North Sea
Wind Power Hub
Programme

Regulatory & market design

Market setup options for hybrid projects

Discussion paper

#2

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About this paper

Why read this report

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 analyses provided in this document aims to empower policymakers in their decision-making by facilitating a balanced and structured discussion. This paper addresses knowledge gaps that remained untouched in the previous discussion paper on market setups by showing the impact of the Home Market setup and the Offshore Bidding Zone setup on the existing national legal and regulatory frameworks in Denmark, Germany and the Netherlands. Moreover, insights are provided into key economic indicators such as efficiency, price dynamics and income distribution and thereby responds to current European discussions. Finally, recommendations of next steps are provided.

Highlights

Early clarity on the market setup is required for hybrid project development to ensure a stable and reliable investment climate for all stakeholders.

Neither the Offshore Bidding Zone setup nor the Home Market setup is more difficult to implement from a national legal and regulatory perspective.

Effects of market setup choice on socio-economic welfare are small, but potential benefits of Offshore Bidding Zone setup are enhanced when there is more diversity in the hub-connected markets. The main difference between market setups is income distribution between project stakeholders.

Structure of the discussion paper

1. Why, What, How
2. National legal & regulatory framework analysis
3. Efficiency, price formation and income distribution analysis
4. Next step

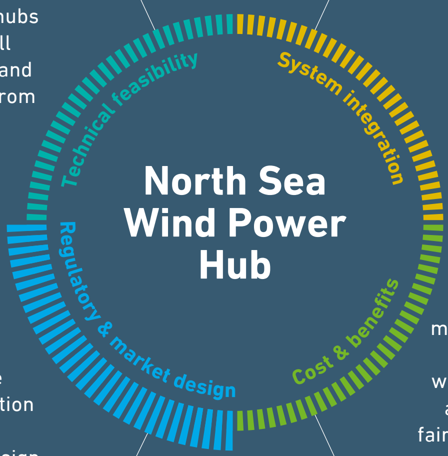
The big picture

The North Sea is a powerhouse of wind energy. Harnessing this power requires us to cooperate across countries and borders to build an efficient network. To show that a solution can be achieved in a cost-effective and secure manner, the North Sea Wind Power Hub is working within four key areas.

This discussion paper explores key topics within regulatory & market design.

How to design and build the physical hubs and spokes that will collect, transform and distribute energy from the North Sea.

How to adapt the energy systems in Northern Europe to integrate a large volume of offshore wind from the North Sea.



How to ensure a stable and reliable investment climate by adapting regulation and creating an efficient market design.

How to ensure that the chosen solution maximises benefits for society and climate while minimising costs and distributing them fairly between countries and stakeholders.

Executive summary

The deployment of renewable energy sources in Europe will increase significantly to support the goal of net zero greenhouse gas emissions by 2050. Offshore wind will have a large part in this, and the European commission stated in its offshore renewable energy strategy[1] that a target of 300GW in 2050 is realistic and achievable. 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 an enabling regulatory framework.

1 The trend towards hybrid projects

As explained in a previous discussion paper[2] and stressed by the European Commission in the offshore renewable energy strategy, hybrid projects are generally considered as a next necessary step to efficiently integrate offshore wind farms in the EU electricity markets.

The term "hybrid projects" as used by the European Commission refers to projects in which the development and implementation of offshore wind and interconnection capacity is combined. The term is not related to the choice of market design or other regulatory aspects.

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 clarity on the market setup is required for hybrid project development to ensure a clear, stable and reliable investment climate for all stakeholders. The earlier published discussion paper of the North Sea Wind Power Hub (NSWPH) programme provided an in-depth analysis of the Home Market (HM) setup and the Offshore Bidding Zone (OBZ) setup. In order to allow policy-makers to make an informed decision on market setups, a follow-up analysis is presented that provides additional insight into the topic.

Read more on page 7

2 Market setups for hybrid projects

This paper intends to dive deeper into the market setup topic by i) reflecting on the compatibility of the market setups given a certain hub-and-spoke concept with the national legal and regulatory frameworks of Denmark, Germany and the Netherlands, and ii) by providing a thorough quantitative analysis of the impact of the market setups on the efficiency, price formation and distributional impacts, also touched upon in the previous discussion paper conceptually.

Read more on page 9

[1] European Commission, *Communication from the commission to the European parliament, the council, the European Economic and Social Committee and the Committee of regions – An EU Strategy to harness the potential of offshore renewable energy for a climate neutral future*, November 2020.
[2] North Sea Wind Power Hub programme, *Market setup options to integrate hybrid projects into the European electricity market – discussion paper*, April 2020.

3 Impact on national legal and regulatory framework

This part of the analysis determines which regulatory and/or legal aspects create potential barriers for the implementation of the home market setup and the offshore bidding zone setup considering a certain hub-and-spoke concept. To date, the North Sea Wind Power Hub has outlined one type of configuration in which the hubs and all OWFs are located in one Exclusive Economic Zone (EEZ), the so-called centralised hub system. Another configuration analysed in this report is the distributed hub system: where the hub-and-spoke project is distributed over EEZs in line with the cable capacity towards shore. In the HM setup, the sub-hub and the OWFs connected to that respective sub-hub form the respective home market. In the OBZ setup, the sub-hub and the OWFs connected to that respective sub-hub form a separate offshore bidding zone.

The analysis shows that neither the OBZ setup nor the HM setup is more difficult to implement and that the distributed hub system encounters less hurdles in the national legislation and regulation. The latter is due to the fact that distributing the sub-hubs over the EEZs allows the respective stakeholders to conduct their classical tasks with respect to the offshore bidding zones / home markets. This is not the case for the centralised hub system under the home market setup where stakeholders might not be able to conduct their classical roles. However, when looking at the combination of a market setup and hybrid project configuration, not one combination is preferable over another. Therefore, more research and input from policymakers is required to make firm recommendations.

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4 Impact on efficiency, price formation and revenue distribution

In order to provide a deeper understanding of the market efficiency and financial impact on stakeholders of the different market setups, this analysis provides detailed insight into the difference in price dynamics, overall socio-economic welfare (SEW) and income distribution (i.e. the dynamics and interdependence of OWF capture price and congestion rents) of the directly involved stakeholders (the OWF developers, the Transmission System Operators (TSOs) and society at large) between the home market setup and the offshore bidding zone setup.

The analysis shows that the offshore bidding zone setup results in marginally more efficient dispatch and capacity allocation, and a marginally higher SEW. The difference between the HM and OBZ setup is caused by: i) a difference in dispatch and capacity allocation between the market setups and ii) a difference in loss handling. Furthermore, a wind forecast reliability margin included in the home market setup modelling to account for potential wind forecast errors also influences the released interconnection capacity on the hybrid asset, and thus the dispatch and capacity allocation efficiency. The main difference between the setups is how income is distributed between consumers, OWFs and TSOs.

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5 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 analyses provided in this document aims to empower policymakers 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. Additional research in the short-term should include a broad exploration of options to ensure a stable investment framework for offshore wind farm developers compensating for the reduced income under the offshore bidding zone setup, and an analysis on potential governance and ownership models to allocate roles and responsibilities for a hub-and-spoke project. Furthermore, more in-depth analyses may be required with respect to the quantitative impact of inter alia loss handling, onshore/offshore power-to-X, 70% rule, advanced hybrid coupling and other market timeframes on the hub-and-spoke project stakeholder under both market setups.

Read more on page 27

1 The trend towards hybrid projects

Combining offshore wind grid connection with interconnection of EU electricity markets and coupling of energy sectors at scale aims to reduce overall system costs, spatial and environmental impact and increase system efficiency.

The deployment of renewable energy sources in Europe will increase significantly to support the goal of net zero greenhouse gas emissions by 2050. Energy scenarios consider offshore wind as a major renewable energy source in the future European energy system. The European Commission stated in its offshore renewable energy strategy[3] that a target of 300 GW is realistic and achievable. 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 an enabling framework.

Highligt

Large-scale offshore wind projects are necessary to meet the goal of net zero greenhouse gas emissions by 2050.

As explained in the previous discussion paper[4] and stressed by the European Commission in the offshore renewable energy strategy, hybrid projects (see text box 1) are generally considered as a next necessary step to efficiently integrate offshore wind farms in the EU electricity markets. Hybrid projects impact the energy system in three ways:

- Reducing overall system costs;
- Increasing security of supply; and
- Reducing environmental impact.

Text box 1: The difference between hybrid projects and hybrid assets

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.

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 are 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.

[3] European Commission, *Communication from the commission to the European parliament, the council, the European Economic and Social Committee and the Committee of regions – An EU Strategy to harness the potential of offshore renewable energy for a climate neutral future*, November 2020.

[4] North Sea Wind Power Hub programme, *Market setup options to integrate hybrid projects into the European electricity market – discussion paper*, April 2020.

Hybrid projects enable system cost reduction

Hybrid projects imply a dual use of the infrastructure where the grid connection for offshore wind farms (OWFs) 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] (SEW), mainly through the fact that the new offshore infrastructure will have a higher utilisation rate than for traditional radial grid connections and conventional point-to-point interconnections, ultimately providing more cost-efficient transmission infrastructure.

Highligt
Three reasons why hybrid projects are a crucial part of meeting the paris agreement.

Hybrid projects benefit security of supply

Furthermore, the coupling of electricity markets in Europe with increased interconnection capacity results in more efficient electricity dispatch, and in combination with increased in-feed of low-priced wind energy results in lower system costs of dispatched energy. This increased market coupling consequently increases the security of supply of the interconnected markets and countries.

Hybrid projects enable environmental impact reduction

Besides major decarbonisation of the energy industry, hybrid projects deliver positive impacts on the environment in two more ways. Increasing amounts of interconnection allows replacing of carbon intensive energy sources by clean offshore wind energy. Coupling the offshore wind energy production to power-to-X production as short– and long-term flexibility, ensures lower carbon emissions from the electricity sector throughout all four seasons.

In addition, the North Sea Wind Power Hub programme (NSWPH) aspires to reduce overall environmental impact of the to-be-developed infrastructure. Combining both interconnection and offshore wind grid connection functionality in one asset translates into a reduced need for cables in the North Sea and landing points in comparison to radially connected OWFs and point-to-point interconnectors. As an overall result less land use is required. It should be noted that the infrastructure is a minor part of the total impact of the offshore renewable energy deployment.

[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.

2 Market setups for hybrid projects

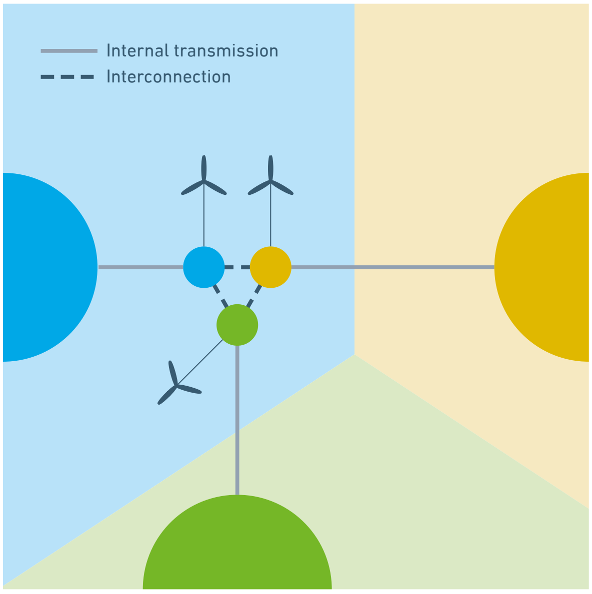
Early clarity on the market setup is required for hybrid project development to ensure a stable and reliable investment climate for all stakeholders. European electricity market principles funnel the market setups options down to only two options: the home market setup and the offshore bidding zone setup.

Early clarity on the market setup is required for hybrid project development to ensure a stable and reliable investment climate for all stakeholders. When considering the various options, several aspects need to be taken into account. From an economic perspective, the European market design is intended to maximise the efficient use of the electricity transmission infrastructure from a socio-economic welfare perspective. Any market setup should adhere to the principles of the European Internal Energy Market and should therefore be transparent, fair and non-discriminatory. Measures implemented in the Internal Energy Market aim to harmonise and liberalise the European electricity markets, and to build a more competitive, customer-centred, flexible and non-discriminatory market-based EU electricity market. Market setups for hybrid projects are expected to be robust and stable over time for all capacity calculation time-frames. These principles funnel the market setup options down to only two options: the home market (HM) setup and the offshore bidding zone (OBZ) setup. The earlier published discussion paper of the North Sea Wind Power Hub programme provided an in-depth analysis of these market setups, see figure 1.

Highligt

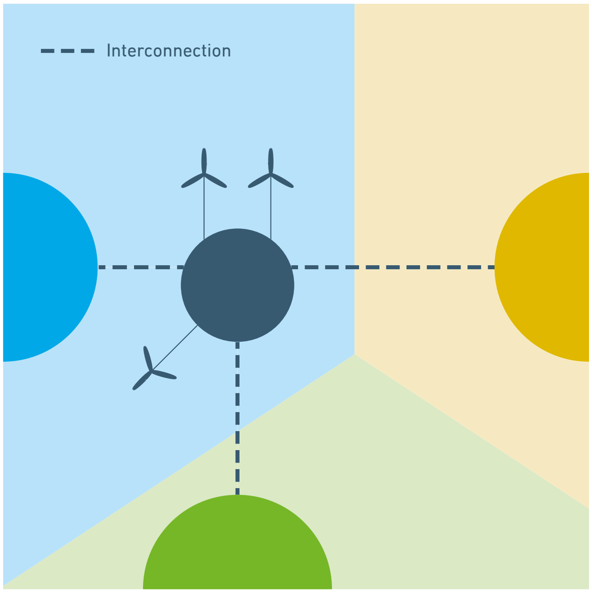
Measures implemented in the Internal Energy Market aim to harmonise and liberalise the European electricity markets.

Figure 1a: Home Market setup



In the home market setup, the offshore wind farm bids and dispatches into its home market and recieves the HM electricity price. The cable between the hub and HM is a hybrid asset, whereas the cables between the home markets are cross-border interconnectors.

Figure 1b: Offshore Bidding Zone setup



In the offshore bidding zone setup, the hub forms a seperate offshore 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.

Figure 1a and 1b: Conclusion

The analysis showed 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 induced by negative prices and wind forecast errors have to be overcome to reach a socio-economic welfare similar to the OBZ market setup. Furthermore, a congestion management risk exists in the HM setup due to onshore portfolio balancing, whereas in case of the OBZ setup, the observed distributional effects of financial streams from the offshore wind farm developer towards the transmission system operator may require additional measures to ensure a fair distribution of risk and revenue among the energy market actors.

This paper intends to dive deeper into the market setup topic by reflecting on the compatibility of the market setups given a certain hub-and-spoke configuration with the national legal and regulatory frameworks of Denmark, Germany and the Netherlands, and by providing a thorough quantitative analysis of the impact of the market setups on the price formation and distributional impacts, which was touched upon in the previous market setup discussion paper.

This paper shows the impact of the two analysed market setups on the existing national and legal frameworks in Denmark, Germany and the Netherlands. Thereby addressing another knowledge gap that remained untouched in the previous discussion paper on market setups for hybrid projects.

Moreover, by addressing the uncertainty on the price-dynamics and income distribution of market setups and providing insights into key economic indicators for (combined) infrastructure development for the involved stakeholders, the North Sea Wind Power Hub programme responds to current European discussions about differences of price dynamics and income distribution between the potential market setups. The executed analysis focusses on quantifying the impact of the different market setups and does not address the value and/or cost-effectiveness of the assumed transmission infrastructure in the analysis.

Finally, the paper concludes with a recommendation of next steps required to facilitate early development and implementation of hybrid projects.

Highligt

This paper adresses untouched knowledge gaps for the home market setup and the offshore bidding zone setup.

Figure 2: Structure of the discussion paper

1. Why, What, How
2. National legal & regulatory framework analysis
3. Efficiency, price formation and income distribution analysis
4. Next step

3 Impact on national legal and regulatory framework

Current offshore projects have to comply with the legal and regulatory framework of the Exclusive Economic Zone (EEZ) they are located in. As such, the location of a hub and offshore wind farms can be highly decisive for the legal and regulatory framework that the hybrid project and its market setup have to comply with. Market setups for hybrid projects define how offshore wind farms are allocated to specific bidding zones and, subsequently, how interconnection[6] capacity between these bidding zones is allocated. Hence, both the market setup and configuration of the multilateral hybrid project are decisive for which national legal and regulatory framework it has to comply with.

This part of the analysis determines which regulatory or legal aspects create potential barriers for the implementation of the home market setup and the offshore bidding zone setup considering a certain hub-and-spoke configuration. These hurdles are identified by assessing different criteria with respect to their compatibility with the national regulatory frameworks. This chapter will explain the methodology of this analysis, followed by an explanation of the results[7], and potential solutions for identified barriers.

3.1. Methodology

The legal and regulatory framework for offshore hybrid projects can be broken down into two main categories and ten criteria, see table 1. The first category 'governance' is related to the architecture of electricity markets and covers how roles and responsibilities are defined in the different countries. The second category 'finance' is defined by aspects as the tariff system, the tax regime and the subsidy scheme. Operational aspects as balancing and transmission aspects are not covered in this analysis as they are out of scope. These areas are included in European regulation and legislation, and therefore similar in all considered countries. Besides, other national aspects that are not included in European regulation or legislation such as decommissioning do not differ between the two market setups and are thus also out of scope. From our view these pillars cover the most relevant sub-criteria.

[6] The terms interconnector and interconnection capacity refers to both infrastructure crossing member state borders and bidding zone borders.

[7] If you want to learn more about this analysis, refer to: *NSWPH, Compatibility of market setups for hybrid projects with national legal & regulatory frameworks*, January 2021.

Table 1: Explanation of analysed criteria

Category	Criterion
Governance	Asset classification
	Responsibilities
	Applicable national regulatory agency
	Tendering scheme
	Planning
	Existence of multiple bidding zones
	Curtailment regimes
Finance	Regulated revenue stream for transmission system operator
	Taxes
	Subsidy scheme for offshore wind farm

The criterion 'asset classification' has been included in this analysis even though it is not necessarily relevant for Germany and Denmark. This is due to the fact that implementing the hybrid asset in the project Kriegers Flak Combined Grid Solution[8] was possible without legal or regulatory changes on a national level.

Analysed hub-and-spoke configuration.

To date, the NSWPH has outlined one type of configuration[9] in which the hub and all OWFs are located in one EEZ (see figure 1a and b for an example of hub-and-spoke projects with this configuration). However, this is not the only imaginable configuration for multilateral hybrid projects, see figure 3a and b. Another configuration analysed in this report is the distributed hub system: the hub-and-spoke project is distributed over EEZs in line with the cable capacity towards shore. This means that in this example the hub is split into three "sub-hubs". A sub-hub with a connection of X GW to shore can at maximum have a sub-hub and offshore wind farm capacity of an equal X GW to prevent structural congestion. In the home market setup, the sub-hub and the OWFs connected to that respective sub-hub form a home market. In the offshore bidding zone setup, the sub-hub and the OWFs connected to that respective sub-hub form a separate offshore bidding zone. In this way, three offshore bidding zones are formed. More complex configurations are also possible, i.e. if the hub and the OWF are in different EEZ. However, due to the complexity these are not considered in this report.

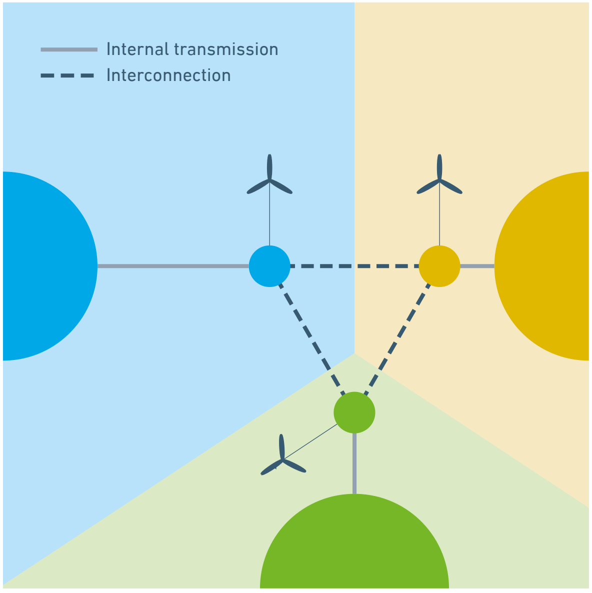
Highligt

Two potential hub-and-spoke configurations are analysed: the centralised hub system and distributed hub system.

[8] The Kriegers Flak CGS connects the Danish region of Zealand with the German state of Mecklenburg-Western Pomerania with a hybrid asset of 400MW. The project partners – Energinet and 50hertz – put it into operation in December 2020.

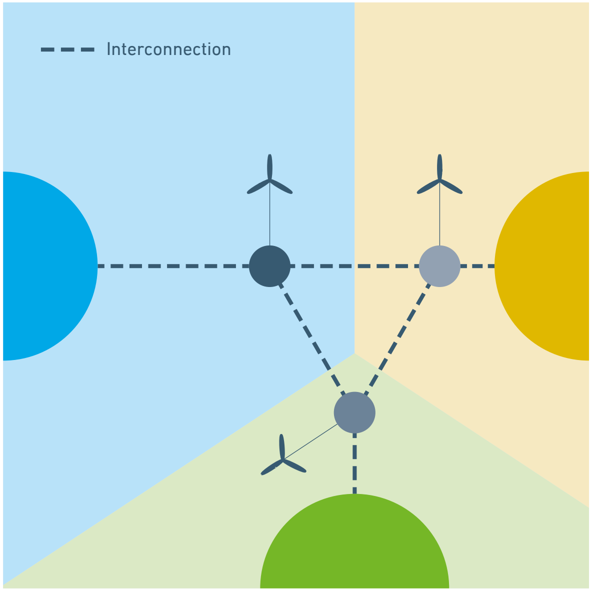
[9] Hereafter referred to as the centralised hub system.

Figure 3a: **Home Market setup**



Overview of the home market setup applied to a hub-and-spoke project distributed over EEZs in line with the cable capacity. The home markets are located in the EEZ of their onshore home market.

Figure 3b: **Offshore Bidding Zone setup**



Overview of the offshore bidding zone setup applied to a hub-and-spoke project distributed over EEZs in line with the cable capacity.

3.2. Main results – Hybrid project configuration and location decisive for hurdles in national regulation and legislation

The current national legal and regulatory frameworks of Denmark, Germany and the Netherlands do not necessarily form a barrier to the implementation of hybrid projects. It should be noted that the premise for the Dutch and German regulation is a one bidding zone configuration. In case the offshore bidding zone setup is to be implemented, regulation and legislation might need to reflect better that there are two bidding zones, but this is not considered to be a barrier from the legal and regulatory perspective. Whether a hybrid project in combination with a certain market setup leads to barriers within the national frameworks is dependent on the configuration and location of the hybrid project. In which EEZ the hub and OWFs are located is directly connected to the perceived regulatory hurdles when implementing a hybrid project with a certain market setup. In the table[10] below, the barriers are summarised for the home market setup and the offshore bidding zone setup per configuration that apply to all the three countries.

Highligt

Whether a hybrid project in combination with a certain market setup leads to barriers is dependent on the configuration and location of the hybrid project.

[10] Additional barriers exists which do not apply to all three countries or which are irrespective of the market setup. These are not included in this table, but explained in the separately published report: NSWPH, *Compatibility of market setups for hybrid projects with national legal & regulatory frameworks*, February 2021.

Table 2: Summary of the barrier analysis per hub configuration and market setup that applies to all countries.

	Home market setup	Offshore bidding zone setup
1. Centralised hub system	Governance and finance barriers: Treaty required for stakeholders to have authority if home market is located in another EEZ. Interconnectors between the home markets can be managed like existing point-to-point interconnectors.	No barriers[11]: responsibility is given to the EEZ in which the hub and OWFs are located. Interconnectors between the hub and the connected countries can be managed like existing point-to-point interconnectors.
2. Distributed hub system	No barriers: respective stakeholders are allowed to manage and finance the home market in their EEZ. Interconnectors between the home markets can be managed like existing point-to-point interconnectors.	No barriers: respective stakeholders are allowed to manage and finance the offshore bidding zone in their EEZ. Interconnectors between the offshore bidding zones can be managed like existing point-to-point interconnectors.

From table 2, it becomes clear that in case the offshore bidding zone is to be implemented, the centralised and distributed hub system seem to be evenly appropriate from a legal and regulatory perspective. If the home market setup is to be implemented, the distributed hub system might be the most convenient configuration. The main problem of the centralised hub system is that the authority of transmission system operator (TSO), national regulatory agency (NRA) and governments is EEZ bound. As such, they do not have authority in a different EEZ. This is a barrier under the assumption that under the HM setup the hub stakeholders of the connected countries want to plan and tender the OWFs, and own, operate, do curtailment in and maintain their own home market. These stakeholders cannot fulfil their classical roles in the situation that their home market part of the hub is located in a different EEZ. Furthermore, taxes and subsidies are arranged on a national level. No international tax system and subsidy system exists in the European electricity system. However, subsidies do not necessarily form a barrier if subsidies are not required by the OWFs.

It should be noted that these barriers also apply to the centralised hub system under the OBZ setup if all involved stakeholders – such as the governments, TSOs and NRAs – want to be involved in the co-tendering, co-ownership, co-construction, co-operation and co-maintenance of the hybrid project. Hence, in that situation both the OBZ setup and the HM setup require expansion of operational and regulatory responsibilities across country borders, asking for alignment between governments.

Highligt

The main problem of the centralised hub system is that the authority of the TSO, NRA and government is EEZ bound.

[11] In case the stakeholders of the hybrid project in the OBZ want to share governance and finance responsibilities, similar barriers exist as under the home market setup.

Expanding operational and regulatory responsibilities across country borders for the centralised hub system.

There are two ways to enable this:

1. **Treaties** on topics like jurisdiction, operation, safety, inspection or supervision, security arrangement and taxes are a possible solution. It is easier to impose additional legislation and regulation than to make exemptions for regulation and depends on the degree of harmonisation within the EU. Further research is required to determine which actions are required per configuration and law or regulation. Fortunately, the Danish, Dutch and German laws are very similar in terms of grid codes, safety and environment and therefore it might also be an option to let the 'foreign' infrastructure meet the local requirements. The treaty between the government of Great Britain and the Netherlands for the BBL pipeline[12] is an example of how this could work. With regard to the interconnectors[13] between the home markets, an agreement between TSOs is required concerning the planning, construction, ownership, income, maintenance and operation. This is business as usual for existing point-to-point interconnectors and therefore not seen as a major barrier; and

2. **Regulatory and/or legal changes** as long-term solution.

Highligt
There are two ways to expand operational and regulatory responsibilities across country borders.

[12] BBL pipeline is a 235-kilometre gas pipeline between Balgzand in the Netherlands and Bacton in Great Britain.
[13] The terms interconnector and interconnection capacity refers to both infrastructure crossing member state borders and bidding zone borders.

4 Impact on efficiency, price formation and revenue distribution

Maximising socio-economic welfare is the overall aim of electricity market design and from that stems the aim to minimise the total cost of dispatch. The allocation mechanism of transmission capacity is a major aspect of an efficient market design as it directly affects the allocation of supply, and thereby the dispatch of generation and the SEW.

In order to provide a deeper understanding of the market efficiency and financial stakeholder impact of the different market setups, this analysis provides detailed insight into the difference in price dynamics, overall socio-economic welfare and revenue distribution (i.e. the dynamics and interdependence of OWF capture price and congestion rents) of the directly involved stakeholders (the OWF developers, the TSOs and society at large) between the home market set-up and the offshore bidding zone setup. This chapter will explain the methodology of the power market modelling, followed by an explanation of the results, and will finally discuss some market implications which require further considerations[14].

4.1. Methodology

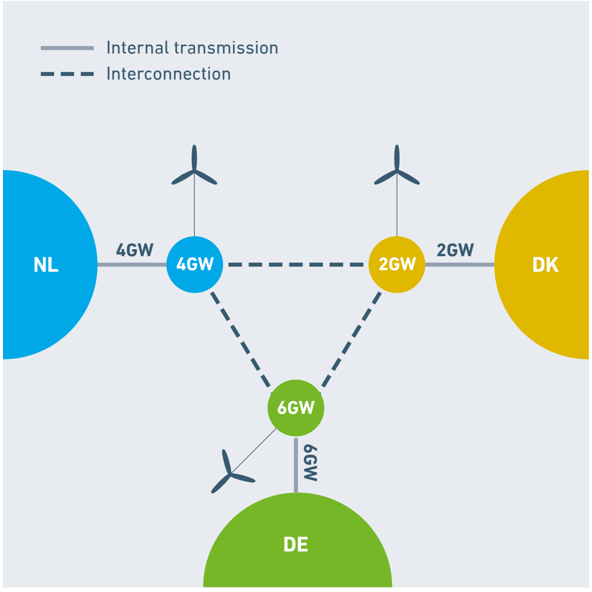
The analysis is based on Net Transfer Capacities[15] (NTC) calculations of the day-ahead power market. Values of ENTSOE TYNDP 2020 National Trend scenario 2030 and 2040 are interpolated for 2035. Losses of interconnection flows are handled implicitly whereas domestic flows – flows to transport the offshore wind energy to the home market – are handled explicitly. The analysis includes two exemplary configurations as shown in figures 4 and 5, in which DK refers to bidding zone DK1 and NO refers to bidding zone NO2. The “core” configuration represents the hub-and-spoke configuration as included in the TYNDP (project #335). The “core plus” configuration additionally includes connections towards Norway and Great Britain, to test the efficiency of the market setup when markets with a different generation mix and weather and/or demand profiles are interconnected via hybrid projects. The technical composition of both configurations is exactly the same under both market setups.

[14] If you want to learn more about this analysis, refer to: Afry, *Market Setup Impact on Price Dynamics and Income Distribution*, October 2020.

[15] The Net Transfer Capacity (NTC) is the maximum exchange between two areas taking into account security standards and future network condition uncertainties. Source: ETSO, *Definitions of Transfer Capacities in liberalized Electricity Markets*, April 2001.

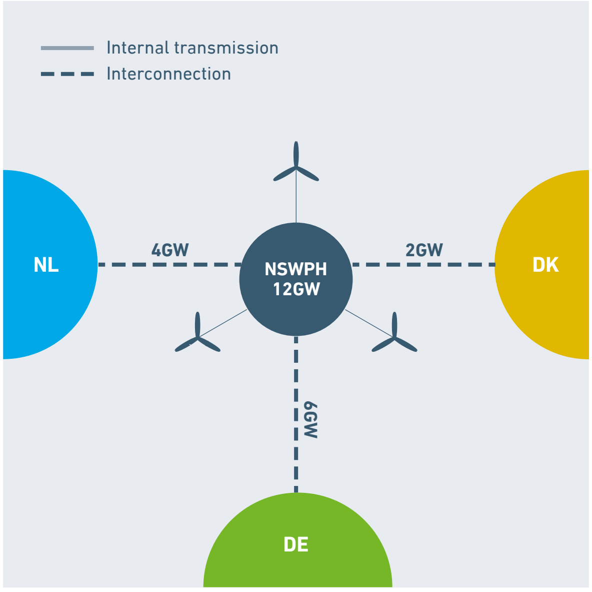
Figure 4: Core configuration

Figure 4a: Home Market (HM)



The core configuration under the home market setup where the hub is divided in a Danish, Dutch and German home market with respectively 2, 4 and 6 GW of OWFs connected. The home markets are connected to the Danish, Dutch and German shore with respectively 2, 4 and 6 GW hybrid assets. The home markets are connected to each other with interconnectors. There are no constraints in terms of direction of cross-zonal flow within the hub.

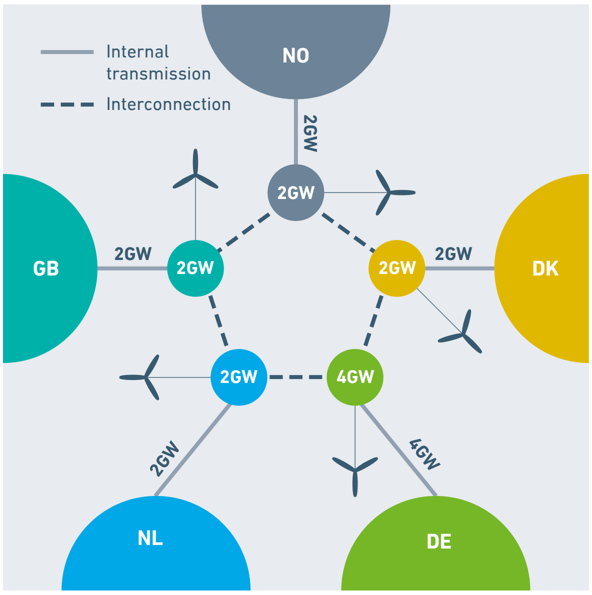
Figure 4b: Offshore Bidding Zone (OBZ)



The core configuration under the offshore bidding zone setup where the hub forms a separate offshore bidding zone with 12 GW of OWF capacity and interconnectors to the Danish, Dutch and German shore with a capacity of respectively 2, 4 and 6 GW.

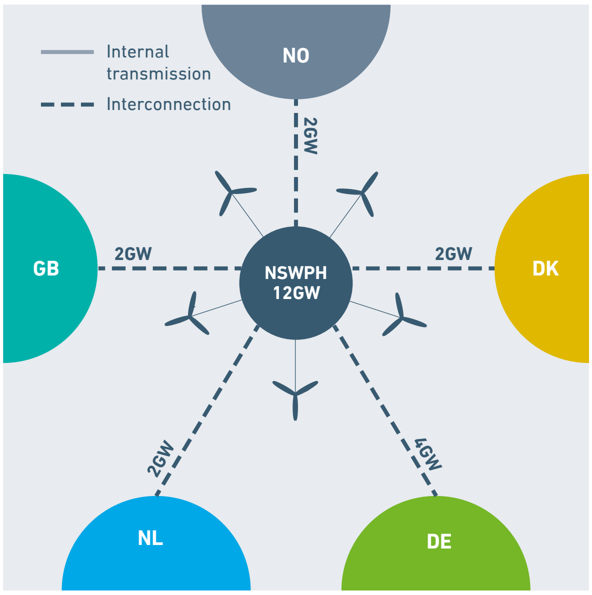
Figure 5: Core plus configuration

Figure 5a: Home Market (HM)



The core plus configuration under the home market setup where the hub is divided in a Danish, Dutch, German, Norwegian and GB home market with respectively 2, 2, 2, 2 and 4 GW of OWFs connected. The home markets are connected to the Danish, Dutch, German, Norwegian and GB shore with respectively 2, 2, 2, 2 and 4 GW hybrid assets. The home markets are connected to each other with interconnectors. There are no constraints in terms of direction of cross-zonal flow within the hub.

Figure 5b: Offshore Bidding Zone (OBZ)



The core plus configuration under the offshore bidding zone setup where the hub forms a separate offshore bidding zone with 12 GW of OWF capacity and interconnectors to the Danish, Dutch, German, Norwegian and GB shore with a capacity of respectively 2, 2, 2, 2 and 4 GW.

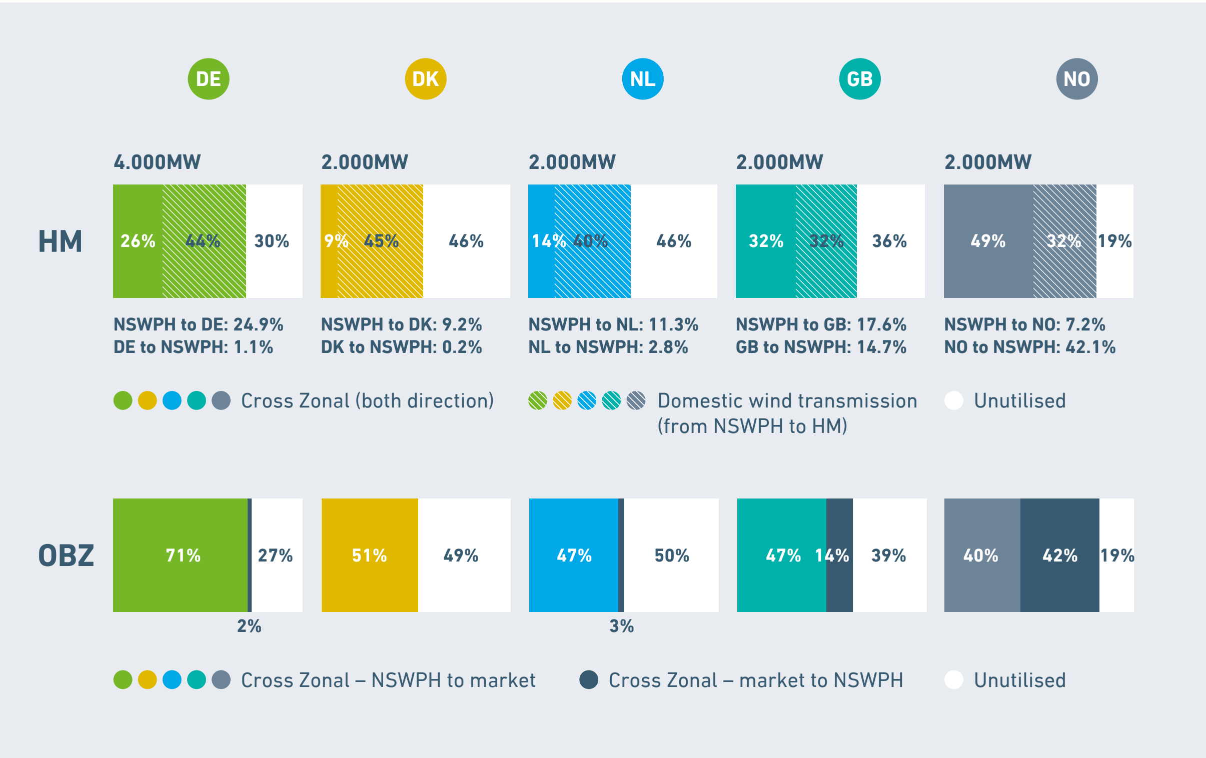
4.2. Power market modelling results – marginal difference between market setups

4.2.1. Slightly more efficient flows under the offshore bidding zone setup

The results of this analysis indicate that the offshore bidding zone setup induces more efficient flows in both configurations. The power market coupling is maximising socio-economic welfare by letting energy flows from the low-price market towards the high-price market. For both configurations Germany has the highest price under the HM setup and the OBZ setup, followed by the Netherlands, Denmark, Great Britain and finally Norway. In order to maximise socio-economic welfare, the energy would either flow from the hub – with a marginal cost price of zero – or from Norway towards Germany. Subsequently, utilisation of the infrastructure between Norway and Germany should be maximised as is happening under the offshore bidding zone setup, where slightly increased utilisation rates are observed, see figure 7.

Highligt
The offshore bidding zone setup induces more efficient flows in both configurations.

Figure 6: Utilisation rates in % by type and direction of flow



Utilisation rates of infrastructure between the hub, Germany, Denmark, the Netherlands, Great Britain and Norway for the core plus configuration. The utilisation rates under the OBZ for Norway do not sum up to 100% due to rounding issues.

The outcome of this analysis as shown in figure 6 also indicates that there is a difference in dispatch and capacity allocation. This difference is expected to be caused by:

Highligt
Different dispatch and capacity allocation between the market setups and loss handling results in different transported volumes.

1. Difference in dispatch and capacity allocation between the market setups: whereas the loss factors[16] of the cables are equal for both market setups, the total losses differ may differ as a result of the different market setups. Under the OBZ setup, the energy flows directly towards the high-priced bidding zone. Under the HM setup the energy is first dispatched/allocated towards the different home market regardless of the electricity prices, and in a second step if price spreads are big enough, they can trigger a cross-zonal flow to a different direction. This impacts the direction of flow and therefore the utilisation of the different cables and total cable losses.

2. Difference in loss handling: in the HM setup, the losses of domestic flows are handled explicitly meaning that the transported volume is reduced by the loss factor. The losses of cross-zonal flows are handled implicitly preventing any exchange when the spread is below the loss factor. In the core configuration, implicit loss handling in combination with small spreads blocks some flows[17] under the OBZ setup, while the domestic flows under the home market are just reduced with the loss factor. In the core plus configuration, the spreads are usually sufficient reflected by more exchange of energy under the OBZ setup, while under the HM setup still all domestic flows are reduced by the loss factor.

Subsequently, both factors can result in a difference in transported volumes between the market setups. It is unclear to what extent the factors impact dispatch and capacity allocation separately and it was not possible to isolate the weighing of the factors. If it is deemed necessary to isolate these factors and determine their individual impact, additional research is required.

4.2.2. Marginally lower dispatch costs under the OBZ setup

The more efficient capacity allocation and dispatch under the OBZ setup also results into marginally lower dispatch costs under the OBZ setup, see figure 7a. Again the difference between the market setups is partially caused by difference in dispatch and capacity allocation between the market setups and by the difference in loss handling. Under the OBZ setup, the energy flows directly towards the high-priced bidding zone replacing the most expensive energy with low-cost wind energy to maximise total European SEW. This is not the case under the HM setup, where the wind energy might replace the most expensive energy in its home market, but which is not necessarily the most-expensive energy from a European perspective. Hence, the OBZ results in marginally lower dispatch costs. When zooming in on country level, see figure 7b, it shows that especially dispatch costs in Germany are reduced under the OBZ setup in comparison to the HM setup and dispatch costs slightly increase for Great Britain and Norway. This is because under the OBZ setup less energy flows towards Norway, but more energy flows towards Germany in comparison to the HM setup, resulting in a German dispatch costs reduction.

[16] The loss factor is 2.7% for the core markets. The Core+ markets include a higher loss factor to account for a longer cable to the shores (e.g. 3.1% for the connection to GB; 4.0% for the connection to Norway).
[17] Most of the flows will still occur since the spread is relative to the offshore bidding zone where the marginal costs of wind energy is just above zero €/MWh causing that the spread usually exceeds the loss the factor.

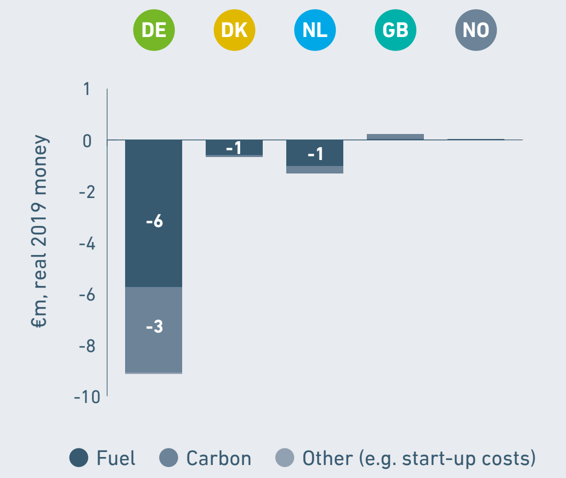
Figure 7: Breakdown of variable cost of dispach of OBZ setup relative to the HM setup

Figure 7a: Total impact across core markets

Item	Impact
Fuel	**-€7m**
Carbon	**-€4m**
Other	**-€0m**
Total	**-€11m**

Total impact across core plus markets divided into fuel costs, carbon costs and other costs of OBZ setup relative to HM setup in €m real 2019 (e.g. start-up costs).

Figure 7b: Impact on the costs of dispatch



Impact on costs of dispatch across the core plus markets on country level. The variable costs of generation is shown in €m real 2019 money, OBZ setup relative to the HM setup.

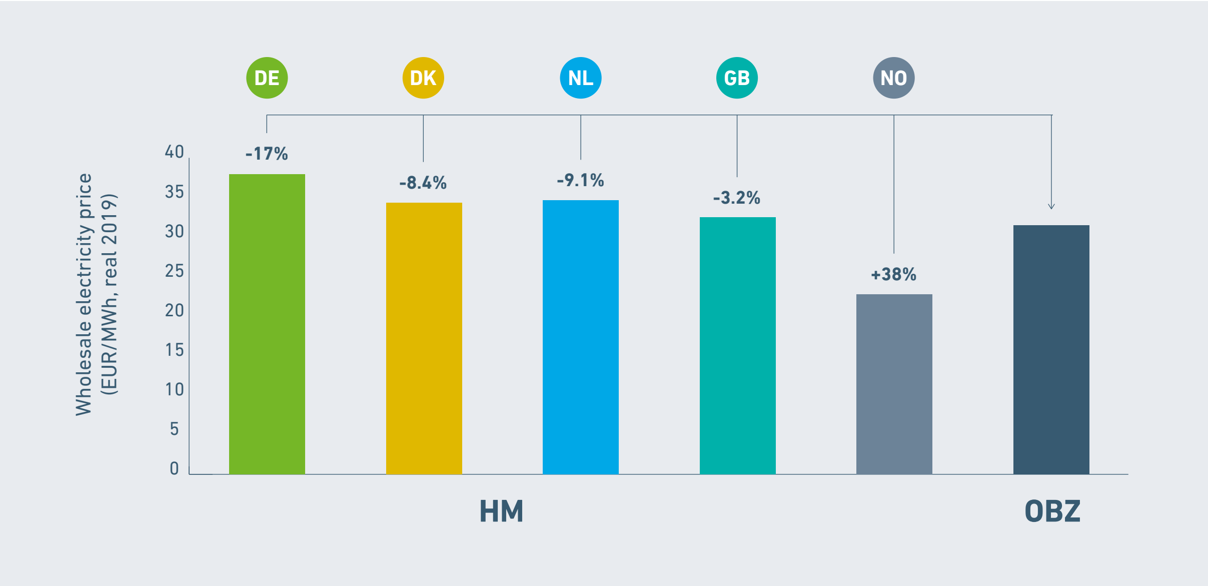
4.2.3. OWF capture prices lower under OBZ setup

The results of the power market modelling confirm that offshore wind farms in an offshore bidding zone receive a lower wholesale electricity price than offshore wind farms in a home market in both configurations, see figure 8. This is especially the case for offshore wind farms which are part of a German home market, which has a wholesale price of 38 EUR/MWh. If the same offshore wind farms are part of the offshore bidding zone, the wholesale price reduces to 31 EUR/MWh. The impact on the onshore bidding zone wholesale prices is not extensive (<0.50%). Figure 8 shows that the offshore bidding zone setup could also result in higher electricity prices for some offshore wind farms. Due to very low electricity prices in Norway, the Norwegian offshore wind farms connected to their home market receive less revenues than when connected to the offshore bidding zone.

Highligt

The power market modelling confirms that OWFs in an OBZ receive a lower wholesale electricity price than OWFs in a HM.

Figure 8: Electricity prices in the home markets and offshore bidding zone



Wholesale electricity prices per bidding zone under the home market setup and the offshore bidding zone setup for the core plus configuration. The percentages reflect the relative difference in wholesale prices between the two market setups for every onshore bidding zone.

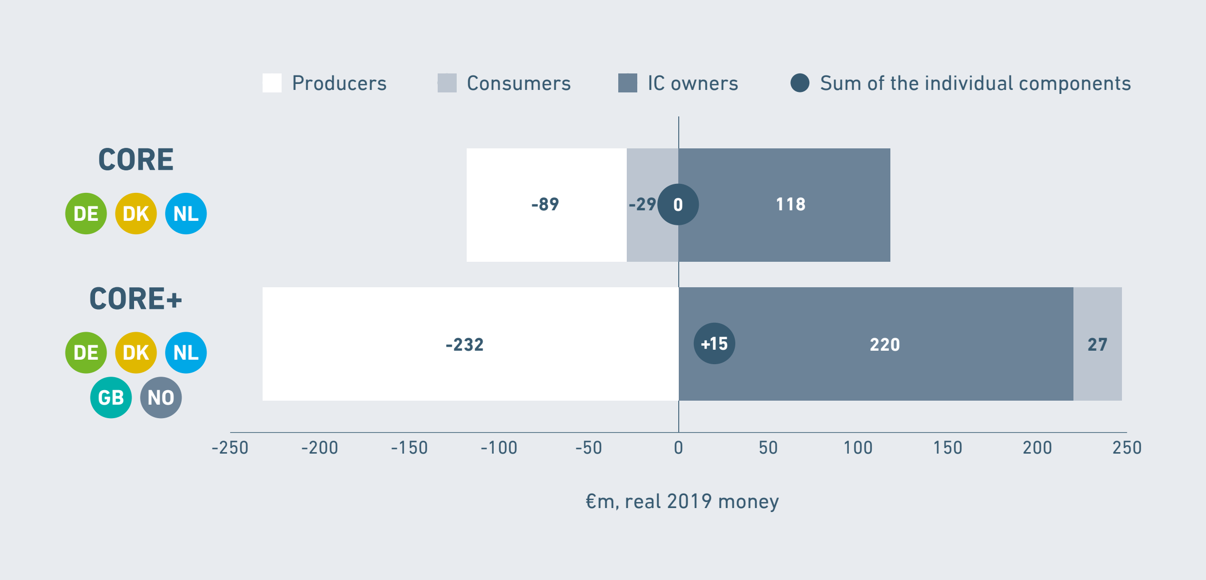
4.2.4. Marginally increased SEW under OBZ setup in core plus configuration

Finally, the power market modelling showed that the SEW increases under the OBZ setup compared to HM setup in case hybrid project configuration contains bidding zones with less correlated electricity prices, see figure 9. This difference in SEW is again caused by the difference in dispatch and capacity allocation between the market setups and the difference in loss handling. Under the core configuration there is no difference in SEW. The difference will only emerge when Great Britain and Norway with less correlated electricity prices are added to the configuration. Adding Norway and Great Britain has a positive impact on consumer income. This is mainly due to the impact on German electricity consumers who benefit from more low-priced energy import under the OBZ setup as earlier explained. There is a negative impact on overall producer surplus, driven by overall lower captured revenues for the hub-connected OWFs under the OBZ setup. The OBZ setup induces more congestion income, because all flows are labelled as cross-bidding zone border flows, whereas part of the flows under the HM setup is labelled as internal flows. As such, congestion rents are earned for only part of the hub-related flows under the home market setup. This higher congestion income under the OBZ setup leads to an overall positive interconnector (IC) owner surplus under the OBZ setup.

Highligt

The SEW increases under the OBZ setup compared to the HM setup when the hybrid project configurations contains more diverse bidding zones.

Figure 9: Socio-Economic Welfare impact and direction per stakeholder, OBZ setup relative to the HM setup



Socio-economic welfare across the markets for the configuration divided into the consumer and producer surplus and congestion income. The figure in the circle shows the net difference between the HM and the OBZ setup. A negative number means that the HM setup results in less of the respective surplus in comparison to the OBZ setup.

4.2.5. Income distribution differences between market setups

The results show clearly that the market setups differ in how income is distributed amongst actors, but the total differences are small. In table 3, it is shown for both configurations that the gained congestion income under the offshore bidding zone setup more than compensates the lost income of OWFs under this setup in comparison to the HM setup. These distributional effects possibly substantiate redistributional measures to create an enabling investment framework for all stakeholders. However, more research is required to determine how this could be done. Furthermore, figure 10 shows that congestion income is also unevenly distributed between bidding zones. Dependent on the country, the country either receives less or more congestion rents under the home market setup than under the offshore bidding zone setup. Germany receives under both setups more than three times as much congestion rents from the hybrid project with the core plus configuration than the other connected bidding zones, while the cable capacity towards Germany is only twice as large as the cables towards the other countries.

Highligt

The market setups differ in how income is distributed amongst the actors.

Table 3: Overview of difference in OWF and congestion income between the market setups for both configurations.

	Core (m€)	Core plus (m€)
Lost OWF income under OBZ setup in comparison to the HM setup	-115	-206
Gained congestion rents under OBZ setup in comparison to HM setup	+124	+220
Net impact	+9	+14

Figure 10: Annual congestion rents per bidding zone for both market setups in m€, real 2019 money.

4.3. Inefficiencies slightly impact the market setup outcomes

The previous discussion paper on market setups explained that a wind forecast reliability margin and negative prices induce inefficient dispatch under the home market setup. In addition to modelling both market setups in situation without inefficiencies, also the impact of these situations was quantified.

In the HM setup, wind forecasts influence the available interconnection capacity. The available interconnection capacity is determined by the total hybrid asset capacity minus the forecasted wind production. In order to factor in potential upward and downward deviations between wind forecast and actual wind production, a wind forecast reliability margin is required. A wind forecast error caused by information asymmetry that the TSOs have (e.g. no insight in availability of individual turbines) is not factored in this analysis. In this analysis on potential inefficiencies, a wind reliability margin is based on the normally distributed deviation between a '24 hours[18] before real time forecast' and actual production. Factoring in the wind error margin causes marginal shifts in income distribution, see figure 11. This follows from a marginal change in flows: less released, and thus, allocated interconnection capacity evokes that more wind energy is transported from the hub towards the home markets. Less energy is transported to Germany since there is less interconnection capacity available inducing a marginal increase in German prices. This price increase is mirrored by a decrease in the electricity prices of all other connected markets negatively impacting the German consumers and positively impacting the German producers. The opposite is true for the other connected markets.

Highligt

Factoring in the wind error margin in the home market setup causes marginal shifts in income distribution.

[18] In current circumstances, wind forecasts can at latest be updated up to 48 hours before real time when the TSOs have to submit information about the cross-border infrastructure for the market coupling. In 2022, this will potentially change to 24 hours before real time and in 2023 potentially to 12 hours before real time.

Figure 11: Overall welfare distribution across the markets divided into the consumer and producer surplus and congestion rents.

Stakeholders	Welfare impact across the markets	
Consumers	↑	**+€293m**
Producers	↓	**-€403m**
IC owners	↑	**+€81m**
Net	↓	**-€29m**

The figures reflect the home market setup outcomes minus the home market setup including wind forecast margin.

The changed electricity price dynamics cause a greater price spread, meaning marginally higher congestion rents for the TSOs. The changed dynamics also result in less producer income, especially in Great Britain and Norway, reflected by an improved consumer surplus due to lower prices.

The used data did not allow to determine margins closer to real time. It should be noted that TSOs can use the intraday market to make excess interconnection capacity available based on improved closer to real time forecasts. Market participants can utilise the withheld margin capacity and thereby lower the negative impact of the wind forecast reliability margin.

Negative prices are expected to occur less in 2035
A separate modelling aimed to quantify the exact impact of negative prices on the socio-economic welfare of the home market setup. However, according to the modelling the occurrence of negative prices in 2035 is almost non-existent due to the dwindling number of renewable power plants with subsidies that allow negative bidding. It should be noted that inefficient policy measures on subsidies could change this and result in more negative price occurrences. In order to "force" negative prices on the model, around 60% of all renewables is required to bid negatively. This results in negative prices in the core markets in around 3.2% of the time and, with that, in too few negative price situations for proper impact quantification.

4.4. Conclusions

To recap, the offshore bidding zone setup results in marginally more efficient dispatch and capacity allocation in both configurations, showed by increased flows towards high-priced bidding zones. In the core configuration, the socio-economic welfare under both market setups is similar. The OBZ setup results in more SEW compared to the HM setup when the hybrid project configuration includes countries with a less correlated electricity markets and when a wind forecast reliability margin is included in the modelling. Therefore, the OBZ is considered to be more robust in providing SEW. The main difference between the setups however, is how income is distributed between stakeholders. Where under the home market setup, higher revenues and thus income is received by the OWFs, this income is under the OBZ setup transferred to the TSOs in the form of congestion rents.

Highligt
The OBZ setup is more robust in providing maximised socio-economic welfare.

4.5. Further considerations

It should be noted that a day-ahead power market modelling does not show the complete picture. The modelling is solely focused on the day-ahead market and does not include the long-term, intraday and balancing markets which largely influence the ultimate capacity allocation, energy dispatch and thus revenue streams. Furthermore, this analysis does not provide an insight into the socio-economic value of the project at large. Such an analysis should provide an insight in the full cost and benefits. This analysis focused on the difference between the market setups. Besides, power-to-X is not included in the modelling. It is likely that: i) the OBZ setup provides more efficient incentives towards power-to-x; and ii) that power-to-X impacts the results.

Highligt
A day-ahead power market modelling does not show the complete picture and gives no insight into the socio-economic value of the project at large.

The power market modelling was based on NTC – values. The NTC approach is a generally accepted approximation of future exchange capacity between bidding zone boarders in long-term studies. The principle assumptions are that (i) any time, the nominated exchange capacities may be used 100% and (ii) the exchanges over each bidding-zone border are independent from each other. However, todays and envisaged methodology for exchange capacity is based on the flow-based methodology[19] (FBMC). FBMC accounts for non-structurally congested internal critical network elements (CNECs) which may reduce the assumed cross-border exchange capacities due to their loading[20]. The loading of the CNECs depend on the concrete physical grid situation triggered by initial market conditions. And as their loading is affected by the exchange over one or several bidding zone borders, the cross-border exchanges become coupled to each other. The underlying algorithm for capacity allocation optimises all exchanges subject to possible restrictions on the CNECs by an overall socio-economic welfare (SEW) maximisation. Introducing advanced hybrid coupling[21] (AHC) – similar capacity allocation methodology as FBMC but then applied to HVDC – could reduce the 100% to a lower percentage to increase availability

[19] Market coupling methodology which optimises the efficiency of power trading by allocating cross-border transmission capacity between the different coupled day-ahead markets, while ensuring that the physical limits of the grid are respected.

[20] A network element either within a bidding zone or between bidding zones taken into account in the capacity calculation process, limiting the amount of power that can be exchanged. Source: ENTSO-E, *Critical Network Element Implementation Guide*, Version 2.2, February 2020.

[21] AHC is coupling HVDC infrastructure with a flow-based approach to the AC grid. The plans for AHC implementation are not bound to a serious time line yet, but it is likely to be implemented before 2030.

on another bidding zone border which delivers overall more SEW. Hence, AHC could limit the utilisation of the hub-and-spoke infrastructure.

If this approach would be applied in this study, the additionally included model restrictions might result in a reduction of exchange capacities in certain hours. As a consequence, price differences might be increased along with increasing amounts of curtailed offshore wind production. Hence, AHC could change the utilisation of the hub-and-spoke infrastructure. As this effect might be of relevant impact to the project stakeholders, it is recommended to analyse it in another analysis.

The current analysis does not consider the 70% rule: a rule to reduce the 100% cross-bidding zone border capacity to 70%. It is still unclear how the 70% rule from the European Clean Energy Package REGULATION (EU) 2019/943 will be regarded for HVDC interconnectors. If the connecting bidding zone only just wants to comply with the 70% rule, they might only make 70% of the interconnector capacity available. This could harm the offshore wind farms in the offshore bidding zones as their income is solely dependent on interconnection flows as opposed to the OWFs in the home market. Hence, the 70% rule might be perceived as a significant risk requiring risk mitigation. Further research is required to determine the impact of this risk and potential mitigation methods.

Finally, grid losses can be either implicitly or explicitly included in the modelling. In this analysis, the interconnection grid losses were implicitly addressed in the market coupling algorithm meaning that the producer is responsible and interconnection flows are only scheduled if the price spreads between the bidding zones outweigh the costs of grid losses. The internal grid losses were explicitly included meaning that all flows can be scheduled and the TSO compensates the grid losses. Whereas this analysis shows that implicit loss handling can be socio-economically beneficial, they might negatively impact the OWF developer in the offshore bidding zone setup, which has to deal with the risk that exchange is blocked by price spreads smaller than the loss factor. This risk is smaller under the home market setup where only part of the flows will be affected by implicit loss handling. Further research is required to determine the proper loss handling and its impact on all stakeholders.

Consequently, this paper gives some first quantitative insights in the market setups for hybrid projects, but more analyses are required to capture the full benefits of hybrid projects and market setups.

Highligt

This paper gives some first quantitative insights in the market setups for hybrid projects, but more analyses are required to capture the full benefits of hybrid projects and market setups.

5 Conclusion & 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 analyses in this paper dive deeper into the implications of the market setups – "Home Market (HM)" and "Offshore Bidding Zone (OBZ)" – to integrate hybrid projects.

The national legal and regulatory framework analysis shows that neither the OBZ setup nor the home market setup is more difficult to implement from a governance and financial perspective. Depending on the hub-and-spoke configuration and location hurdles within these frameworks might be perceived. The power market modelling indicates that the core configuration results in similar dispatch and capacity allocation efficiency and SEW for both the market setups. The potential benefits of OBZ setup are enhanced for the core plus configuration, which is caused by i) a combination of the difference in dispatch and capacity allocation between the market setups and loss handling and ii) a wind forecast reliability margin is included in the modelling. The main difference between the setups is how income is distributed between the consumers, OWFs and TSOs. Redistribution of income and overcoming the legal and regulatory hurdles might require discussion between governments that can lead to inter-governmental agreements. This paper also highlights the requirement of further research in certain areas. Hence, the following analyses are suggested in the short term to facilitate further development of hybrid projects:

1. A broad exploration of options to ensure a stable investment framework for offshore wind farm developers compensating for the reduced income under the offshore bidding zone setup; and
2. An analysis on potential governance and ownership models for hub-and-spoke projects.

Furthermore, operational and balancing pricing aspects will have to be further defined in due time, ultimately before the tendering date of OWFs, as shortly discussed in a previous discussion paper on the market setups. Additionally, more in-depth analyses are required with respect to the quantitative impact of inter alia loss handling, onshore/offshore power-to-X, 70% rule, advanced hybrid coupling and other market timeframes on the hub-and-spoke project stakeholder under both market setups. This will help to further refine the power market modelling and to get a better understanding of the benefits of hybrid projects.

Finally, this analysis shows that treaties might be required for the development of hybrid projects. Generic frameworks might ease the process towards such agreements for complex projects. In the long term, further research is required to determine how this framework can be achieved, who should be involved – top down involving European decision bodies or bottom up starting with a few countries only – and what legislation and regulation aspects should be included.

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