Offshore Co-ordination Project
Conceptual design & unit cost for technology

30 June 2020

Welcome

- ✓ Thank you for joining us! You will be joined in listen only mode
- ✓ Please do not unmute yourself or turn your camera on
- ✓ You can ask questions via the **chat function – please add these throughout the presentation**
- ✓ Questions will be taken away and circulated with a response following the webinar
- ✓ This webinar will be recorded and circulated to all those who signed up to the session today

We will be requesting **feedback** on the content of the presentation in **workshops** this week and a form will be sent out following this for you to complete should you want to feedback

nationalgridESO

The scope of our phase 1 project

1) Technology readiness and cost for offshore integration

2) Offshore conceptual design, impact on Onshore Network and cost benefit analysis

3) A review of the offshore connections process to encourage more coordination

4) Gap analysis and review of existing work

Plus collaborative stakeholder engagement

Agenda

- Conceptual designs
- Unit costs for technology
- Workstream updates
- Next steps

Draft Conceptual Network Designs

DNV GL, The National HVDC Centre, EPNC

June 30, 2020

Executive Summary

Benefits of Integrated solutions

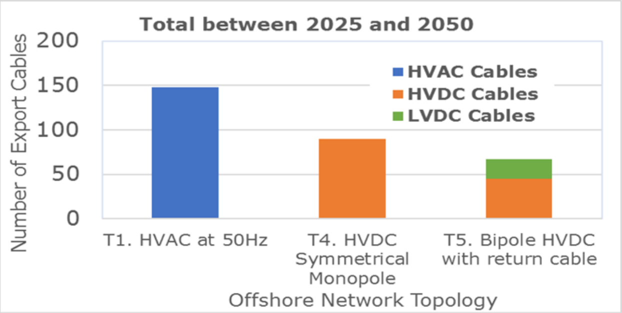
- Integration can reduce offshore network cabling by 39% to 55% with associated other infrastructure efficiency – enabling project sharing assets.
- Integrated solutions have the capability to deliver to the onshore GB system security and capacity need, and be incrementally built to offshore growth.
- Flexible to support "hybrid" Interconnector, EU Meshed Grid & Hydrogen activity

A toolkit of technology options

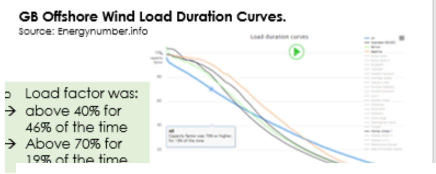
- Four different types of integrated approach- need not be a "one size fits all"- different approaches may be relevant for different growth rates and scales of offshore growth and onshore system needs
- It is not the case that we can say at this stage that integrated HVDC is the only option everywhere. Other incremental options such as HVAC, with parallel HVDC, and radial HVDC may continue to have a role as niche solutions
- We define a set KPIs for applying this toolkit to the GB system.

GB implementation in Overview.

- Only by implementing HVDC solutions can the required levels of offshore growth be achieved.
- Modular, standardised technologies available founded upon existing technology capabilities and precedent.

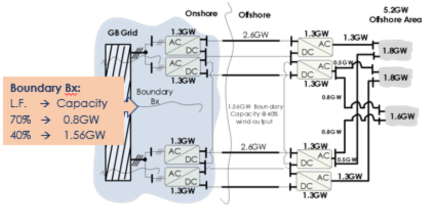


Offshore Wind Load Factor **(L.F.)**



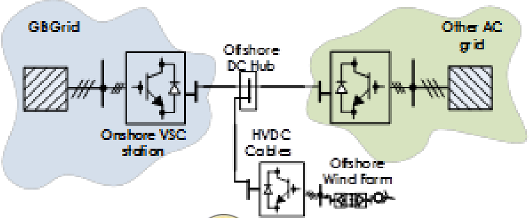
- Load factor was:
  - → above 40% for 46% of the time
  - → Above 70% for 19% of the time

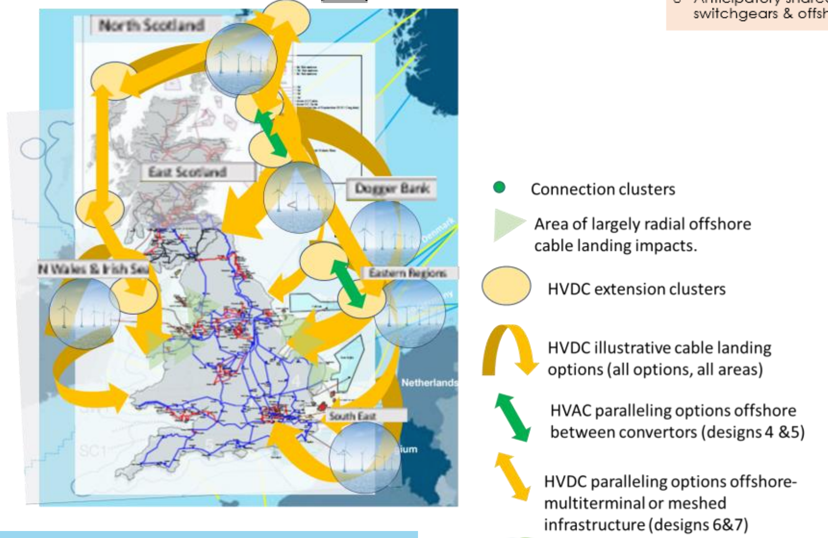
5.2GW Offshore Wind Area



Boundary Bx:
L.F. → Capacity
70% → 0.8GW
40% → 1.56GW

- 1.3GW HVDC capacity per converter and cable;
- 1.3GW offshore HVAC cable capacity & switchgear;
- Anticipatory shared assets including: LVDC switchgears & offshore HVAC switchgear.





Agenda

1. Introduction
2. Regional Offshore Wind Growth
3. Key Design considerations
4. Offshore Transmission Topologies & KPIs
5. Relating this to the GB system
6. Asset Count efficiencies from integrated solutions
7. Conclusions and Next Steps

Introduction

Our, Consortia; Our Background:

University of Strathclyde Engineering

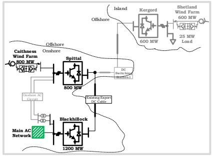
OffshoreWind IndustryCouncil

● DNV·GL

● The National HVDC Centre

● epnc

Caithness-Moray-Shetland



Scottish & Southern Electricity Networks

PROMOTioN PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS

Code modification, Audit, application

Grid Code

cigre

entsoe

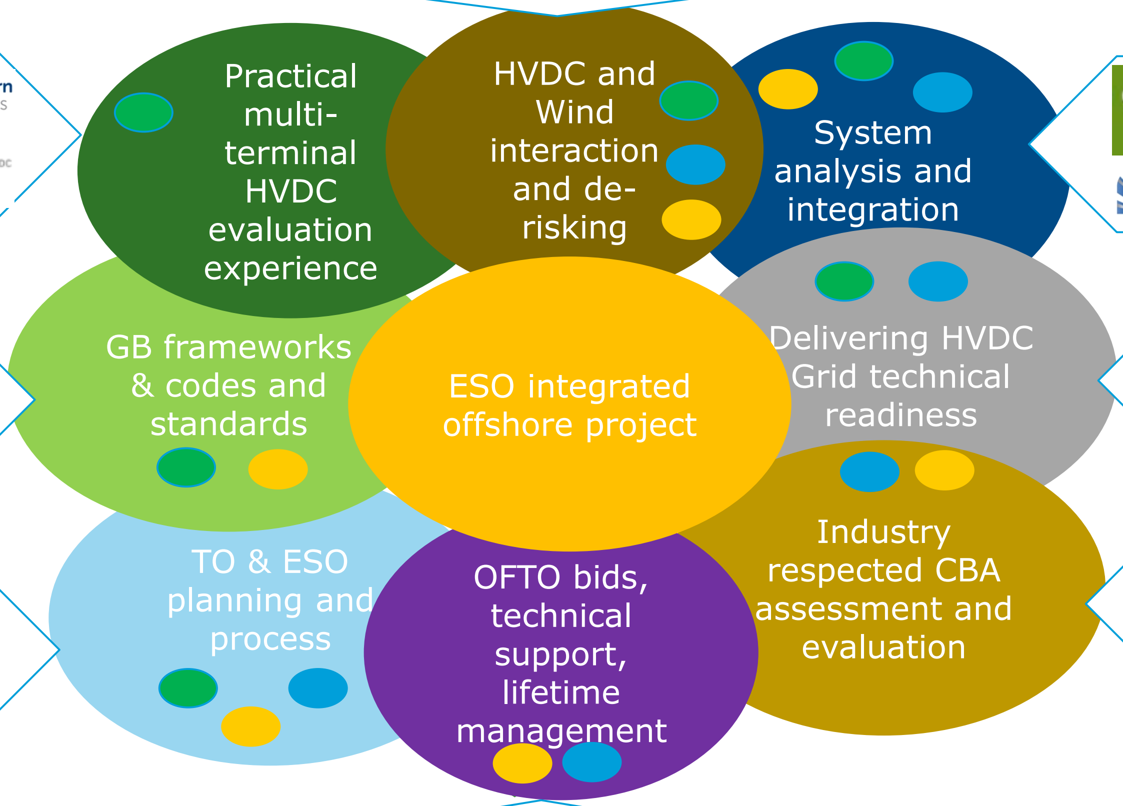
ofgem

Security and Quality of Supply Standard (SQSS)

The Connection and Infrastructure Options Note (CION) Process

System Operator Transmission Owner Code (STC)

Operational Security Standards



Practical multi-terminal HVDC evaluation experience

HVDC and Wind interaction and de-risking

System analysis and integration

GB frameworks & codes and standards

ESO integrated offshore project

Delivering HVDC Grid technical readiness

TO & ESO planning and process

OFTO bids, technical support, lifetime management

Industry respected CBA assessment and evaluation

SP ENERGY NETWORKS

nationalgridESO

Scottish & Southern Electricity Networks

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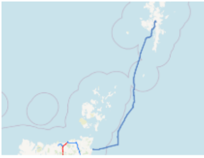
PROMOTioN PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS



Shetland

ofgem

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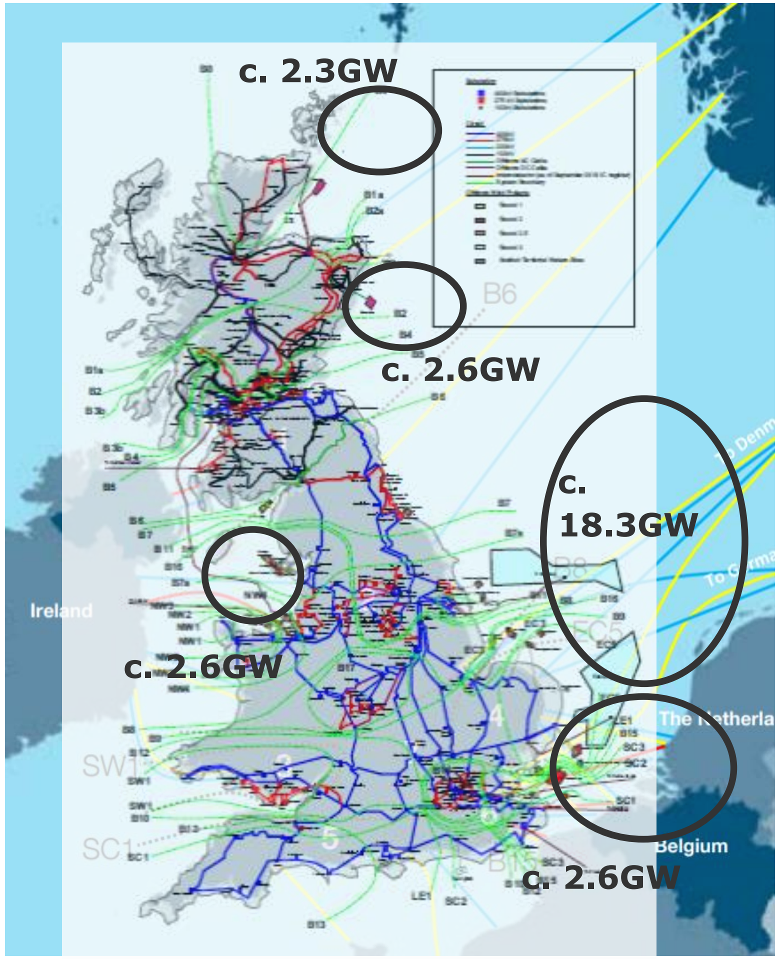
Transmission Capital Partners

GB Offshore- its various factors & considerations

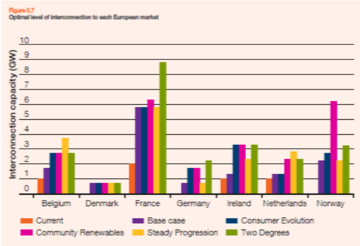
Integration



Onshore, Offshore & Interconnector planning & design

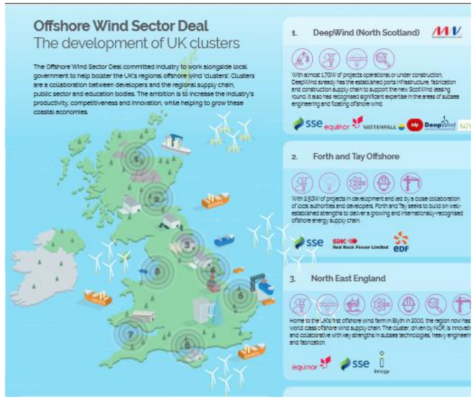
Implementation

Growth of interconnectors



Knowledge from other projects

Supply chains & existing development models



Offshore Wind Sector Deal

The development of UK clusters

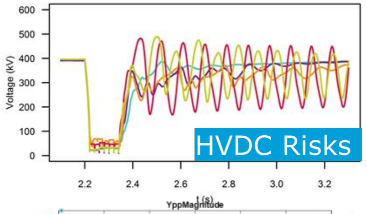
1. DeepWind (North Scotland)

2. Forth and Tay Offshore

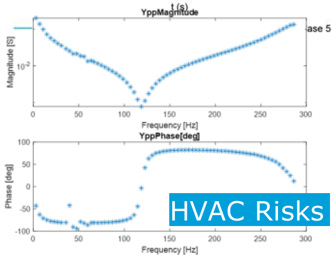
3. North East England

Consolidating Infrastructure, Addressing, Frameworks Codes and Standards

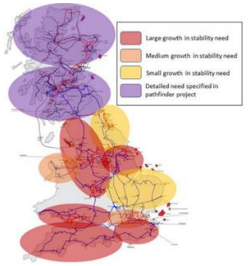
Operation



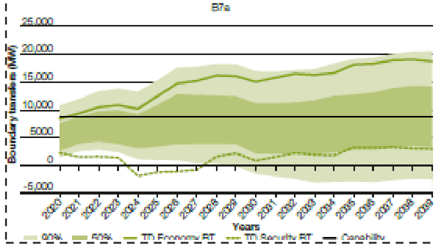
HVDC Risks



HVAC Risks

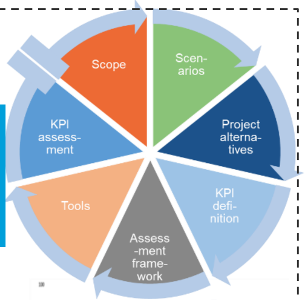


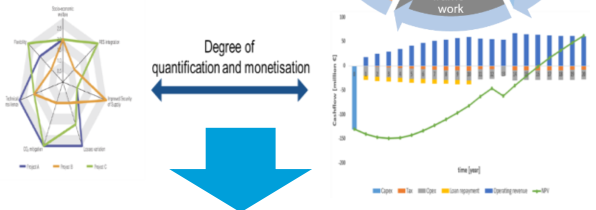
Opportunities



Optimisation

Multi-vector: economic, environmental, technical;





Range of Stakeholders

ofgem Making a positive difference for energy consumers

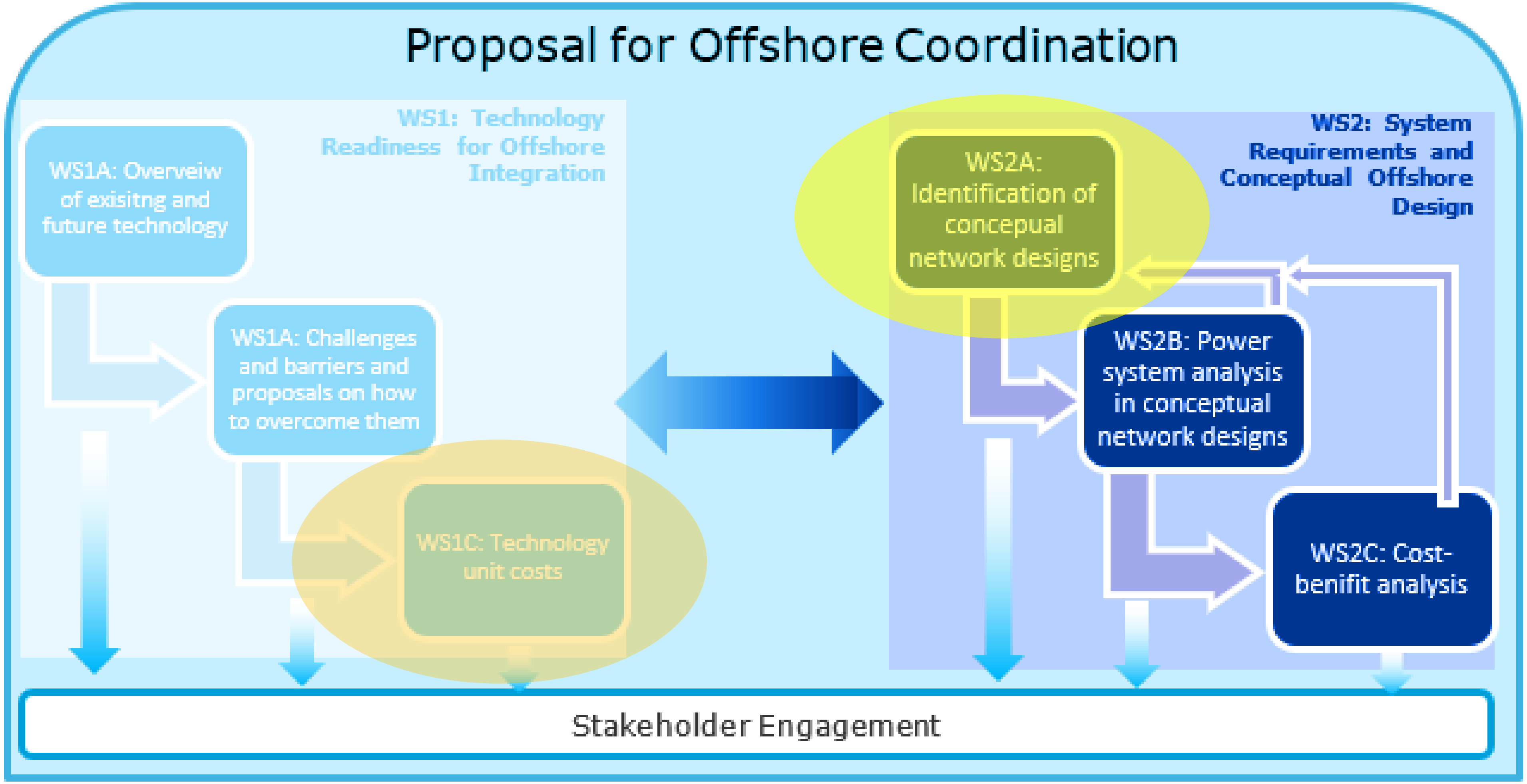
ena energynetworks association

GOV.UK

NATURAL ENGLAND

OffshoreWind IndustryCouncil

Our activities- an overview



Proposal for Offshore Coordination

WS1: Technology Readiness for Offshore Integration

WS1A: Overveiw of exisitng and future technology

WS1A: Challenges and barriers and proposals on how to overcome them

WS1C: Technology unit costs

WS2: System Requirements and Conceptual Offshore Design

WS2A: Identification of concepual network designs

WS2B: Power system analysis in conceptual network designs

WS2C: Cost-benifit analysis

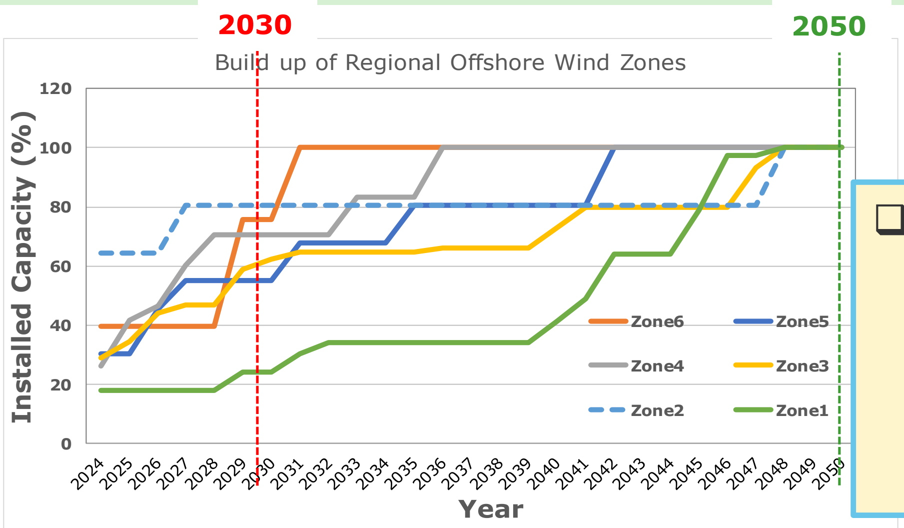
Stakeholder Engagement

Regional Offshore Wind Growth

Regional Offshore Wind Growth

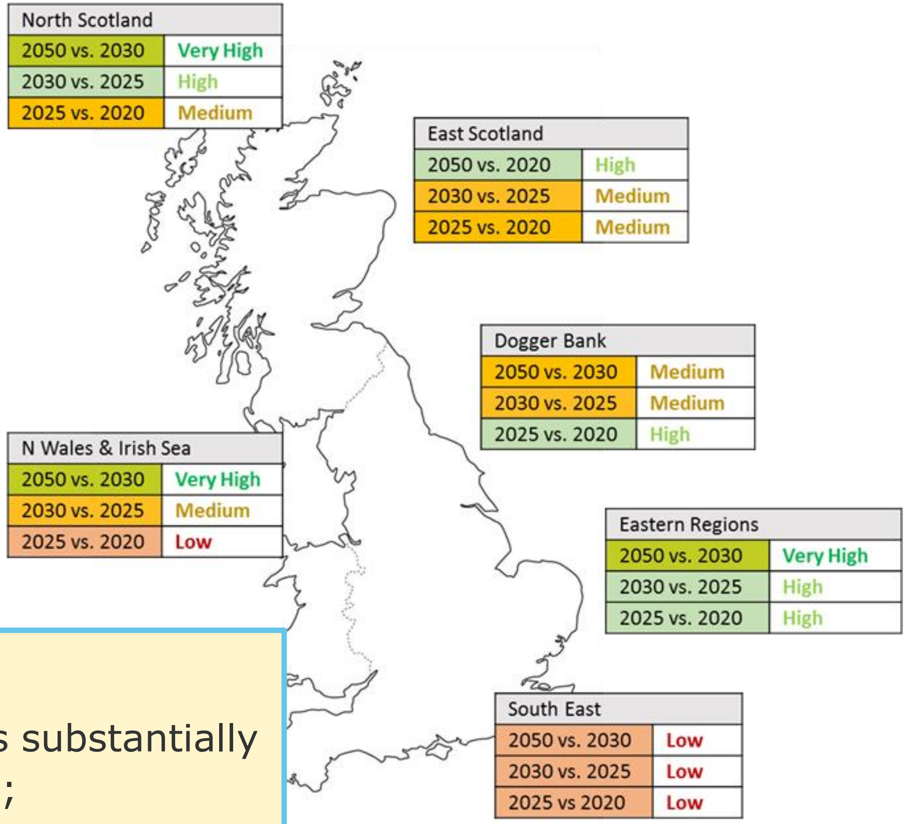
- ❑ Conceptual Network Designs based on:
  - ○ FES2020 Leading the Way (LW) Scenario, which meets 2030 & 2050 GB offshore wind targets;
  - ○ Incremental growth & build-up of installed offshore wind capacities across six regions; and
  - ○ Offshore wind development between 2025 to 2050.

❑ **Incremental Build-up across different Regions.** Source: FES2020



- ❑ Between 2025 & 2050:
  - ○ Shifts in capacity varies substantially in scale across regions;
  - ○ Pace of change varies markedly
  - ○ 30% of the overall growth by 2030.

❑ **Regional Offshore Wind Capacity up to 2050.** Source: FES2020 (not publicly available)



North Scotland	
2050 vs. 2030	Very High
2030 vs. 2025	High
2025 vs. 2020	Medium

East Scotland	
2050 vs. 2020	High
2030 vs. 2025	Medium
2025 vs. 2020	Medium

Dogger Bank	
2050 vs. 2030	Medium
2030 vs. 2025	Medium
2025 vs. 2020	High

N Wales & Irish Sea	
2050 vs. 2030	Very High
2030 vs. 2025	Medium
2025 vs. 2020	Low

Eastern Regions	
2050 vs. 2030	Very High
2030 vs. 2025	High
2025 vs. 2020	High

South East	
2050 vs. 2030	Low
2030 vs. 2025	Low
2025 vs 2020	Low

Key Design conditions

Our Approach to key areas of consideration

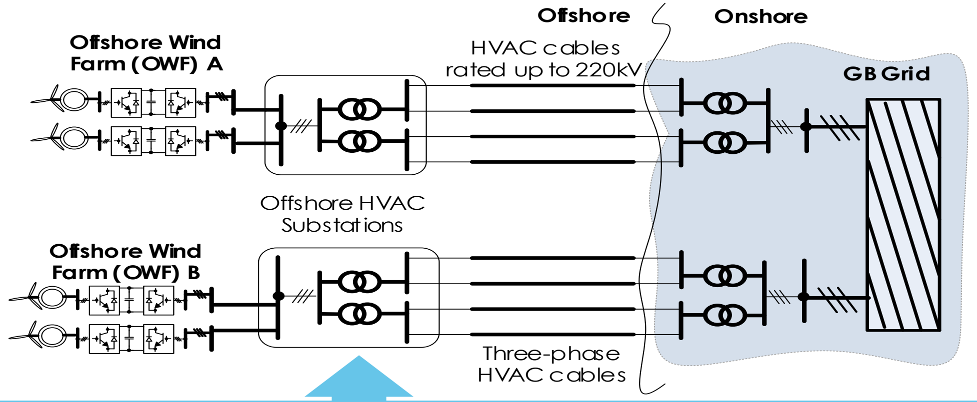
- **Technology**- as informed by separate 1A and 1B workstreams
  - Informed by international experience, technology readiness and barrier mitigation & realizing opportunities.
  - Future proofing across range of possible development where possible
- **Security of supply**:
  - Respecting existing codes and standards offshore and onshore and their application
  - Where there are gaps informing treatment, ensure resulting onshore security is equivalent or better than would be the case for other developments.
- **Development Horizon**: Not seeking to impact existing project delivery timeframes, mindful of practical timeline to establish new design approaches- no earlier than 2024 implementation
- **Flexible** Compatible with, but not dependent upon Interconnection, EU Offshore and Hydrogen growth
- **Sensitive to amenity and implementation**. Seeking minimization and consolidation of infrastructure where possible

Offshore Topologies and KPI

Offshore Network Topologies (1)

❑ Business as Usual (BaU)

- **T1:** HVAC at 50Hz



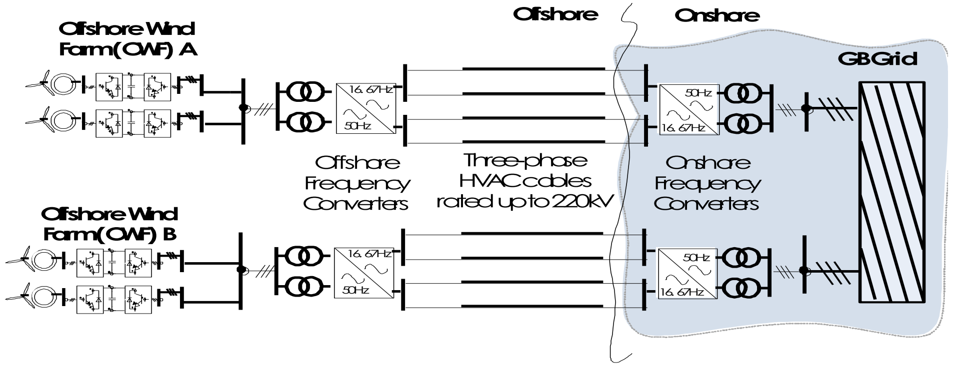
❑ **HVAC option is mature,** but has limited transmission distance, capacity and control capability.

❑ **HVDC technology can facilitate:**

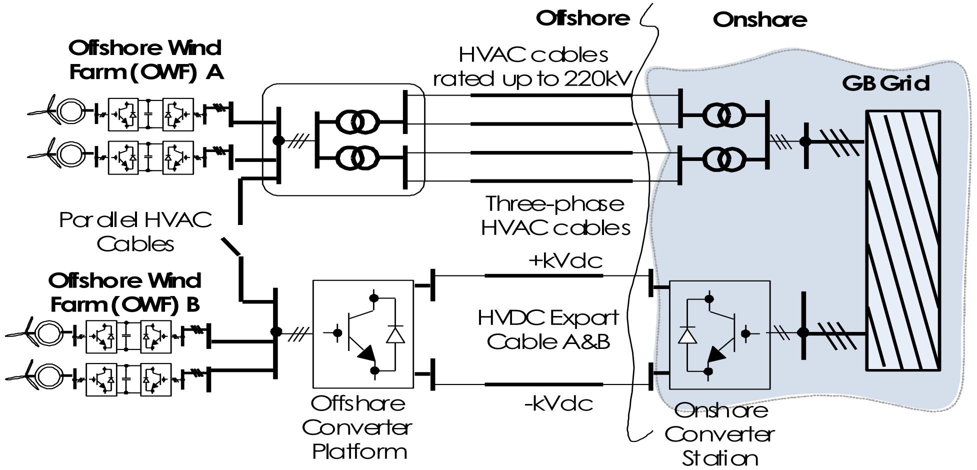
- Longer distances than HVAC option, with flexible landing via onshore end location selection;
- Better control capability and provision of onshore boundary benefit;
- Transmission asset sharing between offshore generation extension and new builds; & reactive power compensation for parallel HVAC cable.

❑ Radial Transition (RT)

- **T2:** HVAC at lower frequency (low TRL at scale)



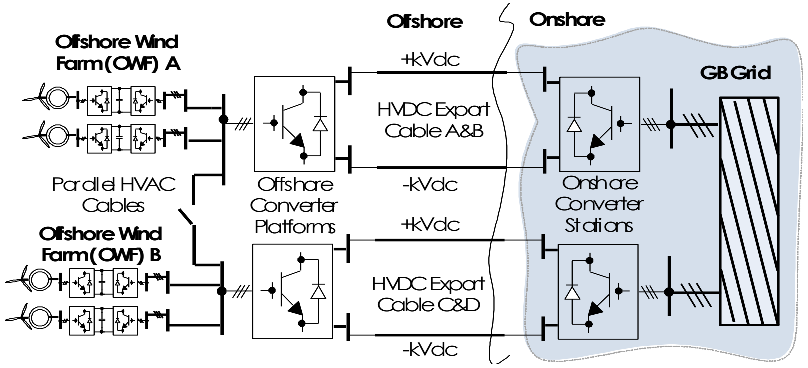
- **T3:** HVAC with parallel **HVDC**



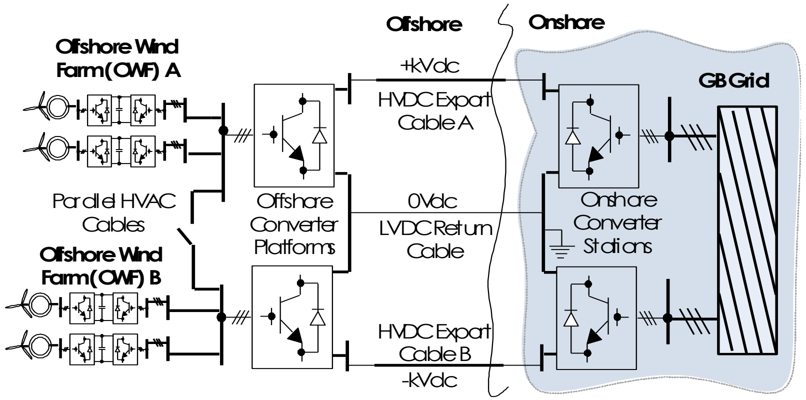
Offshore Network Topologies (2)

❑ Integrated Evolution (IE)

○ **T4**: Symmetrical monopole HVDC link



○ **T5**: Bipole HVDC with return cable link

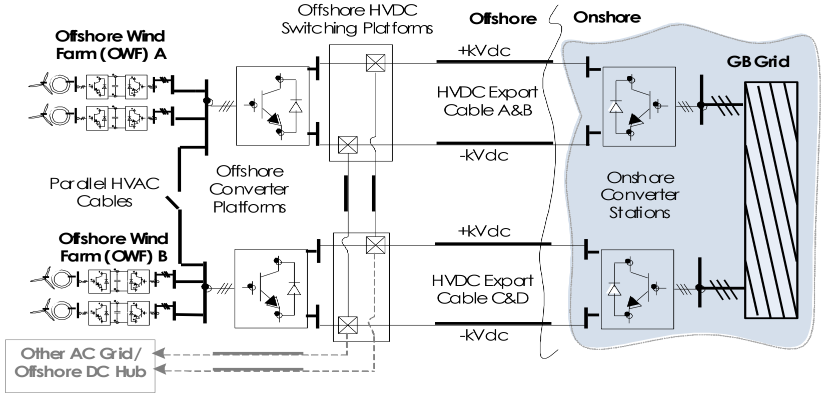


❑ **Shared HVDC** for offshore wind transmission and with offshore AC interlink later for improved redundancy and provision of onshore boundary services. Additional DC terminals can be established for later developments

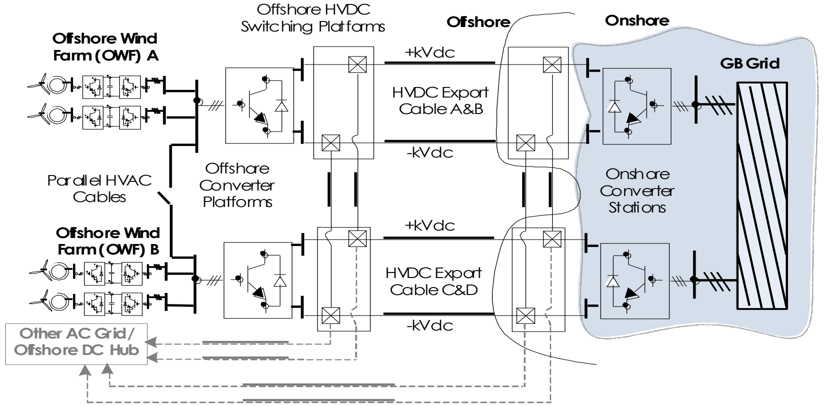
❑ **Multi-purpose HVDC** for offshore wind transmission, interconnection & onshore grid reinforcement across long geographical distances. Requires offshore HVDC hubs & circuit breaker developments.

❑ DC Integrated (DI)

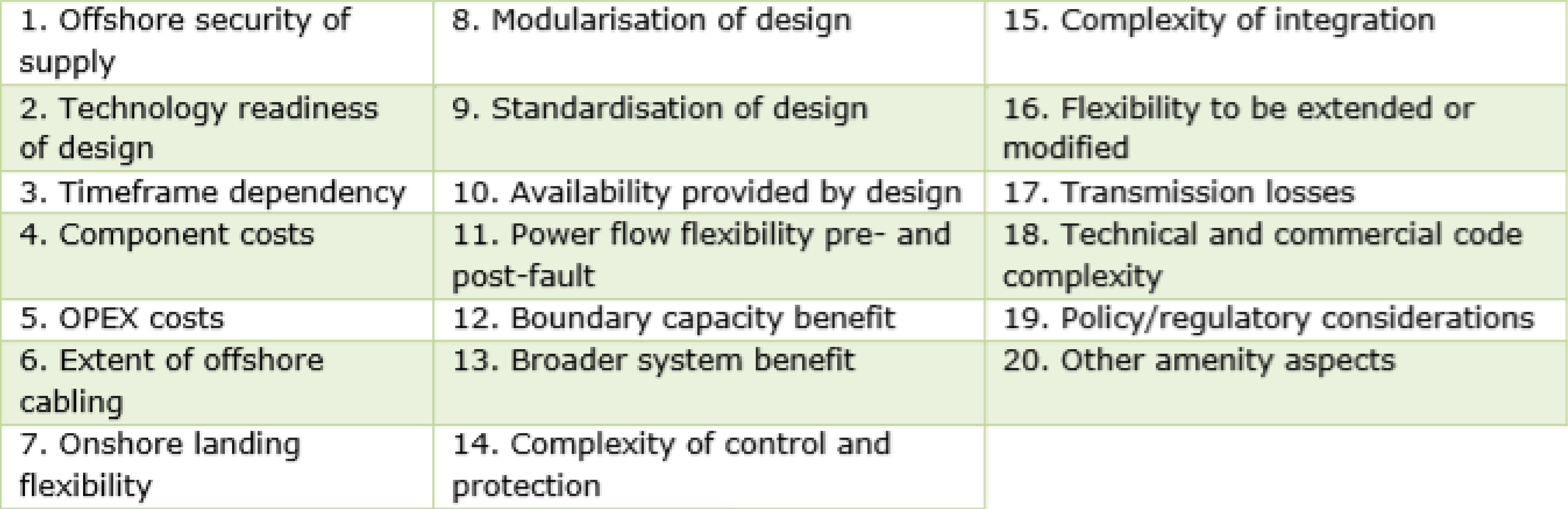
○ **T6**: Radial multi-terminal HVDC system



○ **T7**: Meshed HVDC grid



A range of KPIs considered…



1. Offshore security of supply	8. Modularisation of design	15. Complexity of integration
2. Technology readiness of design	9. Standardisation of design	16. Flexibility to be extended or modified
3. Timeframe dependency	10. Availability provided by design	17. Transmission losses
4. Component costs	11. Power flow flexibility pre- and post-fault	18. Technical and commercial code complexity
5. OPEX costs	12. Boundary capacity benefit	19. Policy/regulatory considerations
6. Extent of offshore cabling	13. Broader system benefit	20. Other amenity aspects
7. Onshore landing flexibility	14. Complexity of control and protection	

Initial Assessments related to KPI areas of Conceptual Designs

❑ **Generic assessment of conceptual designs is performed for 5 (out of 21) KPIs, using RAG analysis.**

Topology	11. Security of supply	15. Maximum Capacity	7. Transmission Distance	12. Boundary Capacity Benefits	2. Technology Readiness
T1. HVAC at 50Hz	Yes	About 1.2GW, with cables each rated 400MW at 220kV AC.	Typically, 80-200km. Limited to coastal landings.	No due to limitation of AC power flow control capability	Mature
T2. HVAC at lower frequency	Due to low TRL	Not available at scale	Up to 400km	No due to limitation of AC power flow control capability	Low
T3. HVAC with parallel HVDC	Yes	Limited by AC link capacity.	Offshore distance limited by parallel AC link	Possible in one power flow direction	Existing
T4. Symmetrical Monopole HVDC with AC interlink	Yes	Limited by HVDC cables. Power ratings up to 4GW and ±800kV DC voltage available by 2030. Also, subject to existing SQSS offshore infeed limit of 1.32GW.	Typically, up to and beyond 400km	Yes. Bi-directional flows possible.	Existing
T5. Bipole HVDC with AC interlink	Yes			Yes	Onshore project experience exists
T6. Radial multi-terminal HVDC	Yes		Suitable for interlinking across different offshore zones.	No for interconnector with T-design. Yes, for H-design with minimum of two onshore landing points.	Control, protection and offshore HVDC switchgear developments.
T7. Meshed HVDC grid	Yes				

HVDC Technology Status- high level markers on cable & convertor technology

- **HVDC** voltage source converters is the key technology for implementation of integrated offshore transmission circuits.

Technology		**Maximum ratings per Converter Bipole/Cable Bipole (except stated otherwise)**					
		Installed (until 2019)		Under construction (up to 2026)		Achievable (up to 2030)	
		Capacity (GW)	**Voltage (kV)**	**Capacity (GW)**	**Voltage (kV)**	**Capacity (GW)**	**Voltage (kV)**
VSC	With overhead lines (Asia) [1]	3	± 500	5	± 800	7	± 1100
Extruded Cables	Cross Linked Polyethylene (XLPE) [2];[3] [4]; [5][6]	1 (Symmetrical	± 400 Monopole)	2	± 525	3	± 640
	High Performance Thermoplastic Elastomer (HTPE) [7]; [5][6]	Not recorded (N/A)	N/A	2	± 525	3.4	± 640
Mass Impregnated Non-Draining Cables	Paper Insulated [8]; [5]	1	± 500	1.4	± 525	2.4	± 525
	Paper Polypropylene Laminate (PPL) [9]; [5]	2.2	± 600	N/A	N/A	4	± 800

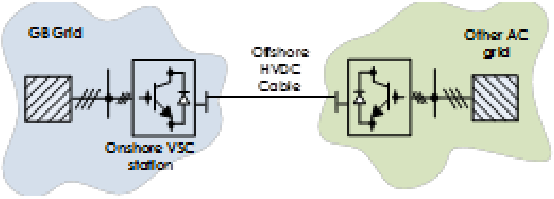
- HVDC-connected wind farms have to date used symmetrical monopoles for radial connections rated up to 900MW and ±320kV DC. However for integrated offshore solutions, Bipole with return cable configuration can offer greater flexibility and increased capacity, which could reduce the extent of cables required and avoid the need for HVDC circuit breakers.

HVDC Applications

❑ **HVDC** voltage source converters is the key technology for implementation of integrated offshore transmission circuits.

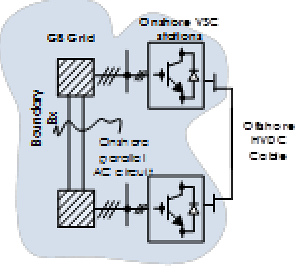
❑ Interconnection

- Linking GB grid to other countries
- Loading depends on price differential between different grids
- Not always fully loaded



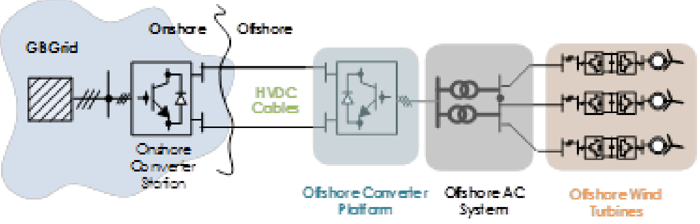
❑ Grid Reinforcement

- Two converters located in same grid for reinforcement & boundary capability improvement;
- Loading follows variable demand profile, renewable generation & plant dispatch - not always fully loaded.



❑ Offshore Wind Connections

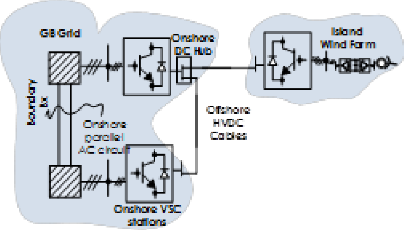
- Load factor is about 50% in GB
- GB projects under-construction with 7 existing in Germany



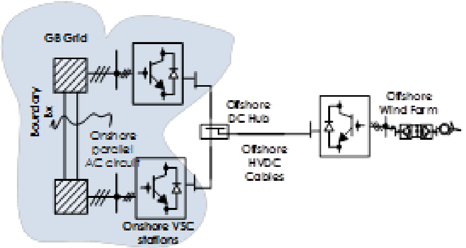
❑ Multi-purpose HVDC

(Can be built in stages across different options)

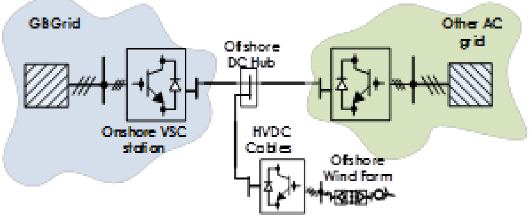
- **Embedded link with onshore DC hub**



- **Embedded link with offshore DC hub**

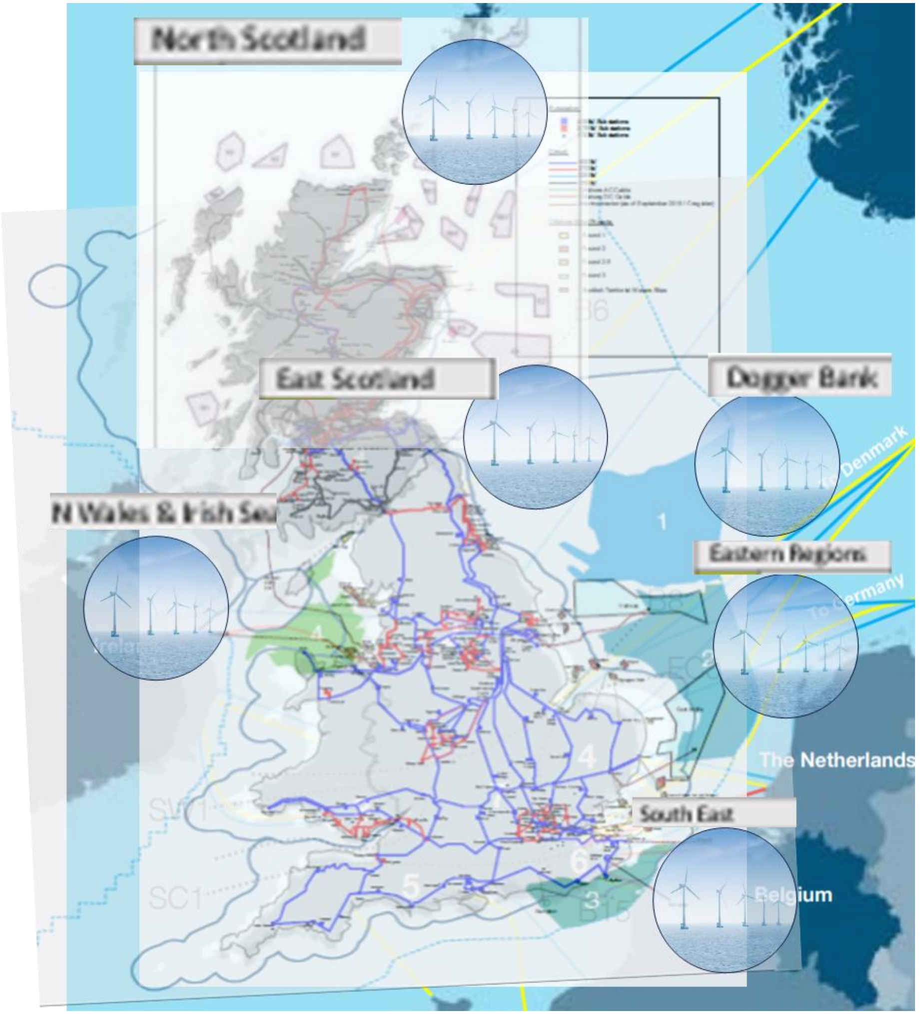


- **Interconnector with offshore DC hub**



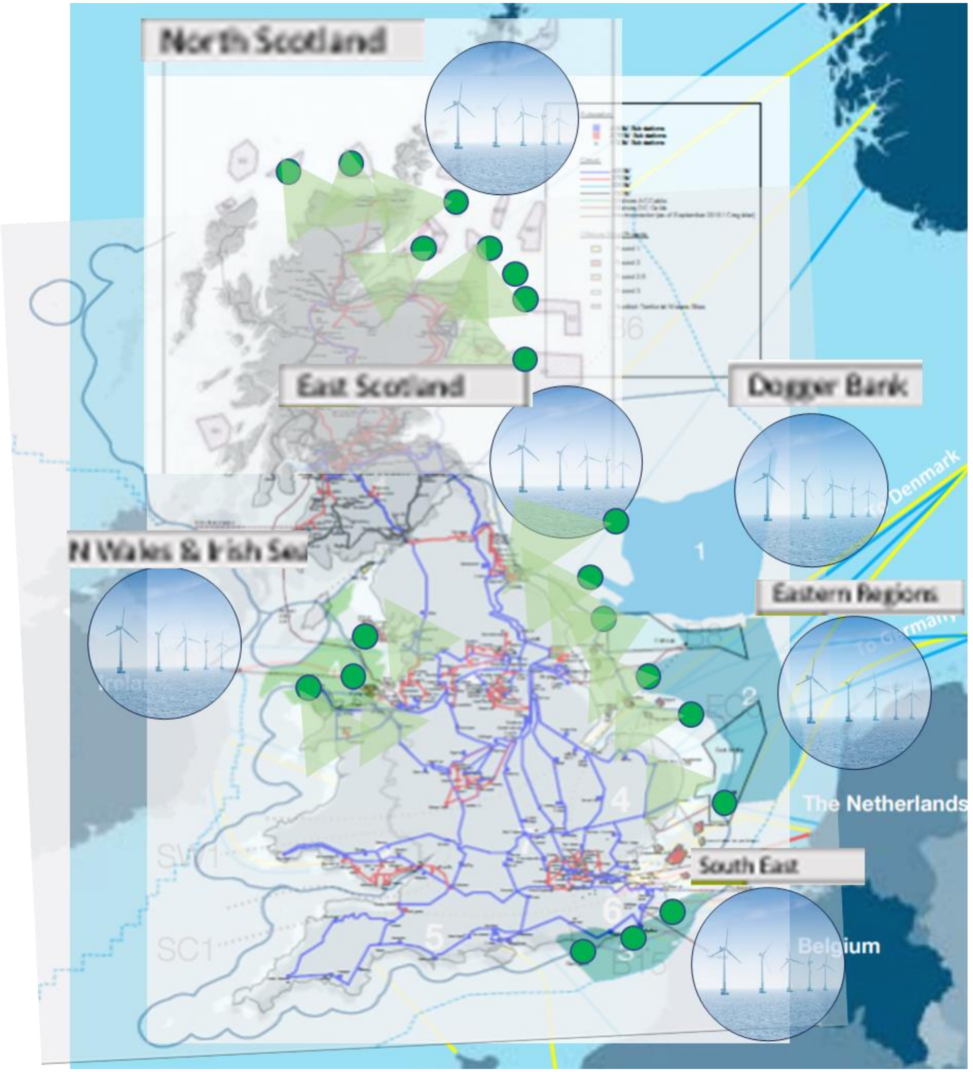
Relating this to GB..

GB development picture Offshore



- Increasing Offshore distances
- Greater diversity in offshore areas
- GB system developed to historic power flow and generation connection requirements.
- Historically separate interconnector connection to, and offshore HVDC reinforcement of the onshore system
- Incremental offshore network development limited in distance and capacity available by HVAC.

Increased use of HVAC technology alone

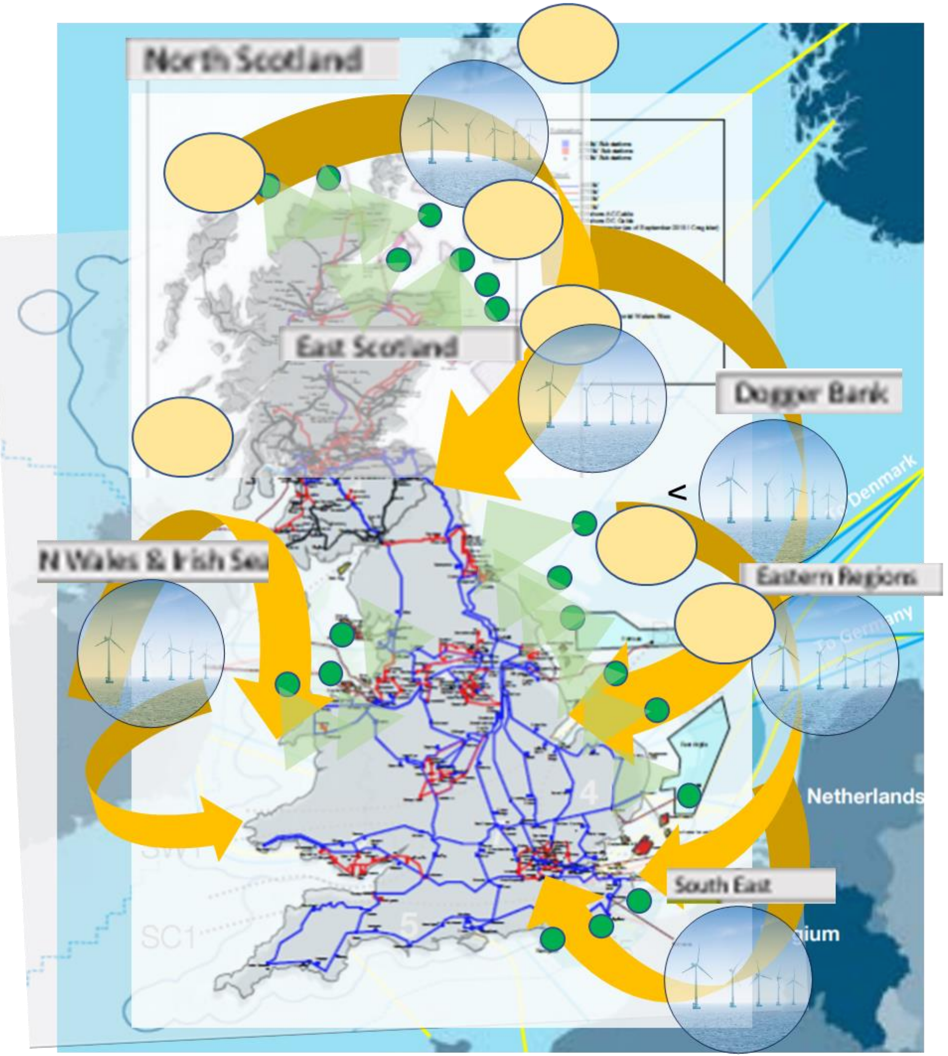


- Limited capability to meet Offshore targets
- Highest asset footprint on and offshore
- Large areas of costal areas affected.
- Little flexibility in how and where to connect onshore
- Range of onshore integration challenges with scale
- Limited co-ordination or consolidation options available
- Use of Low Frequency HVAC were it developed would increase the scale of the above challenges but not change them.

● Connection clusters

▶ Area of largely radial offshore cable landing impacts.

Incrementally increasing HVAC capability, together with HVDC



- Improved capability to grow towards, but not meet Offshore targets
- An ability to limit asset footprint and grow from existing offshore infrastructure
- More limited affect on costal areas than before
- More flexibility in how and where to connect onshore on HVDC routes
- Range of onshore integration challenges with scale remain
- Limited co-ordination or consolidation; options for niche application available

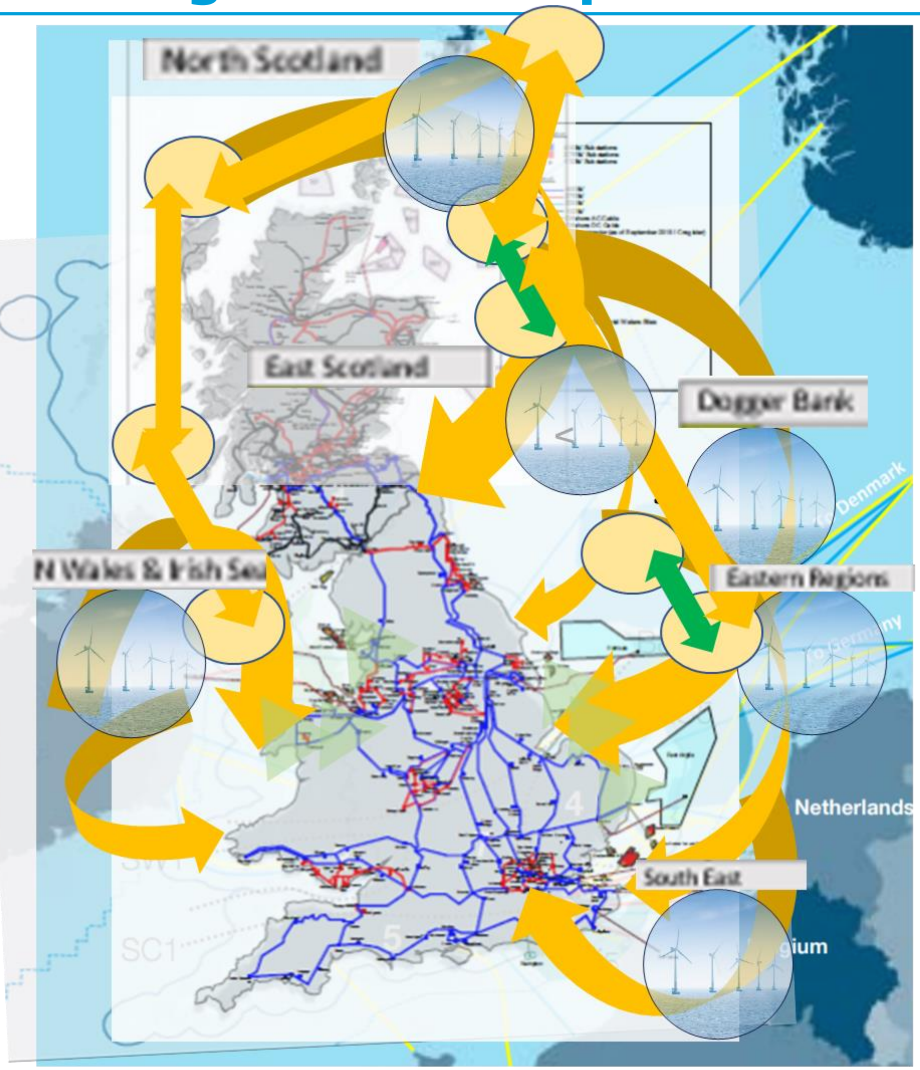
● Connection clusters

▶ Area of largely radial offshore cable landing impacts.

⬭ HVDC extension clusters

↷ HVDC illustrative cable landing options

Range of HVDC options and opportunities



● Connection clusters

▶ Area of largely radial offshore cable landing impacts.

⬭ HVDC extension clusters

↷ HVDC illustrative cable landing options (all options, all areas)

↕ HVAC paralleling options offshore between convertors (AI)

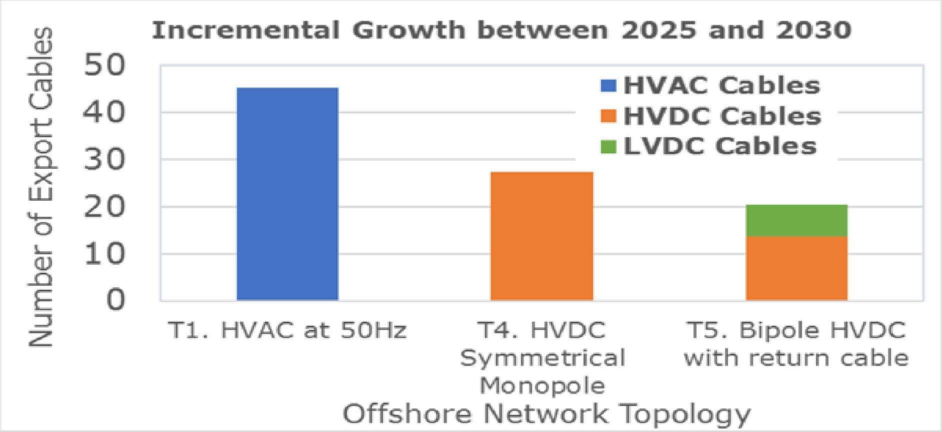
↕ HVDC paralleling options offshore- multiterminal or meshed infrastructure (DI)

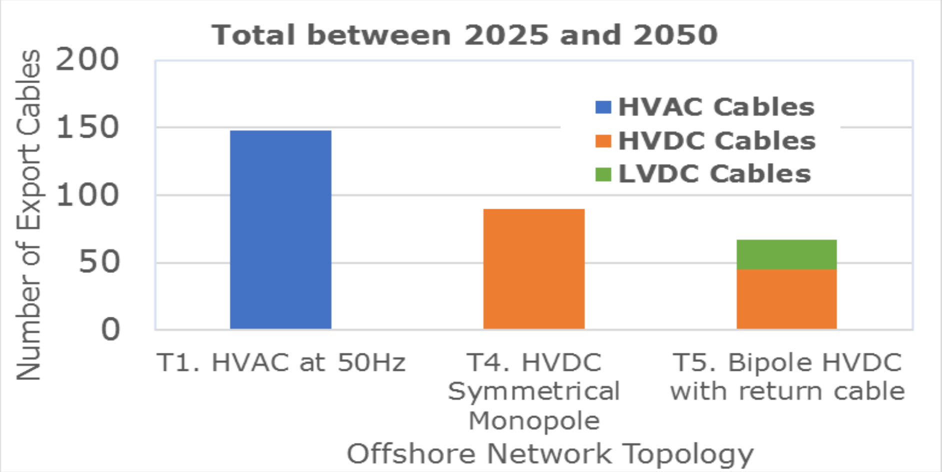
- All options meet Offshore targets
- Integrated options can substantially reduce the assets required
- All reliant on project sharing principles
- Options to integrate with interconnection and HVDC reinforcement of offshore system
- Lowest impacts on coastal areas from integrated solutions- the choice of design is less important that the choice of approach
- Maximum flexibility in how and where to connect onshore
- Onshore integration considerations are consolidated with various opportunities for system support
- High co-ordination required to achieve

Integrated Offshore solutions- asset efficiencies

Offshore Cable Asset Count

❑Offshore export cable link offshore substations to the onshore grid using (HVAC, HVDC or LVDC cables).





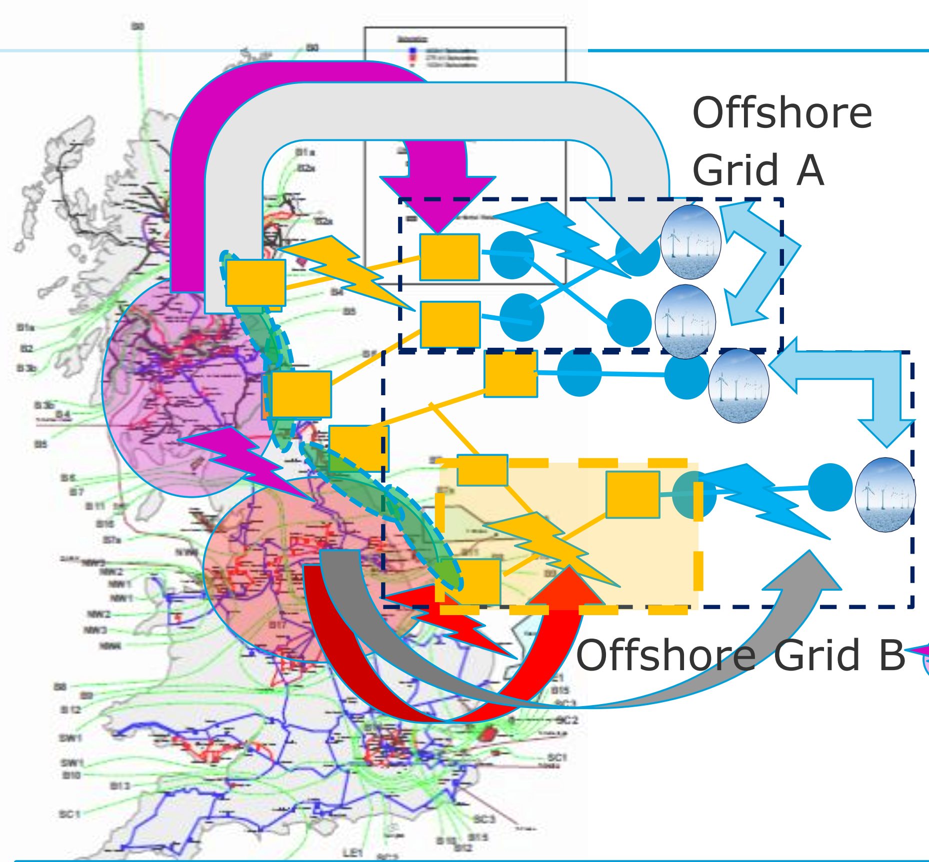
- ❑ **By 2030 & 2050** integrated HVDC options offer between 39% to 55% saving on number of export cables in comparison to HVAC only topologies (T1&T2).
- ❑ IE topologies (T4&T5) have similar number of export cables for DI topologies (T6&T7).

❑ **Key Considerations:**

- ○ 400MW maximum capacity per three-core HVAC cables;
- ○ 1320MW maximum capacity per offshore HVDC cable & HVAC interlinks based on existing SQSS standards;
- ○ Two symmetrical monopole HVDC links use 4 HVDC cables;
- ○ A Bipole HVDC scheme with third return cables uses 2 HVDC cables and 1 LVDC cables; and
- ○ Comparison based on either All HVAC, or All symmetrical monopole HVDC or All Bipole HVDC scheme with return cable up to 2050.

Conclusions and Next steps

Bringing Integrated offshore solutions to life:



Key	Challenges
🟨	Extent of HVDC elements- co-ordination, interaction, stabilization.
●	Extent of HVAC elements- decoupled offshore grid regulation, interaction to WTG, resonance & damping.
⇄	Co-ordination across HVAC island behaviors
↻	Compliance, control and testing needs of WTG
↷	HVDC control resilience onshore fault/ outage & priorities for power recovery
↻	HVDC DC side onshore fault coordinated power recovery management & interoperability
⚡	Onshore fault effect and extent of subsequent onshore voltage recovery
⚡	Offshore DC fault control strategies
▭	Offshore DC fault protection strategies
⚡	Limitation of offshore AC fault effect
⬭	Local community, environmental and amenity impacts
⬚	Regulatory complexity — interaction of codes and standards

Opportunities

- **Holistic design and operation concepts** to limit infrastructure, standardize and modularize integrated offshore solutions
- **Define pragmatic HVAC performance** needs and effective performance tests
- **Develop robust HVAC control philosophies** aligned to overall GB system resilience.
- **Define expected WTG performance** within new network designs and how existing performance needs translate to integrated designs
- **Define overall HVDC and decoupled HVAC control needs** to maintain performance and support onshore system with additional voltage, thermal, frequency response & or inertia, stability support & black start. Leverage future technologies (e.g. VSM)
- **Recommend efficient changes to existing codes and standards**
- **Local and wider socio-economic benefits**

Barriers & solutions

- Roles and responsibilities
- Regulatory, code and standard requirements
- Technology limitation and pipeline development need
- Anticipatory investment benefits and requirements
- Processes and frameworks

Review, Consult, Recommend

Workstream 2B: Power System Analysis on Conceptual Network Designs

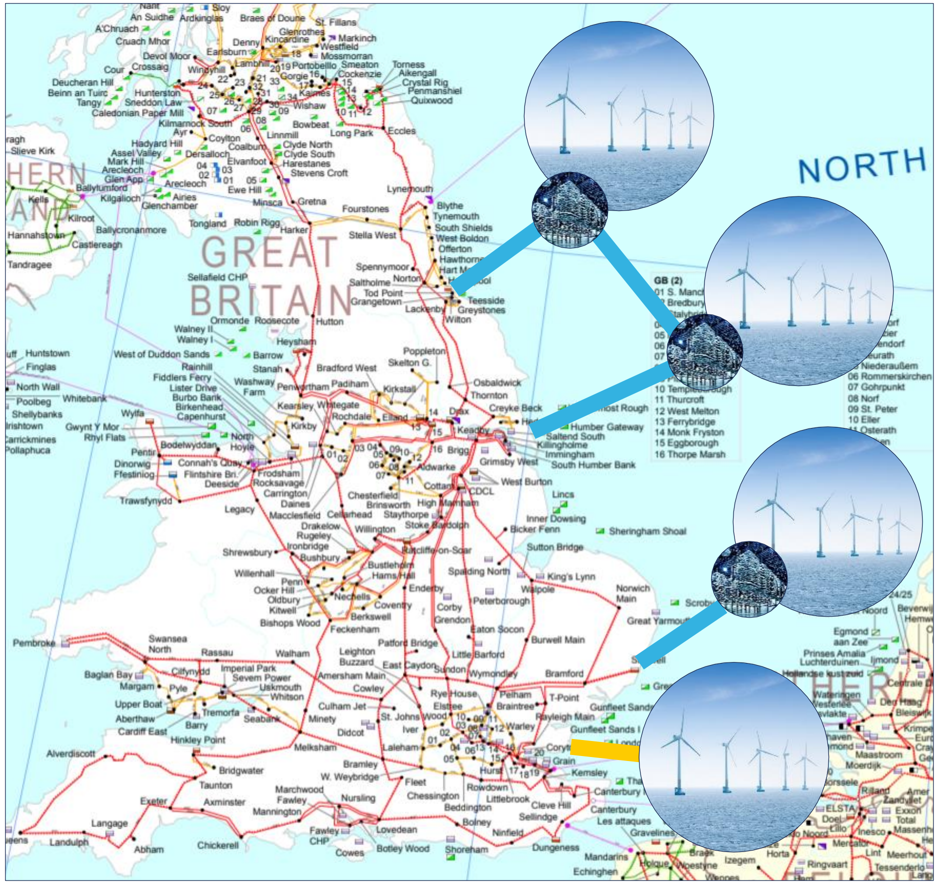
Modelling of Offshore Network Designs
- Based on standard components (WTGs, HVDC, cables, transformers).
- Only intended to demonstrate control of power flows.

Modelling of Onshore Network
- NG ESO to provide validated PowerFactory model suitable for the study.
- Cooperation with NG ESO to define future dispatch/demand scenarios.

Energy Yield and Reliability of Offshore Network Designs
- Calculation of yearly energy production based on wind power profiles.
- Simulation of N-1 and N-2 criteria for the most relevant scenarios.

Reinforcements of Onshore Network
- Identification of bottlenecks caused by the infeed of the offshore network.
- Proposal of potential reinforcements for the onshore network.

Deliverable Report
- Comparison of the offshore network designs.
- Evaluation of the benefits and requirements for the onshore network.



Our Early Conclusions:

- **Advantages of integrated approaches and flexibility of HVDC solutions**
- **Both HVDC and integrated HVDC solutions are available offshore within the development horizon**:
- **Integrated solutions can be developed in a standardised, modular manner to minimise implementation risk.**
- **HVDC Flexibility in distance and interconnectivity offers options for amenity sensitive developments at scale**
- **No one single solution necessarily fits- optimal solutions in context of ESO's FES assumptions will be developed as work progresses.**

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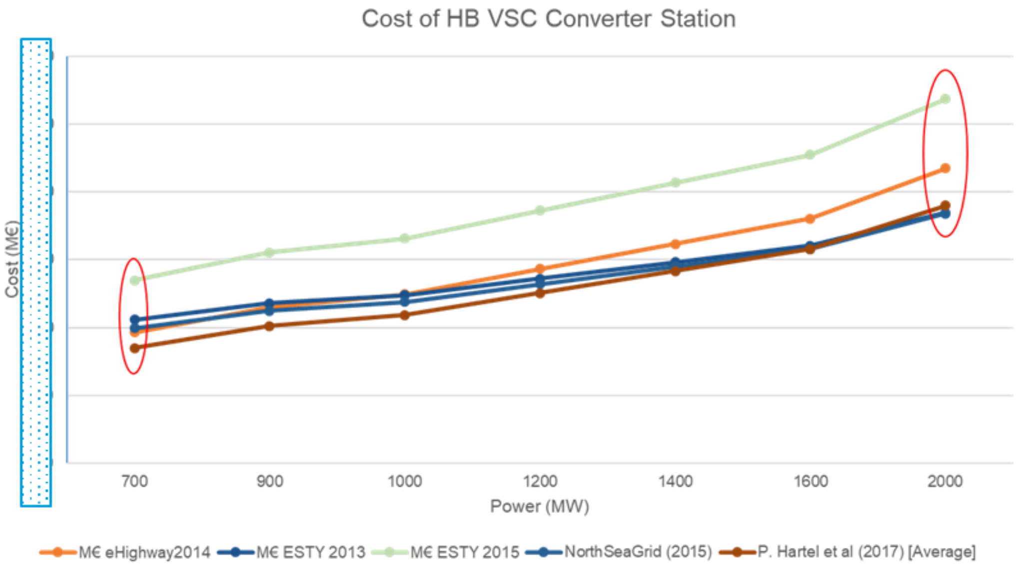
Unit Cost – Assumptions and Methodologies

Agenda

1. **Our approach to gathering cost data:**
   - Cost assumptions, what includes and what not includes, why?
2. **Collection of components**
   - (both categories and ratings), aligned with the high-level conceptual designs.
3. **References to real-world project contracts. Historic cost trends observed**

Assumption and sources

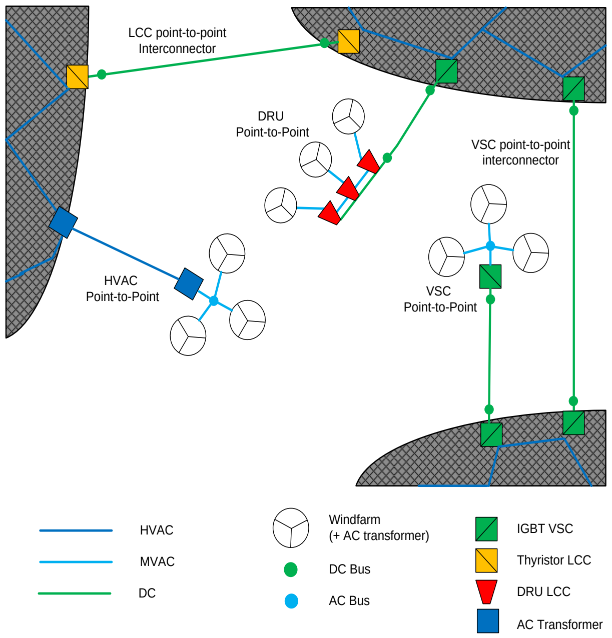
- ❑ **Mature products: HB VSC, Cables, transformers**
  - ➢ Literature: e-Highway, ETYS13, ETYS15, NorthSeaGrid
  - ➢ In-house data
  - ➢ Publicly available contract values
  - ➢ Cost models based on e.g. power rating, voltage level and length
- ❑ **Products under development, but other products exist with similar functionalities and configurations**
  - ➢ Full-bridge (FB) VSC converters, use HB VSC as reference
- ❑ **Unique Products under development: DCCB**
  - ➢ Bottom-up approach
  - ➢ Reconstruct the principle structure of the components, establish the basic configuration, calculate the material costs (IGBTs, mechanical switches, arrestors, etc), add additional cost such as R&D, business margin.



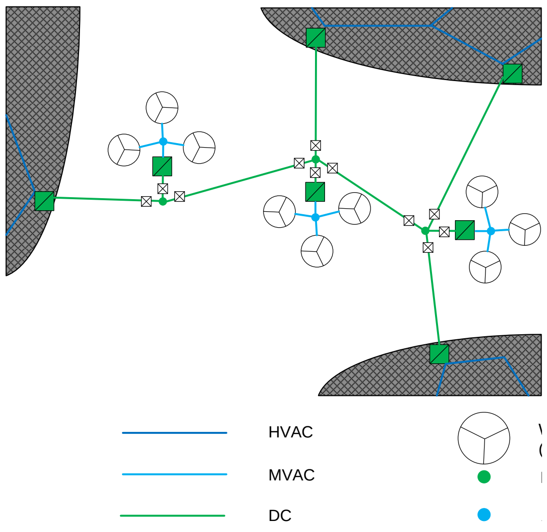
Collection of components

HVDC grid component
Converters station (offshore / Onshore) (half bridge MMC VSC, full bridge MMC VSC)
Cables (HVDC, HVAC) (Submarine, Underground)
HVAC Transformers
Offshore platforms (AC, DC)
Reactive Compensation devices

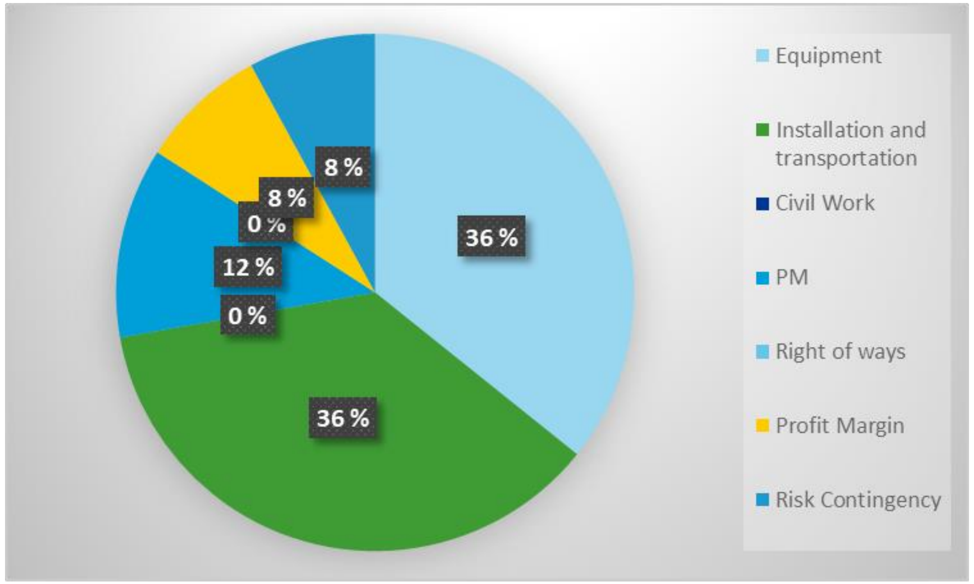
Point-to-Point OWF & IC



All DCCBs



Assumption and sources



❑What do we include?

- Equipment cost, transportation & installation cost, civil works, PM, Risk reserve
- Within procurement cost we include direct material cost, labour cost, R&D cost and profit margins.
- Inflation correction

❑What do we exclude

- Location specific factors, such as water depth, ambient temperature, those will be considered on an average level for the North Sea.
- Project specific requirement such as redundancy, ancillary services and the scope of service contract, the impact of those factors on the cost will be considered on an average level.
- Price fluctuations due to short-term changes in supply and demand will be excluded. We assume a normal market situation.
- Owner cost (e.g. survey, consent/permission)

Technology and dimension principal

- Focus on performances and functionalities, not on implementations.
  - XLPE vs MInd cables
  - Different implementation of DCCBs
  - HVDC platforms solution
  - Less mature technologies such as DRU, LFAC not considered
- Provide a sensible range of ratings considering the application:
  - HVDC rating, [900MW, 2000MW]
  - DC Votlage ±320kV, and ±525kV.
  - AC solution, under 400MW per link, voltage 150 kV, 220/275 kV.

Data collection – samples

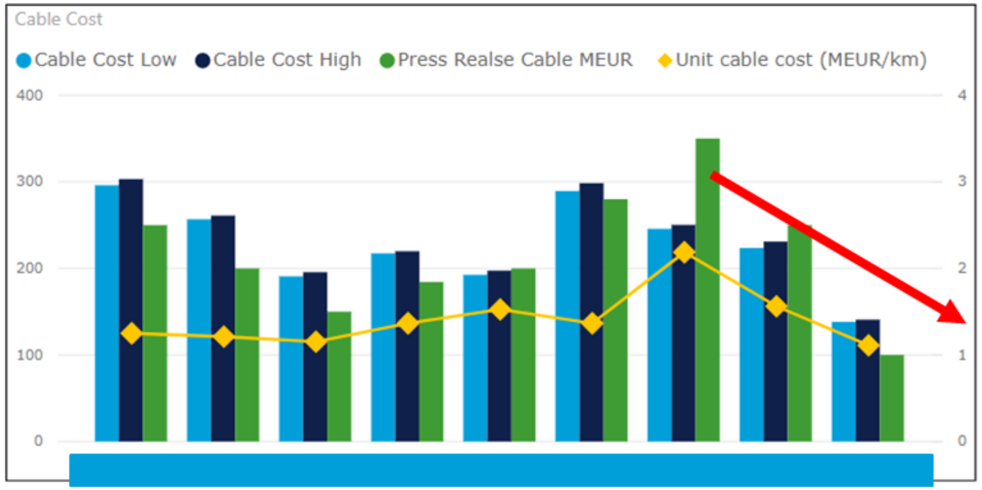
1. Half-bridge VSC HVDC converter station

Voltage (kV)	Rating (MW)	Cost £(M£)			
		Onshore HB MMC VSC (min-max)		Offshore HB MMC VSC (min-max)	
±320	700	[redacted]	[redacted]	[redacted]	[redacted]
	900	[redacted]	[redacted]	[redacted]	[redacted]
	1200	[redacted]	[redacted]	[redacted]	[redacted]
±525	1000	[redacted]	[redacted]	[redacted]	[redacted]
	1400	[redacted]	[redacted]	[redacted]	[redacted]
	1600	[redacted]	[redacted]	[redacted]	[redacted]
	2000	[redacted]	[redacted]	[redacted]	[redacted]

Reference to historical project contract values

- Validation of our cost model again real world projects

Validation Offshore HVDC Projects



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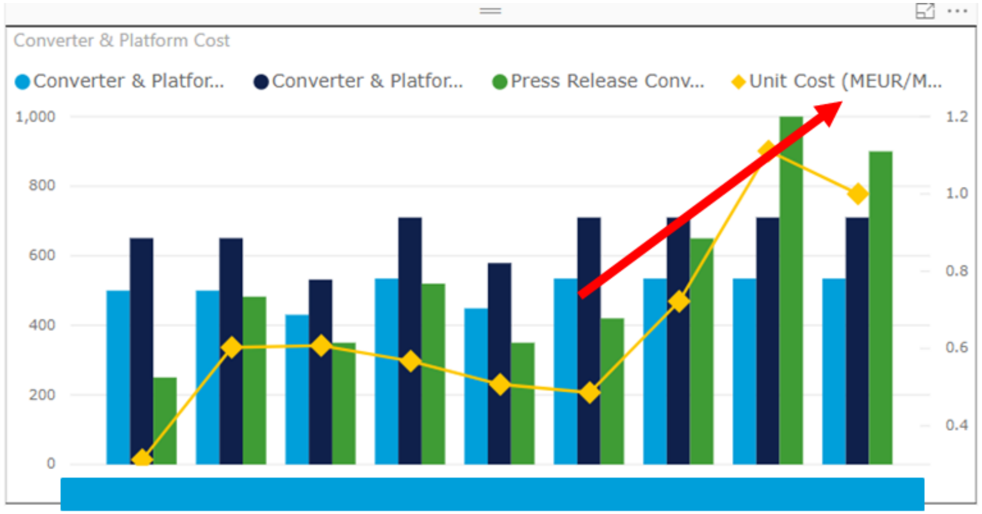

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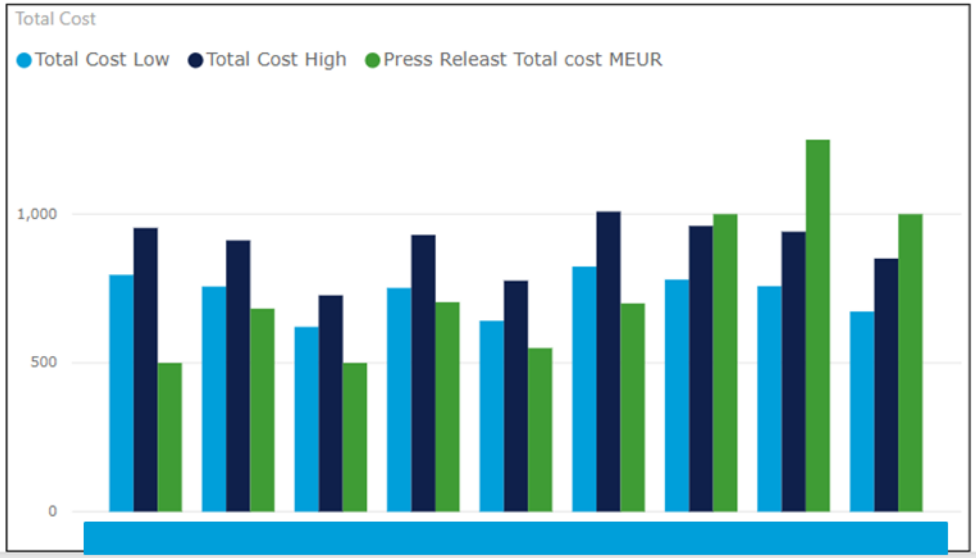


[redacted]

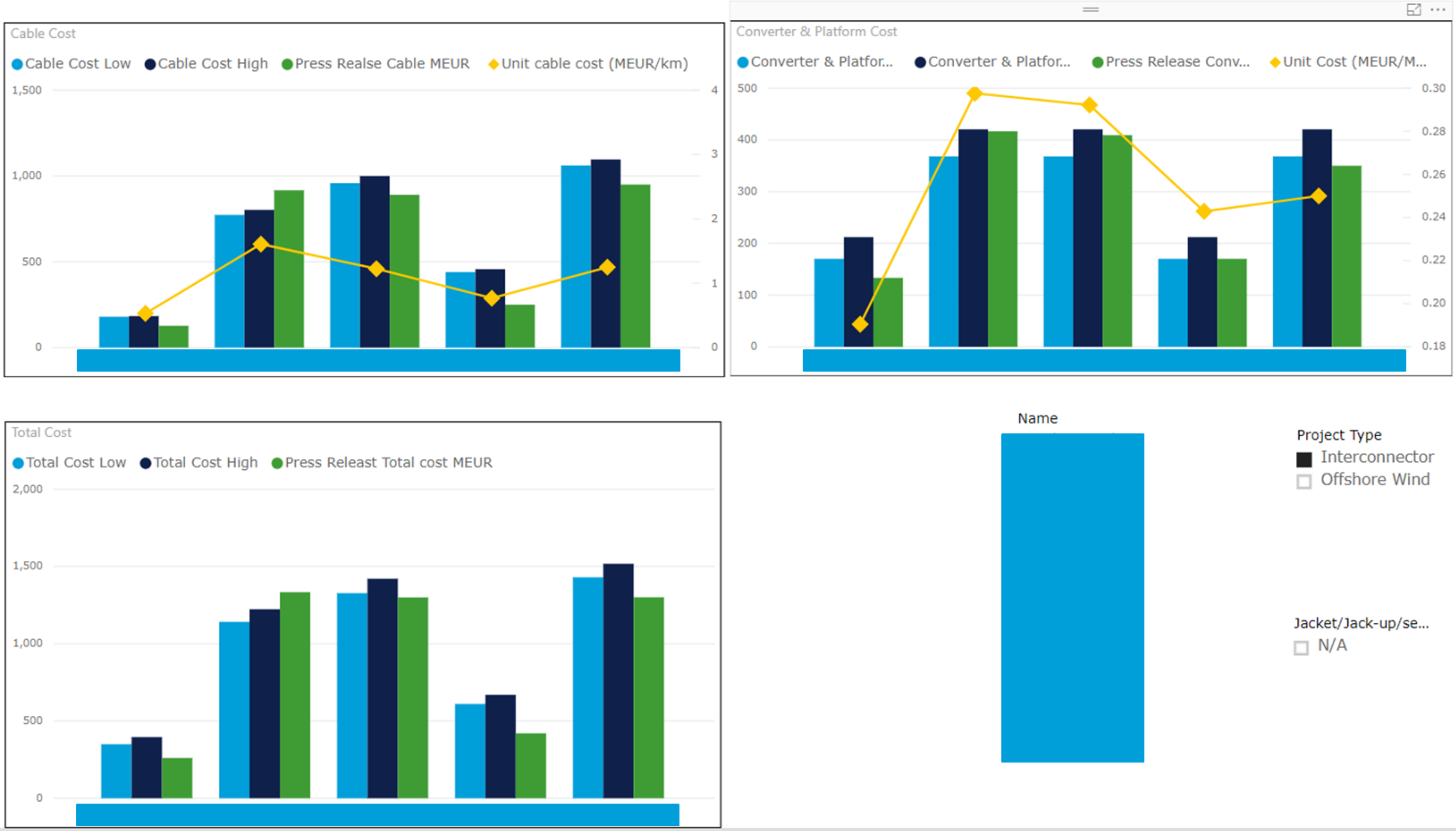
Name

[redacted]

Project Type
☐ Interconnector
■ Offshore Wind

Jacket/Jack-up/se...
☐ Jacket
☐ Jack-up
☐ Semi-Sub

Comparing with Contract values of Interconnector HVDC Projects



Project Type
■ Interconnector
☐ Offshore Wind

Jacket/Jack-up/se...
☐ N/A

Workstream updates

- Connection workstream
- GAP analysis/potential phase 2 work
- Cost-Benefit-Analysis

Next steps

- Recording, slides & feedback form will be circulated to all of those who signed up to our session today
- Workshops and collation of feedback this week
- Follow up on feedback **mid July (w/c 13 July)**
- Further workshops and another webinar **w/c 3 August** on further outputs (Overcoming barriers report, CBA, connection & gap analysis workstreams)

Asks

- Any feedback on what has been presented on conceptual design & unit costs for technology to be feedback to us via workshops or in writing on our feedback form by **COP 3 July 2020**