Connecting Offshore Wind Farms

A Comparison of Offshore Electricity Grid Development Models in Northwest Europe

Commissioned by:

Réseau de Transport d'Électricité and TenneT TSO B.V.

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FOREWORD

Europe is building world's largest power plant: with a targeted 70 GW[1] of offshore wind in NW-Europe, by 2030; potentially even ramping up to 230 GW[2] (Ecofys, 2017) in the 2040s. Relentless innovation and cost reduction have made offshore wind a main component of Northwest-Europe's energy transition, towards zero-emission electricity before 2050. Such large amounts of offshore wind require a co-ordinated approach towards offshore grid developments and secure system integration now and in the future.

Electricity Transmission System Operators (TSO's) have been given the responsibility to realise and operate offshore electricity transmission infrastructure for projects in Belgium, Denmark, France, Germany and the Netherlands. In a context of energy transition, this task has become an important part of their overall mission. To ensure a reliable and uninterrupted supply of electricity via their high-voltage grids for the citizens of the countries they operate in.

The realisation of an interconnected offshore electricity grid is not without its challenges and the benefit of a 'TSO build' approach is not always clear. Therefore, RTE and TenneT have taken the initiative to commission an independent study on offshore grid development models, as an important step in their dialogue with stakeholders. A dialogue that is essential for the future of this ground-breaking development in the global energy transition!

Navigant supports the ambitions echoed for years by the energy industry, system operators, member states, and European institutions to develop a world-leading offshore energy infrastructure in the North Sea. When done right, such a system would bring benefits to the region and wider Europe in terms of the sustainable development of energy, economies, and marine life (Navigant, 2017).

I hope you find this report useful and welcome any feedback and questions you may have.

Kees van der Leun
Director, Navigant
01 July 2019

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[1] *Adding-up the 2030 targets from the country fact sheets in Appendix B (including part of the French target).*

[2] *Navigant analysis shows that a total offshore wind capacity of 230 GW is required in the North Seas by 2045 to ensure a fully sustainable power supply for the surrounding countries in line with the Paris Agreement's objective.*

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DISCLAIMER

This report was prepared by Navigant Netherlands B.V. (Navigant) for Réseau de Transport d'Électricité and TenneT TSO B.V. The work presented in this report represents Navigant's professional judgment based on the information available at the time this report was prepared. Navigant is not responsible for the reader's use of, or reliance upon, the report, nor any decisions based on the report. NAVIGANT MAKES NO REPRESENTATIONS OR WARRANTIES, EXPRESSED OR IMPLIED. Readers of the report are advised that they assume all liabilities incurred by them, or third parties, as a result of their reliance on the report, or the data, information, findings and opinions contained in the report.

OBJECTIVE AND STRUCTURE

The report's objective is to compare different offshore grid development models on a qualitative and quantitative basis. The cost comparison was limited to capital expenditure (CAPEX) input, as operational cost data from UK projects is not available. However, operational aspects are relevant and have been included in the qualitative comparison of pros and cons for each development model.

It provides a factual basis for discussions with governments, regulators, and the offshore wind industry. The analysis has been anonymised and clients were given the opportunity to comment on the draft version of this report before publication.

The document is structured as follows:

Section 1: Provides the introduction of the report and highlights the important role of offshore wind in the energy transition. Offshore grid development is positioned within this wider context.

Section 2: Provides an overview of applied grid connection concepts in selected European offshore wind markets. It highlights difference in requirements per market, e.g., high voltage DC in Germany due to long distance from shore.

Section 3: Contains general information on the two main offshore grid development models currently applied in Northwest Europe.

Section 4: Presents the results of a qualitative analysis of two different offshore grid development models (developer build versus Transmission System Operator [TSO] build).

Section 5: Presents the results of a quantitative cost comparison between the two different offshore grid development models (developer build versus TSO build). Including uncertainties, and limitations.

Section 6: Highlights the main conclusions and recommendation based on the analyses in this report.

Section 7: Information sources used in this report are recorded in the reference list in this final section of the report. Clear links are provided in the text, tables and figures throughout the document.

Appendix A: More detailed 'country factsheets' are included in the Appendix, with some key facts and figures of the country specific offshore wind developments and grid connection models.

Appendix B: Provides the OFTO cost levels from initial to final transfer value.

ABBREVIATIONS

AC	Alternating Current
CAPEX	Capital Expenditure
CfD	Contract for Difference
DC	Direct Current
DEVEX	Development Expenditure
FTV	Final Transfer Value
GW	Gigawatt
KPI	Key Performance Indicator
kV	Kilovolt
LCoE	Levelised Cost of Electricity
MOG	Modular Offshore Grid
MVA	Mega Volt Ampere
MW	Megawatt
MWh	Megawatt-Hour
NETSO	National Electricity Transmission Systems Operator
O&M	Operations and Maintenance
OFGEM	UK Office of Gas and Electricity Markets
OFTO	Offshore Transmission Owner
OHVS	Offshore High Voltage Station
OPEX	Operating Expenditure
PM	Project Management
RES	Renewable Energy Sources
SO	System Operator
TO	Transmission Operator
TRS	Tender Revenue Stream
TSO	Transmission System Operator
TV	Transfer Value
VSC	Voltage Source Converter

EXECUTIVE SUMMARY

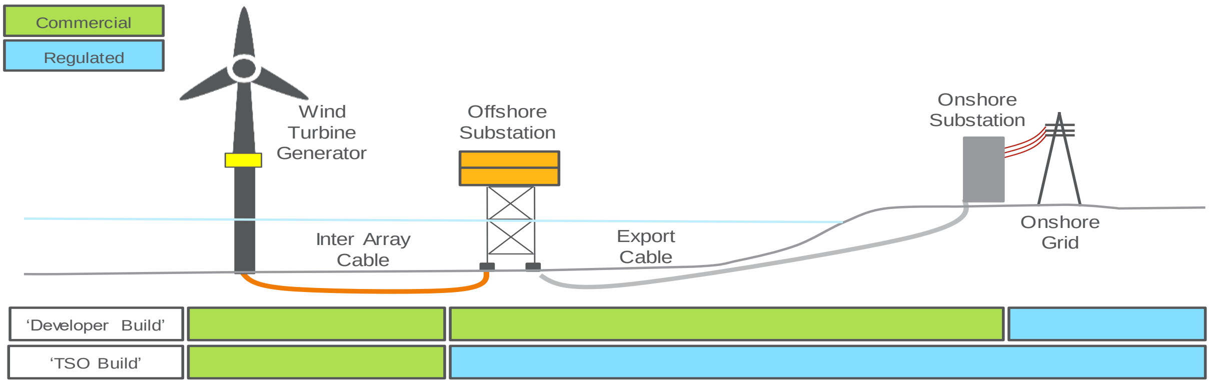
The focus on grid connection costs for offshore wind is increasing

A dramatic cost reduction trend for offshore wind is evident across Europe, driven by technology innovation and reallocation of cost and risks to national governments to allow for scale, standardisation, a steady roll-out and further cost reduction. The first subsidy-free projects were awarded in Germany and the Netherlands in 2017/2018, excluding grid connections. Cost reduction potential for grid connection is lower (DNV-GL, 2019), which makes it an increasingly important element in the total cost of offshore wind electricity and therefore important to provide more insight into the development models.

Two offshore grid development models are applied in Europe:

1. The 'Developer Build' model, where commercial parties develop and operate the offshore transmission assets.
2. The 'TSO Build' model, where the offshore grid development and operation is mandated to the local TSO by the national government.

Figure 1. Allocation for offshore wind farm and transmission asset development and Operation



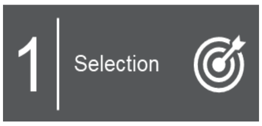
Source: Navigant

Most European offshore wind markets have transitioned from a 'Developer Build' to a 'TSO Build' model. Governments see benefits in the TSO build model and have taken a larger share of the development risk and costs. This could mean that a larger share of offshore wind will be financed with public money and that there is less competition in the offshore electricity transmission market, even though TSO's have an obligation to organise competition in their tenders. It is therefore important to understand the differences in each development model and highlight the pros and cons.

This report aims to provide a factual basis for discussion

This report contains a comparison of the 'Developer Build' and 'TSO Build' offshore grid development models. The aim is to provide a factual basis for discussions between governments, regulators, TSOs, and the offshore wind industry, and to consider the long-term consequences of today's decisions and investments on the energy system.

A three-step approach was followed to compare offshore grid development models:



- Development models
- Cost comparison criteria

- Qualitative categories
- KPI's and cost comparison

- Qualitative analysis
- Quantitative analysis

TSO build, and developer build offshore grid development models vary in terms of cost and risk allocation

Differences in offshore grid development models and regulatory frameworks directly impact development and financing, and indirectly determine multiple areas of long-term offshore grid development (see Figure 2). To realise a stable and secure energy system with large shares of renewable energy sources (RES) in the future, it is important to ensure short term transmission efficiency as well as to consider long term system optimisation.

Figure 2. A summary of potential and perceived pros and cons for each offshore grid development model

	TSO Build	Developer Build
Planning and Design	👍 Holistic approach, early initiation of development, opportunity to standardise design for economies of scale. Shared assets (single connection for multiple wind farms) can limit environmental footprint. 👎 Platform specific developer needs (e.g. with respect to innovations) may not be fully reflected in the design and procurement process of the potentially larger and more complex standardised transmission systems.	👍 A single party is responsible for wind farm and offshore grid scope in planning and design stage. 👎 Incremental development with a short horizon. Developers use different design concepts, which prevents standardisation and asset sharing.
Commercial and Finance	👍 TSO's benefit from more favourable financing conditions and a stable pipeline of projects can reduce costs. 👎 Larger amounts of (pre-) investment capital is required. TSO's do not face the same market (cost) pressures as developers in competitive tenders.	👍 Commercial parties could have more flexible financing options (e.g. higher debt shares which could result in lower Weighted Average Cost of Capital) and competition could lead to cost reductions. 👎 Higher cost of capital (e.g. including transaction costs from developer to OFTO) and a lower potential to reduce societal costs through a coordinated approach.
Construction and Interface Risk	👍 Offshore wind deployment and onshore capacity reinforcements are coordinated. 👎 A complex technical and procedural offshore interface between parties with different drivers. Could result in stranded asset costs if not properly coordinated.	👍 Single party coordination limits the interfaces and reduces the risk of construction delays. 👎 Lack of system perspective: onshore reinforcement not included in developer scope.
Operations and Reliability	👍 Larger standardised asset base (OPEX reduction potential), higher redundancy and greater control by transmission responsible party. 👎 Unavailability penalties might be less effective as ultimately costs could be (partially) socialised.	👍 Non-OFTO only[3]: Risk of export cable and platform failure is with party most effected. O&M of the wind farm and grid connection can be aligned. 👎 Transmission asset typically have a longer design lifetime than a wind farm, which leaves full asset utilisation in the long term uncertain.

Source: Navigant analysis

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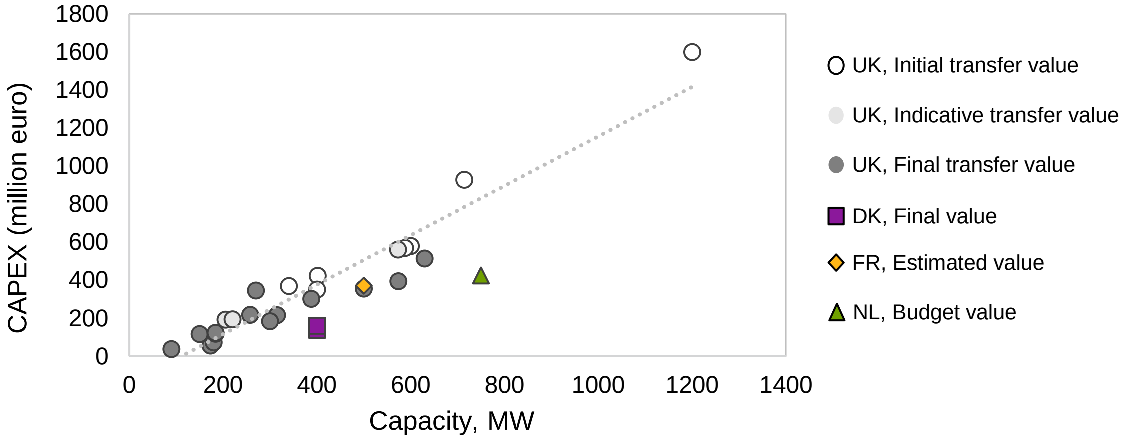
[3] Applicable to existing offshore wind farms in Belgium and the Netherlands (see country factsheets in Appendix A)

Offshore infrastructure can be realised cost-efficiently through TSO build approach

A comparison of publicly available data shows that the UK developer build model has resulted in generally higher CAPEX per installed MW HVAC grid connections than in the TSO build offshore grid development model in Denmark, France and the Netherlands (Figure 3).

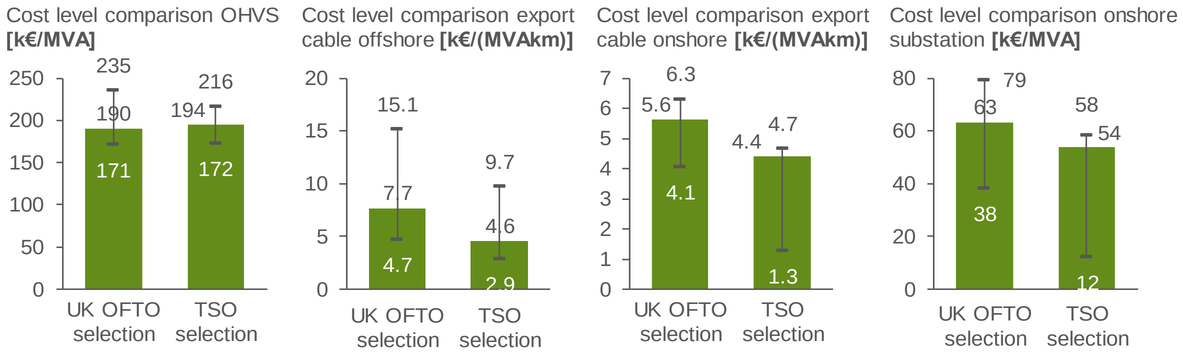
Figure 3 Offshore HVAC transmission system CAPEX comparison.



Source: Navigant analysis based on DNV-GL, 2019, with input from RTE
Note: Trend line only represents UK connection systems

The results of the quantitative cost comparison by Navigant, presented in Figure 4 and further explained in the report, show that cable and onshore substation cost ranges are lower for TSO build compared to developer build grid connections. Offshore platform cost ranges are comparable even though water depth is higher compared to the UK OFTO connections. Also, the TSO selection includes information from budgeted cost, while final transfer values (typically lower than initial transfer values) are used for OFTO projects.

Figure 4. Cost level comparison results (CAPEX only)



Source: Navigant analysis

Overall conclusion and recommendation

This first of a kind comparison has shown that a TSO build approach to AC offshore transmission asset development can be realised at lower cost levels than the developer build approach. Moreover, the longer-term benefits compared to a developer build approach, as summarised in figure 2, are likely to be significant in a context where large-scale and far offshore wind clusters will require innovative system integration solutions to keep cost levels down while maintaining security of supply.

It is recommended to monitor offshore grid cost level development through future updates of this analysis, including realised cost levels from relevant grid connections.

1. INTRODUCTION: THE EVOLVING ROLE OF THE TSO

Cost-efficient and secure integration of offshore wind in the energy system is a challenge.
As Europe's offshore wind industry matures and expands, secure integration of offshore wind energy is a topic of increasing importance. Historically, projects were realised closer to shore and grid integration could be facilitated without (or with relatively simple) grid reinforcements. Future large-scale and far offshore wind clusters will be costly and will likely require innovative system integration solutions to keep cost levels down, including flexibility options like electricity conversion and storage. It will be a challenge to realise offshore wind potential at lowest cost for society while also maintaining security of supply.

Development models for offshore electricity transmission infrastructure are evolving.
Offshore wind farms are connected to the onshore electricity grid with dedicated conversion and transmission technology as well as other technical components. Together these form the offshore transmission system of a wind farm project. The development, construction and operation of each offshore grid connection system takes place in a development model determined by policy and market regulations.

In Europe, two major offshore grid connection development models are applied:

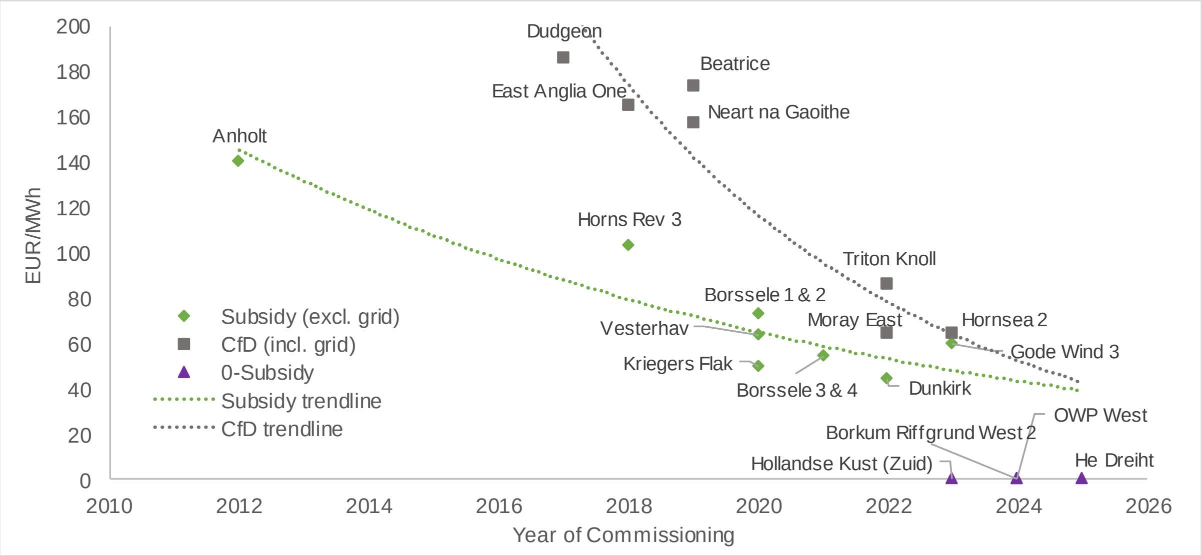
1. The 'Developer Build' model, where commercial parties develop and operate the offshore transmission assets.
2. The 'TSO Build' model, where the offshore grid development and operation is mandated to the local TSO by the national government.

Most European offshore wind countries (Germany, Netherlands, Belgium, France) have adopted a TSO build model. In some of these markets the first-generation wind farms were realised through a developer build model. Now, TSO build offshore grid development models have been applied to de-risk wind farm development, allow for scale, standardisation, a steady roll-out and cost reduction. These national governments have taken more control of offshore wind and grid developments, noting long-term societal benefits of a regulated system with a larger share of the risk and responsibility for the offshore grid allocated to the TSO.

Grid connection costs have become a larger fraction of total cost of electricity
A steep cost reduction trend is visible across offshore wind projects in Europe. Figure 1 shows publicly available tender results from the United Kingdom developer build model (CfD including grid cost) and from Denmark, Germany and the Netherlands (subsidy excluding grid cost). The figure shows a decrease in LCoE for offshore wind farms for both models. Recent tenders without grid connections in Germany and the Netherlands have resulted in 0-subsidy bids. However, the offshore grid remains subsidised, which has led to increasing focus on innovation and investment reduction for grid connection systems in these countries.

Large public offshore infrastructure investments require careful consideration
There are varying viewpoints on the (cost-)efficiency of the two offshore grid development models. This report compares the development models and provides a factual basis for discussions with governments, regulators, and the wind industry, based not only on cost assumptions but also on long-term societal benefits.

Figure 1. Comparing Offshore Wind Cost Reduction Trends in the UK and Europe



Source: Navigant analysis
Note: for zero-subsidy projects it is not possible to determine the cost level as this is only known to the developer. The projects have therefore been included at €0/MWh which is the subsidy level, not the actual cost level.

1.1 Approach to the analyses in this report

The offshore development models and grid connection criteria were selected first; then the comparison categories and cost assessment framework were defined. Both offshore grid development models were compared on a qualitative (pros and cons) and quantitative (cost components) basis. Figure 2 provides an overview of the three-step approach:

Figure 2. Overview of the approach to compare the two offshore grid development models

Approach	Qualitative Comparison	Quantitative Cost Comparison
1 Selection	Offshore grid development models: • Developer Build (UK) • TSO Build (Belgium, Denmark, France, Netherlands)	UK OFTO criteria: • **Final transfer value** should be defined, i.e., license should be granted • **Wind farm size** >200 MW TSO criteria: • **Connection size:** >200 MW • **Connection type:** Alternating Current (AC) Connection should include an **offshore platform.**
2 Framework Definition	Definition of **comparison categories**, which are equally important in both grid development models.	Definition of **cost assessment framework** and key performance indicators (**KPIs**): • Definition of relevant cost assessment framework for UK OFTO and TSO wind farm connections Setup of relevant KPIs to benchmark costs under cost assessment framework.
3 Assessment and Comparison	**Qualitative assessment** of pros and cons for the selected offshore grid development models. Based on the development categories defined in the framework definition.	**Cost assessment** of selected grid connections on the cost components as defined in the cost assessment framework, against the defined KPIs.

Source: Navigant

2. APPLIED TECHNICAL GRID CONNECTION CONCEPTS

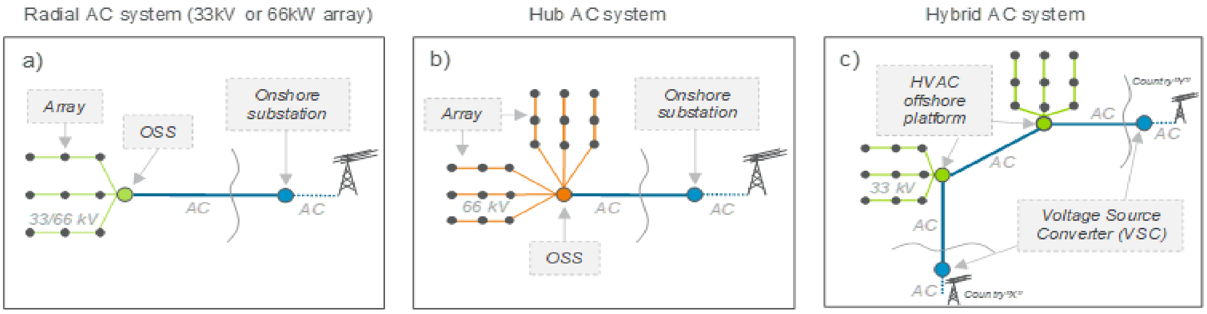
Grid connection technology must be noted when comparing different development models. Each offshore wind farm and grid connection is slightly different in terms of size and connection type. Different transmission technologies are applied independent from the grid development model. Therefore, it is important to understand the technical concepts in order to select the right projects for inclusion in the (cost) comparison framework.

The offshore wind farm location and export cable landing point have a large bearing on the technical grid connection concept. Various technical grid connection concepts have been applied across Northwest Europe to optimise local transmission and onshore grid integration. Most of the current installed capacity is close to shore and connected via alternating current (AC). Offshore connections with long transmission distances in Germany have been connected via direct current (DC) to optimise the transmission system in terms of costs and electrical losses. The ‘tipping point’ for cost efficient application of HVDC technology is determined by the distance from shore (80 km-100 km) and capacity level (>1 GW).

2.1 AC Technology

Figure 3 provides a schematic overview of currently applied AC connection concepts. Radial grid connection with 33 kV array system (a) is a proven technology implemented in most wind farms realized today. As the wind turbine capacity and total wind farm size are increasing, the market is progressively switching to higher voltage levels of inter-array cables, focusing mainly on 66 kV. Additionally, TSO’s are developing hub systems to allow multiple wind farm connections i.e. asset sharing (b). Higher cable voltage levels allow for more wind turbines to be connected to a single inter-array cable, thus lowering the cost by cutting down on the number of strings within the OWF. The 66kV system does require higher substation equipment cost (compensation equipment, switchgear, J-tubes), however, the higher equipment cost is compensated with fewer inter-array strings leaving a positive impact on the total LCoE. Finally, a hybrid AC system solution (c) has recently been installed linking Kriegers Flak wind farm in Denmark with the Baltic 2 wind farm in Germany, which allows the electricity to be traded in both directions reducing the need for power curtailment. To balance the frequencies of Danish and Germany transmission systems, voltage source converters (VSCs) are installed at the onshore interface points.

Figure 3 Schematic AC offshore grid connection concepts



Typical project parameters

Concept schematic	a)	b)	c)
OWF capacity	<~400 MW	<~700 MW	<~600 MW
OWF distance to PCC	~80 km[2]	~80 km[2]	~60 km
Maturity/Roll-out status	Widely applied	Under development	1st project realized
Construction time (FID to Operation)	~2 years	~3 years	~5 years
Relative initial investment cost[1]	€	€	€€
Countries applied	🇳🇱 🇩🇰 🇧🇪 🇬🇧 🇩🇪 🇫🇷	🇳🇱	🇩🇰 🇩🇪

Source: Navigant analysis

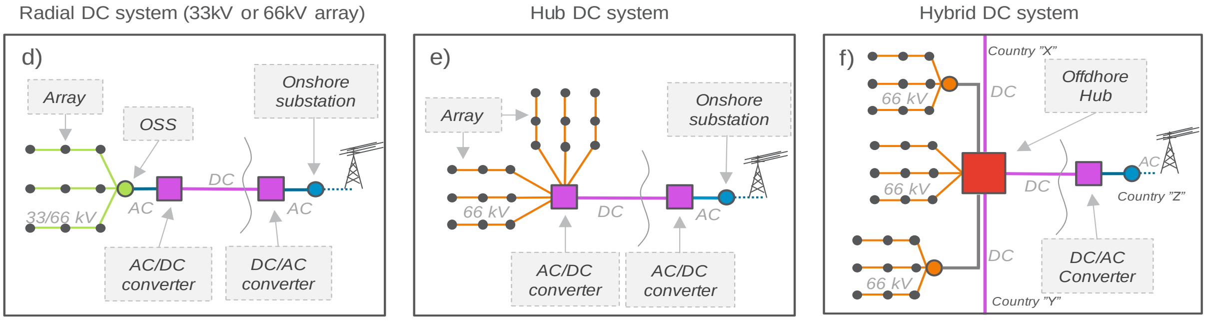
[1] Euro symbols indicate initial investment level requirement, it does not reflect the LCoE

[2] Long distance AC connections applied in the UK with intermediate compensation platforms

2.2 DC Technology

Alternatively, DC technology is beneficial for longer distance (>100 km) and high capacity connections to the grid as it allows transferring electricity with lower losses and no reactive energy. Figure 4 provides a schematic overview of the DC grid connection concepts. The AC output from wind turbine generators must be converted to DC at an offshore location and backwards from DC to AC at the onshore grid connection point, requiring two additional converter stations in the solution (d and e). Nonetheless, high cost of the DC grid connection technology can be rationalized by lower export cable costs and power loss, lower environmental footprint, as well as the pipeline effect of connecting multiple OWFs into a single offshore grid connection point. The radial DC system with a 66kV array cables (e) would potentially lower the total investment costs further by phasing out the collector station and linking OWF strings directly to AC to DC converter station.

Figure 4 Schematic DC offshore grid connection concepts



Typical project parameters

Concept schematic	d)	e)	f)
OWF capacity	~900 MW	~1- 2 GW	>2 GW
OWF distance to PCC	~100 km	~100 km	>100 km
Maturity/Roll-out status	Widely applied	Future	Conceptual
Construction time (FID to Operation)	~5 years	~5 years	?
Relative initial investment cost[1]	€€	€€	€€€
Countries applied	🇩🇪	🇩🇪 (🇳🇱)	🇪🇺

Source: Navigant analysis

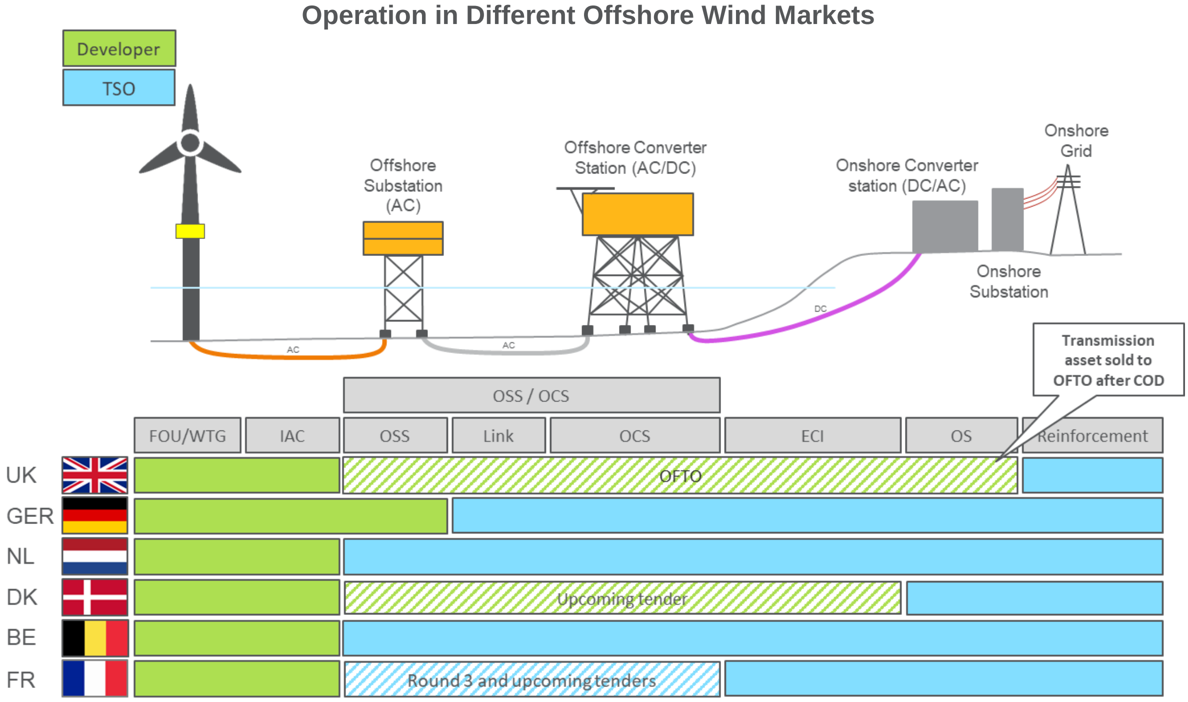
[1] Euro symbols indicate initial investment level requirement, it does not reflect the LCoE

Finally, hybrid DC system (f) solutions are currently discussed among the North Sea countries to accommodate the growth in offshore wind capacity long term by integrating large-scale offshore wind energy into the wider regional energy system in a cost-efficient way. Such solutions are based on a combination of offshore wind generation and interconnection via transmission hubs, where power is collected and brought to multiple markets via high capacity DC cables. This solution could lead to higher asset utilization and increased flexibility in a system with significantly higher shares of Renewable Energy Sources (RES). Large scale solutions like the North Sea Wind Power Hub (between Denmark, Germany and the Netherlands) are being evaluated in the public domain.

3. OFFSHORE GRID DEVELOPMENT MODELS EXPLAINED

National governments allocate responsibilities differently for offshore grid development. Figure 5 shows a schematic representation of grid development responsibility allocation for six European offshore wind markets. The UK is currently the only market with a developer build offshore grid development approach. The grid development models in other countries have generally evolved from direct connections established and operated by commercial parties towards a TSO build grid development model where the TSO has a legal obligation or a government mandate to design, build, and operate the offshore grid. The Danish energy agency recently announced an 800 MW offshore wind tender with a developer build approach towards grid development. Appendix A contains fact sheets that provide information on the various grid development models applied in each market.

Figure 5. Allocation for Offshore Wind Farm and Transmission Asset Development and Operation in Different Offshore Wind Markets



Source: Navigant analysis

3.1 Developer Build

In the developer build model, the tender system is designed to allocate independent stakeholders for developing and building offshore wind farm and the transmission assets. The offshore wind projects in England and Scotland are currently the only ones developed through a developer build model. The development and construction of the radial grid connections can be undertaken either by a wind farm developer or an independent Offshore Transmission Owner (OFTO) in the UK. Thus far the construction of offshore transmission assets has only been performed by wind farm developers. After construction the transmission assets are sold to an OFTO through a competitive auction.

3.2 TSO Build

The TSO build model allocates a government agency and/or national TSO as the responsible stakeholder for offshore grid connection development. This model is used in Germany, Netherlands, Denmark, Belgium, and France, where government agencies or TSOs are responsible for all stages of the offshore transmission asset life cycle, from site development to construction and operation.

National governments announce tenders for offshore wind projects of a specific size within a specified geographical area. For these projects, the TSO typically develops, constructs, and operates the offshore wind farm transmission assets (radial or hubs) and performs preliminary surveys. In this development model, the government or TSO is liable for damages suffered by the project developer when the TSO fails to fulfil its obligations to the grid connection.

If the TSO fails to complete the offshore grid on the designated dates, it is liable for damages incurred by the wind farm operators. The producers of wind energy are entitled to compensation of consequential damages and revenue losses in case of construction delays. Compensation will also be provided in case of restricted availability of the grid system once the offshore grid is commissioned. Such unforeseen costs could partially be socialised through transmission tariffs for electricity consumers after formal approval by the regulator.

3.3 Financing and Cost Recovery

Financing of offshore grid connections consist of three key elements: construction, on- and offshore operations and maintenance (O&M) and in some cases onshore grid reinforcements. However, with careful planning and cooperation between TSOs and authorities such reinforcements can be minimised or avoided. Table 3-1 contains a high-level process overview of the financing and cost recovery for each of these elements.

Table 3-1. General Description of Investments and cost Recovery Mechanisms

	Conditional: Onshore Grid Reinforcement	Construction	Operation & Maintenance
TSO build	• TSO finances onshore grid reinforcements. • Cost recovery via regulated transmission tariffs for electricity consumers.	• TSO finances construction of on- and offshore assets. • Costs are recovered through government subsidy or via regulated transmission tariffs for electricity consumers.	• TSO pays grid operation and maintenance costs. • Costs are recovered through government subsidy or via regulated transmission tariffs for electricity consumers.
Developer build[4]	• TSO finances onshore grid reinforcements. • Cost recovery via regulated transmission tariffs for electricity consumers.	• Either the offshore wind farm developer or OFTO can finance the grid connection • Offshore wind farm developer sells the assets to an OFTO via a competitive tender whereas OFTO recovers its investments via Tender Revenue Stream from onshore TSO. The offshore wind farm developers pay a tariff which partly covers the revenues received by the OFTO.	• TSO is responsible for system operation whereas OFTO maintains the transmission assets. • OFTO recovers its investments via Tender Revenue Stream from TSO. The offshore wind farm developers pay a tariff which partly covers the revenues received by the OFTO.

Source: Navigant analysis

Note: For onshore grid reinforcements, it is more complicated to trace part of the tariffs that are linked to offshore wind deployment. Onshore reinforcements are also performed due to onshore capacity expansion.

In a TSO build model, the TSO has a government mandate to develop and operate the offshore grid. Offshore grid costs are socialised through tariffs and collected from electricity users. Transmission tariffs are regulated by law and monitored by the national electricity regulator. Figure 6 provides a high-level overview of financial and supply flows between consumers, suppliers, and TSOs during wind farm operation.

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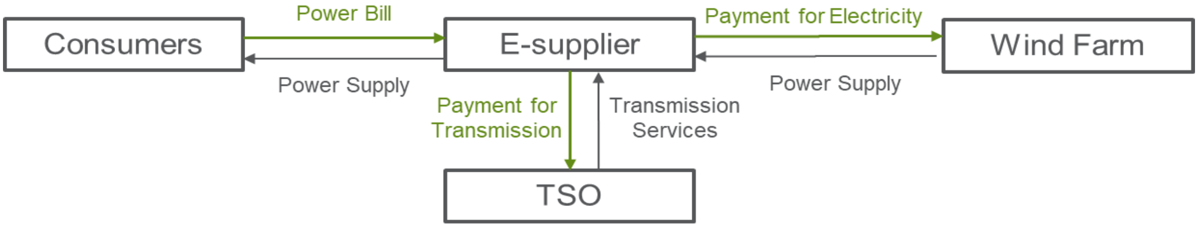
[4] Based on the UK OFTO system as this is currently the only Northwest Europe offshore wind market with a developer build offshore grid development approach.

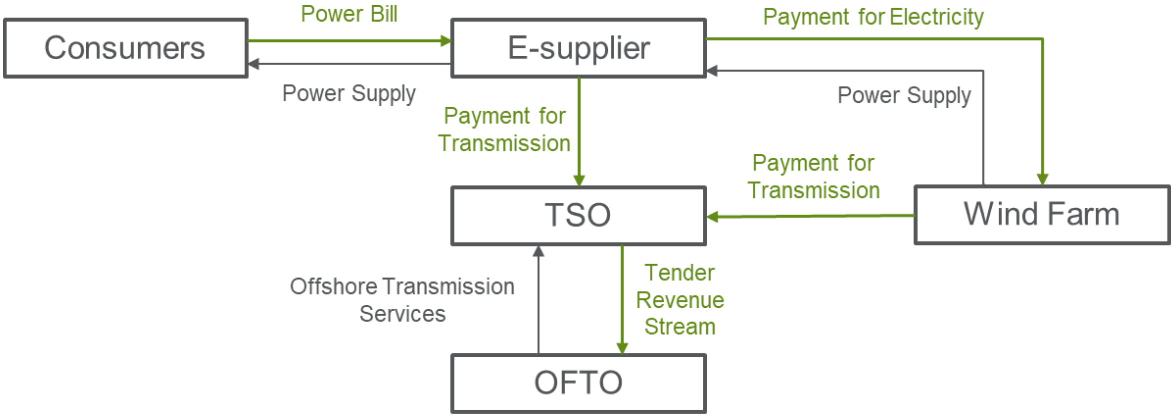
Figure 6. High Level Schematic Overview of Financial and Supply Flows in a Centralised Development Model



Source: Navigant
Note: This could deviate per individual country.

In a developer build model, the TSO reviews grid connection applications and assesses the required onshore grid reinforcements for a stable connection of new offshore wind farms. In the United Kingdom the assets are sold through a competitive tender to an OFTO for operation once the construction of the offshore transmission assets is completed. After taking over the ownership of the transmission assets, an OFTO recovers its investments mainly through a Tender Revenue Stream (TRS). Figure 7 gives a high-level overview of financial and supply flows between consumers, suppliers, National Electricity TSO (NETSO), and OFTO during wind farm operation.

Figure 7. High Level Overview of Financial and Supply Flows in a Developer Build Model



Source: KPMG, 2014.

4. QUALITATIVE COMPARISON

Differences in market models and regulatory frameworks directly impact short term offshore grid development and financing, but also indirectly determine multiple aspects for long-term offshore grid development. Besides direct CAPEX costs, the following four categories are equally important in both grid development models:

Planning and Design: Offshore wind farm areas are assigned by national governments. The offshore grid connection system needs to be designed to bring energy safely and securely to shore while minimising onshore grid reinforcements and environmental impact. The technical design should meet internationally agreed grid codes and other laws and regulations. Timing the onshore and offshore grid connection realisation and alignment of the planning with wind farm installation and commissioning is essential to prevent stranded assets, i.e., either a wind farm or the transmission system is ready to deliver electricity to the grid, but commissioning of respectively the offshore transmission system or the wind farm is delayed.

Commercial and Finance: Offshore electricity transmission assets require high capital investments. Offshore wind projects and grid connection systems are raising increasing amounts of debt worldwide. Expanded scope and activities affect the level of financing required by the developer, which can impact the cost of capital for project financed wind farms.

Construction and Interface Risks: Any wind farm project consists of an offshore part (turbines, foundations, array cables, offshore platforms, and offshore export cable) and an onshore part (onshore export cable and onshore stations), as well as in some cases onshore reinforcements. The offshore grid has key technical and procedural interfaces which must be managed well in both offshore grid development models.

Operations and Reliability: Both TSO and commercial parties (developers or OFTO’s) will benefit from a successful O&M strategy and a reliable transmission and grid connection system. For the TSO a high availability will build and/or strengthen their reputation as a reliable grid operator and will avoid monetary penalties. For a commercial party, it will avoid unnecessary revenue losses.

4.1 Drivers

A TSO and commercial developer are driven by different incentives which impact the real and perceived pros and cons for each development system:

- TSO’s are regulated by national law, their task is to develop and maintain a secure and reliable electricity grid. An increased asset base provides TSO’s with benefits of scale. Higher revenue stream and lower OPEX could optimise societal cost and benefits. Electricity transmission and system operation is a TSO’s core business and new infrastructure projects are always developed with a long-term perspective. TSO’s can contribute to further cost reduction in offshore wind by building a standardised and modular offshore grid.

- Commercial developers are driven by growth and ROI. Offshore wind developers and supply chain partners enabled the Northwest European offshore wind industry to become what it is today. It is important that offshore wind targets and regulatory framework are in place with the right incentives for the industry to further build and innovate.

4.2 Pros and Cons

An overview of pros and cons was created for each model in consideration of the four topics and incentives for grid development. It is not an exhaustive list, but it does contain the most important risks and benefits.

Planning and Design

	TSO Build	Developer Build
Pros		
	• Holistic and transparent view on future developments, systematically considering short-, medium-, and long-term grid development needs. This enables early initiation of the development of the connection. • Efficient grid expansion (incl. permitting, design, and procurement) and onshore grid reinforcements. • Opportunity to standardise design for economies of scale. • Shared assets (a single connection for several wind farms) reduces environmental footprint.	• One party coordination of offshore wind farm and transmission asset scope. • Potential to enhance design efficiencies/compatibility between the offshore grid and the wind farm through integrated design, resulting in tailor-made solutions.
Cons		
	• Standardisation may hamper innovation from developers and the supply chain. • Developers needs may not be fully reflected in the design and procurement process. • Potentially larger and more complex projects, with increased risk of delays for developers if TSO does not deploy offshore transmission assets timely.	• Transmission system development not core business, with incremental grid development on a project-by-project basis. • Risk of failure to recognise future system requirements and the use of different designs prevents standardisation and asset sharing. • Developer must wait for the TSO for onshore grid reinforcements before it can connect to the network. There is still a risk of stranded assets for developer if TSO is not incentivised for on time delivery.

Commercial and Finance

	TSO Build	Developer Build
Pros		
	• For a government-backed TSO, financing conditions are typically more favourable (lower debt and equity return rates) compared to a private developer. • Stable pipeline of projects can reduce procurement and project management costs. • The possibility of the integration of offshore hubs and interconnectors may result in lower societal costs and can address one of the key challenges of wind, intermittency. • Compensation for the developer is in place to (partially) offset the risk of delayed delivery of offshore transmission assets. • Potential for OPEX synergies by operating multiple standardised connections	• Cost optimisation for point to point assets or case by case basis. • Financial bonus for achieving higher availability than targeted (up to 5% of annual revenues). • OFTOs have more flexible financing options, which allow them to be more competitive than TSOs. Flexibility in financing structure of transmission assets, e.g., higher debt shares which could result in lower Weighted Average Cost of Capital than TSOs in the TSO build model.
Cons		
	• There is a high investment involved for TSO to build and maintain large transmission assets. For state owned TSO's the government needs to make sure that there is enough capital available to take on the risk. When shareholder is reluctant to provide equity, this can hold back investment. • TSO's do not face the same cost pressure that developers are driven by to be competitive in tenders.	• The cost of capital for an offshore wind farm or OFTO developer could be higher due to increased equity return rates and debt rates and transaction costs from developer to OFTO. • May not be fully compatible with integrated connections. The potential to reduce societal costs through coordinated approach is low. • Cost and investments are not necessarily optimised from a societal Levelised Cost of Electricity (LCoE) perspective.

Construction and Interface Risk

TSO Build	Developer Build
Pros	
• Offshore wind deployment and onshore capacity reinforcements are coordinated, as TSO oversees transmission assets both on land and at sea. • Large TSOs can coordinate offshore work across its portfolio. Combining Transmission Operator (TO) and System Operator (SO) tasks improve efficiency.	• Risk of construction delays is reduced due to one party coordination. • Offshore interfaces during construction managed by the same party, which provides greater control and increased flexibility.
Cons	
• Stranded asset in case of construction delays, projects not realised. • A significant offshore interface between developer and TSO.	• Increased project management requirements to address non-core business. • Onshore works/grid reinforcement still needs coordination between TSO and developer.

Operations and Reliability

TSO Build	Developer Build [5]
Pros	
• Greater control over the grid by transmission responsible party. • Less parties involved along the e-value chain. • Reliability is determined by the government. Availability is incentivised via mechanism, part of the financial claim shall be borne by the TSO. • Potential OPEX reduction due to a larger asset base and standardised equipment.	• Risk of export cable and offshore substation failure lies with party most affected (does not apply to the UK OFTO regime). • Reliability is incentivised through direct revenue impact (non-OFTO) or an availability target (OFTO). • In case of non-OFTO developer operated projects, O&M of the wind farm and grid connection can be aligned
Cons	
• Regulatory framework needed to incentivise high availability of the grid connection system. • Unavailability penalties might be less effective with a large publicly owned organisation as ultimately costs could be (partially) socialised.	• Mismatch between operating duration of the transmission asset, which is typically longer than that of the offshore wind farm. This leaves full asset utilisation in the long term uncertain. • Creates interface between TSO and developer which may increase response times to grid emergencies. • In case of OFTO regime, the availability penalty is capped up to 10% of annual revenue.

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[5] *This category also covers existing developer build wind farms in Belgium and the Netherlands, which have different benefits in the operational phase than UK OFTO build projects.*

5. COST LEVEL COMPARISON

In this section, the TSO build, and developer build offshore grid development models are compared on a cost basis.

5.1 Approach

A comprehensive comparison of grid connection costs is a complex task due to the intricacy of transmission asset development structure in individual projects, lack of full cost transparency in the industry, and long-term effects of each offshore grid development model. Contrary to a theoretical approach of assumption-based cost evaluation, this analysis is designed more pragmatically, considering known cost data for several projects in selected countries representing TSO build and developer build development models. Development costs are evaluated at a transmission asset main component level (platform, export cable offshore, export cable onshore, onshore substation), based on cost data provide by TSOs for transmission assets in France, Belgium, Denmark and the Netherlands and verified against recently announced cost levels in the UK.

5.2 Methodology

5.2.1 Data Sample

The data sample for the cost level comparison consists of a selection of UK OFTO transmission assets and TSO built assets by TenneT NL, RTE, Elia and Energinet.

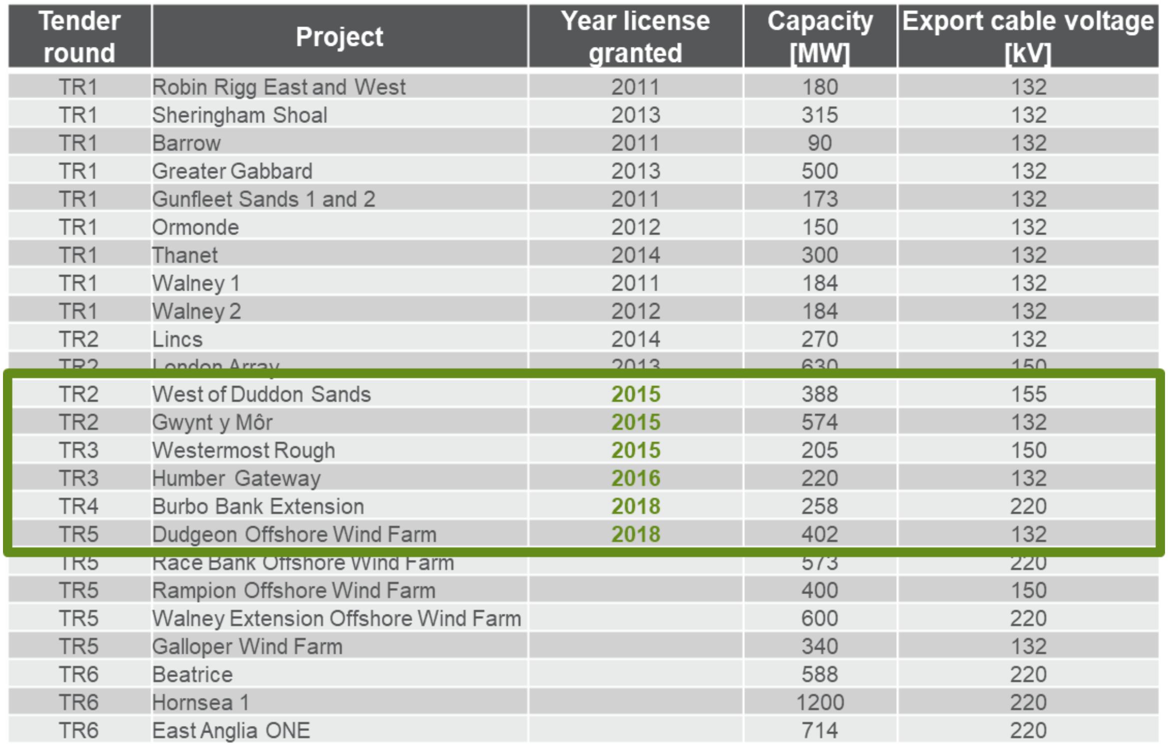
The selection of UK OFTO transmission assets is based on two criteria to ensure a representative dataset:

- OFTO connections should have a final transfer value (FTV) available to ensure using the most accurate and recent cost data for a certain connection. The FTV is determined by Ofgem (Office of Gas and Electricity Markets) when 90%-95% of the costs of the project have been incurred (Ofgem, 2017). The FTV gives more certainty than the indicative and initial transfer values, as these can vary significantly from the FTVs (further described in Appendix B).

- The OFTO license should have been granted from 2015 onwards to ensure recent transfer values are used.

Applying these criteria to the list of OFTO connections in the UK (Ofgem, 2019) yields the selections noted in Table 5-1.

Table 5-1. OFTO Project Selection



Tender round	Project	Year license granted	Capacity [MW]	Export cable voltage [kV]
TR1	Robin Rigg East and West	2011	180	132
TR1	Sheringham Shoal	2013	315	132
TR1	Barrow	2011	90	132
TR1	Greater Gabbard	2013	500	132
TR1	Gunfleet Sands 1 and 2	2011	173	132
TR1	Ormonde	2012	150	132
TR1	Thanet	2014	300	132
TR1	Walney 1	2011	184	132
TR1	Walney 2	2012	184	132
TR2	Lincs	2014	270	132
TR2	London Array	2013	630	150
TR2	West of Duddon Sands	2015	388	155
TR2	Gwynt y Môr	2015	574	132
TR3	Westermost Rough	2015	205	150
TR3	Humber Gateway	2016	220	132
TR4	Burbo Bank Extension	2018	258	220
TR5	Dudgeon Offshore Wind Farm	2018	402	132
TR5	Race Bank Offshore Wind Farm		573	220
TR5	Rampion Offshore Wind Farm		400	150
TR5	Walney Extension Offshore Wind Farm		600	220
TR5	Galloper Wind Farm		340	132
TR6	Beatrice		588	220
TR6	Hornsea 1		1200	220
TR6	East Anglia ONE		714	220

Source: Navigant analysis

The six selected wind farms represent a range of offshore wind farm connections from 220 MW to 574 MW, where most connections except Gwynt y Môr, have a single offshore high voltage station (OHVS). See Table 5-2.

Table 5-2. Selected OFTO Project Specifics

OFTO Connection	Wind Farm Capacity [MW]	# of OHVSs	OHVS Rating [MVA]	Export Cable Connection Rating [MVA]	Export Cable Length Offshore [km]	Export Cable Length Onshore [km]	Onshore Substation Rating [MVA]
West of Duddon Sands	388	1	480	413	41	3	480
Gwynt y Môr	574	2	320	596	21	11	640
Westermost Rough	205	1	280	212	12	15	360
Humber Gateway	220	1	280	220	9	30	320
Burbo Bank Extension	258	1	400	258	24	10	400
Dudgeon Offshore Wind Farm	402	1	400	400	42	47	400

Source: Navigant analysis

From a TSO perspective, the projects representing the cost range consist of the following projects:

- NL - TenneT's standardized grid connection for the roll-out of offshore wind in the Netherlands between 2019-2023, such as the Borssele Alpha grid connection.

- BE - Elia's Modular Offshore Grid connection, which includes an offshore switchyard platform that connects four Belgian wind farms to the onshore grid.
- DK – Energinet's Horns Rev 3 grid connection
- FR - RTE's Round 1 connections (4 in total), which include onshore substations, onshore and offshore export cables. RTE does not build the offshore substation of these connections.

Table 5-3. Selected TSO Project Specifics

TSO Connection	Wind Farm Capacity [MW]	nr. of OHVSs	OHVS Rating [MVA]	Export Cable Connection Rating [MVA]	Export Cable Length Offshore [km]	Export Cable Length Onshore [km]	Onshore Substation Rating [MVA]
NL - standardised offshore grid concept by TenneT	700	1	800	800	Varies per connection	Varies per connection	800
BE - Modular Offshore Grid by ELIA	1030	1	N/A [excluded from comparison]	1170	40	1.4	1085[6]
FR – Round 1 connections by RTE	480-500	N/A	N/A [excluded from comparison]	Varies per connection	16-33 km	15-24 km	616-700
DK –Horns Rev 3 by Energinet	406.7	1	420	420	33	45	420

Source: Navigant analysis based on TSO provided data

Note that:

- For grid connections which did not have component specific apparent power rating (MVA) data available, Navigant assumes a single apparent power rating over the whole line.
- The OHVS of Elia's Modular Offshore Grid is excluded from the cost comparison as it is a switchyard only, thereby not hosting transformers on the offshore substation.
- The onshore substation for the modular grid is an upgrade of the existing Stevin onshore substation. These costs are included in the comparison as this can be explained as a benefit of Elia developing the offshore wind transmission assets in this case (compared to having separate onshore substations for the individual windfarms).
- For RTE's Round 1 connections, the KPIs for each connection were calculated and subsequently, the median of the four connections was taken in the overall comparison.
- The individual UK OFTO OHVS ratings vary between 280 and 400 MVA which is still significantly lower than the OHVS rating TenneT (800 MVA) which should be considered when considering the results. A higher MVA rating of substations may allow for benefits of scale to materialize.

5.2.2 Cost Assessment Framework and KPI Definition

The goal of the cost assessment is to provide a cost level comparison on component basis, such that they are comparable across different connection capacity ratings and connection lengths. However, only the total CAPEX levels for the UK OFTO connections are publicly available through the results of Ofgem transmission asset tenders (OFGEM, 2015, 2016, 2018). No distinction is made between different components. The Navigant E-infra cost model was used to estimate the distribution of total CAPEX costs to its constituent components. Navigant's E-infra cost model is a proprietary model that

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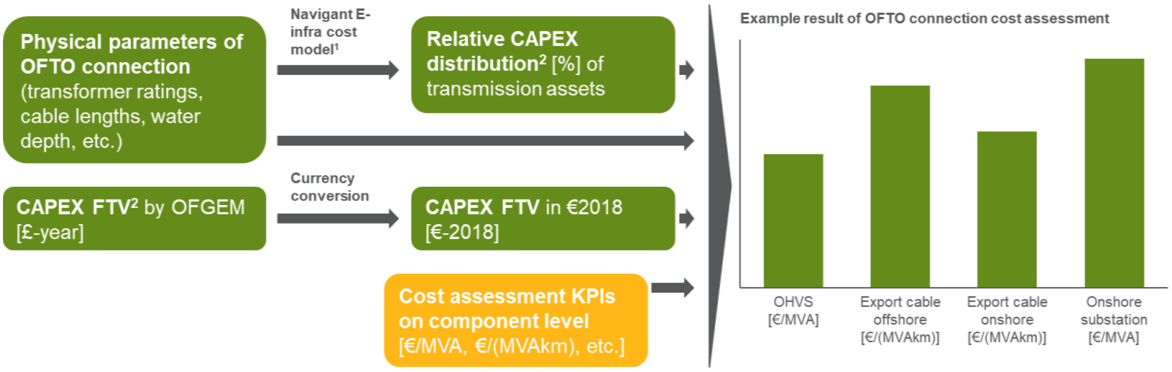
[6] Assumed like OHVS, part of existing onshore substation Stevin

models costs of transmission assets in a bottom-up manner based on physical input parameters of the connection. Cost estimates are based on actual project and public data. Based on the CAPEX build-up as modelled, Navigant estimated the shares of the total CAPEX to different components. Together with the physical parameters it is possible to arrive at specific key performance indicators (KPIs) per connection component, as illustrated in Figure 8.

Figure 8. Process Flow of CAPEX Distribution Estimation



Source: Navigant

The cost comparison methodology is based on comparing the grid connections on four main KPIs, which are related to their specific components:

- OHVS and onshore substation in €/MVA
- Export cable offshore and onshore in €/MVAkm

These KPIs are similar to Ofgem's (KEMA, 2009) and ORE Catapult's (ORE Catapult, 2016) cost parameters. The decision to compare on a per-MVA basis is taken as apparent power ratings are a more direct driver of the sizing and costs of the assets than the real power (MW) connection capacity: transformers are defined by their MVA rating, and not by the real power rating.

The cost levels for the TSO transmission assets from France, Belgium and the Netherlands are provided by RTE, Elia, and TenneT NL. The cost levels from Danish projects were taken from a public source (Energinet, 2017). The same KPIs are applied. TSO cost KPIs are only presented as a combined cost range for all TSOs due to the sensitivity of the individual cost levels.

5.3 Limitations and Uncertainties

Limitations and uncertainties of the quantitative comparison include:

- The maximum MVA rating of the OFTO OHVSs was 400 MVA, while the TSO assets included substantially larger capacities of 800 MVA. To better understand the influence of this rating on the cost factors, this analysis should be repeated for the larger comparable connections in the UK once its FTVs are published. Relevant examples include Hornsea One (1,200 MW), and East Anglia One (714 MW), which are within the range of the selected TSO connections and both connect at 220 kV voltage level.

- Modelling was used to calculate the cost distribution over the constituent components of the OFTO grid connections. This introduces uncertainty in the distribution of CAPEX over components, which could be resolved by gaining direct cost information of the components.

- The cost comparison only considered CAPEX and excluded OPEX, general DEVEX[7] (i.e. non-component specific development costs), electrical losses, and the impacts on the

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[7] It was not possible to exclude general DEVEX for French and Danish connections due to limitations in the provided data.

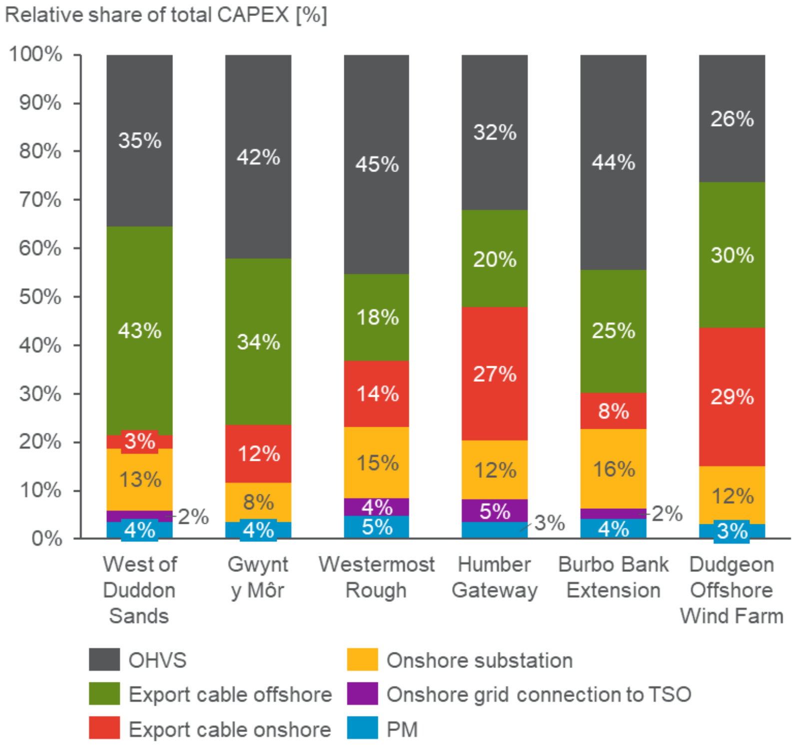
onshore grid or the wider energy system.

- The CAPEX values of ELIA (OHVS and export cable offshore) and TenneT (all assets) include the full current contingency amount. Once these transmission assets are realised, the contingency can be removed and replaced by actual expenditures.

5.4 Results

Cost breakdown distribution of selected UK offshore wind farms, using Navigant's E-infra cost model is presented in Figure 9.

Figure 9. Relative Share of Total CAPEX (%) for Selected UK Offshore Wind Farms



Source: Navigant analysis

The assessment of the modelled cost level contribution for OFTO connections shows the following:

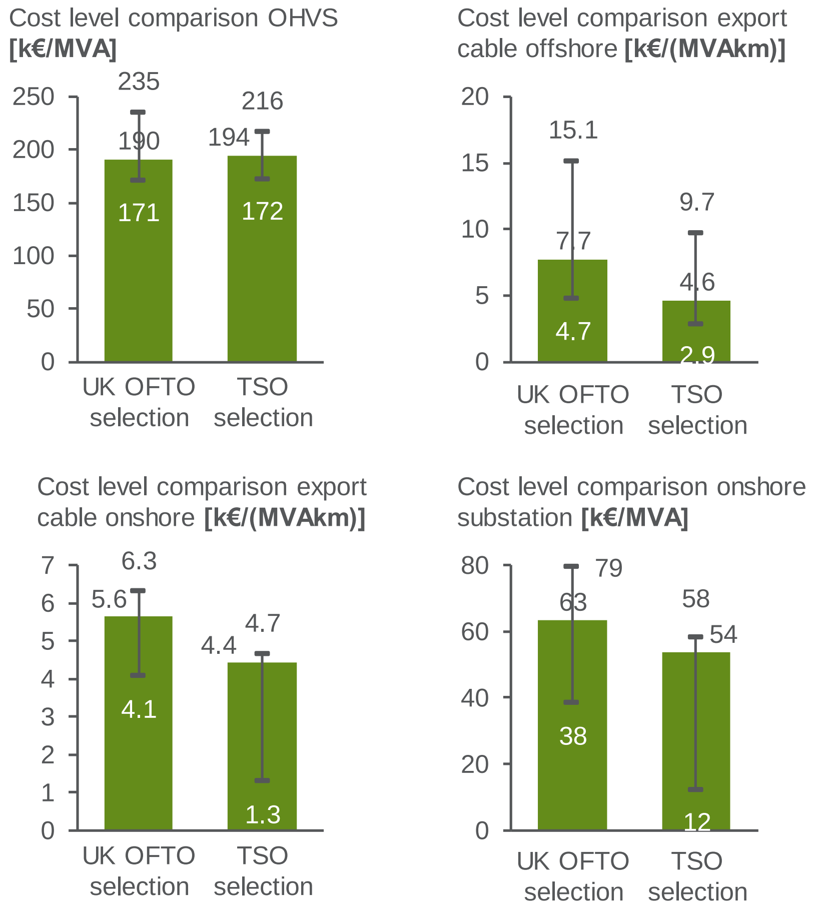
- Offshore assets costs (OHVS and offshore export cable) make up for at least 50% of total CAPEX for all cases. OHVS costs have a relatively larger share for connections with lower export cabling costs such as Westermost Rough and Burbo Bank Extension.

- Onshore substation costs vary between 8%-16% of total CAPEX, mainly dependent on the contribution of OHVSs and export cabling to the total cost.

- Onshore grid connection to TSO varies between 2%-5% of total CAPEX value (when included in total CAPEX scope). Project management costs vary between 3%-5%.

Figure 10 show the cost level ranges (based on min and max values) for the selected OFTO projects, against the TSO expected cost levels on the component level as identified in the cost assessment framework. It shows that offshore substation cost levels are comparable, while offshore and onshore cable and onshore substations cost ranges are lower for TSO developed connections compared to OFTO developed.

Figure 10. Cost Level Comparison Results (CAPEX only)



Source: Navigant analysis

Cost level comparison between OFTO and TSO cost levels shows that:

- **OHVS** cost level range for TSOs overlaps the OFTO cost range, and the median values are comparable (the TSO median being 2% higher than the OFTO median). It should be noted that the water depth (20-35 m) of the TSO OHVSs is on the high end of the range of the considered UK OFTO connections (9-21 m). Note ELIA's MOG OHVS has been removed from this comparison (due to absence of transformers on OHVS).

- **Export cable offshore** cost level range for the selected TSOs (based on an export cable length between 15-67 km) is mostly within OFTO cost range (based on lengths of 9-42 km), with a lower minimum and median value. This may in part be explained by the longer lengths which result in relatively lower fixed costs, when expressed on a per kilometre basis.

- **Export cable onshore** cost level range for selected TSOs is lower than the OFTO cost level. In particular the minimum cost value of the TSOs is significantly lower than the minimum of the OFTO cost range. Note the onshore export cable of TenneT has been removed from this comparison (due to a very short length of 400 meter).

- **Onshore substation** while cost level range for the selected TSOs for a large part overlaps the OFTO range, the median and minimum values are significantly lower. The low end of the TSO range may be driven by cost synergies of the some of the TSO substations (e.g. extension of existing substation or eliminating the need for additional transformers). In general, the TSO cost level is more competitive throughout, evidenced by the maximum TSO cost level being lower than the median of the OFTO cost levels.

6. DISCUSSION AND CONCLUSION

TSO build, and developer build offshore grid development models vary in terms of cost and risk allocation. A direct comparison is not without its uncertainties and limitations. It is possible to highlight the differences in qualities and cost by carefully selecting the most comparable OFTO and TSO grid connection projects in terms of applied connection size and technology type.

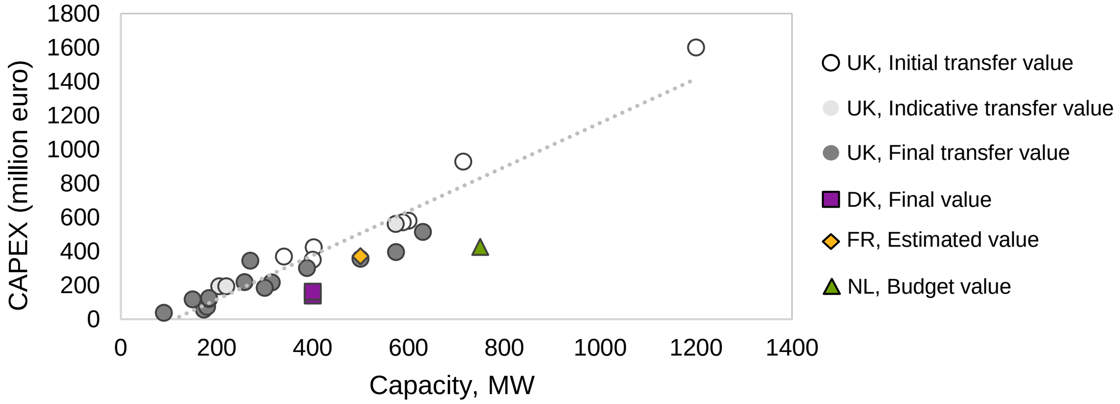
The UK has the OFTO model firmly in place and Denmark recently announced to include the offshore grid in its next tender round. However, this project is still in a very early phase and could not be considered. Hence, five out of six of the evaluated European offshore countries have adopted a TSO build offshore grid development model, where the TSO has the combined responsibility for onshore and offshore grid development in synergy with the responsibility for overall (long-term) system planning and integration of variable renewable energy sources. With a growing offshore wind portfolio secure integration into the onshore energy system will become increasingly important.

The TSO build approach comes with various benefits like early planning, central coordination (including onshore expansion requirements) and the opportunity to apply a modular grid connection concept with economies of scale. Arguably, de-risking of windfarm assets has also helped to lower subsidy requirements for recent tenders (see figure 1). The TSO build approach has also pushed the envelope for important innovations like the application of 66 kV inter array cables and 525 kV export cables in the Netherlands, an Offshore Switch Yard (OSY) in Belgium and the development of a multi-use platform to bring additional value (see Appendix A).

In a developer build model there is one party responsible for the development of the wind farm and the offshore transmission assets. One of the potential benefits of a developer build model identified in this report was that costs for individual connections could be optimised. However, when analysing comparable offshore grid connection cost data from the UK and mainland Europe, it appears that lower cost levels can be achieved with a TSO build approach. Even without considering the wider system benefits that have been identified in the qualitative analysis.

A comparison of publicly available data shows that the UK developer build model has resulted in generally higher CAPEX per installed MW HVAC grid connections than in the TSO build offshore grid development model in Denmark, France and the Netherlands (Figure 11).

Figure 11. Offshore HVAC transmission system CAPEX comparison.



Source: Navigant analysis based on DNV-GL, 2019, with input from RTE
Note: Trend line only represents UK connection systems

The results of the quantitative cost comparison by Navigant (Figure 10) support this conclusion. The results show that cable and onshore substation cost ranges are lower for TSO build compared to developer build grid connections. Offshore platform cost ranges are comparable even though water depth is higher compared to the UK OFTO connections. Also, the TSO selection includes information from budgeted cost, while final transfer values (typically lower than initial transfer values) are used for OFTO projects. It is recommended to monitor offshore grid cost level development by updating future updates of this analysis with actual cost levels from relevant grid connections.

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APPENDIX A. COUNTRY FACT SHEETS

A.1 UK

Assets	Existing Wind Farms	Consented Wind Farms
Development model	Developer build	Developer build
Generation	7.92 GW	11.4 GW
Transmission	AC platforms	AC platforms

Source: Navigant analysis

A.1.1 Offshore Grid Development Model for Existing and Consented Wind Farms

The existing wind farms and transmission assets were realised by developers based on a CfD scheme, including the grid connection to be constructed by the developer. Subsequently, the grid connection system was tendered to OFTOs. The development and construction of offshore transmission assets in the UK can be undertaken either by a developer or an OFTO. To date, the construction of offshore transmission assets has only been performed by wind farm developers.

The NETSO, e.g., National Grid, examines grid connection applications from wind developers, and assesses the required onshore transmission network reinforcements for a stable connection of new offshore wind farms. Note that in this system the NETSO is not liable for any delays related to the transmission assets as it is not involved in its development.

Once the construction of the transmission assets is completed, the assets are sold through a competitive tender to an OFTO. The OFTO tenders are managed by Ofgem, the regulator in the United Kingdom, who grant the operating licenses for the new offshore transmission assets. The developer pays Ofgem for running the OFTO tender. The OFTO tender process consists of multiple stages and usually runs during the construction phase of the offshore wind farm project.

The OFTO is responsible for O&M of the offshore transmission assets. It is subjected to a performance adjustment of its revenues based on their performance against a 98% availability target (either bonus or penalty; the OFTO is liable to pay up to 10% of its yearly revenue). The developer is entitled for compensation in case of loss of revenues due to grid unavailability.

A.1.2 Planned Wind Farms

There is no evidence that the offshore grid development model in the UK will change for planned future wind farm areas.

A.2 Germany

Assets	Existing Wind Farms	Consented	New Zones
Development model	TSO Build	TSO Build	TSO Build
Generation	7.7 GW	3.1 GW	4.2 GW
Transmission	400 MW–916 MW DC platforms 51 MW–300 MW AC platforms	DC	DC

Source: Navigant analysis

A.2.1 Existing Wind Farms

In the German North and Baltic Seas, there are 23 operational offshore wind projects and five under construction, connected through 8 DC and 3 AC grid connection systems in operation.

A major challenge for Germany has been constrained transmission capacity from the north, which has a high generation capacity, to the South, which has a high demand capacity. The key objective of the TSO build model is to maintain a more coordinated and proactive planning of the grid expansion. In the current system, three state-regulated TSOs are responsible for construction and operation of all transmission assets: TenneT and Amprion in the North Sea and 50Hertz in the Baltic Sea.

At the time being, Germany is the only market globally implementing offshore DC grid connection technology, which is done by TenneT in the German North Sea. Given the high investment cost of and long-term planning and construction of DC offshore grid connections, the TSO ownership model provides the certainty of project realisation and project total expense optimisation over its lifetime. The cost of grid development in Germany is recovered through adjusted electricity tariffs.

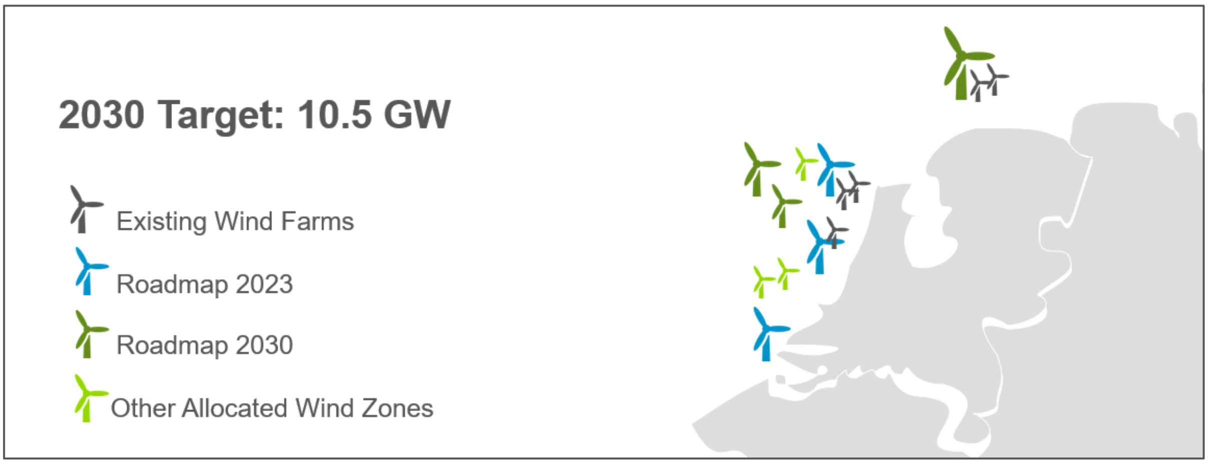
A.2.2 2017 and 2018 Tender

During the 2017 and 2018 tendering rounds, 10 additional projects (of which three were zero-bid) with the total capacity of 3.1 GW were consented and scheduled to become operational between 2021 and 2025. The tendering round projects for 2017 and 2018 will be connected in line with the current grid development plan.

A.2.3 Future Zones

An additional 4.2 GW of capacity is needed to meet the 2030 target. This capacity is to be awarded in the tendering rounds according the TSO build model starting from 2021. No specific grid connection points have been incorporated in the current grid development plan (referring to Zone 3 in North Sea grid development plan).

A.3 Netherlands



Assets	Existing Wind Farms	Roadmap 2023	Roadmap 2030
Development model	Developer Build	TSO Build	TSO Build
Generation	957 MW	3.5 GW	6.1 GW
Transmission	AC platforms[8] 33 kV–220 kV AC	700 MW AC platforms 220 kV AC cables	700 MW AC platforms 2 GW DC platforms 525 kV DC cables

Source: RVO and TenneT

A.3.1 Existing Wind Farms

The existing offshore wind farms and transmission assets were realised by developers based on a concession basis.

A.3.2 Roadmap 2023

In 2013, the Dutch government signed an Energy Agreement with parties in the energy market. It was agreed that 4.5 GW of offshore wind should be completed by 2023, including the existing offshore wind farms. The Netherlands Enterprise Agency is responsible for the execution of the offshore wind energy subsidy and permit tenders on behalf of the Ministry of Economic Affairs and Climate Policy. Its target is to execute five tenders of 700 MW. The government provides a subsidy if necessary, a permit for building the wind farms, site data of the wind farms, and a connection to the electricity network of TenneT TSO. TenneT develops and builds five standard platforms to transport the additional 3.5 GW of offshore wind energy to shore.

A.3.3 Roadmap 2030

The new roadmap calls for an additional 6.1 GW (Ministry of Economic Affairs and Climate, 2019) of offshore wind in the Netherlands by 2030, creating a total offshore wind target of 10.5 GW. Large wind farm areas have been designated north (North of the Wadden) and west (IJmuiden Ver) of the Dutch coast. Offshore grid cost for these future wind farm areas will increase due to the longer distance from shore.

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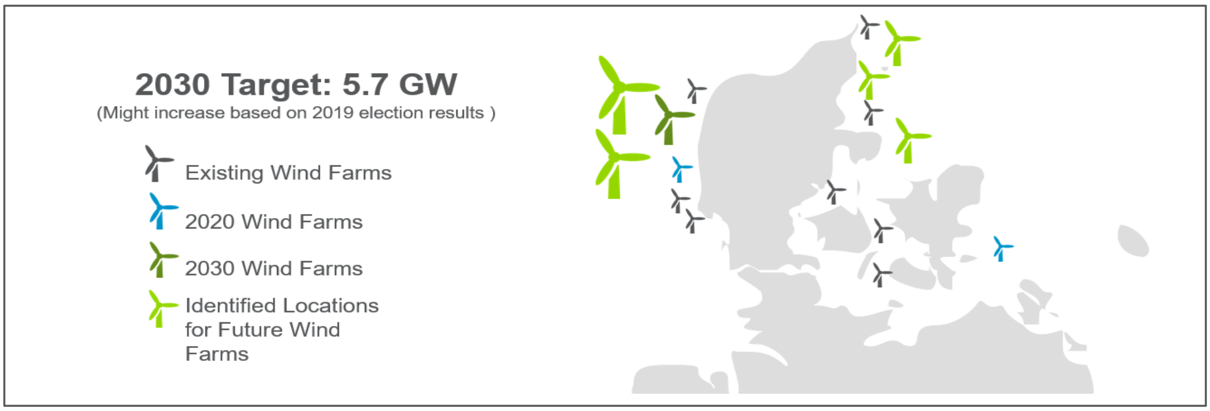
[8] Offshore wind farm Egmond aan Zee does not have an offshore converter platform, but it is directly connected to an onshore AC converter platform.

A.4 Denmark



Assets	Existing Wind Farms	2020 Wind Farms	2030 Wind Farms
Development model	TSO Build	TSO Build	Developer Build
Generation	1.26 GW	1 GW	2.4 GW
Transmission	AC platforms 33 kV–150/220 kV AC	AC platforms 33 kV–220 kV AC	

Source: Danish Energy Agency

A.4.1 Existing Wind Farms

Denmark has three operational offshore wind farms and seven nearshore wind farms, with a total installed capacity of 1.3 GW. The existing transmission assets for offshore projects were realised with a TSO build model, were Energinet was appointed to develop, construct and operate the offshore grid. The TSO was liable for damages suffered by the developer in case of unfulfilled obligations. For the near-shore wind farms (from Energy Agreement 2012), the developer was responsible for the connection to the nearest onshore transformer station. Because only after the winner of the tender was announced, the development areas were known, while the areas do not have a pre-defined capacity (max 200 MW each). In this scenario the developer had to pay to Energinet their incurred costs for preliminary investigations. In other tenders the developers also paid for full site investigations and the EIA (Danish Energy Agency, 2017).

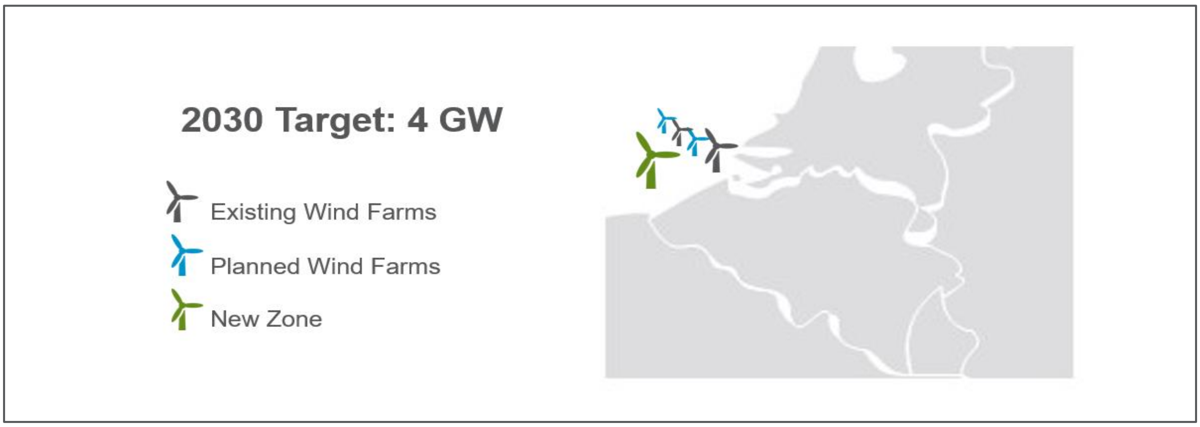
A.4.2 2020 Wind Farms

Two offshore wind farms, Horns Rev 3 and Kriegers Flak, with the combined capacity of 1 GW, are currently under construction in Denmark. Both wind farms are planned to be fully operational in 2020. Following the TSO build model, Energinet.dk developed the offshore grid connection for Horns Rev 3 and will remain the transmission asset operator. An additional 350 MW of near shore might be added at a later stage (Wind Power Offshore, 2019).

A.4.3 2030 Wind Farms and beyond

Denmark’s new Energy Agreement includes building three new offshore wind farms by 2030. Construction and operation of the offshore substation and export cables will be included in the first tender ‘Thor’. It is unclear why the Danish government decided to change to a developer build offshore grid model (Danish Energy Agency, 2019). The scope of the grid connection will be financed together with the overall subsidies through the Danish state budget. As Energinet will still be responsible for developing the onshore grid connection, the winner of the tender will need to repay the costs to Energinet. The Danish government identified locations for 12.4 GW future offshore wind energy in April 2019. The government also estimates that the country has a potential to add a total of 40 GW offshore wind capacity.

A.5 Belgium



Assets	Existing Wind Farms	Planned Wind Farms	New Zone
Development model	Developer Build	TSO Build	TSO Build
Generation	1,540 MW	710 MW	2 GW
Transmission	AC platforms 33 kV–220 kV AC direct connections	AC Platforms Offshore Switch Yard 220 kV AC cables	AC Platforms Offshore Switch yard 220 kV AC cables

Source: Elia

A.5.1 Existing Wind Farms

In 2019, Belgium will have six operational wind farms with an installed capacity of approximately 1,540 MW. The existing wind farms and transmission assets have been realised under a concession basis, where offshore wind developers receive renewable energy certificates from the Belgian energy regulator, the Commission for Electricity and Gas Regulation (CREG), for the generated electricity and can sell these to the TSO at an LCoE-based price.

A.5.2 Planned Wind Farms

Another 710 MW of offshore wind from two projects is currently under construction and will be connected to the so-called Modular Offshore Grid (MOG). The MOG will group and connect the offshore produced energy of four wind farms, so that it can be injected in the Belgian onshore grid via a meshed grid composed of fewer sea cables than an individual solution. It consists of a platform built and operated by the Belgian TSO Elia, the transmission installations on the platform of the windfarm Rentel and four submarine cables connecting the platforms between them and with the Stevin 380kV-substation in Zeebrugge (source: Elia). These additional windfarms will also be supported by an LCoE-based subsidy mechanism.

A.5.3 New Development Zone, Post-2020

The Belgian government wants to reach the target of 4 GW of installed capacity by 2030 and it aims to reach this target by following a TSO build model with the new 2 GW. In December 2018, the federal government approved new offshore wind zones (“new zone”) and introduced a law that establishes the guidelines for a competitive bidding procedure for awarding domain concessions to future offshore wind projects. The permits required for the construction and operation of the offshore wind farms will be integrated in the tender process and will be granted to the winning bidder. The subsidy, if required, will also be determined by the competitive tendering. The new offshore wind farms will be connected to several platforms that will be part of the Modular Offshore Grid, built and operated by the Belgian TSO Elia.

A.6 France

Assets	Round 1	Round 2	Round 3	Future potential
Development model	RTE develops and build the assets except the offshore substation. Following a change of law in 2018, the TSO now also finances the connections, which was previously allocated to the developers.		TSO Build	TSO Build
Generation	2 GW	1 GW	400–600 MW	Round 4: 1 GW seabed Round 5: 250 MW floating Round 6: 250 MW floating
Transmission	AC	AC	AC	-

Source: RTE and Business Green, 2019

A.6.1 Round 1 and 2 Zones

In 2011, a total of 2,000 MW was awarded across four development zones: Fecamp, Courseulles-sur-Mer, Saint-Brieuc, and Saint Nazaire. The Saint Nazaire project was officially 'launched' on June 14th, 2019, when appeals against the operating permit were officially dismissed (Offshorewind.biz, 2019).

In 2013, a total of 1000MW were awarded across two development zones, off the coast at Treport, and Iles d'Yeu - Noirmoutier. No projects from the 2nd auction round have materialized yet because of length of the appeal process and the short term (2023) offshore wind target is currently under revision within the multi-year planning framework. All 6 projects are in various stages of development, with commissioning expected between 2022 and 2024. The 1st and 2nd auction rounds include offshore grid connection as part of the TSO scope (except offshore substation in the developer scope), but the assets were financed by the developer. In 2018, the scope formerly financed by the developer was transferred to RTE (except the offshore substation).

A.6.2 Round 3 zone

In the 3rd round, the development zone in Dunkirk was auctioned with the capacity between 400-600 MW. Nine interested stakeholders and consortiums submitted their proposals, among which the leading companies in Europe. The results were announced on 14th June 2019. The cost of grid connection, including stranded costs in the event of tender being abandoned, will be carried out by the grid operator RTE under the new French law. RTE will recover the cost from the transmission tariffs. RTE will also need to compensate developers for any delays delivering the connection and partial or total loss due to malfunction of the connection. This compensation will be limited.

APPENDIX B. OFTO COST LEVELS FROM INITIAL TO FINAL TRANSFER VALUE

The UK OFTO tender process includes three valuation stages (Ofgem, 2017) of the transmission assets:

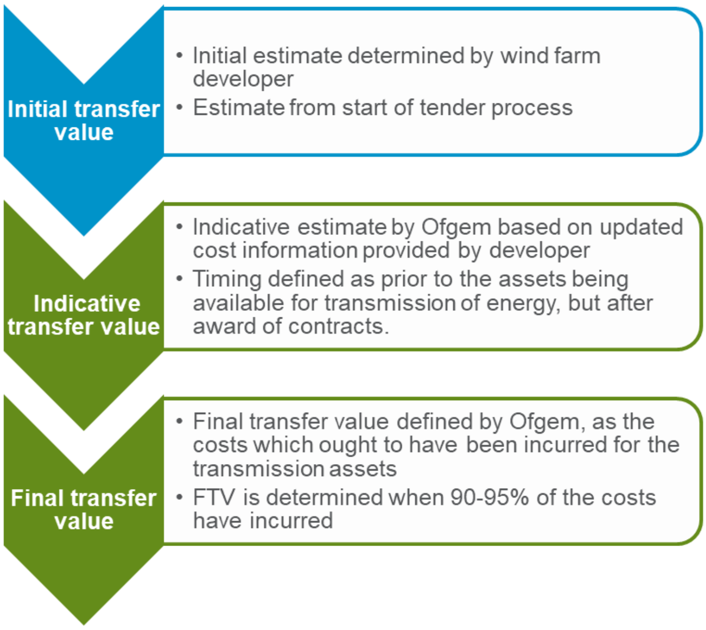
1. **Initial transfer value:** "Developer's initial estimate of how much they anticipate the offshore transmission assets will cost to build."

2. **Indicative transfer value:** "Estimate of costs which ought to be incurred, given that the construction of the transmission assets has not yet reached a stage where they are available for use for the transmission of electricity. At this stage, the developer submits updated cost information (e.g., signed contracts for fabrication and installation of assets) upon which Ofgem, with the support of its consultants, carries out a forensic accounting review and (if required) a technical review." At this stage, construction could already have started.

3. **Final transfer value:** "The assessment, referred to in the regulations, of the costs which ought to have been incurred in connection with development and construction of the transmission assets. It is the amount to be paid to the developer by the OFTO for the transmission assets. The trigger point for commencing this assessment has been when circa 90%–95% of the project costs have been incurred. At this point, there has been sufficient cost certainty for Ofgem to make a robust assessment of the extent to which costs have been economically and efficiently incurred."

The total transfer value consists of CAPEX, development costs, interest during construction, and contingency and transaction fees. Note that costs for project management (PM) are split in such a way that PM costs directly related to components are associated with the total CAPEX value, while general PM costs are allocated to the development cost category.

Figure B-1. From initial to final transfer value



- Initial estimate determined by wind farm developer
- Estimate from start of tender process

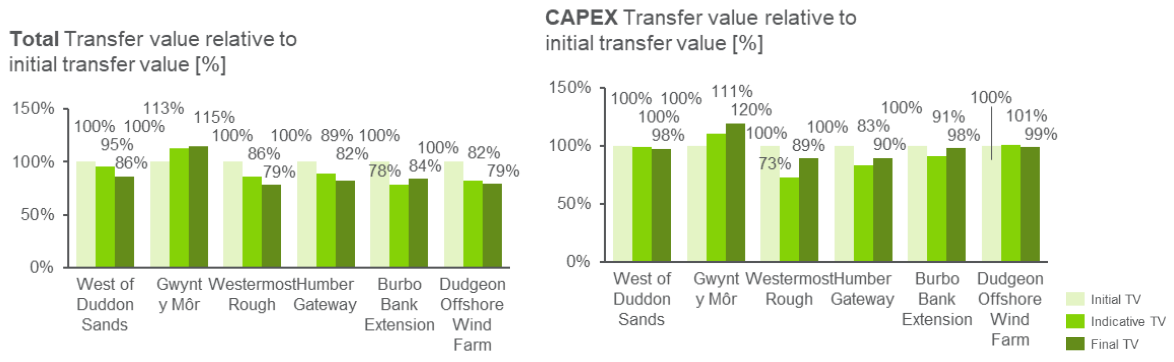
- Indicative estimate by Ofgem based on updated cost information provided by developer
- Timing defined as prior to the assets being available for transmission of energy, but after award of contracts.

- Final transfer value defined by Ofgem, as the costs which ought to have been incurred for the transmission assets
- FTV is determined when 90-95% of the costs have incurred

Source: Navigant

Cost developments from initial transfer value to FTV can undergo significant deviations throughout the process, as depicted on the right of Figure B-2. Note that Ofgem's cost assessments only explain cost deltas between indicative and FTV.

Figure B-2. Relative comparison of total and CAPEX transfer values



Source: Navigant

West of Duddon Sands
Decrease in both CAPEX (2%) and total transfer value (TV) (14%). CAPEX reduction between indicative and final TV mainly due to reduced onshore civil engineering costs, foreign exchange losses, onshore project substation, onshore substation PM, cable load out, and cost reallocations, while onshore substation construction costs increased.

Gwynt y Môr
Significant increase of both CAPEX (20%) and total TV (15%). CAPEX mainly increased due to increase in offshore substation costs, offshore cable jointing, installation delays, and onshore substation costs. This was partially offset by decrease of other onshore costs.

Westermost Rough
Significant decrease in both CAPEX (11%) and total TV (15%). CAPEX transfer value increased between indicative and final TV mainly due to reallocation of costs from development onshore substation, offshore substation and export cable construction costs, and costs for the onshore substation that were not included in the indicative TV.

Humber Gateway
Significant decrease of CAPEX (10%) and FTV (18%). CAPEX transfer value increased from initial to final TV mainly due to reallocation of development costs, offshore substation commissioning, subsea cable storage, and installation cost, while subsea cable related costs and claims were reduced.

Burbo Bank Extension
Slight decrease in CAPEX (2%) and significant decrease in total TV (16%). CAPEX transfer value increased from initial to final TV mainly due to reallocation of costs from development to CAPEX. Inclusion of offshore platform fabrication costs, onshore substation and offshore substation travel, and PM costs. Other smaller cost components were disallowed.

Dudgeon Offshore Wind Farm
Slight decrease in CAPEX (1%), and significant decrease in total TV (21%). Cost decrease from initial TV mainly due to decrease of contract and PM costs while CAPEX increased mainly due to cost reallocation from development and platform commissioning.