North Sea
Wind Power Hub
Programme

Market setup options to integrate hybrid projects into the European electricity market

Discussion Paper

NSWPH | April 2020

North Sea
Wind Power Hub
Programme

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Executive summary

The deployment of renewable energy sources needs to increase significantly to support the Paris goal of net zero greenhouse gas emissions by 2050. Offshore wind capacity deployment rates in the North Sea need to more than double towards 2040 while maintaining security of supply. In a step-by-step approach to accelerate the connection and integration of large scale offshore wind in the North Sea. The North Sea Wind Power Hub (NSWPH) programme aspires to have the first "Hub-and-Spoke" hybrid project operational in the early 2030s. This requires international coordination, long-term policy targets and a robust regulatory framework.

Hybrid projects

Increasing scale and development rates of offshore wind deployment across the North Sea and the increasing complexity to integrate these large volumes of offshore wind efficiently into the onshore grid, necessitates a holistic view to plan the required infrastructure. Hybrid projects, which combine offshore wind grid connection and cross-border interconnection capacity, are generally considered as the next necessary step to efficiently integrate offshore wind farms in the EU electricity markets. Such dual functionality of infrastructure allows for socio-economic welfare[1] maximisation. However, as a result, interconnection and offshore wind farm flows need to be co-optimised.

In this paper, hybrid projects refers to projects in which the development and implementation of offshore wind and interconnection capacity is combined, but is not related to the choice of market design or other regulatory aspects.

Market setups and bidding zones

Efficient utilisation of the electrical infrastructure across EU electricity markets requires the physical reality of the grid to be taken into account to ensure efficient dispatch of the EU electricity system. The market setup, which defines how offshore wind farms are allocated to specific bidding zones and subsequently how interconnection capacity between these bidding zones is allocated, is therefore a crucial topic. Early decision making and clarity on the future market setup is required for all involved stakeholders: TSOs, offshore wind farm developers, regulators and ministries. In order to allow policy-makers to make an informed decision on market setups, a fact-based analysis is presented that provides a clear and complete insight into the topic.

Assessment of market setup options

Four market setups were introduced by Roland Berger[2], as commissioned by the European Commission, to integrate hybrid projects into the EU electricity market. In the analysis presented

[1] In the context of this discussion paper the socio-economic welfare refers to the economic surplus and consists of the producer surplus, consumer surplus and congestion rents.

[2] Roland Berger, "Hybrid projects – How to reduce costs and space of offshore development : North Seas offshore energy clusters study", May 2019.

in this discussion paper, two of these market setup options are considered unrealistic due to incompatibility with the fundamental non-discriminatory principle and the robustness and stability requirements of bidding zones as set out in the Capacity Allocation and Congestion Management Guideline, Commission Regulation (EU) 2015/1222, hereafter "CACM".

The impact of the remaining two market setup options – the so-called Home Market (HM) and Offshore Bidding Zone (OBZ) – is analysed against six assessment criteria:

- compliance with current European regulation;
- dispatch and capacity allocation efficiency and socio-economic welfare;
- price formation in implicit auctions;
- distributional effects;
- revenue impact for offshore wind farms; and
- balancing and operational impact.

The analysis shows that the HM setup requires exemptions or European regulatory changes to ensure optimal use of wind energy by means of priority access of offshore wind. Even with these exemptions or regulatory changes, inefficiencies have to be overcome to reach a socio-economic welfare similar to the OBZ market setup. While in the HM setup a congestion management risk exists due to onshore portfolio balancing, the observed distributional effects of financial streams, in case of the OBZ setup, may require additional measures to ensure a fair distribution of risk and revenue among the energy market actors.

Next Steps

To facilitate development and implementation of hybrid projects, a decision is needed with respect to the market setup that caters for efficient integration of the offshore wind energy in the electricity market. The analysis provided in this document aims to empower policy-makers in their decision-making by facilitating a balanced and structured discussion. It also points to additional research required to further clarify the dynamics and operability of the considered market setup options. Such additional analysis should include on the short term, amongst others, an analysis of the revenue impact for offshore wind farms in an OBZ market setup by means of power market modelling and a discussion on mitigation measures for possible unwanted distributional effects. In the longer term, operational rights and obligations for offshore wind farms and TSOs as well as roles and responsibilities for all market players and TSOs need to be further outlined for both market setups. Furthermore, the impact of offshore load on the efficiency of the market setup needs to be investigated.

Context

The European energy transition requires a long-term, integrated and internationally coordinated approach on offshore wind development.

The deployment of renewable energy sources in Europe will increase significantly to support the goal of net zero greenhouse gas emissions by 2050. This fundamentally changes the current energy supply and demand patterns, requiring the energy system to become increasingly flexible to maintain security of supply.

Offshore wind capacity in the North Sea is expected to more than double by 2040 (see figure 1). All energy scenarios consider offshore wind as a major renewable energy source in the future European energy system, with estimates ranging from 230 GW - 380 GW[3] in Europe by 2050. Several long-term scenarios (e.g. European Commission, Fraunhofer, PRIMES, Greenpeace, WindEurope, ENTSO-E, IEA) set out a range of 70 GW to 150 GW of offshore wind in the North Sea as early as 2040. To enable this rapid acceleration in deployment and integration of large-scale offshore wind, with maximum socio-economic benefit, there is an urgent need for international coordination, long-term policy targets and a robust regulatory framework.

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

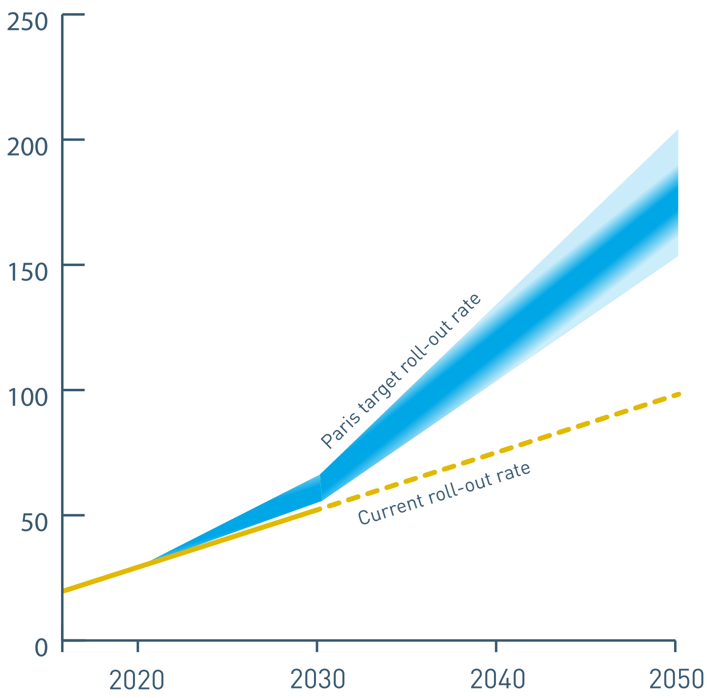


Figure 1. Current roll-out rate of offshore wind is insufficient to meet Paris Agreement.

[3] EC: "In-Depth Analysis in support of the Commission Communication COM (2018) 773 'A clean planet for all'", November 2018, p77.

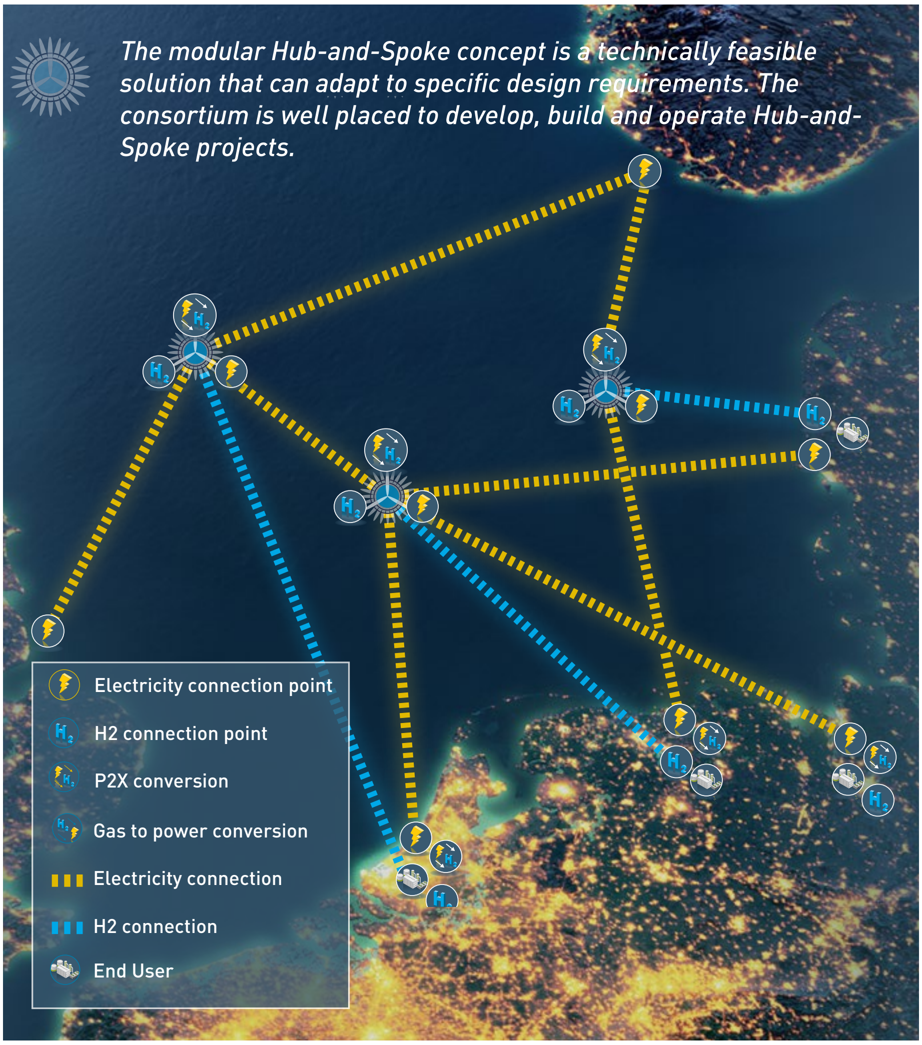


Figure 2. In hybrid projects, as the Hub-and-Spoke project, offshore wind grid connection and interconnection are combined. In the future, offshore load in the form of P2X can be added to the hubs and connected to the offshore gas grid.

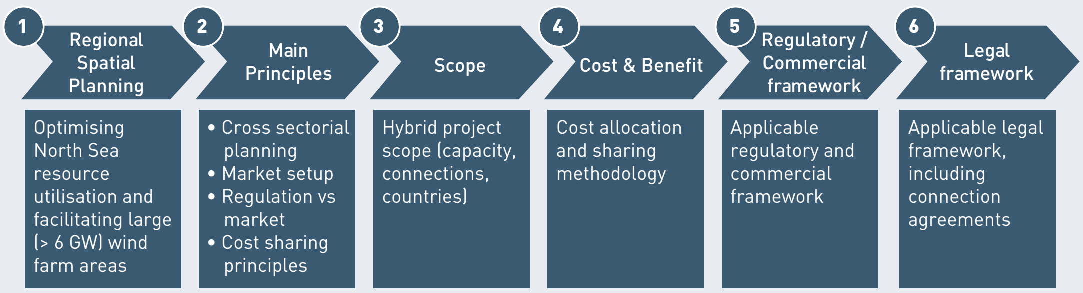
Currently, the approach to plan, design and operate offshore grid infrastructure is pre-dominantly nationally focused and lacking a total energy system perspective that allows for synergies and cost-efficient development and operation of the offshore infrastructure. Enabling smart and cost-efficient integration of offshore wind will rely on solutions that include:

- ✓ combining offshore wind grid connection with interconnection of EU electricity markets in hybrid projects, to maximise efficient use of infrastructure;
- ✓ connecting offshore wind farms from one country to demand centres in another, to optimise utilisation of resources;
- ✓ coupling energy sectors at scale, to provide large scale flexibility (see figure 2).

To enable such smart and cost-efficient solutions, a change in the approach is required based on a number of intergovernmental agreements to provide the framework and market conditions to develop, realise and integrate large scale offshore wind in line with the climate targets. To arrive at such international agreements a thorough and structured approach is needed to discuss and decide upon the overarching topics concerned (see text box 1).

Text box 1: *To enable hybrid, cross-sector projects ("hubs") to connect and integrate large scale offshore wind, it is necessary to kick-start and facilitate structured discussions on key regulatory, legal and commercial aspects. The aim of such discussions is to establish agreements and legal frameworks that align interests and provide certainty for Member States, project participants and other stakeholders. To facilitate the relevant discussions, a list of key topics and their logical flow has been outlined below. The topics build on regional spatial planning and main principles regarding market setup and regulatory framework, and are sequenced such that key subjects and decisions affecting the subsequent topics are addressed prior to moving forward in increasingly more detailed discussions, enabling a gradual approac and coherent results.*

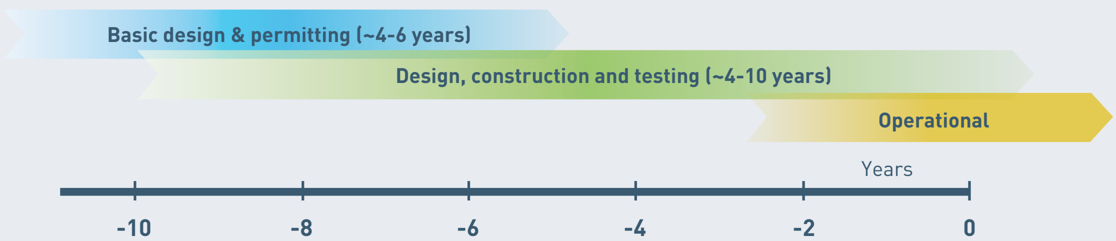
Figure 3. Various intergovernmental agreements addressing overarching topics required for large scale offshore development. Market setup is the topic of this discussion paper.



Based on their societal task, the NSWPH consortium of Transmission System Operators (TSOs) wishes to pro-actively engage with stakeholders to ensure that the critical topics are addressed in time to meet the climate targets. Given the transmission operator expertise, the TSOs offer advice to policy-makers on regulatory principles to achieve most efficient investment and operation. It is recognised that there is a need for governments to act and to agree on the main principles enabling the development of smart and cost-efficient solutions.

The North Sea Wind Power Hub (NSWPH) programme aspires to have the first Hub-and-Spoke –hybrid- project operational in the early 2030s to facilitate a step-by-step approach to accelerate offshore wind scale-up in the North Sea, (see https://northseawindpowerhub.eu/vision/). Regulatory principles are required to be in place before an investment decision can be made. Cost-recovery and the applied governance model for these investments are therefore to be determined before the final investment decision. As the market setup for hybrid projects impacts the revenues and rents for both offshore wind developers and infrastructure developers, clarity on the main principles of the market arrangements is a prerequisite for more detailed considerations of the regulatory principles.

Figure 4. Hybrid projects as the Hub-and-Spoke projects have long lead times. Depending on design choices, permitting obligations and the ability to execute project development activities in parallel it is expected that it will take some ~10 years from project initiation to operational.



Hybrid Projects -
Market Setup Main Principles

Early decision-making and clarity on the market setup discussion is required for all involved stakeholders: TSOs, offshore wind farm developers, regulators and ministries. In order to allow policy-makers to make an informed decision, a fact-based analysis is needed that provides a clear and complete insight into the topic.

Currently, in various national and EU working groups on offshore electrical infrastructure, discussions are taking place on how to efficiently integrate large scale offshore hybrid projects, see text box 2, into the electricity market. A complete assessment of the pros and cons of the various discussed options offers a basis for an informed decision on this important topic by policymakers.

Text box 2: *The term "hybrid projects" as used by the European Commission, North Sea Energy Cooperation, ENTSO-E and Roland Berger, refers to projects in which the development and implementation of offshore wind and interconnection capacity is combined. However, the term hybrid is also used in the context of "hybrid assets" which reflect infrastructure with the dual functionality of internal transmission and interconnection. The latter term only comes into existence when we are talking about a "Home Market" setup where the infrastructure serves multiple purposes at the same time and which therefore requires special regulatory treatment. When applying an "Offshore Bidding Zone" setup to the infrastructure, there are no hybrid assets as there will only be interconnectors and bidding zones. These two market setups will be further explained and analysed in the following chapter.*

It is important to not interchangeably use those two terms as they mean different things. To prevent confusion, from now on the term "hybrid projects" will be used to refer to the physical/construction part of projects in which offshore wind and interconnection capacity is combined. The term "hybrid assets" will solely be used to refer to infrastructure assets, which are used for both interconnection and internal transmission, and only exists when discussing the "Home Market" setup.

This paper intends to provide a thorough basis for a structured discussion between policy-makers (and other stakeholders) regarding the options for future market arrangements regarding the large scale roll-out of offshore wind in North Sea: from the context of the market setup for a hybrid projects (such as the Hub-and-Spoke project) and the need for decision-making by policy-makers, through the possible policy options for policymakers and assessment of these options, to the next steps required to develop the market setup decisions that will facilitate the development of future hybrid projects (see figure 5). This paper does not include an analysis on whether the market setup is future proof with respect to offshore connection of P2X facilities. So far, this has not been considered as offshore P2X is likely not techno-economically feasible for a first Hub-and-Spoke project in the early 2030s.

Figure 5. Structure of the discussion paper.

The increasing scale and development rates of offshore wind deployment across the North Sea and the increasing complexity to integrate these large volumes of offshore wind efficiently into the onshore grid, necessitates a holistic view to plan the required infrastructure. Hybrid projects are generally considered[4] a next necessary step to efficiently integrate offshore wind farms in the EU electricity markets. This implies a dual use of the infrastructure where offshore grid connection and interconnection functionalities are combined. Optimising the grid connection and interconnection capacities from a holistic energy system perspective allows maximising the socio-economic welfare[5], mainly through the fact that the new offshore infrastructure will be utilised more than in traditional radial grid connections.

Bidding zones as an instrument to efficiently use the electricity system

Efficient utilisation of the electrical infrastructure across EU electricity markets requires the physical reality of the grid to be taken into account to ensure efficient dispatch of the EU electricity system. As such, separate bidding zones are currently present to reflect structural congestion in the grid. In case of hybrid projects – where grid connection capacity for offshore wind farms and cross-border interconnection capacity are developed in conjunction – it can become unclear in which bidding zone the offshore wind farms should bid their energy into. This is essentially a question regarding the allocation of wind farms to specific bidding zones and subsequently of interconnection capacity between these bidding zones.

Fundamentally the market setup is intended to maximise the efficient use of the electricity transmission infrastructure from a socio-economic welfare perspective. Thus, the fundamental principles for the overarching European energy market design intend to promote free and fair competition between all producers and suppliers of energy, including amongst others:

- wholesale markets in all energy commodities and related products and services should be open to competition and intermediation;
- the management, operation of transmission and distribution systems should ensure objective, transparent and non-discriminatory access to the network;
- cross-border markets should be without barriers.

Starting from these basic principles various market setups can be considered. When doing so it is important to recognise that any change in the market design that involves an overhaul of fundamental European legislation requires significant time and effort and therefore poses a risk for the development and realisation of hybrid projects in the early 2030s. At the same time, derogations or exemptions on a case by case basis should be avoided where possible, to ensure a long-term and robust framework that allows all stakeholders to prepare for, and invest in, the anticipated large scale roll-out of offshore wind.

[4] *Roland Berger, "Hybrid projects – How to reduce costs and space of offshore development : North Seas offshore energy clusters study", May 2019.*

[5] *In the context of this discussion paper the socio-economic welfare refers to the economic surplus and consists of the producer surplus, consumer surplus and congestion rents.*

In addition, it is important to recognise that the market setup influences the capture price for generators. The wider impact of the market setup needs to be considered in relation to the capture prices for generators and the consequences on revenue streams of all stakeholders involved (also for TSOs). This allows for a balanced decision on the market setup that takes into account how revenues are distributed and which mitigation measures can be taken to redistribute revenues across stakeholders.

Finally, when taking into account the real time operation of the transmission systems, it is important to consider the impact of the chosen market setup on the operability of this infrastructure (both transmission and system services) and the offshore wind farms (balancing of the generators portfolios).

These considerations are summarised in terms of assessment criteria to evaluate the pros and cons for different market setup options in the table below.

Table 1. Summary of assessment criteria.

I. Compliance with current European regulation	Analysis to what extent the proposed market setup complies with the European Clean Energy Package REGULATION (EU) 2019/943 and Capacity Allocation and Congestion Management Guideline, Commission Regulation (EU) 2015/1222.
II. Dispatch and capacity allocation efficiency & socio-economic Welfare	Analysis to what extent the proposed market setup facilitates: (1) efficient dispatch of demand and supply; (2) efficient use of transmission assets; and (3) efficient congestion management.
III. Price formation in implicit auctions	Analysis of the price formation mechanism of the proposed market setup.
IV. Distributional effects	Analysis of the distributional effects of the proposed market setup on the socio-economic welfare.
V. Revenue impact for offshore wind farms	Analysis to what extent the proposed market setup influences the business case for the offshore wind farm developers and their subsidy requirements.
VI. Balancing and operational impact	Analysis to what extent the proposed market setup influences the operability for the TSO of the electricity grid and its balancing responsibilities.

Analysis of market setups to integrate hybrid projects

In this section different possible market setups to integrate hybrid projects into the EU electricity market are assessed. Following the analysis by the Roland Berger (commissioned by the EC) the following market setups can be considered:

1. Home Market	The offshore wind farm bids and dispatches into its Home Market and receives the HM electricity price. The cable between the hub and HM is a hybrid asset, whereas the cables between the hub and the other bidding zones are cross-border interconnection.
2. Dynamic flows to high-price market	The offshore wind farm bids and dispatches into to the high-price market, which can differ from hour to hour, and receives the corresponding price. The cable between the hub and HM is a hybrid asset, whereas the cables between the hub and the other bidding zones are cross-border interconnection.
3. Dynamic flows to low-price market	The offshore wind farm bids and dispatches into to the low-price market, which can differ from hour to hour, and receives the corresponding price. The cable between the hub and HM is a hybrid asset, whereas the cable between the hub and the other bidding zones is cross-border interconnection.
4. Offshore Bidding Zone	The hub forms a separate offshore bidding zone, in which the offshore wind farms submit bids and are dispatched. Via market coupling the offshore generation is matched with onshore demand. The electricity price within the offshore bidding zone is the result of market coupling and is equal to the electricity price of the bidding zone connected by uncongested cross-border interconnection.

Any selected market setup is required to **be transparent, fair and non-discriminatory,** as these are the key principles of the European Internal Energy Market. With the First Energy Package in 1996 to harmonise and liberalise the European electricity markets, measures were implemented to build a more competitive, customer-centred, flexible and non-discriminatory market-based EU electricity market[6]. Also, market setups are expected to be **robust and stable over time** for all capacity calculation time-frames, as this enhances the liquidity of the market in all respects and creates a favourable investment environment for energy companies. Article 33.1.c.i of the Capacity Allocation and Congestion Management Guideline, Commission Regulation (EU) 2015/1222, hereafter "CACM",

[6] https://www.europarl.europa.eu/factsheets/en/sheet/45/internal-energy-market

states *"the need for a bidding zone to be sufficiently stable and robust over time"* and *"the need for bidding zones to be consistent for all capacity calculation time-frames".*

Market setup 2 ("Dynamic flows to high-price market") implies positive discrimination of offshore wind farms which are connected through a hybrid asset, as these are granted the capture price of the highest priced connected bidding zone. Similarly, market setup 3 ("Dynamic flows to low-price market") implies negative discrimination of offshore wind farms which are connected through the hybrid asset, as these are granted the capture price of the lowest connected bidding zone.

Also, both market setup 2 and 3 do not meet the criteria of robustness and stability as defined in the CACM guideline, as the prices of the affected bidding zones can vary by the hour, implicating that offshore wind farms need to swap bidding zones. Consequently the affected bidding zones are possibly changing by the hour and are therefore neither stable nor robust.

Thus, based on these fundamental market design requirements **options 2 ("Dynamic flows to high-price market") and 3 ("Dynamic flows to low-price market") are not further considered** in this discussion paper. The remaining two market setup options are considered in more detail below and shown in figure 6.

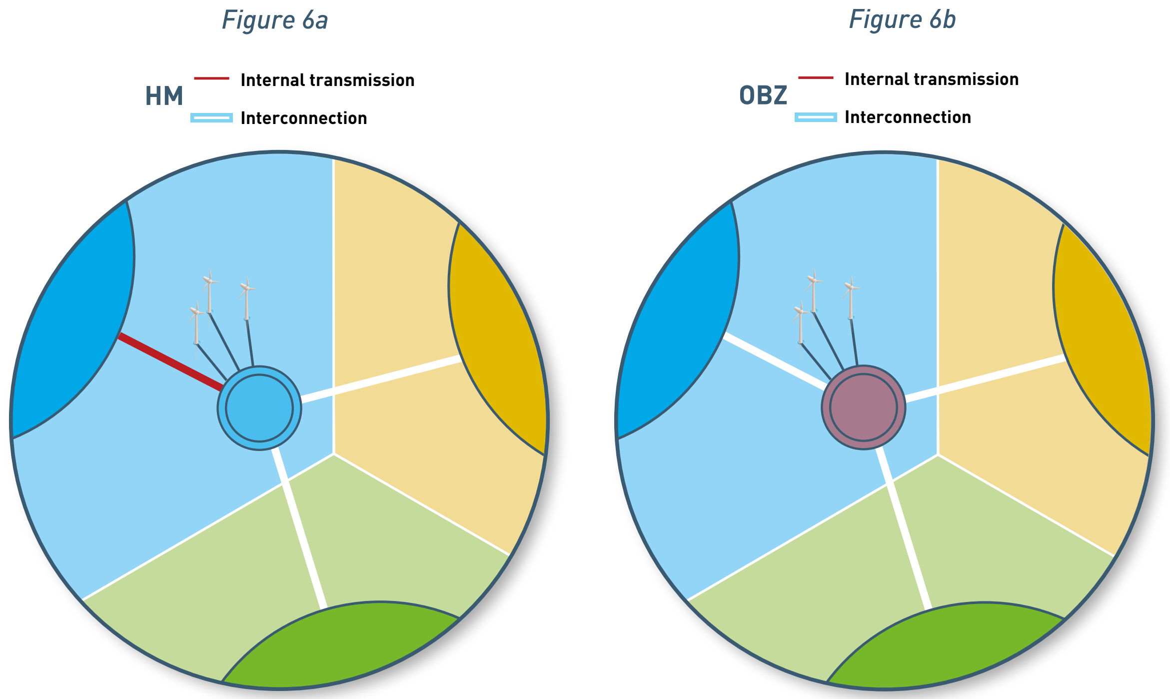


Figure 6. Two market setup options to integrate hybrid projects in the European electricity market are analysed. The figure represents three onshore bidding zones, associated (offshore) economic exclusion zones (EEZ) and one hybrid project that collects the wind power and provide grid and interconnection. The hub is connected via cables to the onshore bidding zones. In the HM setup (a), the hub belongs to the blue bidding zone. In the OBZ market setup (b) the hub forms an independent bidding zone.

The Home Market (HM) setup is considered to be organised as follows: all offshore wind farms connected to shore through a hybrid asset are bidding into their existing home markets and, in line with the European Clean Energy Package REGULATION (EU) 2019/943, hereafter "CEP", no priority access is provided to the offshore wind farms with respect to the infrastructure capacity. In addition, no derogation on CEP regulation is assumed, requiring TSOs to provide (at minimum) 70% of the cross-border interconnection capacity for cross-border trade. The offshore wind farms will subsequently receive the electricity price of their home market and are also able to operate as a Balance Responsible Party (BRP) within that bidding zone. In the HM setup it is assumed that the total offshore wind capacity involved is of the same order of magnitude as the total infrastructure capacity, thus involving implicit structural congestion with respect to either of the connections to the different energy markets.

The Offshore Bidding Zone (OBZ) setup is considered to be organised as follows: all offshore wind farms connected to shore through interconnection cables are bidding into a newly created offshore bidding zone that reflects the structural congestion in the grid. The transmission systems between the newly created offshore bidding zones will then solely function as cross-border interconnection assets that provide cross-zonal transmission capacity. The wholesale electricity price in the newly created offshore bidding zone and the dispatch of the offshore wind farms will be the result of the market coupling algorithm. Moreover, the offshore wind farms will operate as a BRP within the newly created offshore bidding zone. In the OBZ setup it is assumed that the total offshore wind capacity involved is of the same order of magnitude as the total infrastructure capacity, thus involving implicit structural congestion with respect to either of the connections to the different energy markets.

The two market setups are analysed[7] with respect to the different assessment criteria (see table 1).

Assessment criteria I: Compliance with current European regulation

From a regulatory perspective the two market setups are distinctive in their compliance with CEP and CACM. Considering the techno-economic setup of a hybrid project in combination with an OBZ setup or a HM setup, the primary regulation that impacts the HM market design is Article 16(8) of the CEP regulation states that:

- "for borders using a coordinated net transmission capacity approach, the minimum capacity shall be 70 % of the transmission capacity respecting operational security limits after deduction of contingencies";
- "for borders using a flow-based approach, the minimum capacity shall be a margin set in the capacity calculation process as available for flows induced by cross-zonal exchange. The margin shall be 70 % of the capacity respecting operational security limits of internal and cross-zonal critical network elements, taking into account contingencies";
- and "the total amount of 30 % can be used for the reliability margins, loop flows and internal flows on each critical network element".

[7] *During the analysis there was fruitful and mutual exchange with PROMOTioN, a project 'PROgress on Meshed HVDC Offshore Transmission Networks' funded by the European Union.*

For the HM market setup this regulation forms a barrier when the wind capacity of the hub is larger than 30% of the capacity of the transmission line to its home market as the 70% ruling states that at least 70% of the cross-border interconnection capacity should be made available for cross-border trade. This means that only 30% of the hybrid asset capacity would remain available for the wind power or that exemptions or regulatory changes are required. Four exemption routes are identified, as shown in figure 7, to deal with Article 16(8) from CEP:

1. Route 1 relates to the exemption route as found in recital 66 of the Electricity Regulation, which states that hybrid assets combining offshore wind and interconnection are eligible for exemptions valid for new DC interconnectors via article 63 under the condition that the investment would not take place without the exemption, and that the interconnector would be built outside of the regulated domain, which implies that it should be a merchant interconnector;
2. Route 2 relates to that priority dispatch of renewable energy sources is allowed according to Article 12(2) for "demonstration projects for innovative technologies, subject to approval by the regulatory authority, provided that such priority is limited to the time and extent necessary for achieving the demonstration purposes";
3. Route 3 is an exemption via Article 64 (1), which states that "the Member State can demonstrate that there are substantial problems for the operation of small isolated systems and small connected systems". However, it is questionable whether a project as the NSWPH can be seen as a small isolated system. Besides, also this exemption route shall be limited in time; and
4. Route 4 via Article 13 outlines the conditions and requirements for redispatch and countertrade measures, which need to be taken in case priority access of wind is not allowed and more than 30% wind energy is produced.

In the OBZ market setup this problem is non-existent. In the OBZ market configuration, in line with the CACM guideline, the bidding zone borders are based on structural congestion, thereby defining the transmission assets from the offshore hub to shore as "cross-border interconnection capacity" which can be fully made available to the market.

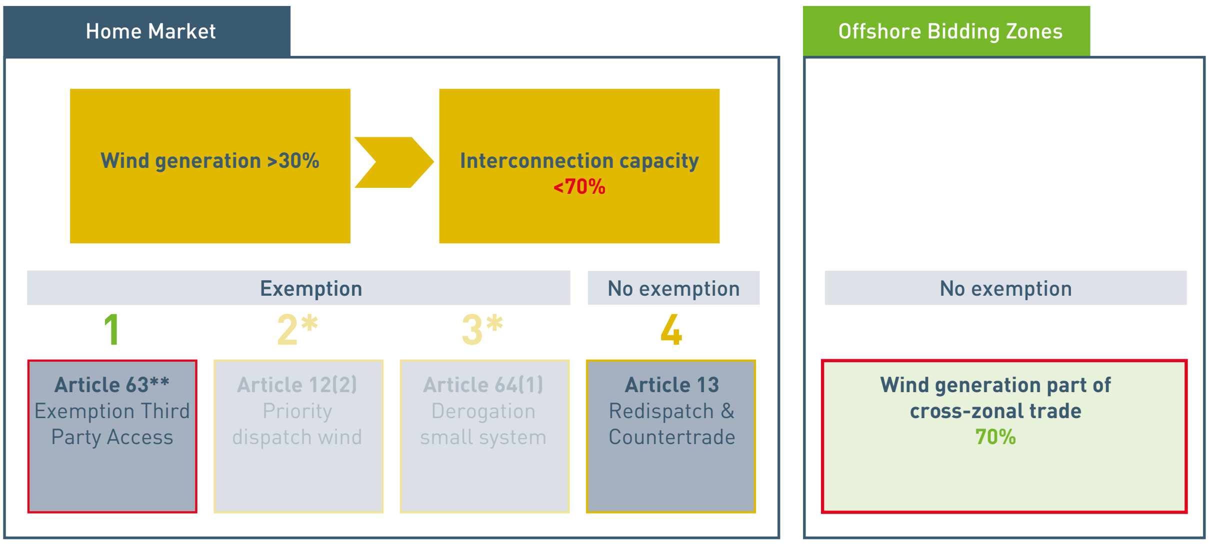


*Figure 7. Exemptions or regulatory changes to the CEP are required for the HM setup to function, which is not the case for the OBZ setup. *Route has been considered but deemed not promising. ** In consideration of recital 66.*

As such, a hybrid project in combination with the pure HM setup, as shown in figure 6, would cause major flaws in the dispatch of units and requires a significant amount of redispatch actions or countertrades. To overcome this, several exemptions on CEP regulation are required to ensure priority access of wind energy and an adaptation of a pure HM setup is required where the offshore wind farms connected to the hub are allocated to different existing onshore bidding zones (see figure 8). This latter measure ensures that the access rights for offshore wind farms do not exceed the transmission capacity to its respective home market. However, it implies that in the Hub-and-spokes project, the hub is split in line with the cable capacities and the offshore wind farms get one of the connected bidding zones designated as home market. Further analysis is required to determine the terms of this designation as this may impact the revenue income of offshore wind farms. Note that in all of the following, the term HM setup, refers to the configuration shown in figure 8, i.e. including an allocation of wind farms to their respective home markets.

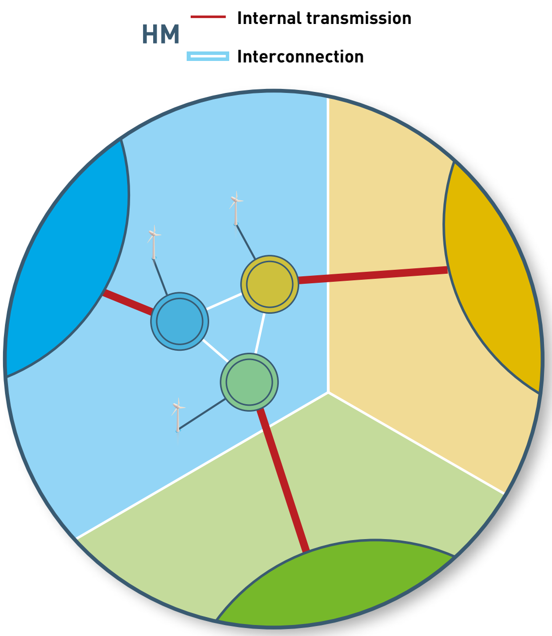


Figure 8. In order for the HM setup to function, priority access has to be allowed and the home market access right of the offshore wind farms cannot exceed the transmission capacity to the home market. This requires the hub to be split in three home market zones with allocation of the offshore wind farms to one of the connected bidding zones.

Assessment criteria II: Dispatch and capacity allocation efficiency and socio-economic welfare

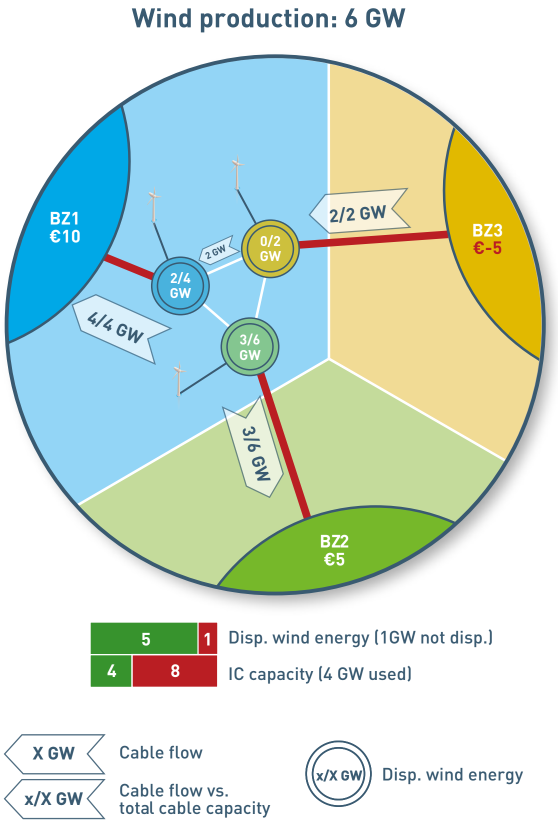
The overall aim of electricity market design is maximising socio-economic welfare (SEW), which is in the context of offshore wind projects the total net benefit for society and in this paper defined as the economic surpluses of electricity consumers, producers and transmission owners in the form of congestion rents. As such, the aim of the market design is to minimise the total cost of generation. Since the allocation of transmission capacity directly affects the allocation of supply, and thereby the dispatch of generation, the allocation mechanism of transmission capacity is a key factor for an efficient market design. The assessment of the two setups is distinctive due to the fact that capacity allocation for cross-border interconnection capacity is varying in the two setups. If transmission capacity is not allocated efficiently, this will have a negative impact on the SEW.

The HM setup with priority access of offshore wind farms could induce inefficiencies due to the following:

1. Priority access for offshore wind farms may lead to inefficient use of interconnection capacity in case of negative prices and less than 100% wind production (see figure 9);
2. Congestion management to reduce capacity restrictions between the home market and the hub may not be economically efficient; and
3. Wind forecast errors impact the available amount of cross-border interconnection capacity, because in the HM setup wind forecasting is required to determine available cross-border interconnection capacity. Wind forecasting is done two days in advance as needed in the capacity calculation, which increases the risk on the wind forecasting errors.

These possible inefficiencies are not applicable to the OBZ market setup, because in this market setup the physical reality of the grid and offshore wind farm and interconnection flows are co-optimised by the market coupling algorithm, which ensures the most cost-efficient dispatch of units.

Figure 9. As an example, wind power is less efficiently dispatched in a HM setup than in an OBZ setup in case one of the onshore bidding zones has a negative price. In the HM setup, this situation leads to dispatch of less cost-efficient units from BZ2 instead of the offshore wind farms belonging to BZ3, which are not dispatched.



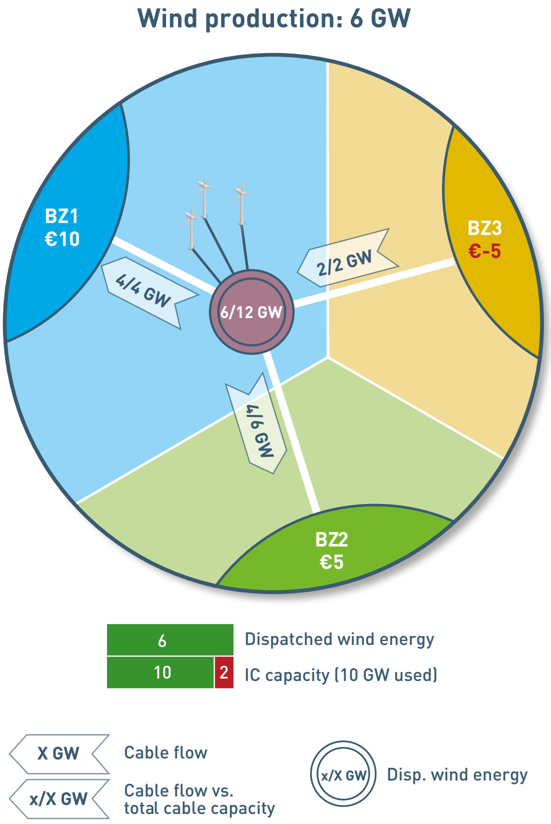


Figure 9a) In case of a HM setup, BZ1, BZ2 and BZ3 will release respectively only 2GW, 3GW and 1GW interconnection capacity in the direction of the hub to allow priority access of wind energy. BZ1, BZ2 and BZ3 will release their complete capacity in the other direction. Offshore wind energy from the hub will not be scheduled in BZ3, because the electricity price in BZ3 is lower than the zero marginal cost price of wind energy. BZ3 will export 2GW to BZ1 resulting in a congested cable from BZ1 to the hub. This makes that only 4GW of cross-border interconnection capacity is used.

Figure 9b) In an OBZ setup, the market coupling algorithm will lead to export of electricity from BZ3 to the hub, because the electricity price of BZ3 is lower than the zero marginal cost of the hub. The hub has the second lowest electricity price and will thus be allocated second. From the remaining 10GW cross-border capacity to BZ1 and BZ2, 2GW is used for the flow from BZ3 to BZ1 and 6GW can be used for export of wind energy from the hub. This means that 2GW of cross-border interconnection capacity remains unused.

Assessment criteria III: Price formation in implicit auctions

In the following, the price formation is only analysed for the OBZ market setup, since in the HM setup the offshore wind farm will receive the cleared electricity price of the home market.

The price within a bidding zone is determined by its domestic demand and supply and potential imports and exports. As long as transmission capacity is available from one bidding zone to another, their prices cannot diverge since the market would have utilised the available capacity to exploit the market spread. Similarly, the full utilisation of an interconnector implies a price spread at that border. The price in a bidding zone equals its marginal cost of production, except if the total production capacity is dispatched and the bidding zone is importing from a bidding zone with higher marginal costs of production. In this case the price is above the local marginal costs of production. However, the price could never be below the marginal costs of production. As such, the price in an offshore bidding zone with only offshore wind will therefore be zero if not all potential wind in-feed can be dispatched due to congestion on all interconnectors from the offshore bidding zone. This is not the case for a hub in a HM setup, which by definition will receive the price from its home market. **The price of an OBZ always equals the price of all bidding zones to which uncongested interconnectors exist** (see figure 10).

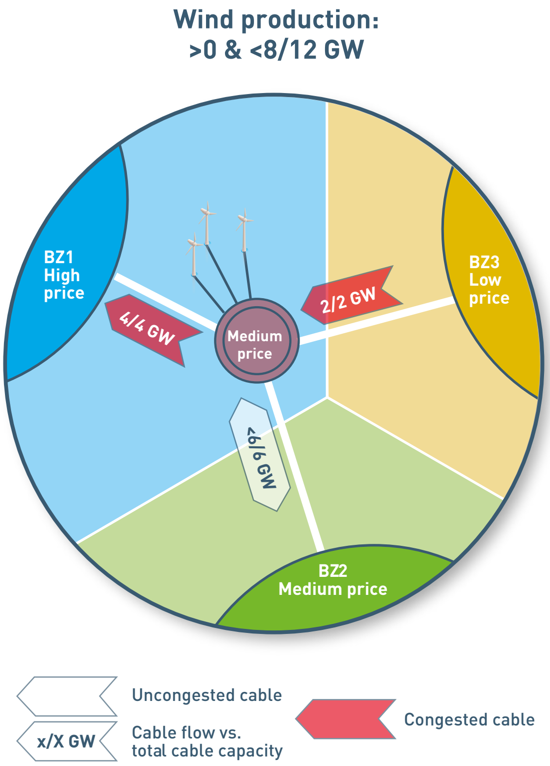


Figure 10a) Example of price formation in an OBZ market setup. Here the price converges to the medium price due to the uncongested interconnector to the medium-priced bidding zone.

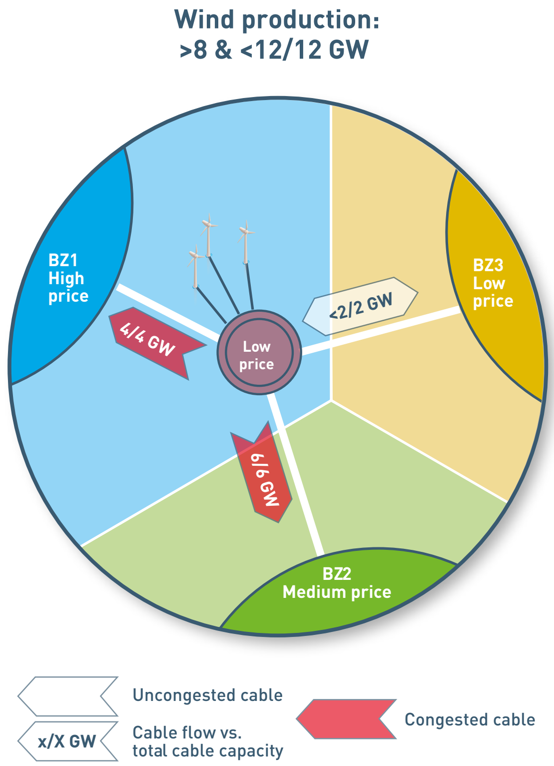


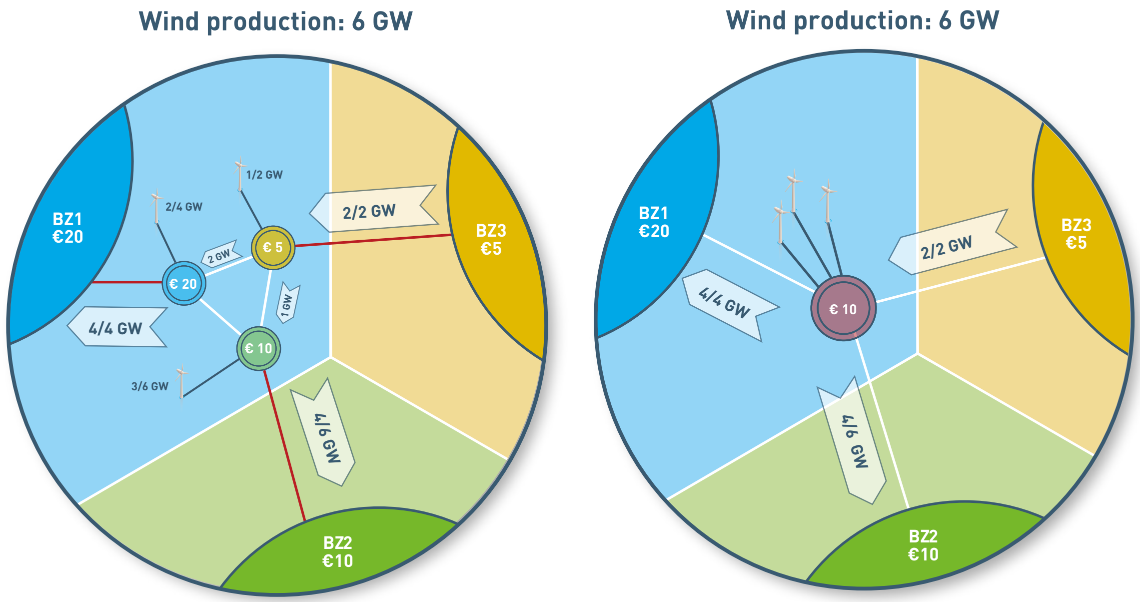
Figure 10b) Example of price formation in an OBZ market setup. Here the price converges to the low price due to uncongested interconnector to the low-priced bidding zone.

Some uncertainty still exists regarding price formation for the OBZ market setup in continuous markets like the intraday market. In intraday there is not one single price, but separate contracts with individual cleared electricity prices which result from the trades. Besides, offshore wind farms could be sellers or buyers in the intraday market depending on the change in wind forecast. The resulting offshore wind farm's intraday price is determined by different connected bidding zones depending on whether selling or buying is considered[8].

Assessment criteria IV: Distributional effects

When an offshore wind farm in the HM setup is connected to the hub and belongs to a high-price home market, it gains the price spread per MWh in-feed due to the home market access compared to the economic value of the wind power at the hub. At the same time TSO congestion rent is reduced by the same amount. Similarly, if in the HM setup the hub is connected to a low price home market, the offshore wind farm loses the price spread per MWh in-feed due to the home market access. Therefore, the home market access can also be perceived as a transfer of the congestion rent to the offshore wind farms (see figure 11a and 11b).

[8] *It should be noted that uncongested interconnectors offer capacity in both directions, whereas congested interconnectors can still offer capacity in the opposite direction.*



Consumer surplus	X	€/h
Producer surplus (exc. OWFs)	Y	€/h
OWF surplus (H1 + H2 + H3)	75	€/h
Congestion income hub-BZ1	0	€/h
Congestion income hub-BZ2	5	€/h
Congestion income hub-BZ3	30	€/h
Socio-economic welfare	110	€/h

Consumer surplus	X	€/h
Producer surplus (exc. OWFs)	Y	€/h
OWF surplus (H1 + H2 + H3)	60	€/h
Congestion income hub-BZ1	40	€/h
Congestion income hub-BZ2	0	€/h
Congestion income hub-BZ3	10	€/h
Socio-economic welfare	110	€/h

X GW — Cable flow
x/X GW — Cable flow vs. total cable capacity

Figure 11. Example of price formation in a HM setup (a) and OBZ market setup (b) with an assumed total infeed of 6GW. The wind production is evenly divided over the offshore wind farms. In the HM setup (a), the offshore wind farms receive the electricity price of the home market they belong to. This can either be BZ1, BZ2 or BZ3. Besides, BZ3 will export 2GW to BZ1 and export 1GW to BZ2, because the electricity price is lower in BZ3 than in BZ1 and BZ2. There will be no additional interconnection flows, because the cable between the highest-price zone BZ1 and the hub is congested. In the OBZ setup (b), the hub electricity price converges to BZ3, because 4GW of the hub will feed into BZ1 and 6GW will be exported to BZ2. This means that 1GW remains to be exported to BZ3 and this line is uncongested. In the table below the figures, the economic surplus of the socio-economic welfare is explained for both setups.

In case the resulting distributional effects are considered unwanted by policy-makers, it can be considered to mitigate these effects by way of compensation, redistribution or other financial instruments.

It should be noted that only coupled auctions as the Single Day-Ahead Coupling have been considered. The findings also hold for the future Single Intraday Coupling - Auctions as they are basically equivalent to the Single Day-Ahead Coupling. The continuous markets as XBID have not been included in this initial assessment due to their variety and pay-as-bid nature. However, during the continuous intraday market cross-border capacity is allocated “first-come-first-served” and free of charge. No congestion rent arises at the TSO and the value of the capacity is directly captured by the trades which utilise the capacity. On the one hand, intraday rents of the TSO are equally zero in both setups. On the other hand, the value of intraday capacity is absorbed by the market (consumer surplus, producer surplus and OWF surplus) while the share allocated to the OWF depends on timing and market conditions.

Assessment criteria V: Revenue impact for offshore wind farms

The revenues of an offshore wind farm connected to a hub from energy sales are different for the HM setup and the OBZ setup. The revenues are determined by sold and purchased amounts of electricity and the associated prices. While the present theoretical assessment can only describe tendencies of selected influencing factors, only a holistic market simulation on a large data basis can show the expectable difference in revenues and which setups results in higher average revenues.
With regard to the total amount of dispatched generation, the HM setup will result in higher revenues for OWFs than the OBZ setup in case of negative prices in the neighbouring bidding zones. Although this situation leads to an economically inefficient dispatch, it is advantageous from the OWFs point of view as it provides new trade opportunities.

With regard to the level of prices, it very much depends on whether a home market is predominantly higher priced than the others or not. Whether an OBZ or a HM setup results in the higher prices therefore is a matter of chance and no general statement could be made.

With regard to the level of risk in the expected revenues, it should be noted that risk and opportunity are two sides of the same coin. Investors are normally not just risk-seeking or risk-averse, but assumed to be risk-neutral. Therefore, the level of risk might not matter so much. However, it could be shown that the price volatility at the hub is probably lower in a OBZ market setup compared to the HM setup. The reason is the higher share of interconnector capacity compared to the market volume and thereby the higher portfolio effect on the prices. However, further research is required to get a better understanding of the pricing behaviour of an offshore bidding zone and whether the price of the offshore bidding zone and the overall revenue by offshore wind farms is structurally different, possibly requiring additional measures to compensate.

In addition, in the OBZ market setup a financial risk is borne by the offshore wind farm in case of congestion and consequently not being able to fully dispatch. The pricing behaviour of an offshore bidding zone and the dispatch risk for offshore wind farms needs to be taken into account (and further investigated) to provide sufficient investment certainty for offshore wind farm developers.

Assessment criteria VI: Balancing and operational impact

The main concern with the HM setup is that even though market participants are fully financially responsible for their imbalances, the absence of an offshore imbalance price does not incentivise them to solve imbalances on the location of the OWF. This potentially leads to congestion problems on the transmission infrastructure between the hub and the home market. In the HM setup the BRP of the OWF can for example compensate any deviation between the expected and realised energy production by portfolio adjustments on the mainland. The increased or decreased generation at the hub will still need to be carried onshore, which can then only be done by changing the flow on the transmission infrastructure or through countertrading in case the cable cannot cope with the difference.[9] In contrast, in a HM setup a congestion risk is borne by the TSO in case the offshore wind farm developer uses its offshore wind farm to balance its onshore portfolio and this leads to transmission limitations between the hub and the home market.

In case of an OBZ setup, depending on how the imbalance price is determined, better financial incentives can be given to the BRP of the OWF. However, there are fewer opportunities, depending on the balancing market design and the availability of cross-zonal capacity on the new bidding zone border, for the OWF owner to participate in balancing markets. The balancing market design for the OBZ design needs to be investigated further to ensure correct incentives and sufficient opportunities.

Operational and balancing pricing aspects will have to be further defined in due time, ultimately before the tendering date of OWFs.

The questions which need to be answered are: Who has the capacity calculation responsibilities?; Will the location of control, in this case the HVDC station, be onshore or offshore?; How will the imbalance price be determined?; How can the power balances be distributed over the HVDC if multiple countries are connected to the hub?; To which LFC area/block[10] will the OWFs belong in case a TSO-owned AC-offshore grid is included in the Hub-and-Spokes design?; What balancing responsibilities does the TSO have on the offshore grid?

As such, additional research should be initiated to look into these specific details to allow for a transparent, non-discriminatory and fair market setup.

[9] It should be noted that the BRP is responsible for energy per imbalance settlement period (15 minutes), so any fluctuations in power output during the ISP would not be part of the financial responsibility of the BRP in either setup.

[10] The OWFs do not belong to any LFC area/block (or synchronous area), as long as there is no TSO-owned AC grid offshore within the relevant hub.

Conclusion and next steps

The analysis provided in this discussion paper identifies the implications of two market setups – "Home market (HM)" and "Offshore Bidding Zone (OBZ)" – to integrate hybrid projects and also provides an insight into the efficiency of these different market setups. The detailed assessment of the two market setups shows a clear distinction with respect to all assessment criteria. The analysis shows that the HM setup requires significant regulatory changes and induces inefficiencies (leading to less socio-economic welfare), which the OBZ does not. At the same time, also in case of the OBZ adaptations are required to ensure a fair distribution of revenue and risk between regulated and market parties and operability of the system. This requires a well-structured discussion that can lead to an inter-governmental agreement by the involved governments. This analysis aims to facilitate such a discussion while also informing decision makers that additional research is required to further understand and explain the dynamics and operability of the possible market setup.

As such, the following additional analysis is suggested to further facilitate the decision-making process:

1. Analysis of the impact on revenue for offshore wind farms and congestion rents for TSOs;
2. Analysis of mitigation measures for unwanted distributional effects depending on the market setup.

In addition, before implementation and prior to tendering offshore wind farms which will be connected through hybrid projects, the operational rights and obligations for offshore wind farms (i.e. BRPs) and TSOs need to be clarified. This will require additional analysis from the stakeholders involved.

Finally, an analysis on whether the market setup is future proof with respect to offshore connection of P2X facilities is lacking in the current assessment. Beyond 2030 other offshore developments (such as offshore P2X) can be expected to be techno-economically feasible, requiring a more detailed analysis on the impact of offshore load in relation to the appropriateness of the market setup as this highly influences capacity allocation. PROMOTioN[11] did conduct research on compatibility of P2X with market setups for hybrid projects and determined that small bidding zones, which is similar to the OBZ setup, results in a more economic efficient dispatch than the National markets, which is similar to the HM setup. Also here, still an techno-economic potential analysis on P2X in relation to the market setups is required to determine the profitability and feasibility of such technologies and corresponding timeline.

[11] *PROMOTioN, 'D12.3 Deployment Plan', 2020.*

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