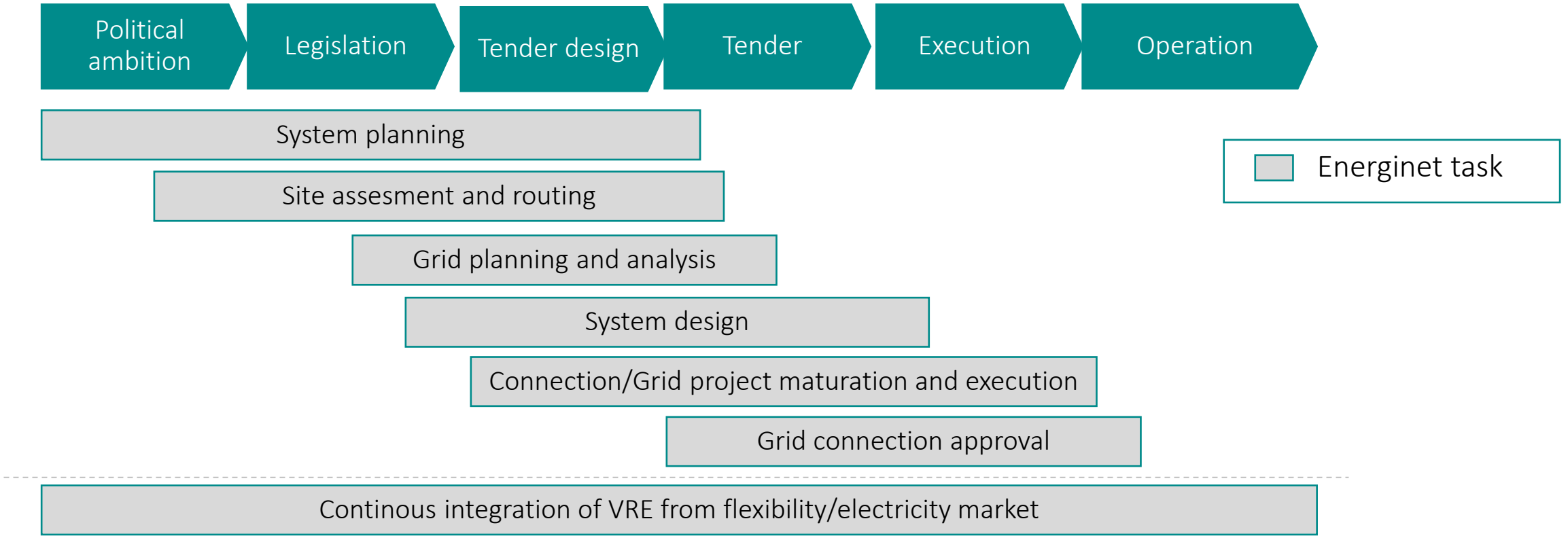
BUILD-OUT OF DANISH OFFSHORE WIND
– FROM PILOT TO LARGE SCALE

ENERGINET

ENERGINET IMPORTANT ROLE IN REDUCING RISKS AND COSTS FOR OSW

Energinet is part of OSW development from political agreement to operation.

6-8 years from political agreement to operation (tender model)



THE IMPORTANT ISSUES FOR THE SYSTEM OPERATOR

Recommendations for timing and important issues (not exhaustive)

PLANNING	**Ambition** Integrate OSW target in long term grid planning	**Location** Identification of location and cable routing	**Connection point** On shore or offshore connection point	**Requirements** Connection requirements and dialogue on fulfillment	**Commissioning** Assesment and test of requirements for connection	**Curtailment** Rules for curtailment and flexibility
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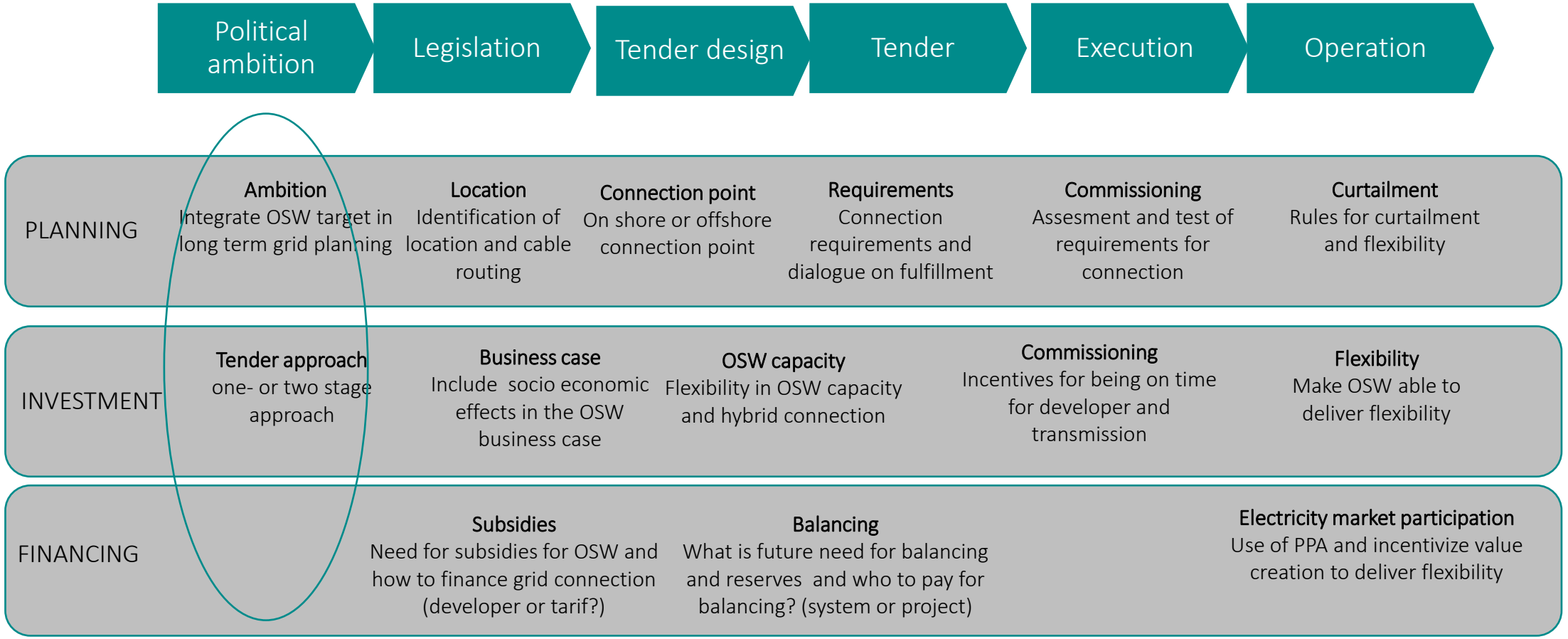
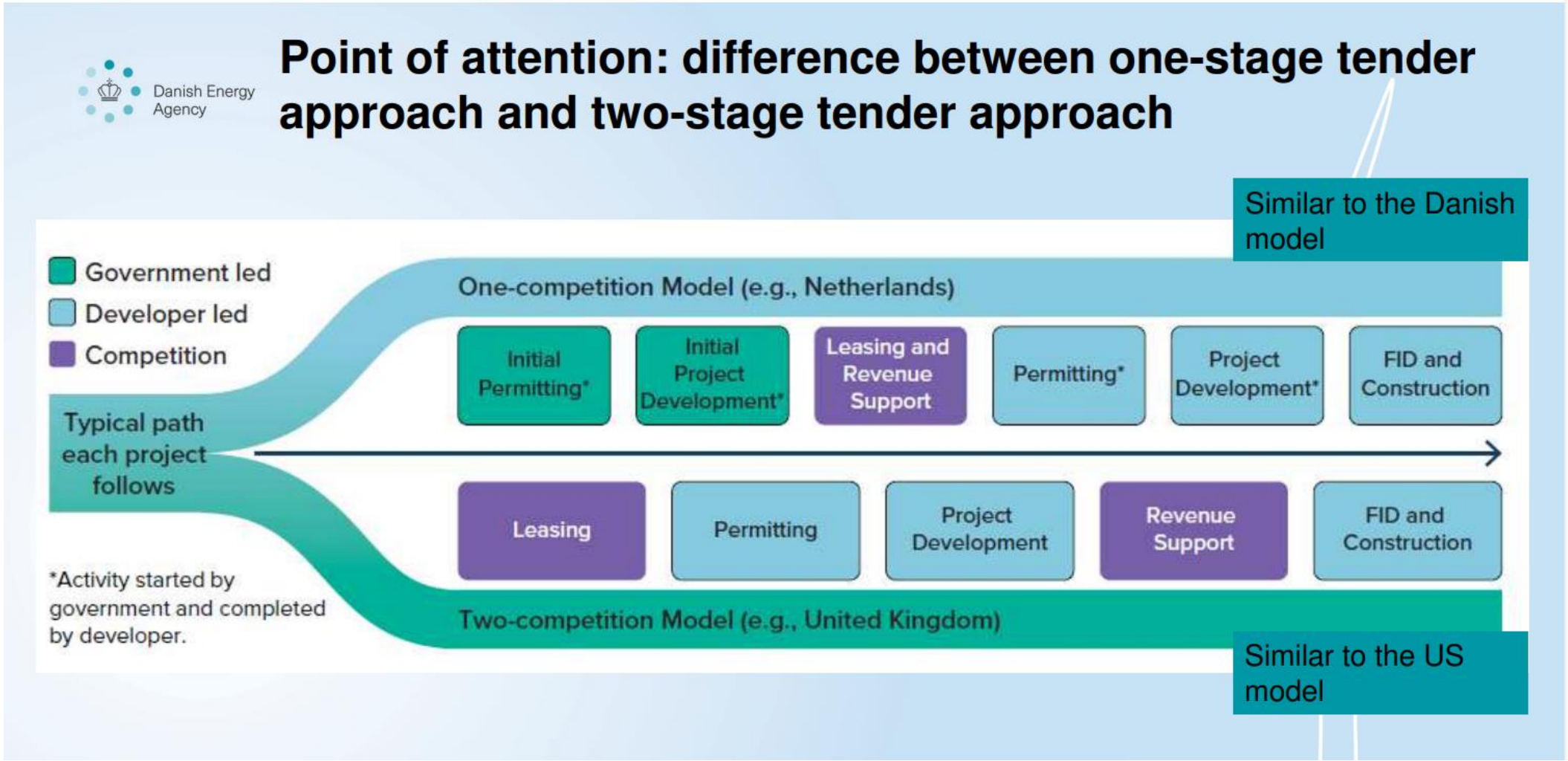
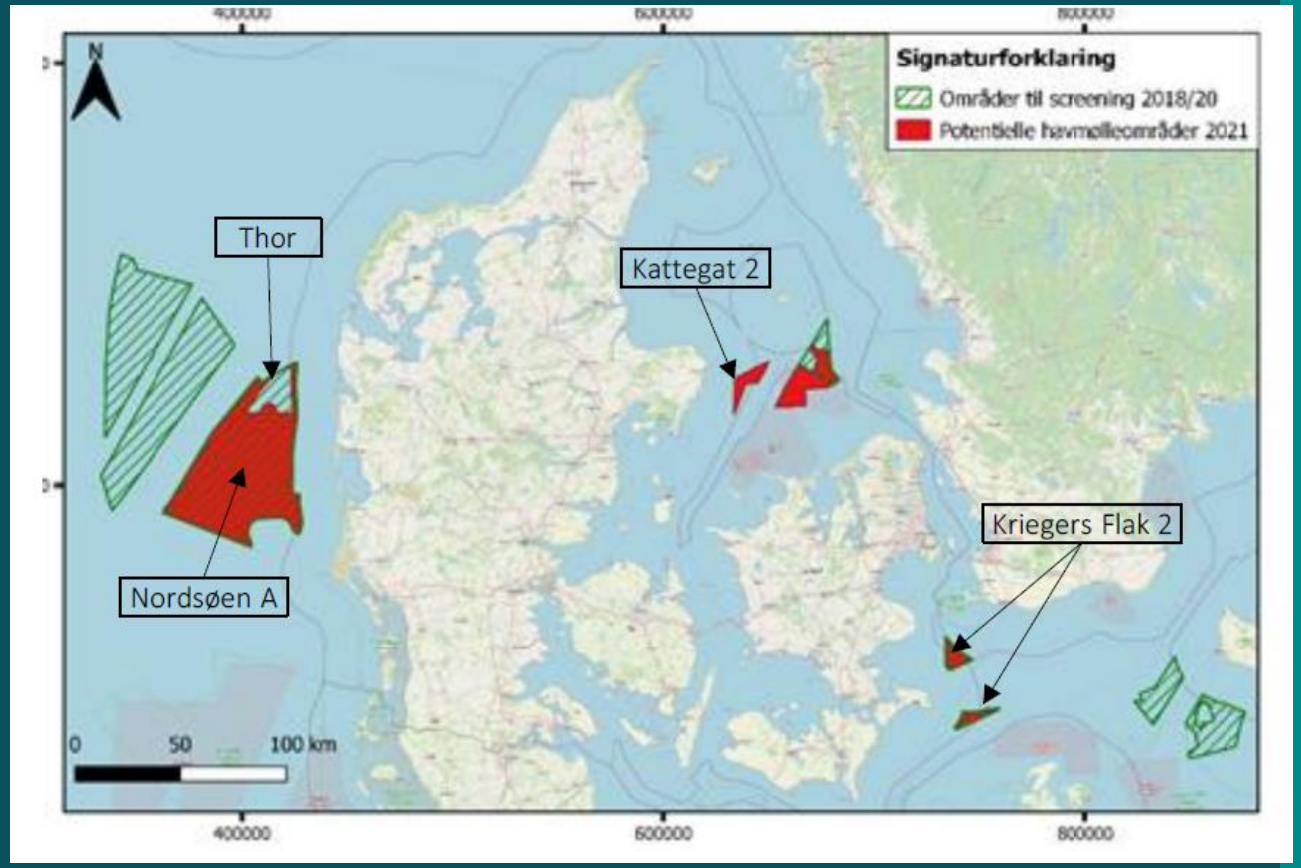


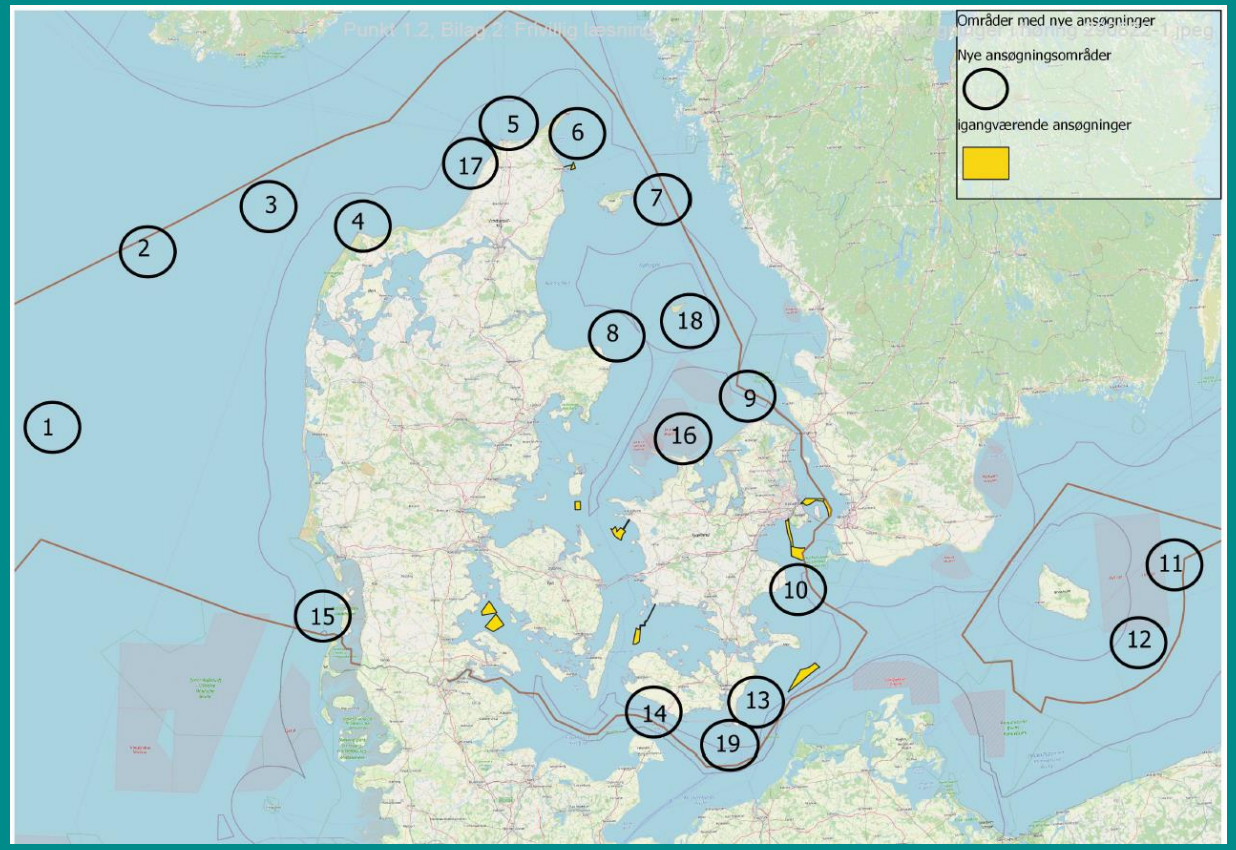
DIFFERENT TENDER SETUP INFLUENCE OSW CAPACITY AND AND GRID PLANNING



ONE-STAGE TENDER
– DEVELOPER CERTAINTY ON CONNECTION COSTS AND CONNECTION DATE



TWO STAGE OPEN DOOR
- DEVELOPER CERTAINTY ON SITE



INTEGRATION OF OSW PLANS IN GRID PLANNING

The map is result of bi-annual grid planning by Energinet.

The map shows the volume of energy that must be relieved on a connection if no other measures are taken.

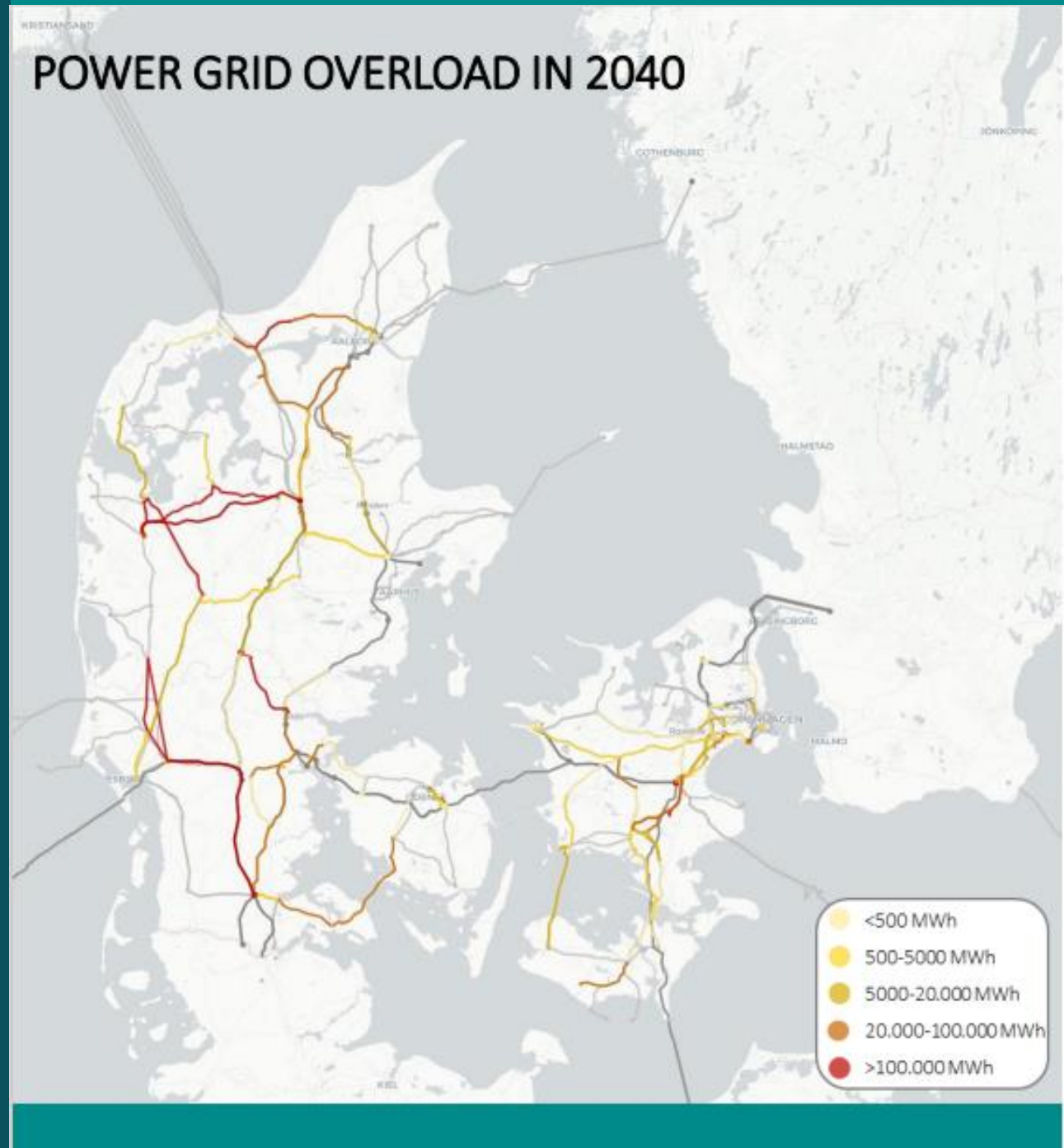
The needs will be solved with mix of:

- Grid investments
- Operational solutions
- Market solutions
- Stakeholder dialogue (location)

Uncertainty on expected OSW build out on long term (after 2035) and manage with sensitivities and anticipatory investments

Long-term development plan for the power grid 2022 (energinet.dk)

Energinet_tariff_reform



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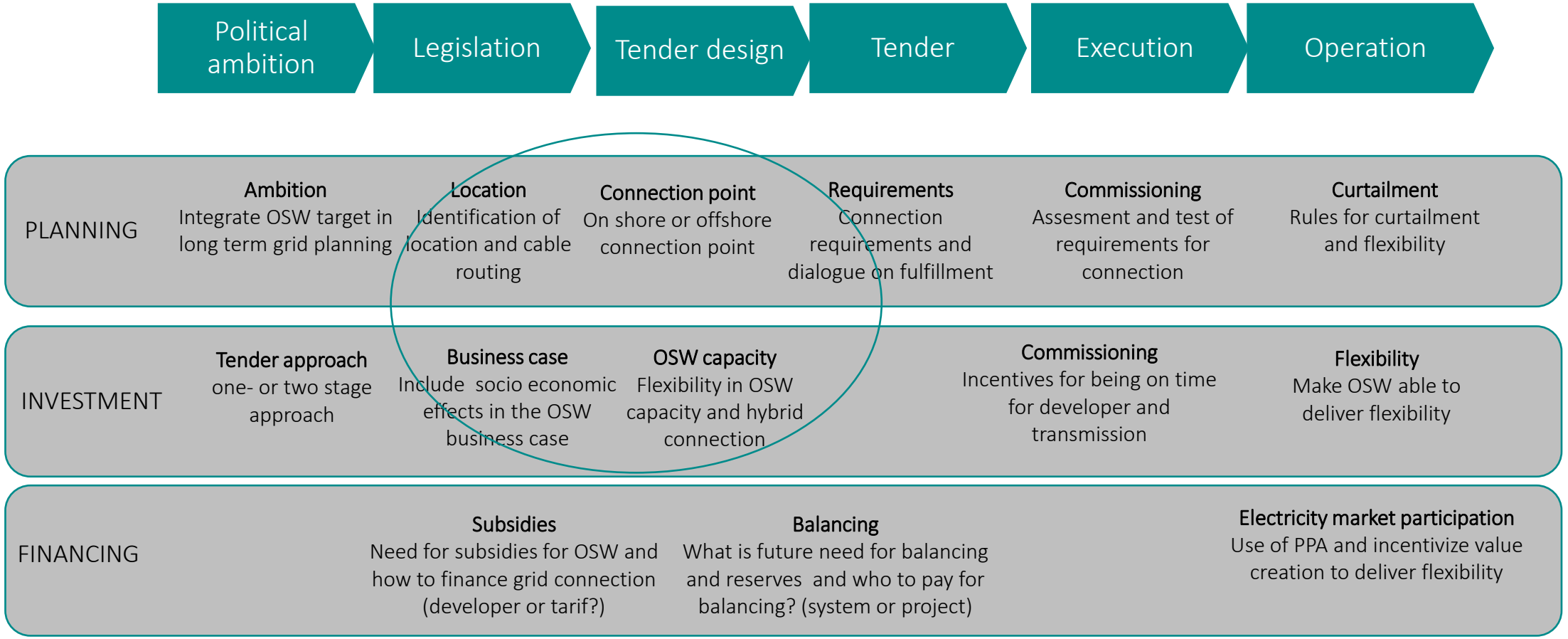


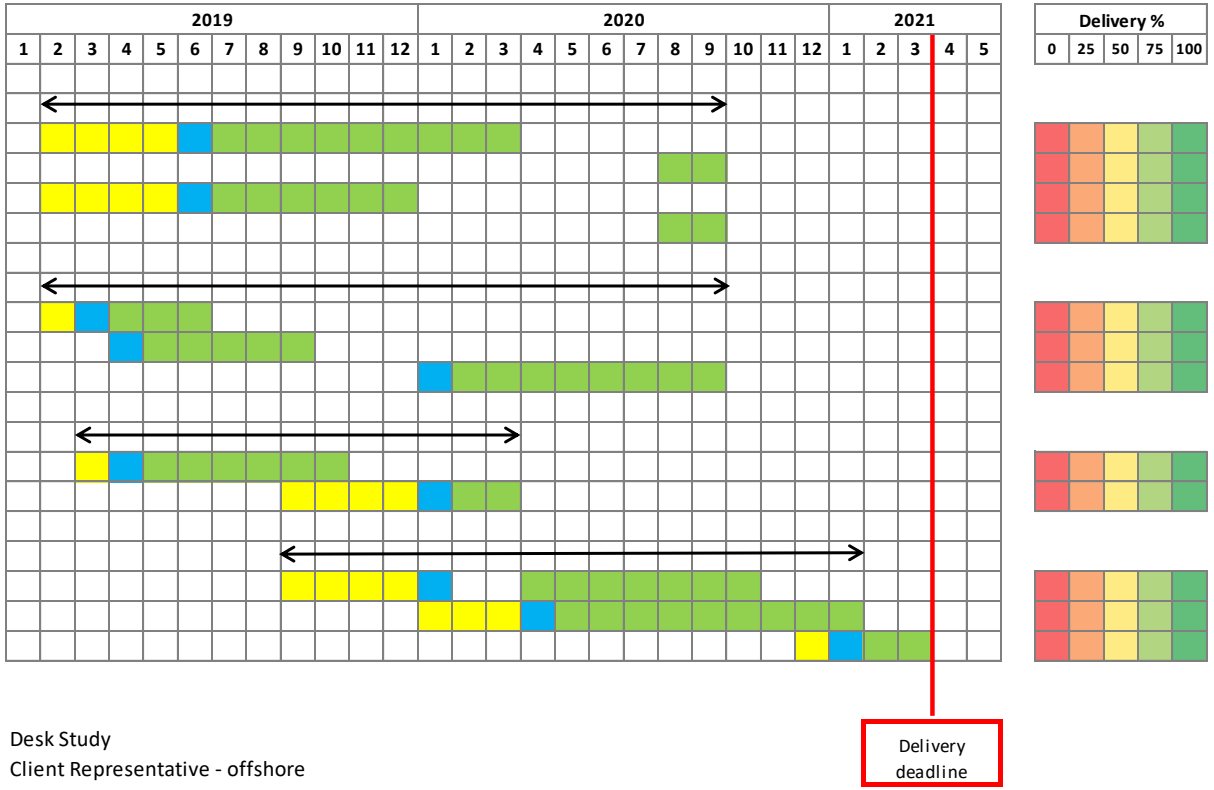
ENVIRONMENTAL ASSESMENT TAKES TIME AND IS COSTLY!

Thor offshore wind farm

Activity overview: Seabed site investigations 2019 - 2021

2021-04-15

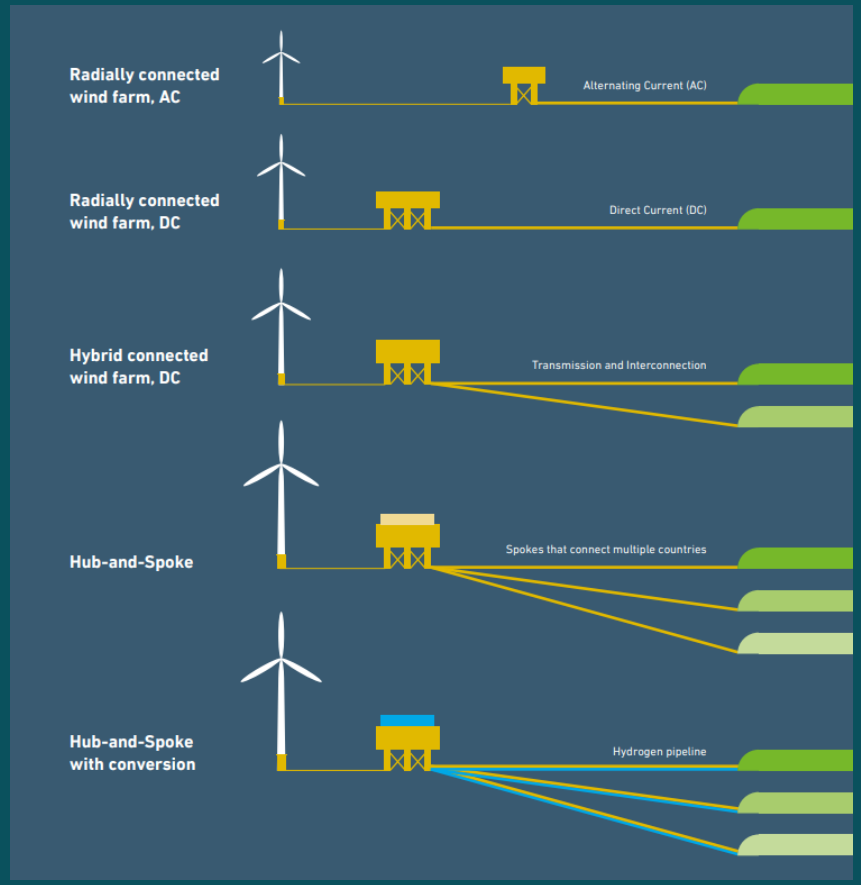
Line	Main activity	DS	CR
10	**Geophysical survey**		
11	Offshore wind farm site		X
12	Offshore wind farm site - 2nd bathy survey		
13	Cable routes		X
14	Cable routes - 2nd bathy survey		
20	**Marine archaeology**		
21	#1 Geology and sea level	X	
22	#2 Pre-survey site assessment	X	
23	#3 Post-survey site assessment	X	
30	**UXO activities**		
21	#1 Threat and risk assessment	X	
33	#2 UXO survey for prelim. geotechn. inv.		X
40	**Geotechnical investigations**		
41	Preliminary investigations, boreholes and CPTs		X
42	3D geological model	X	
43	Landfall investigations		



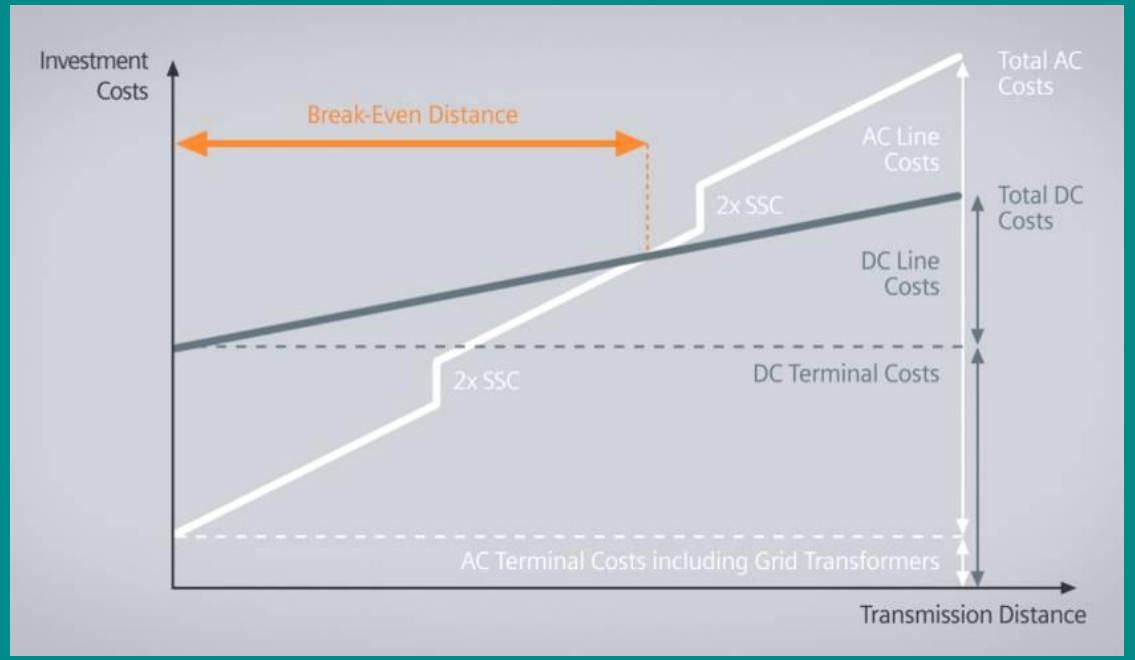
Procurement
Contract
Delivery

DS Desk Study
CR Client Representative - offshore

DIFFERENT CONNECTION CONCEPTS



SITE CONDITIONS AND CONCEPT MUST BE OPTIMIZED



Microsoft Word - 18-04246-24 Technical issues related to new transmission lines in Denmark 5454267_3468242_0.DOCX (energinet.dk)

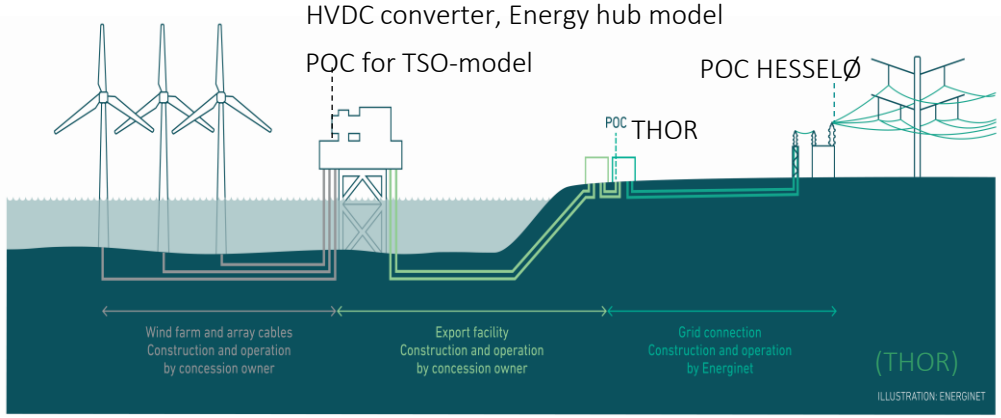
hvdc_for_pdp8_support_eng0107.pdf (ens.dk)

POINT OF CONNECTION: ONSHORE VS. OFFSHORE

Historically POC has been offshore to reduce risk and increase competition between developers to reduce costs for OSW.

Advan-tages	Onshore POC (large scale radial)	Offshore POC (small scale radial)	Energy hub POC (HVDC)
Value chain	Competition for larger share of OSW project	Reduce complexity for OSW developer	Connect more large OSW parks to more countries
Invest-ment	Coordination turbine and offshore connection	Optimized grid and offshore connection, especially if weak grid	Part of regional grid planning and system cooperation
Planning	Optimize location of turbines and onshore facility	Coordinated EIA and land acquisation	Agreements between national TSO's
Operation	Developer clear responsibility if outage and for onshore connection requirements	TSO responsibility for connection code requirements onshore	Operation of HVDC critical for stability and SoS
Finance	Larger part financed by developer	Offshore connection financed by tariff	Congestion rents

HVDC converter, Energy hub model



No third party developer or owner of offshore transmission cable allowed in Denmark

ECONOMICS – FIVE EXAMPLES

Budget for offshore and onshore connection very dependent on specific site and need for internal transmission grid upgrades

	Anholt, 2013	Horns Rev 3, 2019	Kriegers Flak (2021)	Thor (2024)	Bornholm Energy hub	North sea energy hub
Capacity	400 MW	407 MW	605 MW	1000 MW	2 GW	3-10 GW
Point of connection	Offshore	Offshore	Offshore	Onshore	Onshore Hub	Offshore Hub
Budget for connection*	170 mio. Euro	230 mio. Euro	386 mio. Euro** (interconnector)	92 mio. Euro***	2.4 bill Euro****	3.8-14.0 bill. Euro****
Planning time from approval (political agreement)	2010-2013 (2008)	2013-2016 (2012)	2014-2020/2021 (2012)	2018-2023 (2018)	2022-2030 (2021)	2022-2035 (2021)
Off/onshore cable Offshore Transformer Onshore cable station Extension onshore Extension internal grid	30/56 km Yes Yes Yes (220 kv) No	35/58 km Yes Yes Yes (220 kv/400 kv) Yes (29 km 400 kv)	85/105 km Yes Yes Yes (220/400kv) Yes (400 kv+ btb HVDC)	- - Yes Yes Yes	Ca. 1000 km yes Yes Yes Yes (HVDC)	Ca. 1700 – 7200 km yes Yes Yes Yes (HVDC)

*public available budgets from Energinet application for project

**Energinet part of investment and incl. 150 mio. Euro EU subsidy

*** only budget for onshore connection. Offshore cable and connection responsibility of developer

****based on report from consultant – business case and ownership model still being devoped, a209704-001_cost_benefit_analyse_endelig_version.pdf (ens.dk)

HYBRID CONNECTION - HESSELØ (EXP. 2027)

- Onshore connection at substation
- 1 GW connection to grid
- Developer can suggeset to optimize size of OSW park above 1 GW and combine with battery, solar or consumption/electrolyzer before connecting to grid

(From 2023 also possible to apply for direct line to consumption (ie. Electrolyzer) connected to grid and potentially also with agreement on limited grid access to reduce costs and time for connection)

[Hesselø Offshore Wind Farm | Energistyrelsen (ens.dk)]

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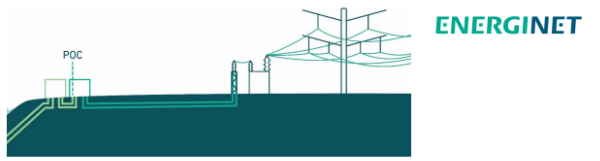
CONNECTION REQUIREMENTS

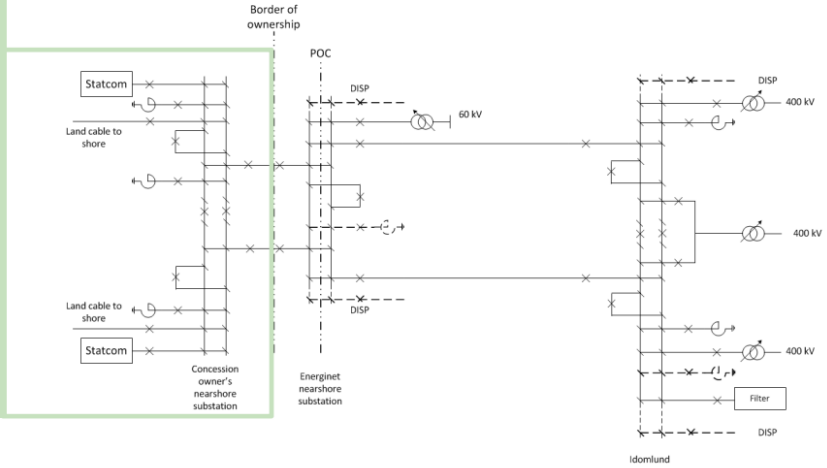
Example from Thor OSW, 1 GW

WHAT TO BUILD

Estimate of maximum technical content of concession winner's nearshore substation:

- Housed GIS
- Voltage level of 220 kV
- Double busbar with breaker divided busbar and one-breaker bays
- Busbar coupler in each of the two sections of the busbar – two bays wide each
- Two bays for concession winner's cables coming from landfall
- Two bays for concession winner's cables going to the POC
- Three bays for shunt reactors
- Two bays for STATCOM's / harmonic filters
- Three shunt reactors
- Two STATSCOM's / harmonic filters
- Auxiliary supply (10/04 kV and battery backup). No diesel generator included
- Protection, SCADA and communication housed in building together with auxiliary supply
- Fence and approx. 10 meter plant belt around the substation





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REQUIREMENTS

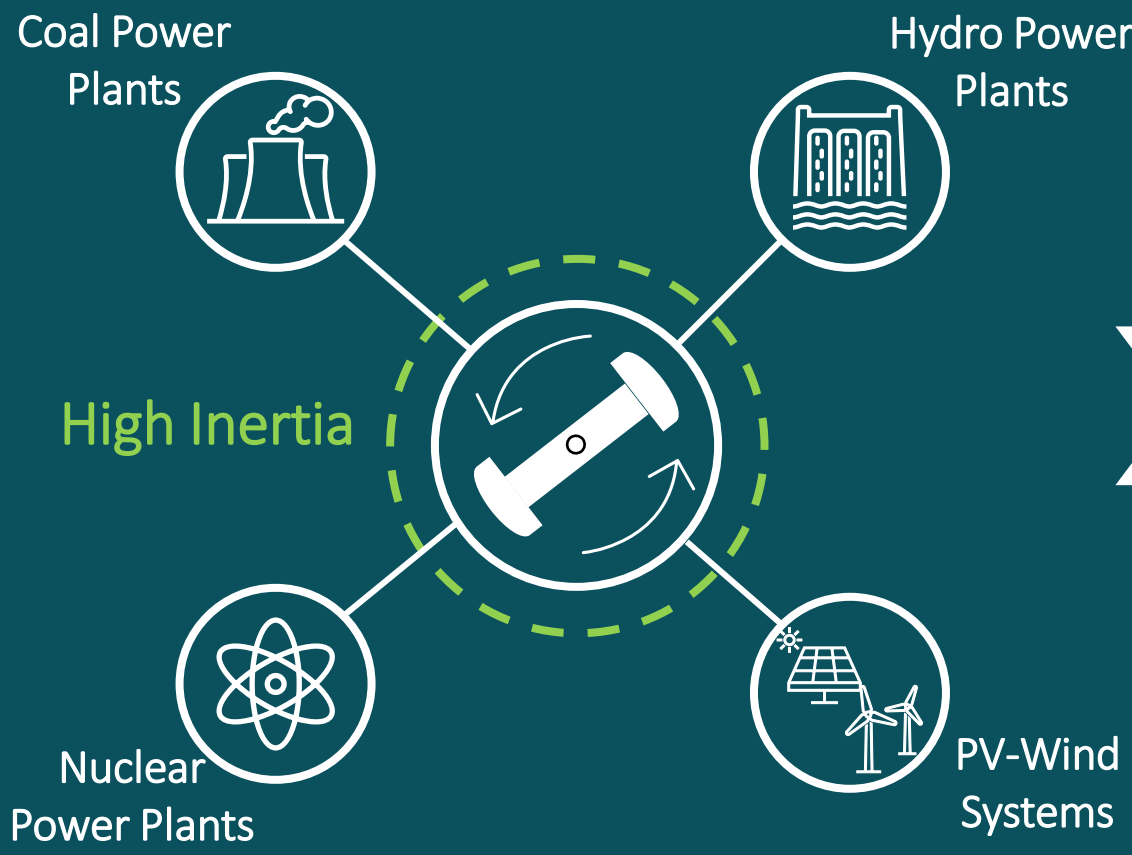
1. The wind farm and the export facility must be **compliant with all grid code requirements** in POC.
2. Must be constructed and at all times operated in such a way, that **no incident can cause loss of more than what equals dimensioning fault** in the DK1-area – currently 682 MW.
3. Energinet will facilitate the EIA for all onshore activities. **The concession winner will be responsible for handling any adjustments needed on their part**.
4. **Purchase of land needed** for construction of concession winner facilities will be the responsibility of the concession winner.
5. **Other permits** than the EIA permit and the addendum to the municipal spatial plan needed for construction of concession winner facilities will be the responsibility of the concession winner.

Energinet recommendations for offshore wind grid codes to EVN
grid_codes_d3.4_oct_2020_0.pdf (ens.dk)

FROM GENERATOR TO INVERTER DOMINATED SYSTEMS

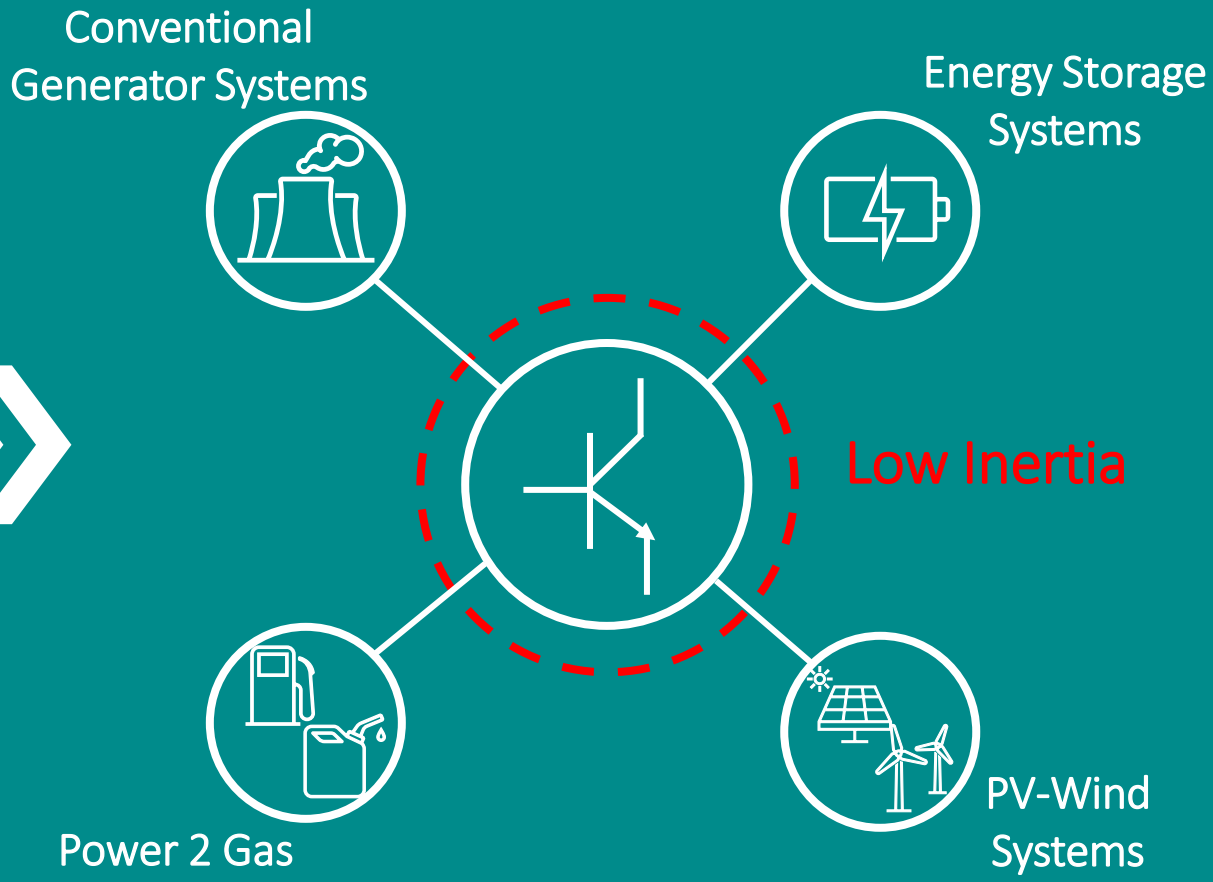
- REQUIREMENTS FOR SUPPORT TO STABLE ELECTRICITY SYSTEM IMPORTANT TO INCLUDE IN TENDER PHASE

STRONG GRID



Generator Dominated Power system

WEAK GRID

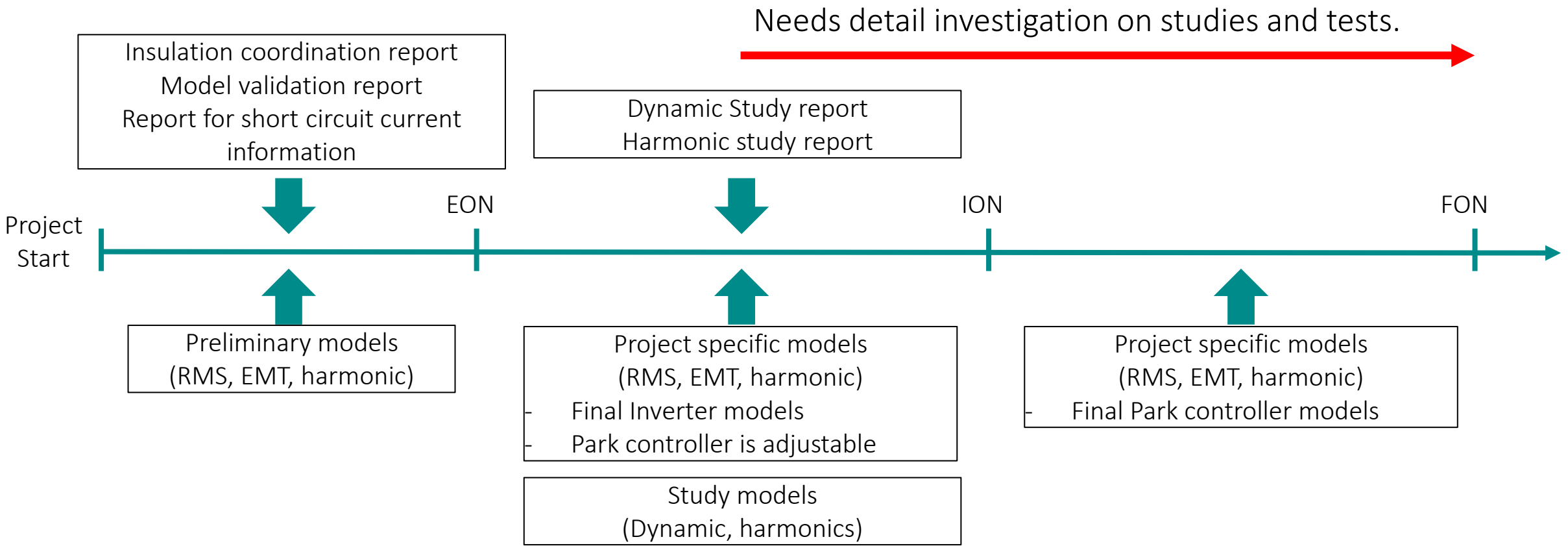


Inverter Dominated Power System

STABILITY ISSUES EXPERIENCED IN DIFFERENT PROJECT PHASE

Overview of delivery Time line of (model and report)

EON : Energization Operational Notification
ION : Interim Operational Notification
FON : Final Operational Notification



* The time line is referring only to ”studies and models”. Any other documentations required are not shown in the diagram (Ex: Single line diagram, Grid test plan, etc)

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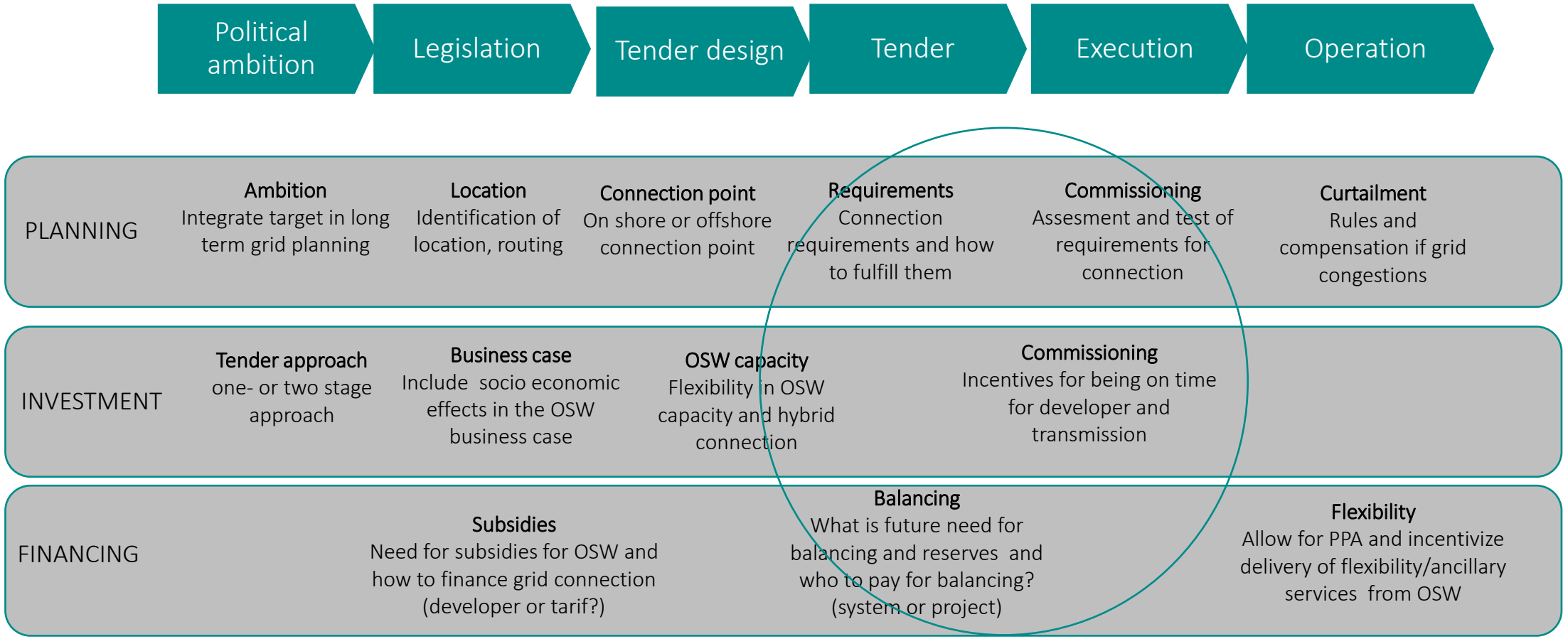
Recommendations for timing of decisions



COMPENSATION FOR CURTAILMENT

(simplified table)	Connection agreement with full grid access*	Connection agreement with limitations in grid access**
Connection delayed	Compensation, spot price for expected production	Compensation, spot price for expected production
Planned outage	Compensation, spot price for expected production	No compensation
Non planned outage	Compensation, down regulation price for expected production***	No compensation

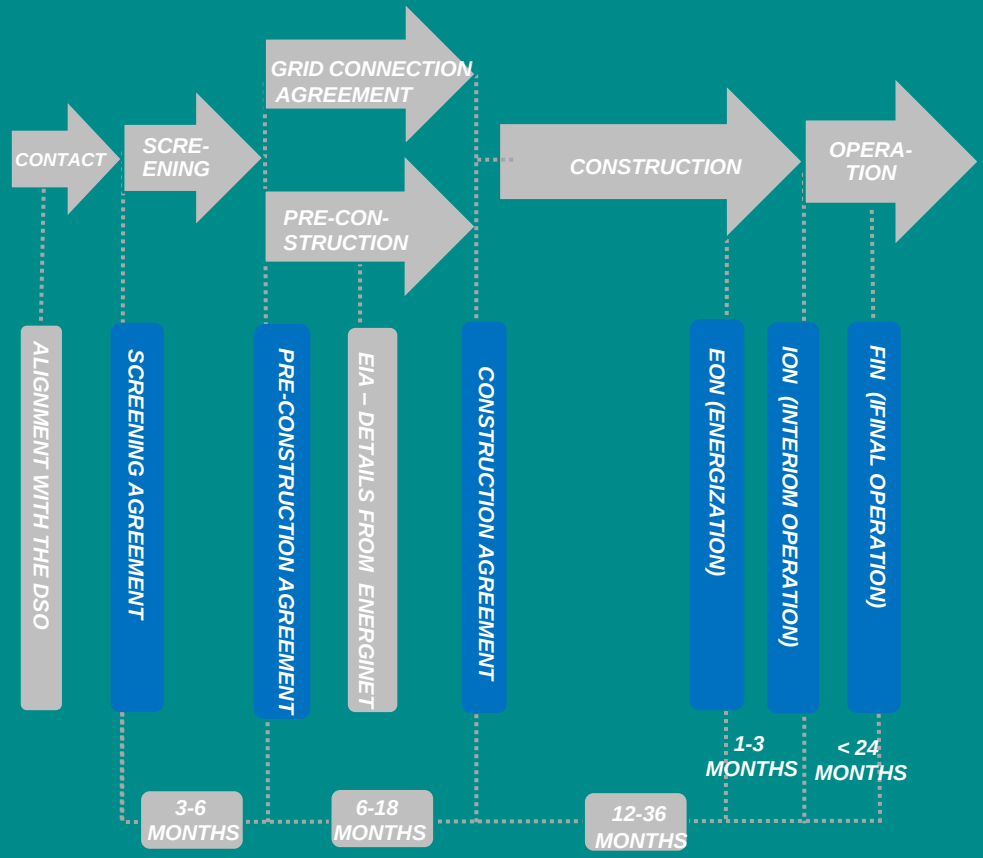
Less than 1% of wind production are curtailed annually due to to grid congestions

**in offshore wind tenders always full grid access. Not possible to choose limited grid access.*

***investor can choose limited grid access for faster connection and with risk of curtailment.*

****down regulation price is normally lower than spot price. From 2022 curtailment will be based on lowest costs bids in energy balancing market.*

PROCES FOR GRID CONNECTION



CAPACITY RESERVES FROM RENEWABLES AND FLEXIBLE DEMAND

ENERGINET

Assumptions: Forecasting precision and tools have high enough quality to meet firmness requirements.

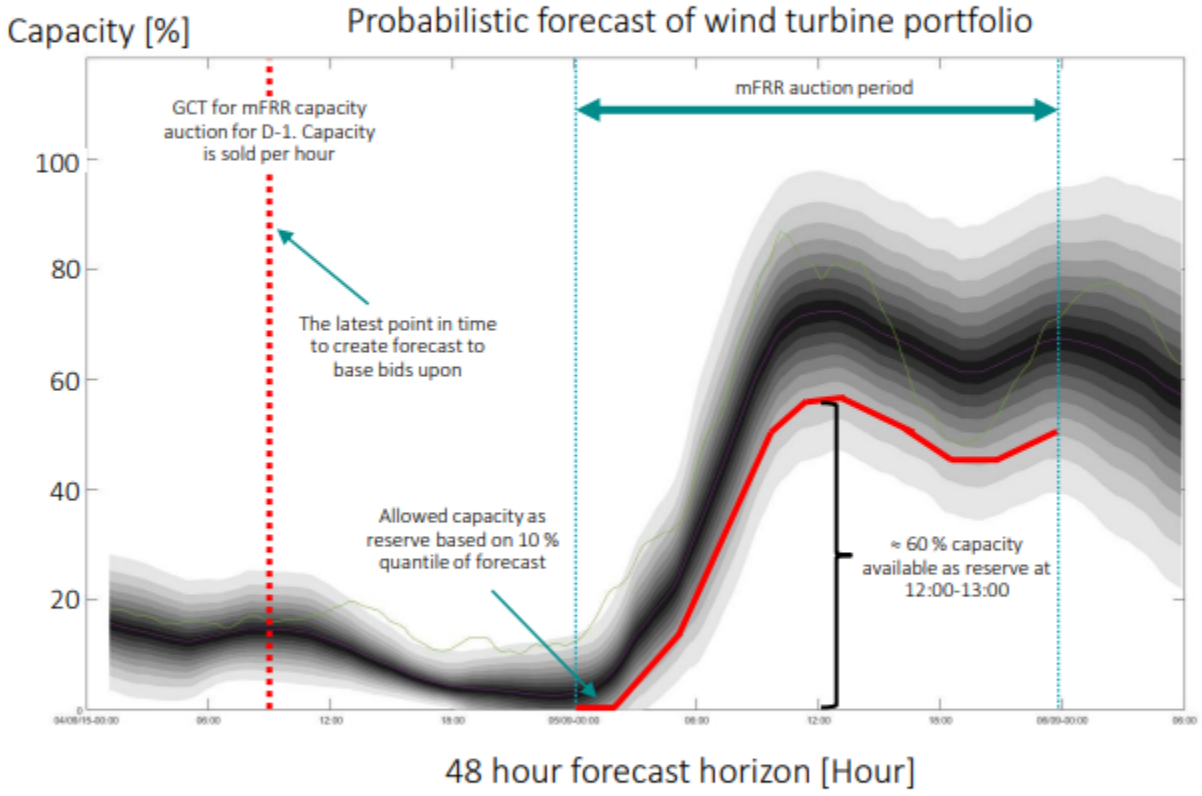
Result: Increased liquidity and better utilization of existing resources.

Method: Precision of forecasting must be proven based on at least 3 months of historical data.

Renewables & Flexible demand will be allowed to bid in capacity equal to the **10 % quantile of a probabilistic forecast**, to ensure that the capacity is available.

The rest can be bid into the energy markets, day-ahead and intra-day from the 10 % quantile and up.

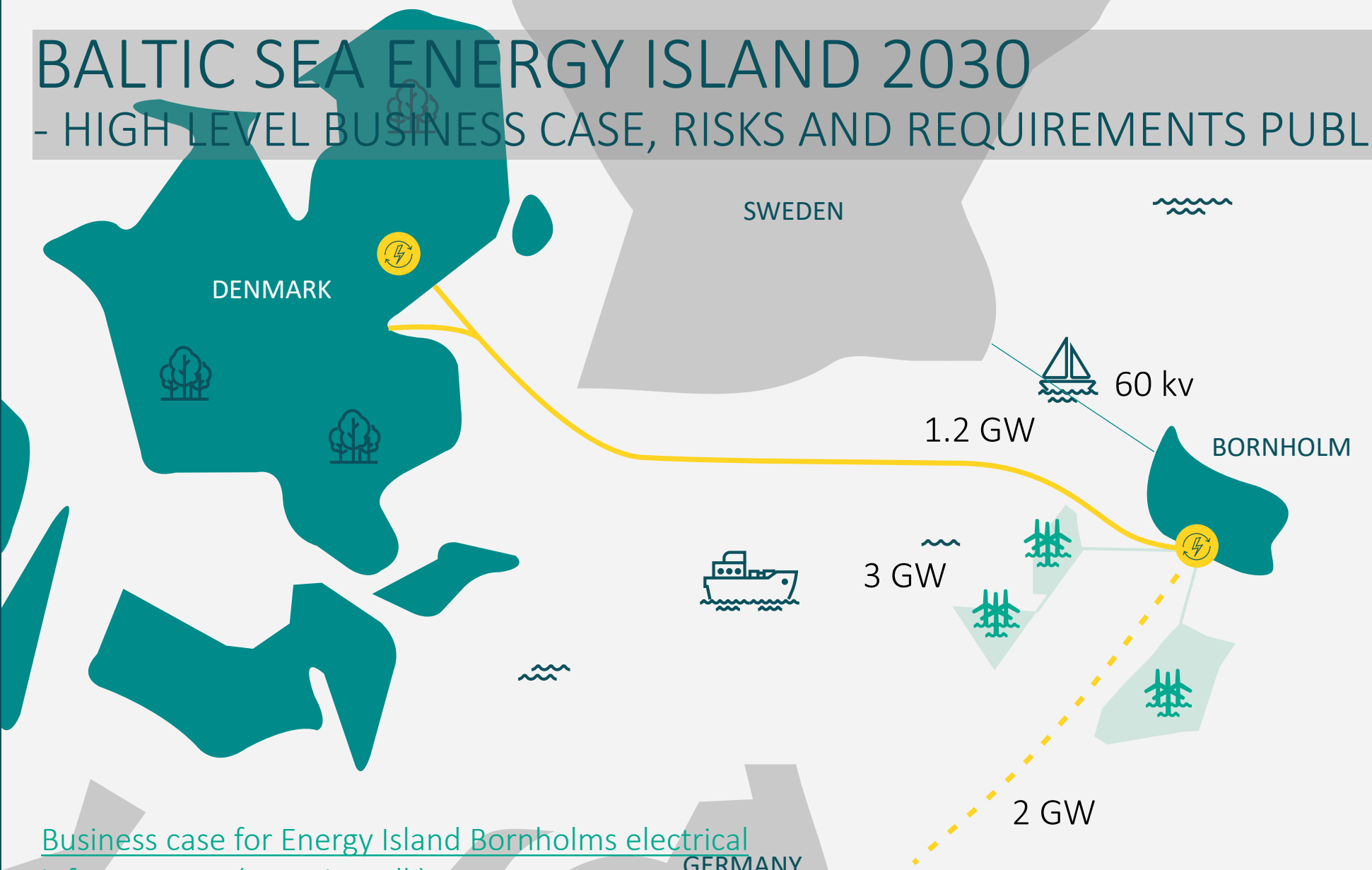
At times with the largest uncertainties the spread is larger, and hence the capacity that can be bid is reduced (to maintain firmness)



The Figure shows the spread of production from a wind turbine portfolio, where every shade represents 5 % quantile.

BALTIC SEA ENERGY ISLAND 2030

- HIGH LEVEL BUSINESS CASE, RISKS AND REQUIREMENTS PUBLIC AVAILABLE



High voltage station
Conversion of alternating to direct current and vice versa

[Business case for Energy Island Bornholms electrical infrastructure (energinet.dk)]

[Energy Island Bornholm | Energistyrelsen (ens.dk)]

[Offshore energy hubs - high level system description and requirements (energinet.dk)]

FROM PILOT TO LARGE SCALE OSW BUILD OUT

WHAT TO LEARN FROM FIRST PROJECTS?

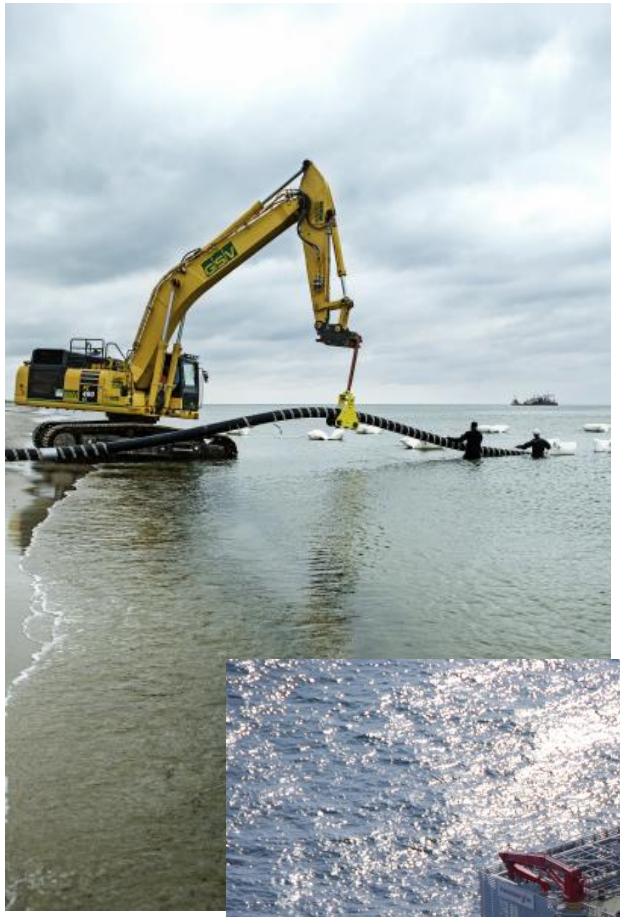
- Establish regulatory foundation
- Integration in long term energy planning (grid takes longer time than projects)
- Develop supply chain
- Dialogue with (foreign) investors and stakeholders
- Get experience with offshore wind connection
- TSO important role to reduce costs, risks and uncertainty for developer

TIMING OF STEPS FROM POLITICAL DECISION TO OPERATION

1. Settle responsibility for planning, investments and financing of grid connection
2. Grid planning: location
3. Grid connection: choice of technology, concept and procurement strategy
4. Grid connection requirements: technical criteria and operation

GENERAL CHALLENGES IN LARGE INFRASTRUCTURE PROJECTS

- Consents and approvals on state and local level
- Timeplan uncertainties and risks for delays and changes in project
- Technology development and changes in capacity during project development
- Competencies - large demand for same competencies and challenge for both TSO and approving/regulating authorities



ENERGINET

THANKS FOR YOUR ATTENTION

VISION

GREEN ENERGY FOR A BETTER WORLD

For more information please contact: pmr@energinet.dk or visit www.energinet.dk/EN

A BALANCING ACT