# Deployment considerations for HVDC Meshed Offshore Grids in the Northern Seas

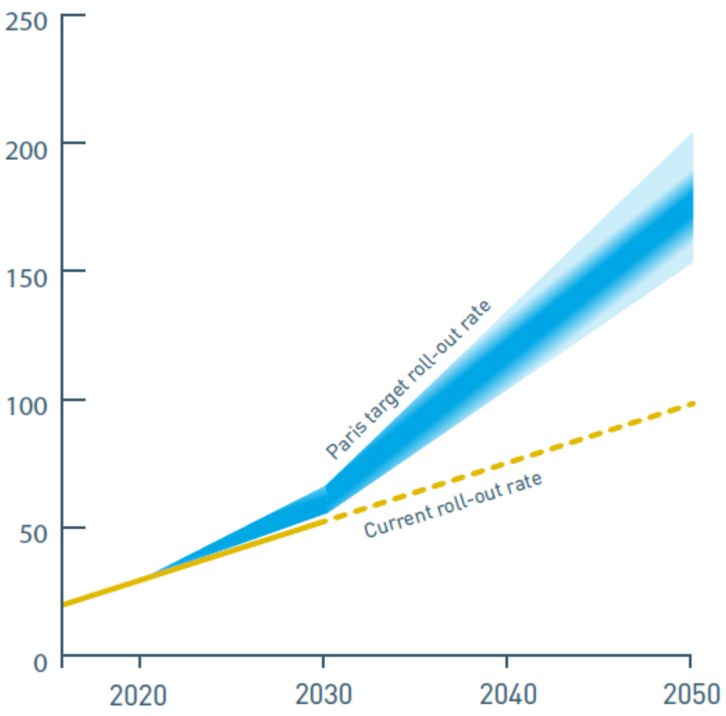
TenneT ● John Moore


This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 691714.

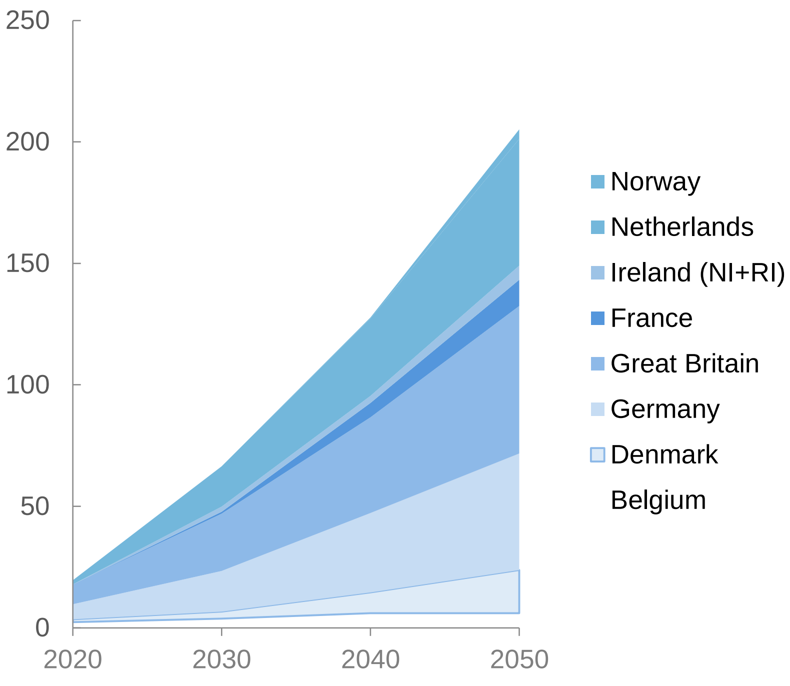
# What is the challenge for transmission operators?

***Current roll-out rate of offshore wind is insufficient to meet Paris target.***

*Projected installed offshore wind capacity range in the North Sea [GW]*




***PROMOTioN worked together with different stakeholders to balance national ambition and top down targets***




- To hit 2050 Carbon targets we need to accelerate the build of Offshore Wind
- Distance to shore increases as near shore locations filled and resistance increases: 55km today to >100km
- Preparation time increases
- Uncertainty as to technological change and need
- A consistent Legal & Regulatory environment is required to facilitate more efficient evacuation and anticipatory investment
- The infrastructure requires to adopt and provide flexibility options at scale and interact with the onshore grid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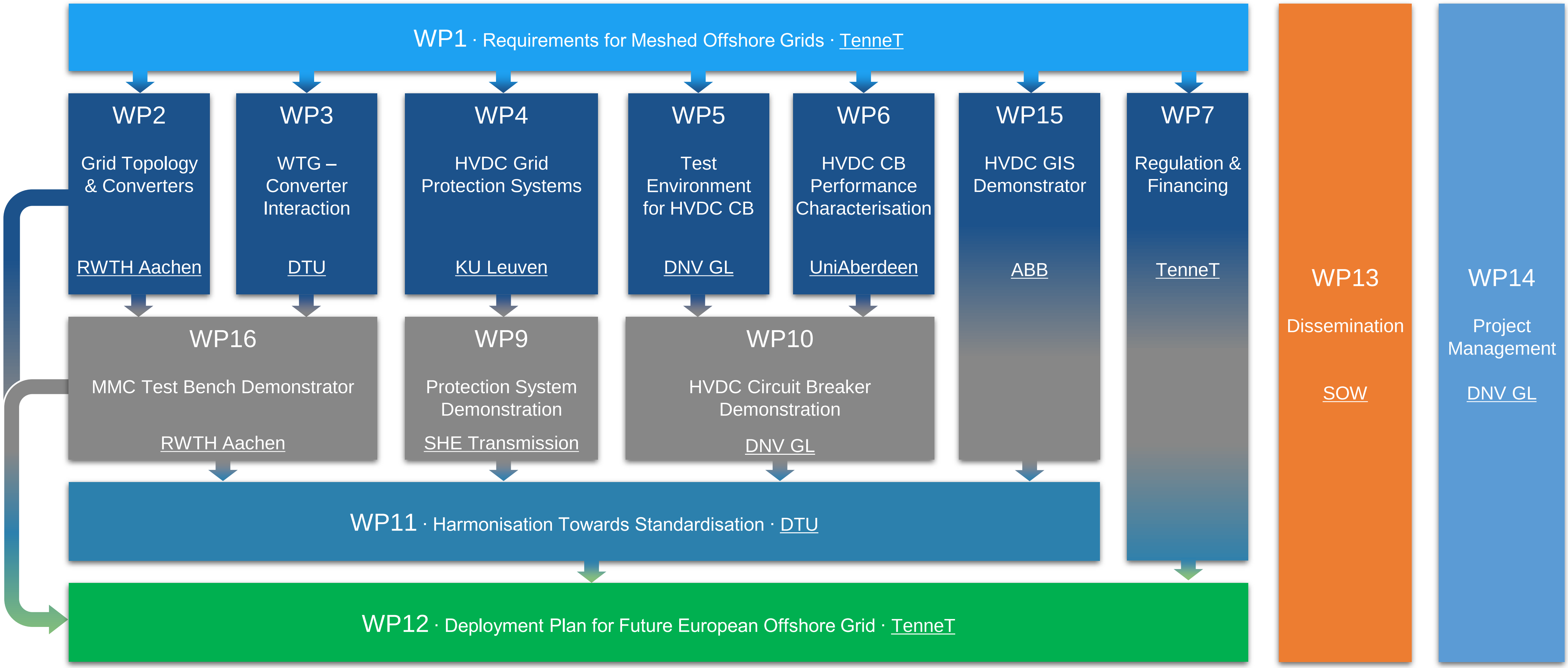
# PROMOTioN researches into technology and broader issues





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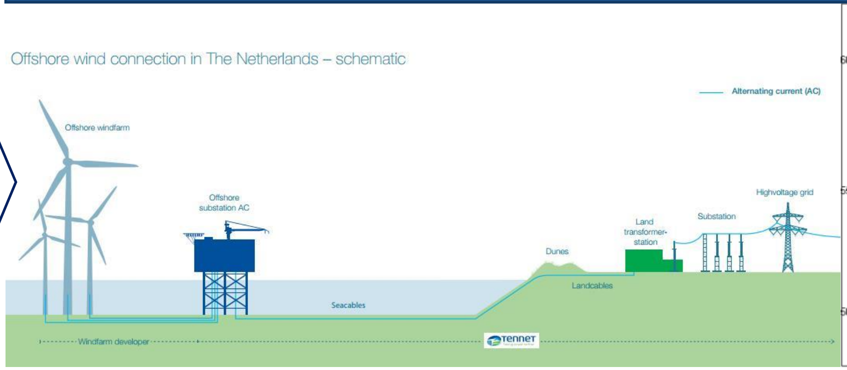
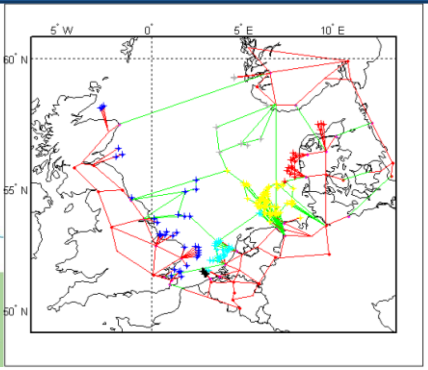
To produce a Deployment Plan for European future offshore grid development.

Technical

Governmental

Financial




Economic

Market

Legal & Regulatory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# Two parallel paths to a Deployment plan:

- Offshore Wind Generation Scenarios
- Topologies
- Technological Choice
- Cost Benefit Analysis

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- Economic Analysis (CBA methods & CBCA Proposals)
- Financing & Potential legal structures
- Legal & Regulatory
- Governmental
- Market Structures


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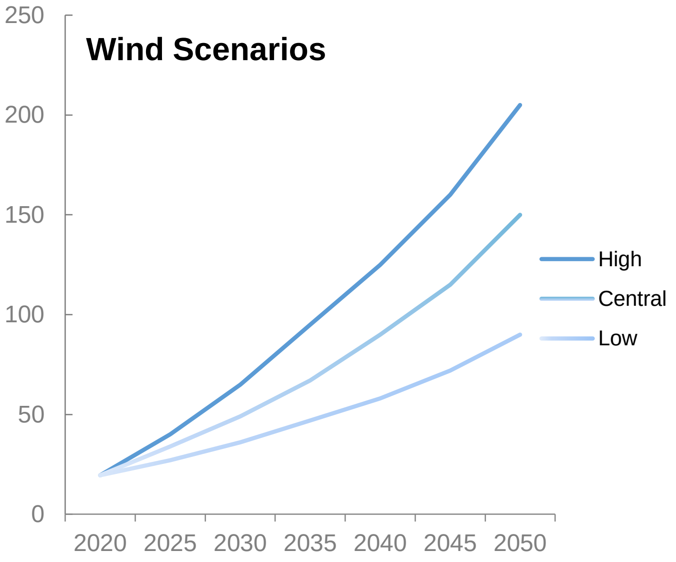
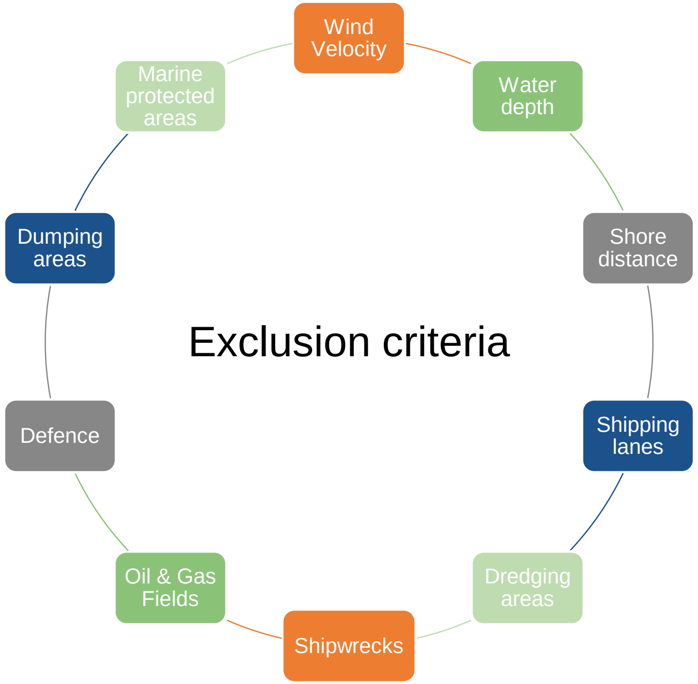
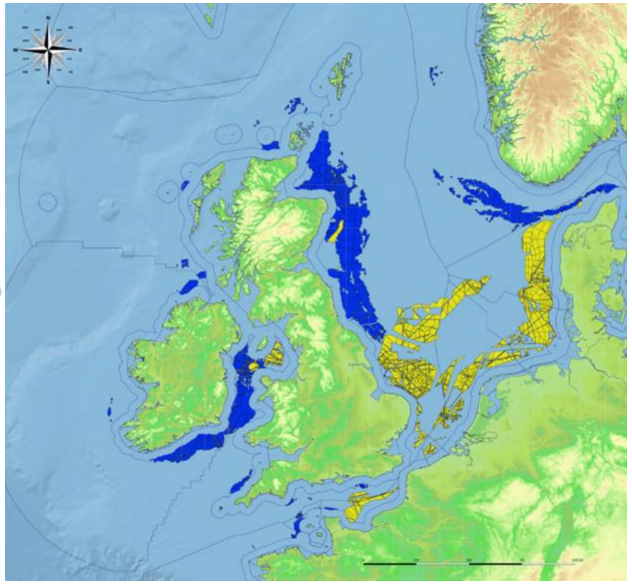
Offshore Wind Generation Scenarios → Topologies → Technological Choice → Cost Benefit Analysis

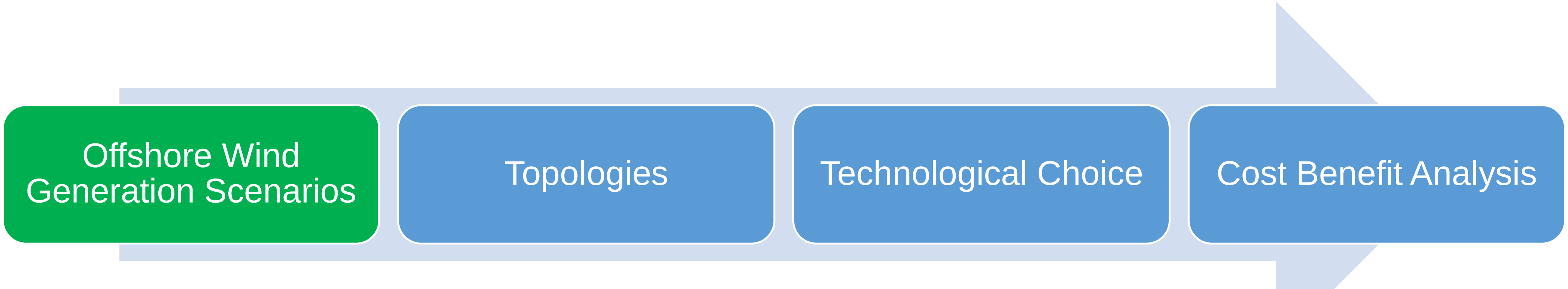
1. Top down market
2. GIS mapping studies
3. Country Allocation




PROMOTiON Projected Locations






# PROMOTiON Recommends

- PROMOTiON High scenario projects higher growth than current ENTSO-e scenarios in order to reach 2050 Carbon reduction targets,
  - Our high scenario is not the highest we have seen in parallel studies.
  - Be aware of space constraints and ability to deliver.

- Optimising offshore wind potential is subject to political influences and does change, e.g. new governing trends shift towards an increased emphasis on RES
  - Positive increase in Wind potential (e.g. DK – greater ambition) can lead to use of better locations for generation. EU Clean Energy Package encourages cooperation.
  - Use local powers for more rational allocation of spatial planning (e.g. NL rationalises spatial planning).

- High development of offshore wind leads to some utilisation of Nature 2000 areas
  - Prioritise and coordinate spatial planning for offshore wind
  - We fixed wind development, but could be optimised more per concept.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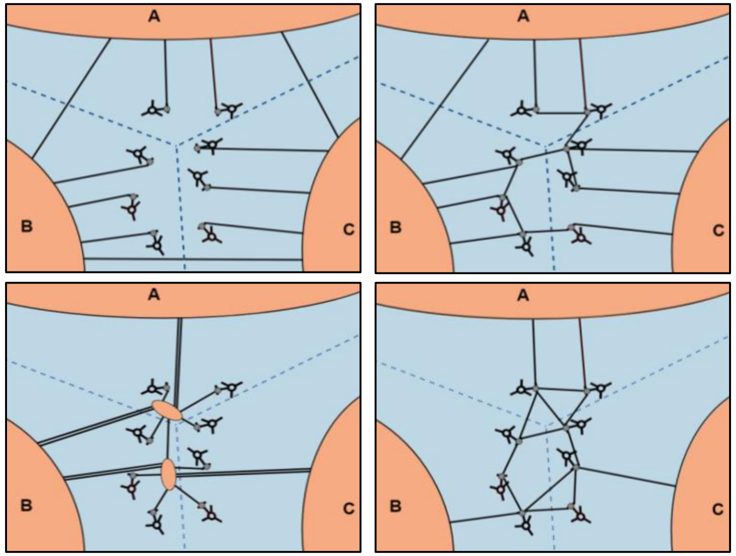
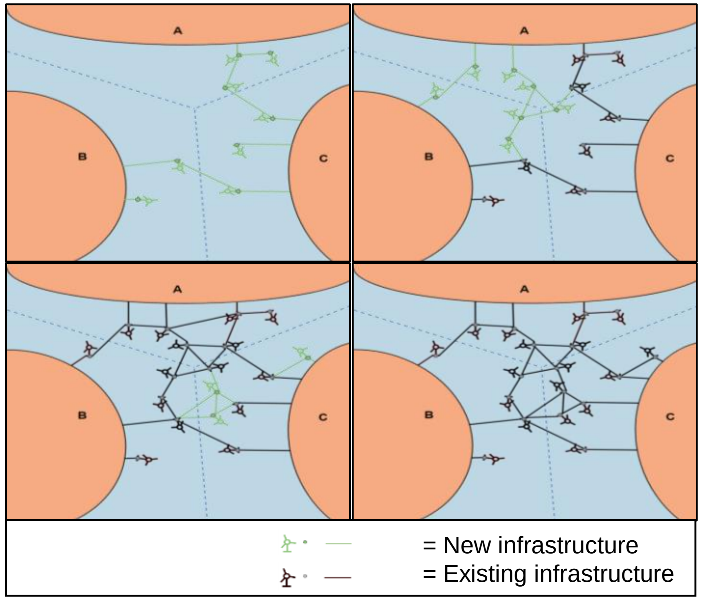
Offshore Wind Generation Scenarios → Topologies → Technological Choice → Cost Benefit Analysis

1. Concepts
2. Temporal development
3. Optimisation




Step 1: Primary Optimization (Minimization of the investment cost to evacuate offshore wind energy) → Step 2: Secondary Optimization (Optimization of the interconnection capacity between countries) → Step 3: Technical feasibility of the proposed grid

Setup of a detailed grid model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Offshore Wind Generation Scenarios | Topologies | Technological Choice | Cost Benefit Analysis

# PROMOTioN Recommends

- Islands planned and built early on in the period (2025 – 2030)
  - PROMOTioN assumes a current status quo that concentrates energy into (small) hubs as Business as Usual
  - For maximum Cost-Benefit, the optimiser suggests a benefit in the use of islands.
  - This is a theoretical model, and requires feasibility and further optimisation.
- Meshing and multi-terminal connections are important and should be used where appropriate
  - Technical choice of bipole architecture and N-1 security criterion reduces benefit of redundant paths
  - Cable maximum power is matched to onshore infeed constraints.
  - The optimisation does not have large amounts of meshing, but it does provide material cost savings in some cases.
- Early planning facilitates meshing later in the period (2040 onward)
  - As distance to shore increases, meshing of offshore wind clusters becomes more cost effective
- Adopt standards to facilitate meshing, but we anticipate ‘stacked’ meshed systems rather than an entire meshed offshore grid
- Interconnection between windfarms of different countries in order to save on cable costs and increase cable utilisation


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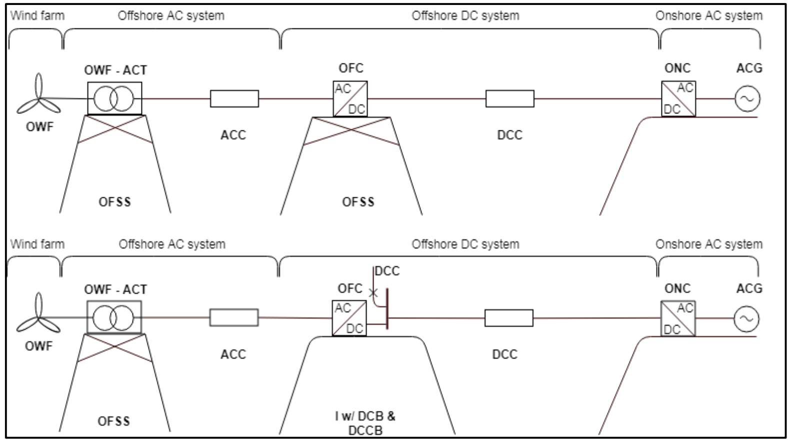
Offshore Wind Generation Scenarios → Topologies → **Technological Choice** → Cost Benefit Analysis

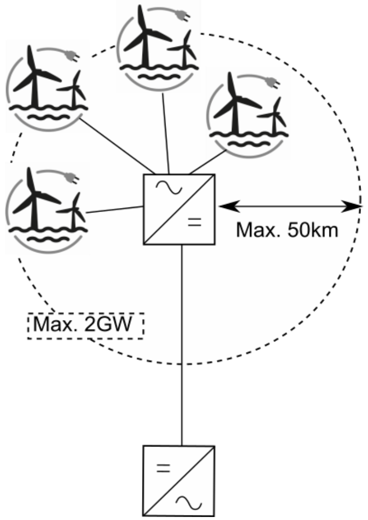
1. Cost data / inputs
2. Clustering
3. Hub design: bare bones and Protection
4. Costing the network

**Cost Data Collection**

*Standard voltages, e.g.525 KV*
*Standard configuration: Bipole with fixed return*
*Standard cable sizes – current Max 2 GW*
*No onshore load shedding – N-1*




*Different Hub structures per Concept with different components (standard architectures depend on distance/power flows)*
*Protection Strategies determined by WP4*




## Costs Analysis

| Investments | Protection Costs (where required) | Operating Costs |
|---|---|---|
| - AC equipment & cables<br>- DC Hub Equipment<br>- cables | | |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Offshore Wind Generation Scenarios → Topologies → Technological Choice → Cost Benefit Analysis

# PROMOTioN Recommends

- Design standard Platforms that can be either modular or built out for multi-terminal use.
  - Protection equipment requires increased space on platforms such that costs increase quickly
- Plan early and well and anticipate future capacity needs to minimise cable costs.
  - Small changes to the topology can have major costs impact
  - Direct connection of AC inter-array cables saves high AC platform costs
- Shorter distance connections will still be in AC, and therefore utilise (cheaper) AC meshing where large power concentrations (Hub model)
- HVDC protection costs dependent on choice of fault clearing strategy
  - Protection may be done fully selective which requires many expensive DC Circuit Breakers
  - Smart protection using grid splitting may significantly reduce protection costs


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Offshore Wind Generation Scenarios → Topologies → Technological Choice → **Cost Benefit Analysis**

1. Network Costs
2. Benefits Analysis
3. Non Quantitative analysis
4. KPIs - LCoT

## Costs Analysis

| Investments | Protection Costs (where required) | Operating Costs |
|---|---|---|
| - AC equipment & cables<br>- DC Hub Equipment<br>- cables | | |

| # | NAME | METHOD |
|---|---|---|
| B1 | Socio Economic Welfare | Quantitative |
| B2 | RES Integration | Quantitative |
| B3 | CO2 Variations | Quantitative |
| B4 | Societal Well-being | Qualitative |
| B5 | Grid losses | Quantitative |
| B6 | Security of Supply – Adequacy | Quantitative |
| B7 | Security of Supply – Flexibility | Qualitative |
| B8 | Security of Supply – Security | Qualitative |
| B9 | Security of Supply – Resilience | Qualitative |
| S1 | Environmental | |
| S2 | Social | |
| S3 | Other | |

**Cost-Benefit Report per Concept-Scenario**


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Offshore Wind Generation Scenarios

Topologies

Technological Choice

Cost Benefit Analysis

# PROMOTioN recommends

- Where sufficient generation concentration use European Hub concept to deliver significant savings in costs for support structures
- Multi-terminal connections depend on anticipatory investment, therefore steer deployment through organised and structured planning.
- Cooperate across Europe to build grid infrastructure (connect hubs in country A to country B if shorter distance)
- Mesh where appropriate not for meshing’s sake
  - Meshing leads to lower curtailment and higher security of supply, but at higher costs for additional infrastructure.
- Different grid goals may lead to additional benefits of the different topologies per region – but overall quite similar. Optimise on grid elements
  - PROMOTioN constraints on onshore load shedding result in retaining 2GW cables. This results in partial redundancy and therefore lower benefits compared to BAU.
- Environmental and social impact of concepts different but none more impactful than the others



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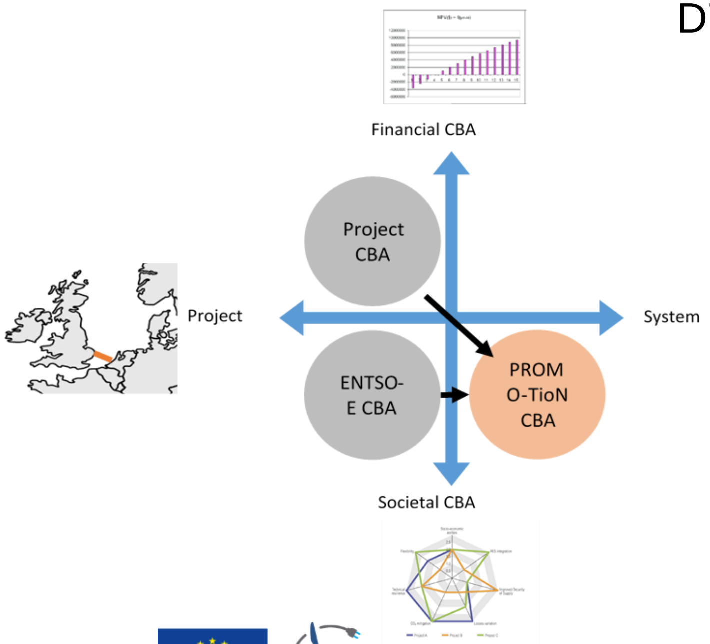
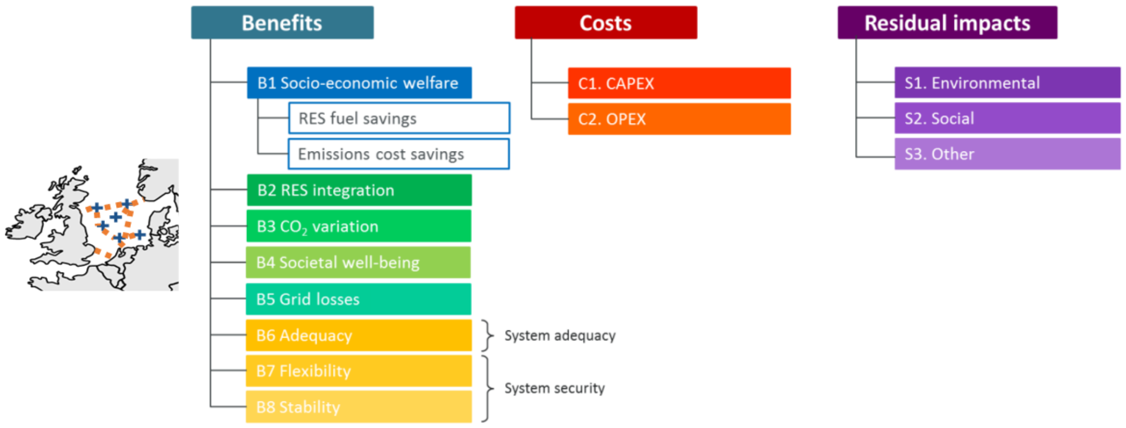
Economic Analysis (CBA methods & CBCA Proposals) → Financing & Potential legal structures → Legal & Regulatory → Governmental → Market Structures

1. Application of improved and standardised (ENTSO-E) CBA techniques
2. Formal and standard Cross Border Cost Allocation

D7.2 analyses how to best allocate cross border costs




## D7.11 Cost Benefit Analysis - Method



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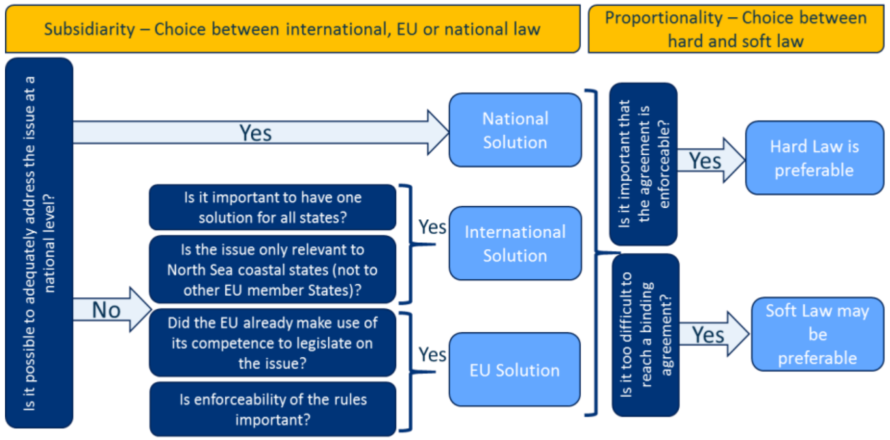
Economic Analysis (CBA methods & CBCA Proposals) → **Financing & Potential legal structures** → Legal & Regulatory → Governmental → Market Structures

1. Financing Investments
2. Potential structures for transmission owners/operators

1. A clear definition of responsibilities and liabilities of investors, constructors and managers of the meshed HVDC offshore grid is advisable, to allow institutional investors, debt and equity providers the clarity needed to make an assessment of the investment risk. Offshore grid asset ownership should be designed to ensure the participation of multiple funding sources to support the challenging volume of required investments.
2. Grid ownership when meshed is likely to become more "blurred":
   1. e.g. with North Sea Wind Power Hub, we already see a consortium ownership. Incumbents are likely to see a dilution in ownership, and need similar controls/management to cross border interconnectors.
   2. PROMOTioN recommends clear rules for Cross Border Cost Allocation, in order to clarify the discussion, but we also accept pragmatism in the eventual finance of new grid infrastructure.

| NSG TSO | Co-operation of national TSOs/third parties | Tenders before construction | Tenders post construction |
|---|---|---|---|
| • System operation, asset operation (O&M), ownership, construction<br>• Owned by National TSOs or national TSOs & private investors, or private investors | • Extension of the current national structures<br>• Each actor applies their current approach within its own EEZ | • Asset operation (O&M), ownership and construction<br>• Private or public investors/ national or international/ public-private consortia | • Construction carried out by national TOs or a single TO<br>• Assets tendered to third parties (private investors) for ownership, maintenance and asset operation |

Economic Analysis (CBA methods & CBCA Proposals) | Financing & Potential legal structures | **Legal & Regulatory** | Governmental | Market Structures




North Sea coastal states should work to develop a multilateral mixed partial agreement (a North Sea Treaty) which can serve as a framework for formalising the rules of a meshed offshore grid.

1. Cooperation – Develop a mixed partial agreement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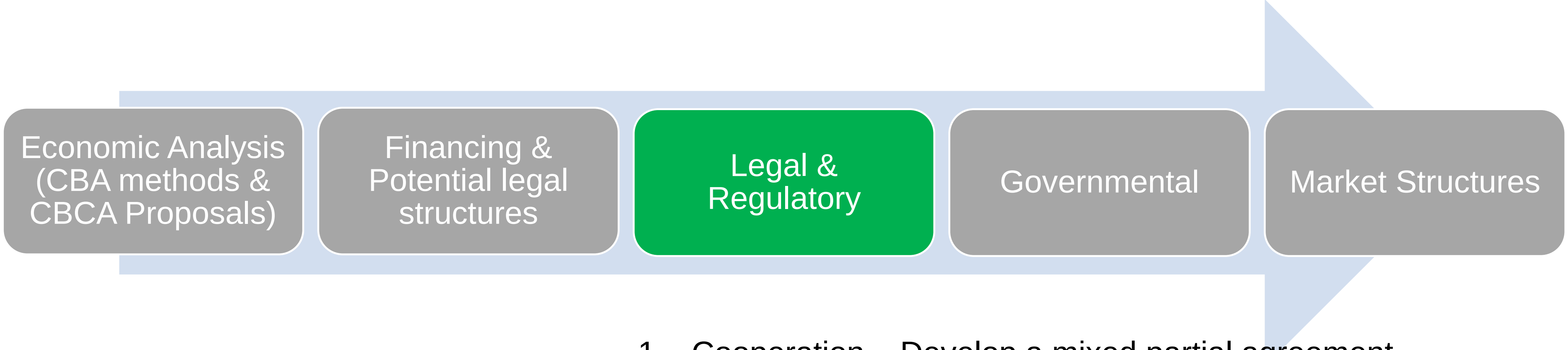
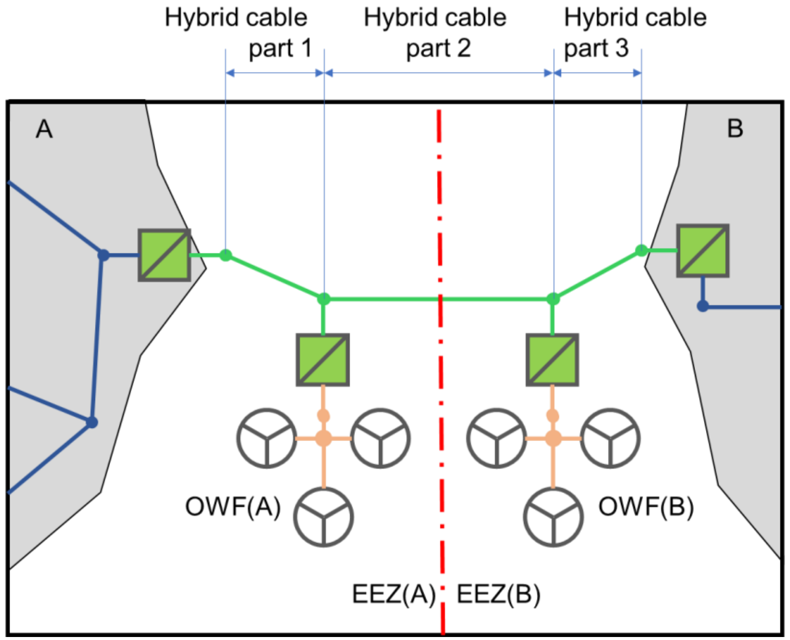



1. Cooperation – Develop a mixed partial agreement
2. A robust Legal definition of an Offshore Hybrid Asset




North Sea coastal states should adopt a common interpretation of the law of the sea regarding hybrid assets within the MOG, by taking a broad interpretation of UNCLOS terminology. This definition of hybrid assets should be set out in a multilateral (mixed partial) agreement that is used for the governance of the MOG.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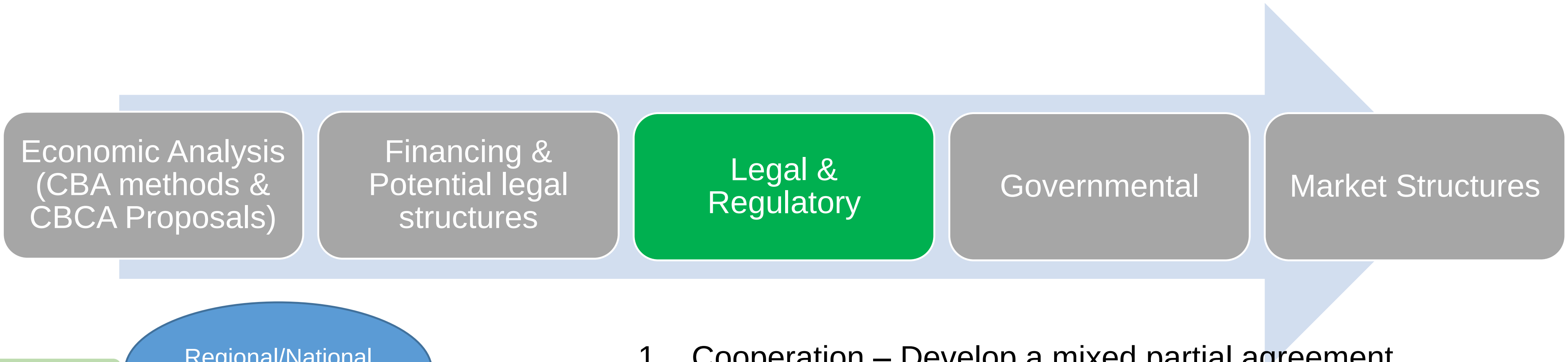
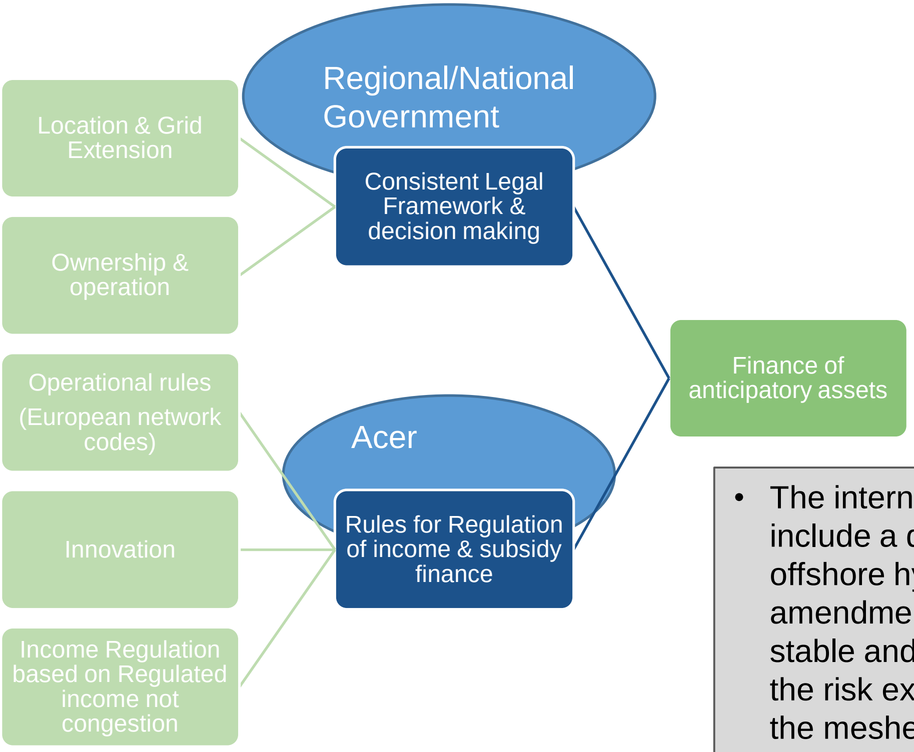
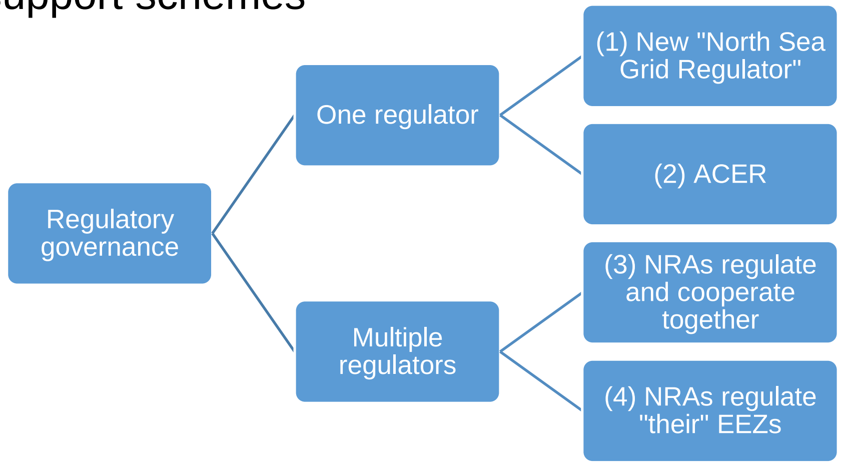



1. Cooperation – Develop a mixed partial agreement
2. A robust Legal definition of a Hybrid Asset
3. Agreement on approach to regulating the grid (who and how)
    1. Finance of Anticipatory assets
    2. Transmission owner income regulation
    3. Coordinated offshore wind support schemes

- The internal market regulation should be amended to include a definition and a substantive provision on how offshore hybrid assets should be regulated. The amendments should be designed to support a long-term, stable and predictable regulatory framework, so to reduce the risk exposure on capital in relation to investments in the meshed offshore grid.
- It is recommended that NRAs organise themselves in a specific regulatory coordination group to oversee grid development and operations through strong, mutual cooperation.





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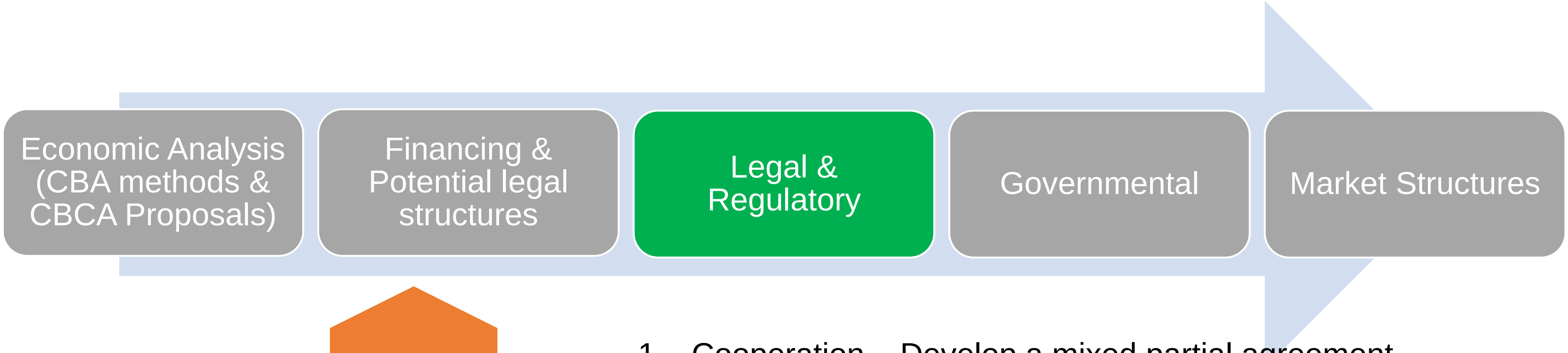


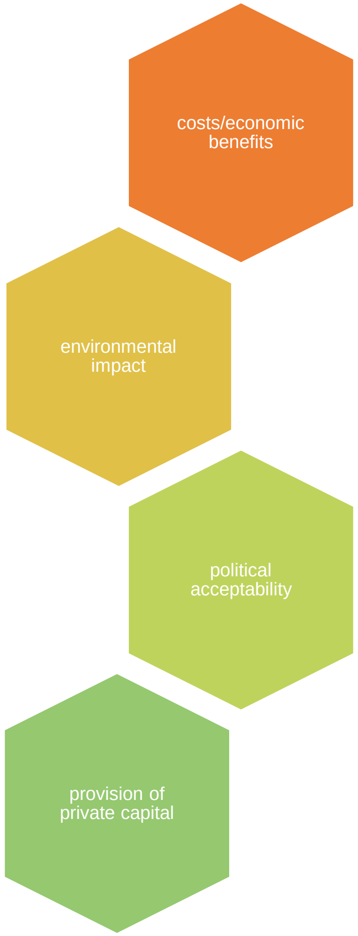


1. Cooperation – Develop a mixed partial agreement
2. A robust Legal definition of a Hybrid Asset
3. Agreement on approach to regulating the grid (who and how)
   1. Finance of Anticipatory assets
   2. Transmission owner income regulation
   3. Coordinated offshore wind support schemes
4. Decommissioning regulation

The internal market regulation should be amended to include a definition and a substantive provision on how offshore hybrid assets should be regulated. The amendments should be designed to support a long-term, stable and predictable regulatory framework, so to reduce the risk exposure on capital in relation to investments in the meshed offshore grid.


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Economic Analysis (CBA methods & CBCA Proposals)

Financing & Potential legal structures

Legal & Regulatory

Governmental

Market Structures

National Stakeholders
• Finance Ministry
• Economic Affairs
• Environment
• Fisheries
• Defence
• Nat. reg. agency
• Etc.

National Concepts
• Business as Usual
• National Meshed

International Stakeholders
• EU agencies
  - ENTS-E
  - ACER
  - CPMR
• Regional Agencies
  - NSMC
  - OSPAR
  - ICES
  - NorthSEE
• Global Institutions
  - UNCLOS
• Manufacturers
• OWF developers

Regional Concepts
• European Meshed

- Simplify at National level in short term
- Align National and International decisions
- Work on international solutions

1. Planning & permit Processes alignment/simplification
2. Stakeholder participation and Consultation

- Streamline the permitting process to reduce the risk of legislative change during the permitting phase. Legislative changes should not retroactively impact projects already approved. Once granted, permits/licenses will remain valid for the duration of the construction and operation phase.
- A central approach for grid planning and strong coordination of grid development plans in terms of timing and location is recommended to increase the transparency of future network investments requirements and their cross-border impact.


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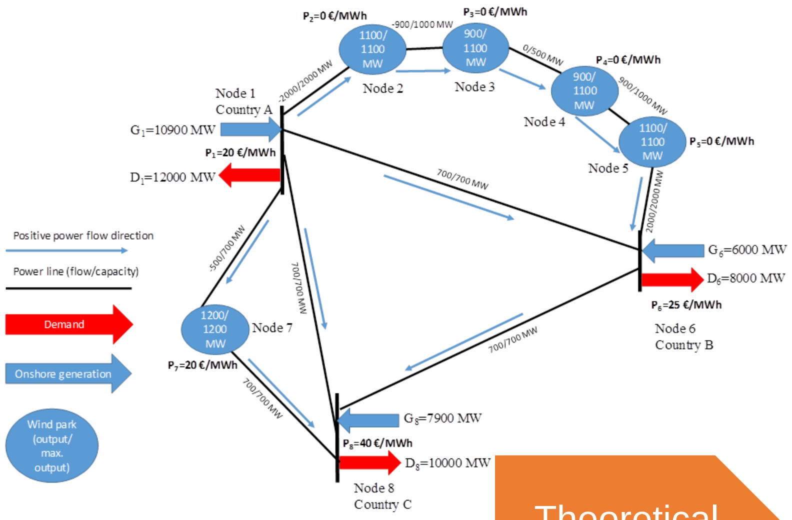
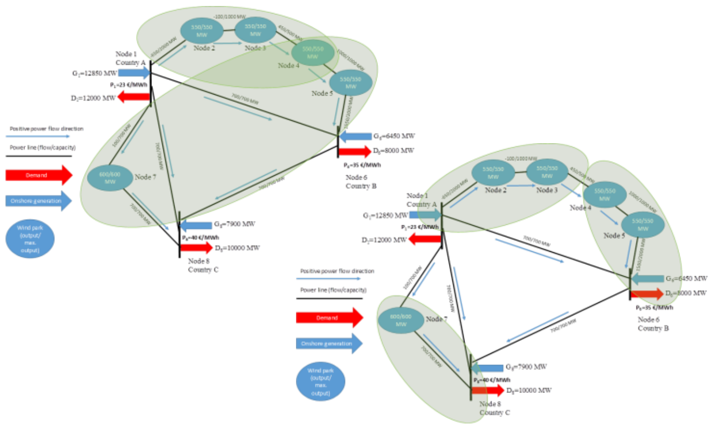
Economic Analysis (CBA methods & CBCA Proposals) | Financing & Potential legal structures | Legal & Regulatory | Governmental | **Market Structures**

1. Market structures from extension of country bidding zone into EEZ to small zones models
2. Market models where meshing exists



Theoretical example grid → Test for different Mkt models → Test for different Wind loads

- In the short term, current practice of extending the National Bidding zones to the country EEZ is sufficient
- With an increase in development and meshing, then a small zones approach may be more appropriate.
- Market management and organisation has not been studied, but new trading tools could be implemented to support this proposal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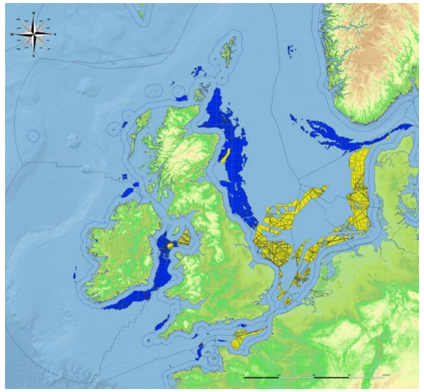
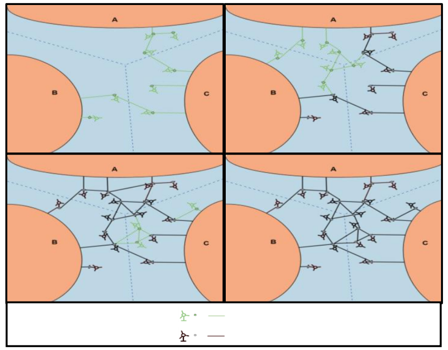
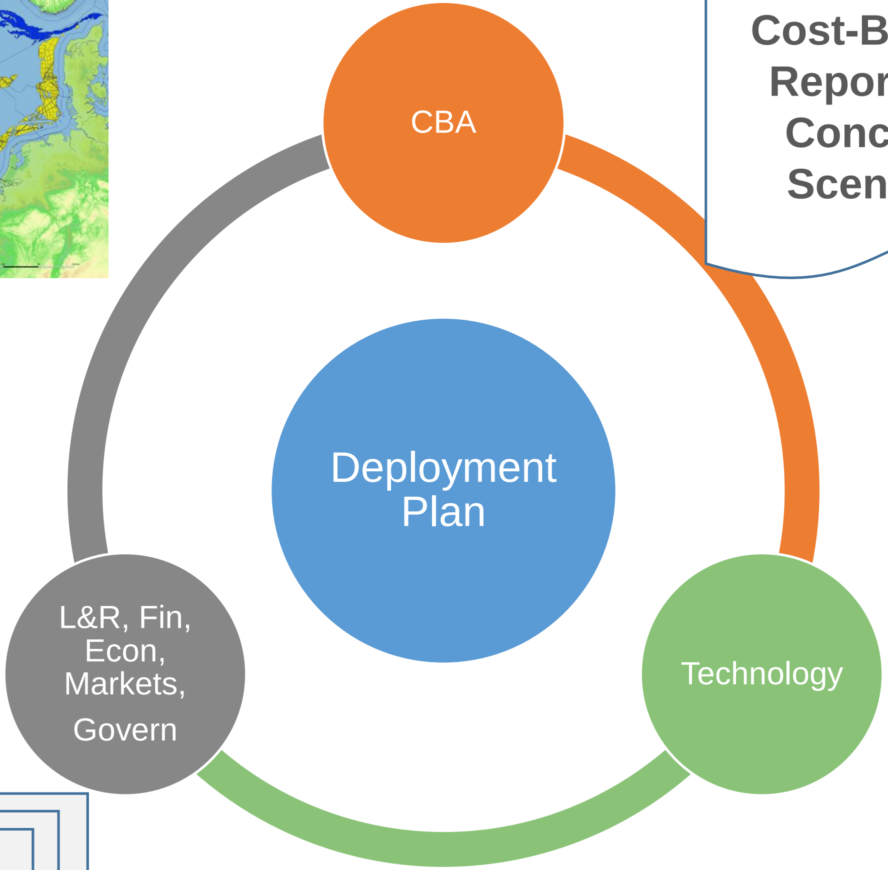




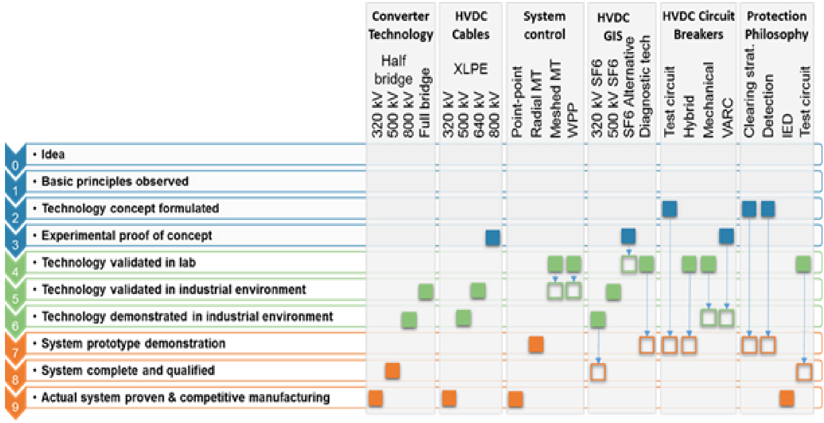



**Cost-Benefit Report per Concept-Scenario**

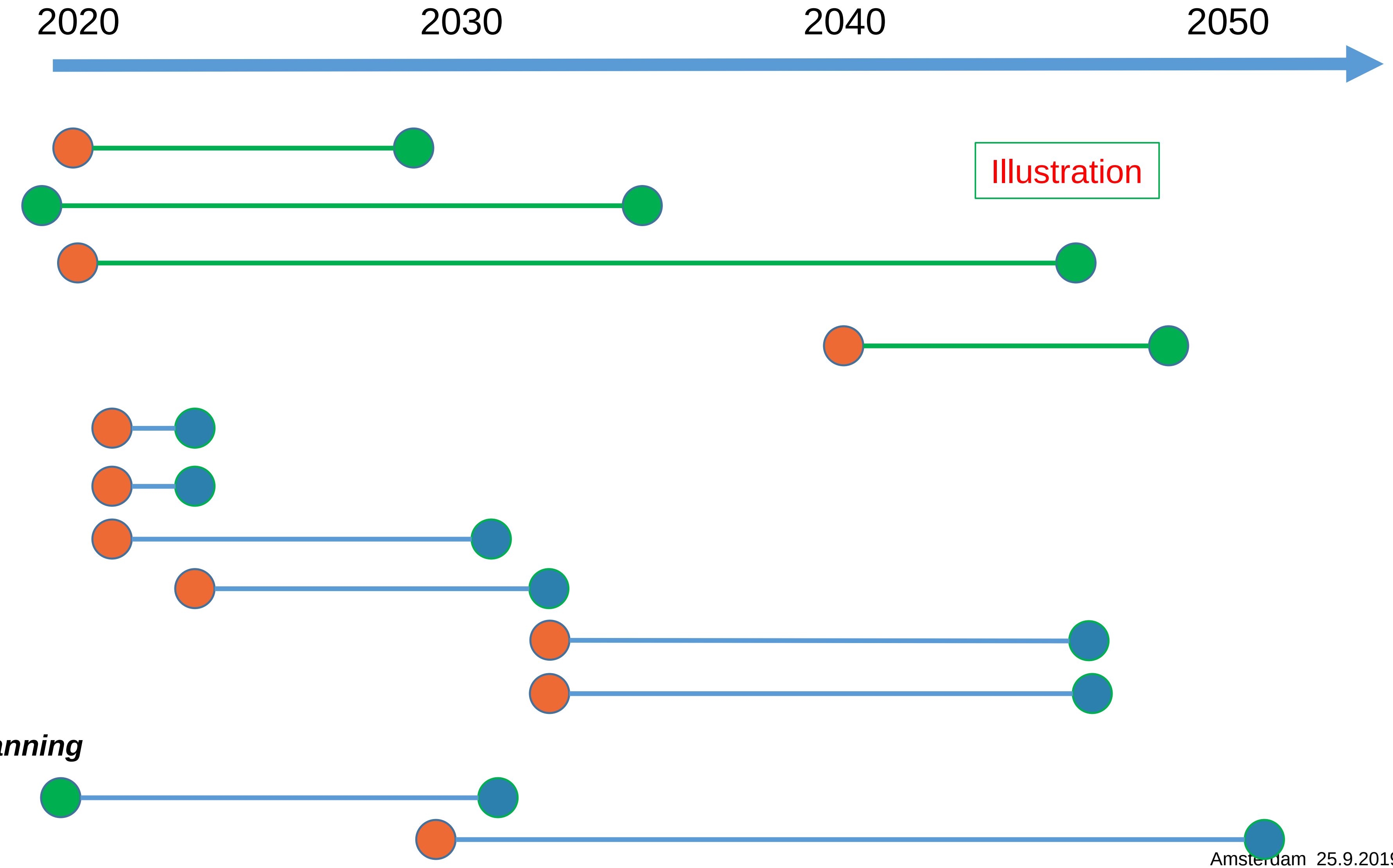
- Hybrid Assets
- CBCA
- Planning
- Environment
- Finance
- Small Zones

- Procurement

Short term Projects



# Deployment plan gives direction and says what is needed – we suggest ground rules for potential development and interoperability




***Legal & Regulatory***

- *Hybrid Asset*
- *Mixed partial agreement*
- *Coordinated planning*

***Market Models***

- *Small Zones Bidding Zone*

***Technology***

- *Anticipatory investments*
- *Interoperability*
- *Island solution*
- *DCCB Industrial test*
- *Application of DCCBs*
- *Application of GIS*

***Wind Generation Roll-out Planning***

- *National*
- *European*



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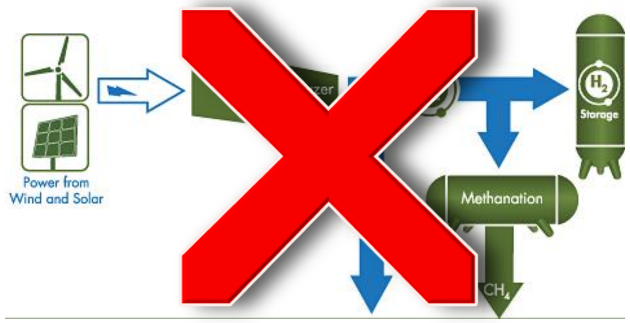
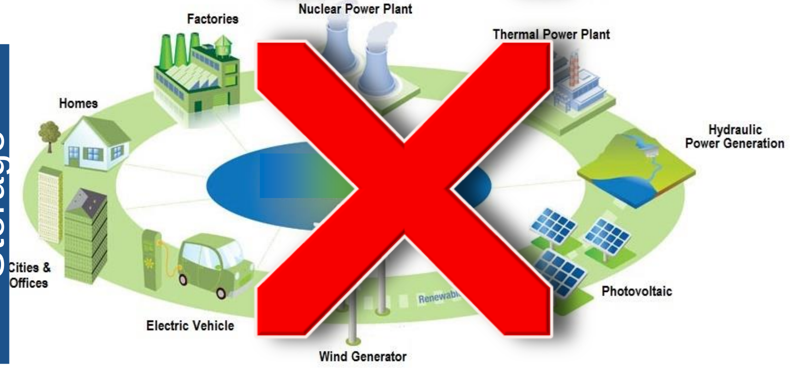
# Boundaries of the deployment plan
# - what we propose as the best solution will never be built

Power to Gas

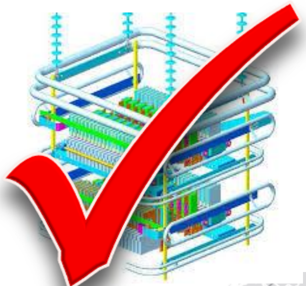



Power to Consumption


Distributed Storage

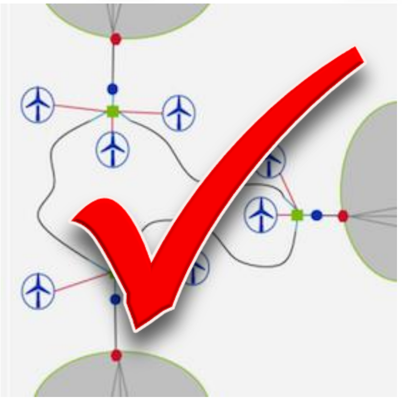



**Primary Goal:**
**E**fficient, secure evacuation of offshore generated wind energy to shore



New Technology

Grid Reinforcement



Aggregated viewpoint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APPENDIX

# DISCLAIMER & PARTNERS

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## PROJECT COORDINATOR

DNV GL Netherlands B.V.
Utrechtseweg 310, 6812 AR Arnhem, The Netherlands
Tel +31 26 3 56 9111
Web www.dnvgl.com/energy

## CONTACT

John NM Moore - john.moore@tennet.eu

Jelle van Uden - jelle.van.uden@tennet.eu

TenneT TSO B.V.
Postbus 718
6800 AS Arnhem
Nederland

## PARTNERS

DNV GL Netherlands B.V., ABB AB, KU Leuven, KTH Royal Institute of Technology, EirGrid plc, SuperGrid Institute, Deutsche WindGuard GmbH, Mitsubishi Electric Europe B.V., Affärsverket Svenska kraftnät, Alstom Grid UK Ltd (Trading as GE Grid Solutions), University of Aberdeen, Réseau de Transport d'Électricité, Technische Universiteit Delft, Statoil ASA, TenneT TSO B.V., Stiftung OFFSHORE-WINDENERGIE, Siemens AG, Danmarks Tekniske Universitet, Rheinisch-Westfälische Technische Hochschule Aachen, Universitat Politècnica de València, SCiBreak AB, Forschungsgemeinschaft für. Elektrische Anlagen und Stromwirtschaft e.V., Ørsted Wind Power A/S, The Carbon Trust, Tractebel Engineering S.A., European University Institute, European Association of the Electricity Transmission & Distribution Equipment and Services Industry, University of Strathclyde,  S.L., Prysmian, Rijksuniversiteit Groningen, MHI Vestas Offshore Wind AS, Energinet.dk, Scottish Hydro Electric Transmission plc

## About PROMOTioN

PROMOTioN is a European Union funded Horizon 2020 project consortium, formed to address the technical, regulatory, financial and legal challenges for offshore HVDC transmission networks. It consists of 33 organizations including European HVDC manufacturers, Transmission System Operators (TSO), academic institutions, testing institutions and consultants. This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691714.

For more information please visit www.promotion-offshore.net


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# Any Questions?


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