Impact of offshore bidding zones on hybrid projects: A case study of LionLink

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Impact of offshore bidding zones on hybrid projects: A case study of LionLink

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Management Summary

The ambitious Dutch offshore wind targets aim for more than 21 GW of installed capacity by the mid-2030s, including a hybrid project—an offshore wind farm connected to two bidding zones. These hybrid projects are envisioned to be operated under offshore bidding zones (OBZs) to integrate into the European electricity market. Thus, to participate in the tenders of hybrid-connected wind farms, developers need clarity on how this relatively new market setup of OBZs will affect their business cases.

With this study, TNO provides quantitative insights into the impact of OBZs on offshore wind business under the 2030 energy scenario (TYNDP Global Ambition) by taking the case of LionLink—a planned interconnector that connects a 2000 MW wind farm to the UK and the Netherlands. The results from power market simulations of LionLink show that:

- The electricity prices in the OBZ are always equal to or lower than prices in the Dutch bidding zone. Consequently, the expected yearly income for a 2000 MW wind farm, bidding in the day-ahead market, is reduced by approximately 33% when operating under the OBZ compared to the current home market (HM) set-up.
- Due to the non-symmetric interconnection capacity of LionLink configuration (1800 MW to the UK and 2000 MW to the Netherlands), prices at the OBZ can be higher than prices in the UK bidding zone.
- Connecting a price-responsive electrolyzer in the OBZ marginally increases the day-ahead prices in the OBZ, resulting in only around a 1% increase in wind farm revenue with a 200 MW electrolyzer and around 2% with a 1000 MW electrolyzer.
- Due to the lower prices in the OBZ, resulting from the high penetration of renewable energy in the UK, the full load hours of an electrolyzer connected to the OBZ are more than double those of an electrolyzer connected to the Dutch bidding zone or operating in the home market setup. This makes the business case for an offshore electrolyzer significantly better and shows the higher market efficiency presented by the OBZ set-up.

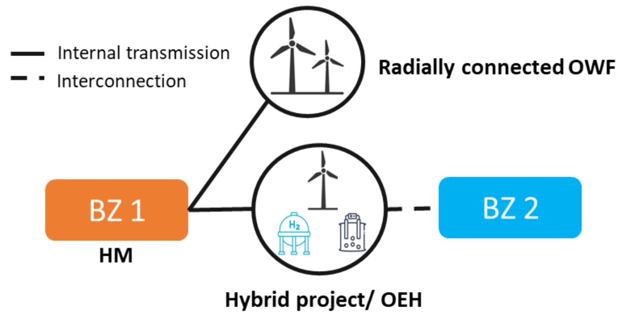
This study has been supported by the RELACOE project and TNO's internal knowledge funding and is planned to be extended with a more comprehensive analysis of meshed hybrid projects and energy hubs envisioned towards 2040 and 2050.

1 Motivation and introduction

1.1 Offshore hybrid projects

Offshore wind is envisioned to be the key renewable energy source in the energy transition plans of European Countries which is depicted by their ambitious deployment targets. The North Seas are seen as the green European power plant, with combined offshore wind targets of at least 300 GW by 2050 [1]. In the Netherlands, offshore wind targets are set to 21.5 GW in 2030 from 4.7 GW in 2024, 50 GW in 2040, and 72 GW in 2050. The successful deployment of offshore wind highly depends on both the development and efficient utilization of offshore infrastructure, as well as the implementation of market mechanisms conducive to investments in generation and flexibility.

Cost-efficient utilization of offshore infrastructure can be achieved by connecting large-scale offshore wind farms (OWFs) as *hybrid projects,* often referred to as offshore energy hubs (OEHs). Hybrid projects, unlike traditional radially connected OWFs, have an interconnection with different bidding zone(s)[1] in addition to the link with the home market (HM). It is expected that hybrid infrastructure will reduce overall system costs, spatial and environmental impact, and increase system efficiency [2].



Hybrid projects or OEHs combine generation and interconnection, i.e., OWF(s) connected to more than one bidding zone. These projects can also contain offshore conversion and storage assets [2].

Offshore network development plans by ENTSO-E, for the Netherlands, envision 31 GW out of 72 GW of offshore wind planned for 2050 to be connected as hybrid projects [3]. The Netherlands is involved in several prospective hybrid projects: the connection of an energy island in the Danish Economic Exclusive Zone (EEZ) to a Dutch energy hub; OWFs in the German EEZ to OWFs in Denmark and the Netherlands and the hybrid connection between Belgium and the Netherlands. A hybrid interconnector is already planned between the Netherlands and the United Kingdom (LionLink).

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[1] A bidding zone is the largest geographical area in which bids and offers from market participants can be matched without the need to attribute cross-zonal capacity. Bidding zones in Europe are mostly defined by national borders.

1.2 Market integration in Offshore Bidding Zones (OBZ)

The hybrid connection, instead of radially linking the OWF to HM, brings challenges to the market integration of hybrid projects from the perspectives of the current EU regulatory framework, market efficiency, and system operation [4]. One of the biggest challenges arises from the 70% rule (European Clean Energy Package (CEP) REGULATION) which mandates allocating a minimum of 70% of interconnection capacity for cross-border market trade. This rule aims at maximizing the inter-zonal transmission capacity to enhance the security of electricity supply, mitigate price volatility, provide flexibility, and create a level playing field between domestic and cross-border trades. Figure 1(a), illustrates the challenge of the 70% rule. In this example, assuming that the 70% ruling is implemented, 1400 MW of interconnector is assigned for cross-border trade where energy flows from BZ 2 to BZ 1 as price in BZ 1 < BZ 2. This 1400 MW energy will flow from the offshore link between OWF and the onshore system thus only 600 MW of this link is available for OWF whose generation is 1000 MW. So, the problem with the traditional way of bidding in the HM arises when the connection between OWFs and the HM is unable to transport full wind generation, as well as provide 70% of its capacity for cross-border trade. In such a case, a TSO facing congestion on this connection can either reduce the physical flow by curtailing wind output or not adhere to the 70% requirement [5].

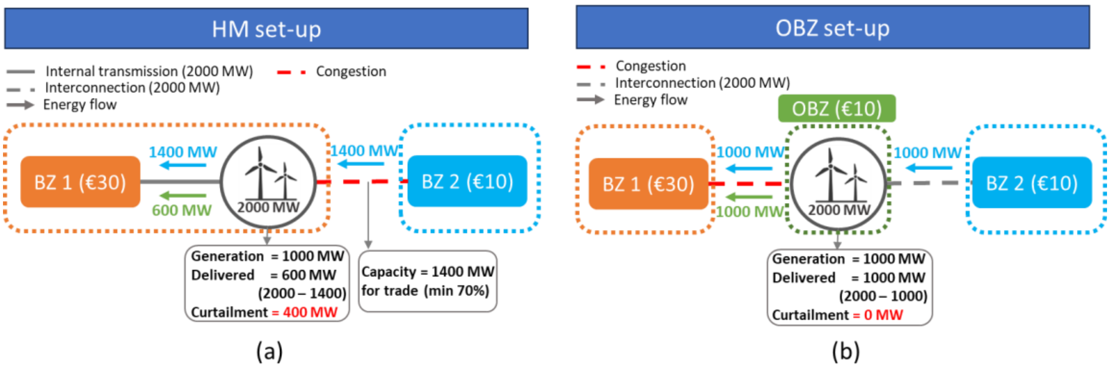


Figure 1: (a) An instance of a Hybrid project operating under HM set-up with 70% ruling implemented. (b) An instance of a Hybrid project operating under OBZ set-up.

The dilemma regarding the 70% ruling can be conveniently resolved for TSOs by making the hybrid OWFs/ energy hubs separate bidding zones, so-called Offshore bidding zones (OBZs) [6]. This is shown in Figure 1(b) where OBZ considers the link between BZ 1 and OWF as an interconnector with its capacity considered in market clearing, thus accounting for congestion on it. This set-up is better aligned with the physical reality of available transmission capacity. Therefore, there is no curtailment of OWF. OBZs are generally a preferred solution to integrate offshore hybrid projects into the system from market efficiency and system operation perspectives. For a detailed explanation of OBZs and associated market and regulatory issues, we refer the reader to a discussion paper [4].

- European Commission (EC) states that “it is the Commission’s view that establishing OBZs provides a good approach to ensure compliance with the cross-border trading rules” and that “OBZs achieve a higher degree of overall efficiency than the ‘home zone’ approach” [6].
- ACER and CEER also provided broad support to the EC’s proposals on how to integrate offshore renewable energy into the internal energy market (i.e., via OBZs) [5].
- ENTSO-E’s opinion is along the same lines and it also uses OBZs as a working assumption.
- TenneT in a blueprint for establishing OBZs mentions that “OBZs with flow-based market coupling are necessary for a seamless integration in European electricity markets and are best aligned with the European target model and the existing governance model and regulatory framework” [7].

System operators and policymakers consider OBZs to efficiently integrate hybrid projects in power systems

1.3 Rationale and goal of the study

The discussion on OBZs so far has largely focused on system and regulatory aspects conducted by TSOs and regulatory bodies. The perspective of offshore wind developers, whose business models can be highly affected by OBZs, is notably absent. While it is known that prices in OBZs are generally lower, the quantification of the economic performance of OWFs and other assets (such as offshore hydrogen production) operating in OBZs has not been extensively assessed. It is of vital importance to have an adequate picture of the future well before developers bid for hybrid project tenders, being able to minimize the regulatory and price risk associated with the market structure faced by their businesses.

Scope of study:

This study presents numerical insights resulting from power market simulations with both OBZ and HM set-ups, implemented for an actual hybrid project under a 2030 energy scenario. The goal is to analyse the day-ahead (DA) power market price formation and its dynamics; its relation with the configuration of the offshore infrastructure, and the quantification of its collective impact on the business cases of generation and flexibility assets present in the OBZ.

Out of scope:

We acknowledge the importance of regulatory, operational (e.g. balancing) aspects of OBZs, the impact of advanced hybrid coupling, (as discussed in [7]) and the impact of financial contracts and support schemes (PPA, CfD, FTR), however, they are not in the scope of this study.

The case in focus for this study is the LionLink project, shown in Figure 2, a hybrid interconnector planned to be operational by 2031. It will connect the United Kingdom and the Netherlands via a Dutch 2000 MW OWF [8]. The OWF is planned to be connected to the Dutch shore with a 2000 MW connection and with 1800 MW to the UK. To study the behaviour of potential flexibility assets in OBZs, a 200 MW electrolyser is assumed co-located with the OWF (not part of the LionLink plan).

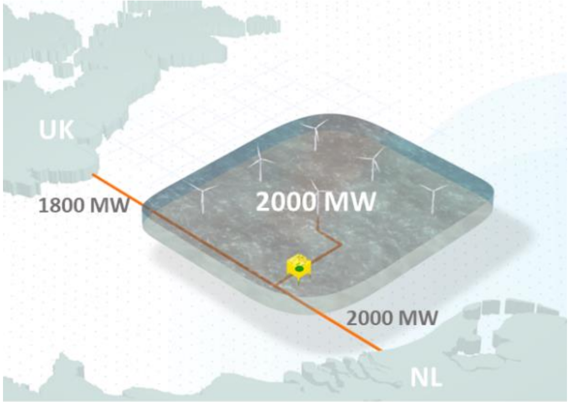


Figure 2: Lion Link, planned hybrid interconnection between UK and NL (source: TenneT)

Goals of the study

- Assess the dynamics of DA price formation at OBZ for a realistic hybrid project configuration, and compare it with the HM set-up to provide numerical insights.
- Evaluate the level of impact of OBZ on hybrid connected OWF's revenue.
- Analyse the behavior of P2G located at OBZ through a high-level business case.

To achieve these goals, the case of LionLink is modelled and simulated considering OBZ and HM set-ups under the 2030 energy scenario. Figure 3 presents the overview of the methodology applied in this study.

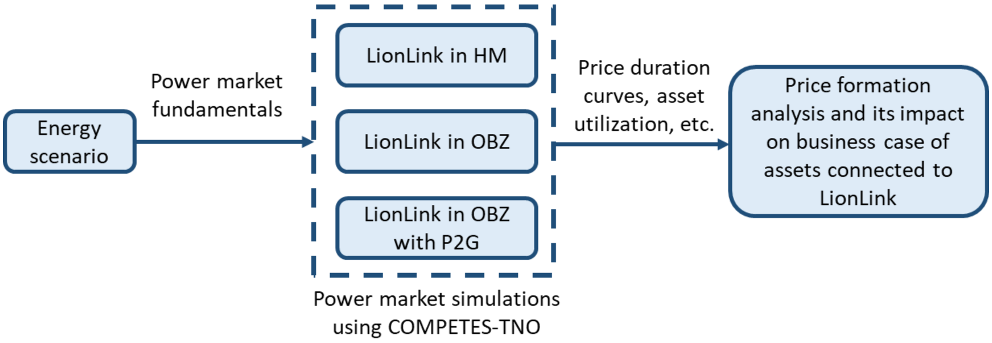


Figure 3: Steps followed to achieve the results presented in this study.

2 Modelling set-up

This section describes the model used to simulate the day-ahead power market, the energy scenario modelled, and the key modelling assumptions for this study.

2.1 2030 Energy scenario

The energy scenario (generation, demand, flexibility, storage, etc.) used in this study, for COMPETES-TNO simulations, is based on the Global Ambition elaborated by ENTSO-E in their Ten Year Network Development Plan 2022 (TYNDP-22). This scenario considers the CO2 emission reduction targets of the European Commission of -55% in 2030 and carbon neutrality by 2050. The storyline behind this scenario reflects a centralized approach to achieving the COP21 climate goals. This translates into a focus on decarbonizing the energy supply through large-scale technologies, with support of low carbon imports, and integration of nuclear and CCS [9]. With a focus on transporting electrons from offshore generation, this scenario presents a reasonable choice for this study. Furthermore, all the scenario data is publicly available. Note that for modelling the Dutch energy system a more granular database is used for its conventional power plants based on the S&P database.

2.2 Power market model

This study uses the COMPETES-TNO model to simulate energy flows and price formation in the European DA electricity market with an hourly resolution for a year (i.e., 8760 h). The COMPETES-TNO is a power optimization and economic dispatch model owned by TNO that has been employed for several European and national studies [10]. The geographical scope of the model covers 27 EU countries, additionally the UK, Switzerland, and Norway. The Balkan and Baltic countries are aggregated under one node each. The electricity trade flows between the different regions are represented through Net Transfer Capacities (NTC). The following assumptions are made:

- We only simulate the DA electricity market, and do not consider short-term intraday markets or long-term contracts, e.g., PPAs.
- The OWF and P2G connected to the OBZ in the LionLink are considered Dutch; therefore, their installed capacity is part of the generation mix and demand of the Netherlands, respectively.
- Inflexible demand is provided exogenously by the Global Ambition scenario and the allocation of flexible demand assets (P2X, storage, etc.) is determined endogenously, based on price-responsiveness. Particularly for P2G (electrolysers) a willingness-to-pay of around 46 EUR/MWh is considered based on SMR costs for producing grey hydrogen. At this value, simultaneous power-to-gas and gas-to-power activation is avoided.
- The hourly generation profiles for variable renewable energy production in modelled EU countries are from the climate year 2015 available as an open data source at Renewables.ninja [11].
- For the OWF connected to LionLink, the generation profile is based on the weather data of the Dutch North-West hub in the North Sea available at the DOWA platform.

3 Results: Impact of OBZ on the business cases

In this section, power market simulations are performed to analyse price formation in the bidding zones resulting from HM and OBZ set-ups for the LionLink configuration shown in Figure 2. The first case of simulations considers a 2000 MW OWF, originally planned as a hybrid project connected to LionLink. The second case assumes an electrolyzer (P2G) co-located with the OWF as a flexible demand. For both cases, we evaluate the revenues of the hybrid connected assets under HM and OBZ set-ups within the 2030 energy scenario.

Before presenting the simulation results, a numerical example is provided to develop an intuitive understanding of the price formation in OBZ for a simple hybrid interconnection similar to the configuration of LionLink, albeit with different interconnection capacities.

3.1 Illustration of price formation on OBZ

Market clearing in OBZs is envisioned to be implemented just as in any (onshore) bidding zone. However, unlike conventional bidding zones, OBZs likely have limited to no demand connected to them. To match the supply of wind (or solar) energy with onshore demand, OBZs are highly dependent on interconnectors. The DA electricity price at the OBZ is determined by its marginal price: the value of one unit of additional production. In the absence of (substantial) load, this is the price of the adjacent bidding zone to which the transmission capacity is available. This is further illustrated by the OBZ configuration in Figure 4. The OBZ consists of 2000 MW OWF connected to the onshore bidding zones with 2000 MW interconnectors.

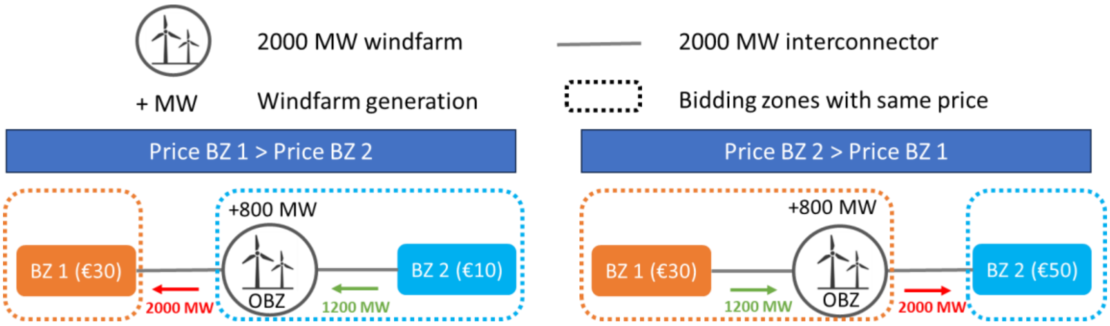


Figure 4: DA market price formation on OBZ with simple hybrid interconnection

When the price at BZ 1 is higher than BZ 2 the interconnector towards the BZ 1 renders to be congested. Market prices of connected bidding zones diverge whenever there is congestion at the interconnectors. Therefore, the OBZ takes the price of BZ 2, as there is no available transmission capacity to BZ 1. Vice versa holds when price BZ 2 > price BZ 1 in Figure 4. In a simple and symmetrical configuration of Figure 4, it can be seen that OBZs will generally take the lowest price of both onshore bidding zones. Next, the price formation for LionLink's case is presented.

3.2 Offshore wind farm connected with LionLink

In this subsection, the results of the power market simulation with LionLink are presented. Recall that the LionLink configuration differs slightly from the configuration used to illustrate price forming in OBZs from the previous section, as the connection from the OBZ to the UK is 1800 MW instead of 2000 MW.

To analyse the power market simulation results, we examine the relationship between hourly prices in the OBZ, Netherlands, and UK. This is reported in Figure 5, in which the amount of wind production on the OBZ is shown in color. Figure 5(a) shows that the prices in the OBZ are always lower than or equal to the prices in the Netherlands, which was expected based on the illustrative example in the previous subsection (see Figure 4). However, in the case of the UK (see Figure 5(b)), during low wind production periods (dark purple), the price in the OBZ can be higher than in the UK market. This is attributed to the asymmetrical capacity of LionLink, with 1800 MW between the OWF and the UK, compared to 2000 MW between the OWF and NL connections. Note that, for this scenario, prices in the UK are generally lower than prices in the Netherlands (see Figure 5(c)), explaining why the prices in the UK are not often higher than in the OBZ.

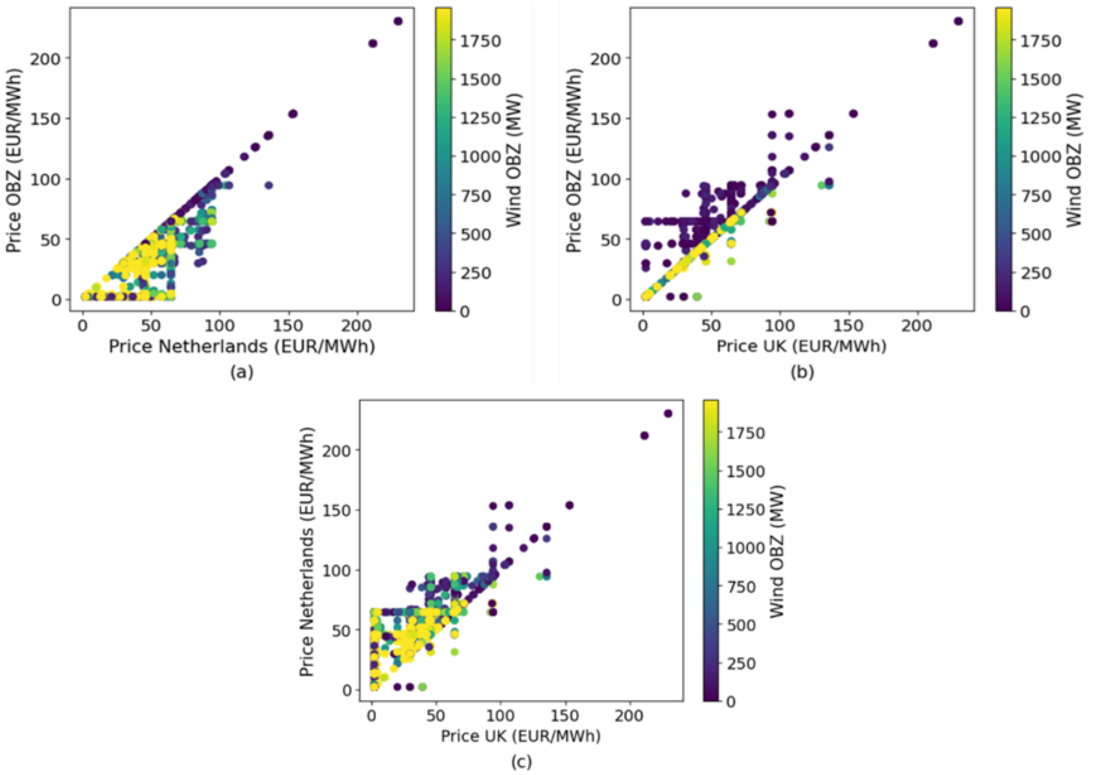


Figure 5: Relationship between the resulting DA market prices at the bidding zone of (a) the Netherlands versus the OBZ, (b) the UK versus the OBZ, and (c) the UK versus the Netherlands. The color-coding characterizes the amount of wind production in the OBZ. Each dot represents one hour of year-round (8760 hours) calculations.

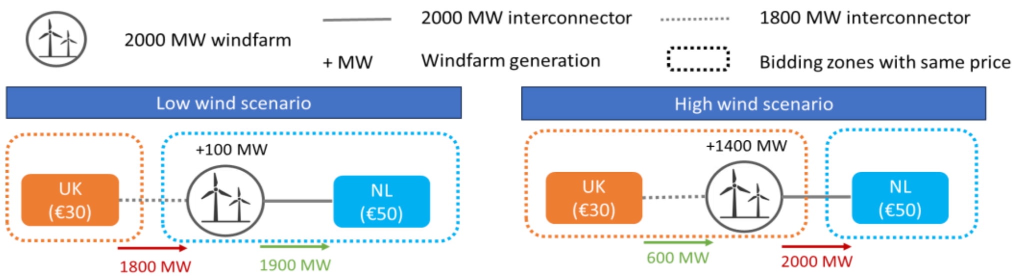


Figure 6: Effect of asymmetry in connection capacity of LionLink on price formation in OBZ

The effect of asymmetry in connection capacity is elaborated with the help of illustration in Figure 6. Here, for a low wind scenario (below 200 MW), the interconnector between the UK and the OBZ is congested, therefore the OBZ clears at the (higher) price of the Netherlands. For wind production above 200 MW, the price at the OBZ will take the UK price (when the UK price is lower than the NL price).

The price duration curves in Figure 7 show that the prices in the UK are substantially lower than in the Netherlands due to an ambitious roll-out of renewables in the UK for the 2030 scenario selected (TYNDP Global Ambition). As the OBZ tends to adopt the lowest price from adjacent bidding zones (except for wind output under 200 MW), OBZ prices are often quite similar to those in the UK and therefore lower than Dutch prices.

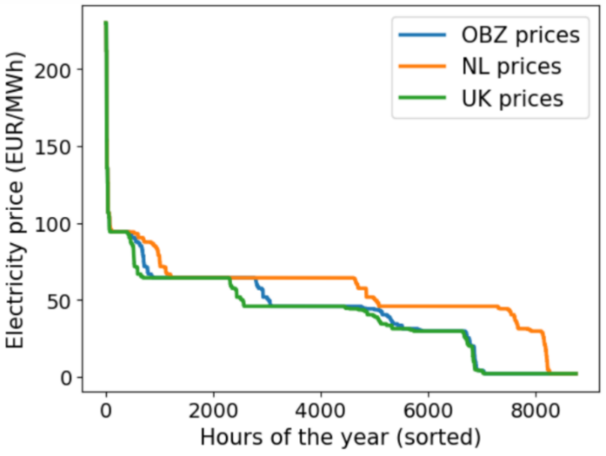


Figure 7: Price duration curves for The Netherlands, United Kingdom, and the OBZ, performed by COMPETES-TNO model

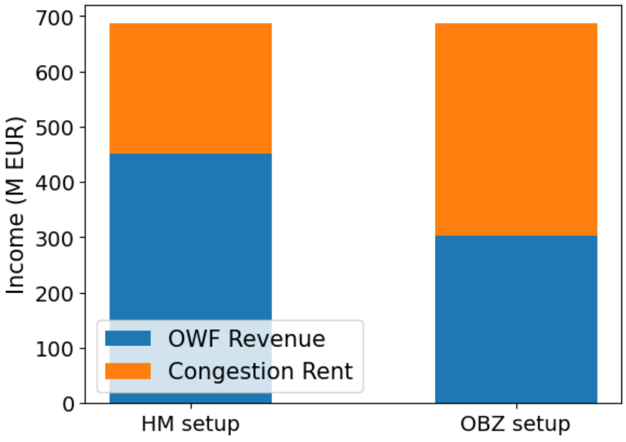
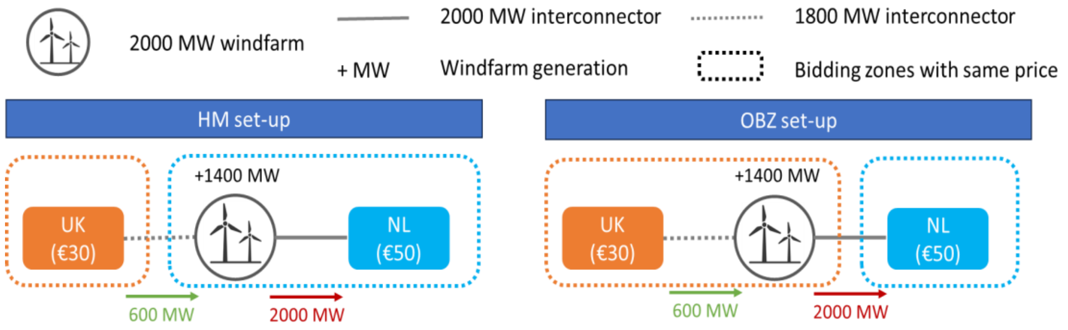


Figure 8: Distribution of OWF revenue and congestion income in HM and OBZ set-ups.

The price dynamics associated with the introduction of an OBZ compared to the existing structures of HM only, have a significant impact on the business case of offshore wind operators, as illustrated in Figure 8. It presents OWF revenues and congestion rents for the HM set-up as well as the OBZ set-up. It reveals a significant disparity in revenue for an OWF dependent on DA market prices in OBZ and HM set-ups. Specifically, the annual revenue for the OWF operator decreases from around 450 million EUR to 300 million EUR in the OBZ compared to the HM set-up. However, this reduction in revenue for the wind farm operator is exactly offset by the increased amount of congestion rents[2] received by the interconnector operator. Without redistribution of this congestion rent, the OBZ clearly poses a challenge to the business case of offshore wind. We explain this revenue distribution in the textbox below with an example.

Example of congestion rent and OWF income distribution:



For the instance shown in the figure, congestion rent and OWF revenue are calculated for HM and OBZ set-ups, and the resulting distribution is reported in the table below. It is assumed that in HM the network operator restricts the use of the interconnector considering OWF production. Thus, the congestion rent results only from 600 MWh flowing on the interconnector and causing congestion. Whereas, in the OBZ set-up, the operator of the interconnector collects a congestion rent for the full 2000 MWh from the OBZ-NL interconnector. The additional congestion rent is the same as the OWF operator's revenue drop.

Set-up	HM	OBZ
Wind revenue	**€70k** = 1.400 MWh * €50/MWh	**€42k** = 1.400 MWh * €30/MWh
Congestion rent	**€12k** = 600 MWh * (€50 - €30)/MWh	**€40k** = 2.000 MWh * (€50 - €30)/MWh
Total	€82k	€82k

3.3 Offshore wind farm and P2G connected with LionLink

In the second case, an electrolyser (P2G) is added to the 2000 MW OWF, analyzing both a small (200 MW) and a large (1000 MW) electrolyser. First, we will look at the price dynamics after adding the electrolyser. After that, we will look at the business case from the perspective of the offshore electrolyser.

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[2] Congestion rent refers to the revenue earned by grid operators from the price difference between bidding zones connected to the congested interconnector. Mathematically, it can be calculated as the product of the difference in electricity prices between zones, and the amount of energy flowing between those zones.

Figure 9 shows the comparison of price duration curves for NL and the OBZ with an electrolyser of 200 MW, and an electrolyser of 1000 MW, and the price duration curve for the OBZ without P2G from the previous case is included for reference. Furthermore, the strike price for the P2G installation is indicated in yellow dashes. Below this price, it is profitable to activate the P2G installation.

It is clear from Figure 9 that the electrolyser connected to the OBZ (slightly) increases prices at the OBZ. This is further elaborated in the explainer box below.

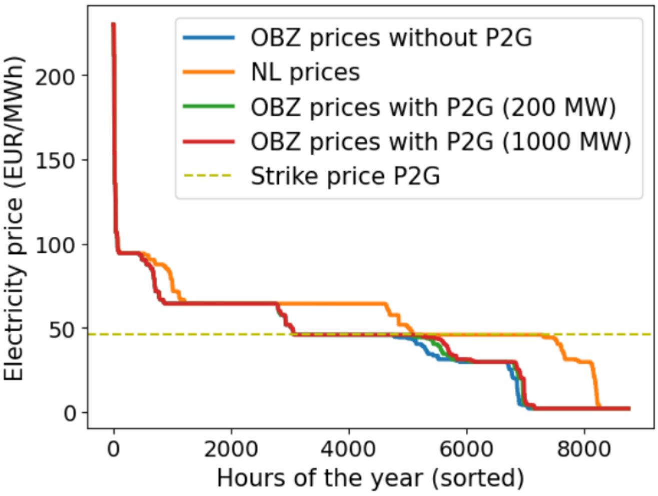

Figure 9: Price duration curves for the Netherlands, OBZ with P2G (200 MW and 1000 MW) and the OBZ without P2G. Strike price is the price above which P2G will not operate.

Explanation of OBZ price increase due to 200 MW electrolyser:

The increase in price in the OBZ by adding an electrolyser seems limited from our analysis. This is foremost explained by the fact that the OWF is very well connected (a 2000 MW wind farm with a 3800 MW connection). Furthermore, in the analysis the total amount of electrolysers is not increased, an electrolyser is only moved from the Dutch bidding zone to the OBZ. Therefore, in most cases, the wind production in the OBZ can be matched with the demand for the onshore (either in the Netherlands or the UK) electrolyser as well.

Figure 10 shows for which cases the electrolyser in the OBZ does increase the price of the OBZ:

1. During hours with low wind production at the OBZ (between 200 to 400 MW, purple dots) and electricity prices below the electrolysers strike price, the 200 MW electrolyser in the OBZ decreases the net infeed in the OBZ to between 0 and 200 MW through utilization. This leads to congestion on the OBZ-UK interconnection, causing the OBZ to adopt a higher price from the Dutch bidding zone instead of the UK bidding zone. These hours are mostly observed around summer (hours 3000-7000) when there is low wind at relatively low prices due to solar production. This effect arises as a consequence of the configuration being non-symmetrical, see also Figure 6.
2. This difference can also occur at higher wind speeds (yellow dots) by the fact that in hours when OBZ takes the UK price the 200 MW electrolyser appears as connected to the UK bidding zone instead of the Dutch bidding zone, driving the UK price up, and with it the price in the OBZ.

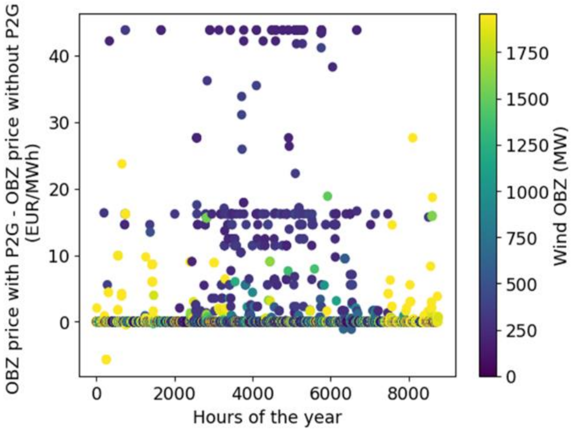

Figure 10: The price increase due to adding a 200 MW electrolyser to the OBZ.

Figure 9 shows that, considering the strike price of P2G, the full load hours of the electrolyzer in the OBZ (around 5400) are significantly higher than those of an electrolyzer connected to the Dutch home market (around 2500), taking advantage of the lower prices in the OBZ. From the perspective of a developer producing green hydrogen, the OBZ therefore presents an opportunity for an improved economic business case. As depicted in Figure 11, assuming a value of 6 EUR/kg for green hydrogen[3], the business case for an offshore electrolyser operating in the OBZ looks significantly better than an electrolyser connected to the HM. With the number of full load hours of the electrolyser more than doubling within the OBZ configuration, electricity costs increase, but income from the produced green hydrogen also more than doubles.

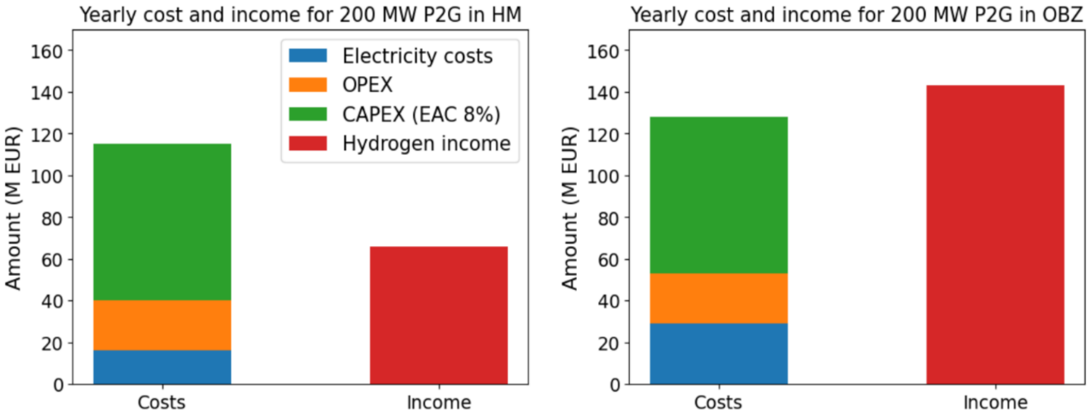

Figure 11: Simplified breakdown of costs and income for a 200 MW offshore electrolyser in the HM (left) and in the OBZ (right). The assumed green hydrogen value is 6 EUR/kg.

Finally, Figure 12 reports the incomes generated in the hybrid project for connected assets under different set-ups. The yearly OWF revenue increases by around 3M EUR in the OBZ with a P2G set-up compared to the OBZ set-up. This increase is attributed to the 200 MW electrolyser connected to the OBZ, which drives prices up slightly in the OBZ, as reported in Figure 9. Although a larger electrolyser (1000 MW) raises prices more, the revenue is still far below that of the OWF in the HM set-up.

The profit of the offshore electrolyser increases significantly when it is connected to the OBZ, taking advantage of the lower prices compared to the Dutch bidding zone. This is not offset by lower congestion rent and results in a higher total income. This demonstrates that an OBZ configuration leads to higher system efficiency, as its prices consider

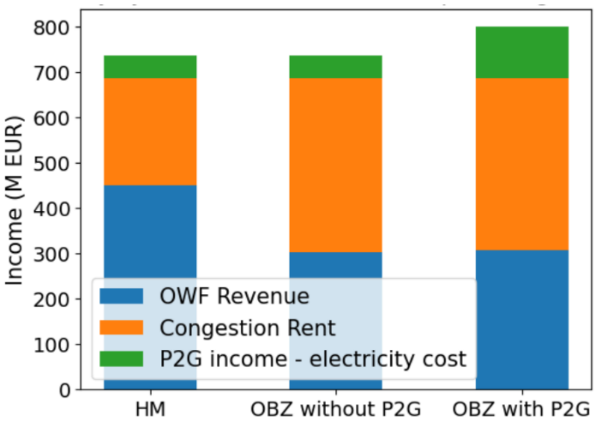

Figure 12: Yearly income of hybrid project for given set-ups. In the HM and the OBZ set-ups, the 200 MW electrolyser is operating in the Dutch bidding zone, whereas in the OBZ with P2G configuration, it operates in the OBZ.

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[3] The future value of green hydrogen is unknown and studies show a wide range of numbers. For this analysis a value of 6 EUR/kg is chosen, different values would linearly scale the hydrogen income in Figure 11. Note that the willingness-to-pay for an electrolyser in the model is set to a lower value to avoid simultaneous power-to-gas and gas-to-power, see subsection ‘Power market model’ and point 4 of the Discussion.

transmission availability. In contrast, the HM configuration leads to inefficiency[4], as high prices in the Dutch bidding zone prevent the offshore electrolyser from producing hydrogen, despite the availability of cheap electricity from the UK.

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[4] Negative day-ahead prices (not considered in this study) could also lead to lower system efficiency in the HM configuration, when the OBZ is connected to more than two different bidding zones.

4 Conclusions and discussion

4.1 Conclusions from case study

The market simulation results for the LionLink case study led to the following conclusions:

1. DA market electricity prices in the OBZ are always equal to or lower than prices in the Dutch bidding zone. Due to the non-symmetric[5] capacity of LionLink configuration, prices at the OBZ can be higher than prices in the UK bidding zone.
2. The expected yearly income for a 2000 MW wind farm bidding in a DA market under a HM set-up (wind farm gets Dutch market prices) is EUR 450M, compared to EUR 300M when connected to the OBZ, a reduction of approximately 33%. This reduction is completely offset by an additional annual income of EUR 150M in the form of congestion rent for the TSOs.
3. Connecting an electrolyser (that responds to DA prices) to the OBZ increases the DA prices at the OBZ, but only marginally. The additional annual income for the 2000 MW wind farm developer (in case it is a separate actor from the electrolyser developer) because of these higher prices is EUR 3M, an increase of about 1% for the small electrolyser (200 MW), and around twice as much for the larger electrolyser (1000 MW).
4. Lower prices at the OBZ present an opportunity for offshore electrolyzer developers. As the OBZ leads to higher market efficiency, the full load hours of an electrolyzer connected to the OBZ of LionLink (around 5400) are more than double compared to one connected to the Dutch bidding zone (around 2500), making the business case for an offshore electrolyzer significantly better in the OBZ.

4.2 Discussion

This case study includes a single OBZ configuration under a single scenario for which the OBZ prices are significantly lower than Dutch prices because of the (relatively) high amount of RES penetration in the UK. It is difficult to draw general conclusions on OBZs based on the results of this study case alone, however, they point to the following implications:

1. The exact configuration of hybrid projects and developments in neighboring bidding zones are paramount for price forming on OBZs. Wind farm developers should have clarity on OBZ configurations and developments, such as additional interconnectors at an early stage to assess the viability of their business case and the dependency on coupled markets.
2. Prices on OBZs are generally (although not always) lower than prices in the home market. This could pose a high risk to the already challenging business case of offshore wind farms without subsidies. As the missed income for wind farm developers is completely offset by higher congestion rent for TSOs, wind farm developers could be indirectly[6] compensated by support scheme mechanisms to (partially) mitigate the difference between the OBZ and home market prices. For example, Financial Transmission Rights[7] or Contracts for Difference.

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[5] In the LionLink configuration, there is a 2000 MW connection to the Netherlands and a 1800 MW connection to the UK.

[6] Current legislation prohibits redistributing congestion rent income to e.g. wind farm developers for revenue compensation except under conditions proposed in [16].

[7] An FTR is a right to receive financial compensation for the price difference between two bidding zones.

3. Due to the generally lower prices at OBZs, they are expected to be attractive for offshore electrolyser developers. On the other hand, offshore electrolysers are not expected to increase DA prices in the OBZ to significantly improve the business case of OWF developers, especially when the OBZ is well connected to home markets.
4. This study assumes that electrolysers (both onshore and offshore) operate based on DA prices and have a willingness-to-pay of around 46 EUR/MWh, to avoid the simultaneous operation of power-to-gas and gas-to-power[8]. However, at high prices of green hydrogen (e.g. >6 EUR/kg), the electrolyser is likely to be willing to pay a higher electricity price as long as the hydrogen is considered green. For example, when there is a Power Purchase Agreement between a wind farm and the electrolyser. The higher willingness-to-pay (for green electricity) of the electrolyser would lead to a higher amount of full load hours of the electrolyser, but potentially at higher costs, as electricity prices increase because of overall system inefficiency (due to simultaneous operation of power-to-gas and gas-to-power)[9].

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[8] If the willingness-to-pay of the electrolyser is higher than the marginal costs of a gas-fired power plant, the market will clear both the electrolyser and the gas-fired power plant, leading to inefficient production of grey hydrogen and high electricity costs.

[9] See also footnote 8. At a high willingness-to-pay of the electrolyser for green electricity only, green electricity is converted into hydrogen even though at high electricity prices this electricity could also have been used to reduce electricity generation of gas-fired power plants, leading to increased electricity costs.

5 Outlook 2050

This study is focused on LionLink which is a simple hybrid project, in terms of configuration, planned for the start of 2030. However, as shown in Figure 13 and Figure 14, several projects with more complex meshed structures and with connections to several bidding zones are being considered in plans for 2040 and 2050. For meshed hybrid projects, it becomes even more difficult to anticipate the effects that the HM concept will have on the market dispatch [4], further strengthening the case for OBZs. Consequently, it also complicates the price formation on the OBZs, and a rule of thumb such as 'the OBZ takes the price of the lowest adjacent onshore bidding zone' no longer always holds (see an example below). This necessitates a deeper analysis of the economic impact of meshed OBZs on the assets operating within them. Therefore, TNO is extending this study with a follow-up that will encompass, in the context of OBZs, a business case analysis of OWFs, the potential of flexibility (such as P2G and storage), the effects of long-term financial contracts (PPAs, green HPAs, etc.), and the impact of infrastructure in the North Seas towards 2050.

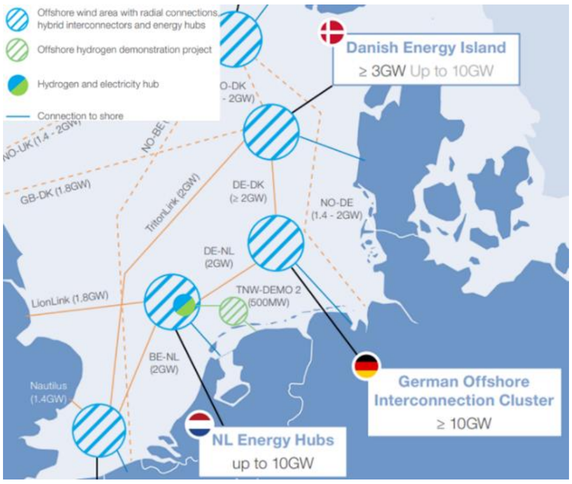


Figure 13: Initial offshore grid (update 2024) Cross border projects in mid 2030s time horizon [14]

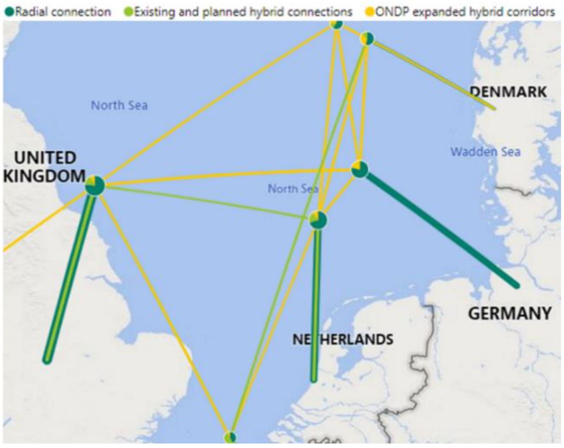
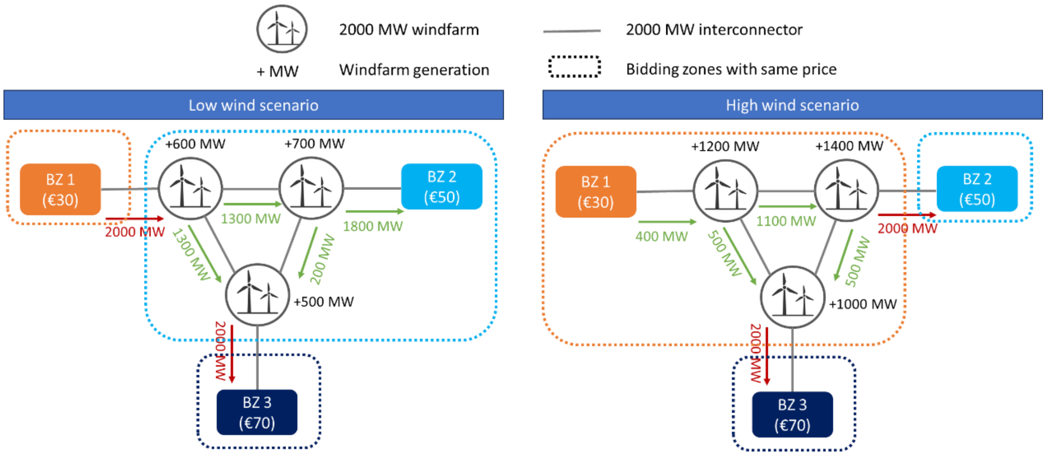


Figure 14: Offshore Transmission Corridors in 2050 [3].

Example of price formation at OBZs for meshed hybrid projects:



The figure illustrates an example of price formation on OBZs for meshed hybrid projects. In this example, for a low wind scenario (holds for wind output lower than 1000 MW), the interconnector from the onshore bidding zone with the lowest price (BZ 1) is congested. This is because, next to offshore wind, there is transmission capacity available from BZ 1 to onshore bidding zones with higher prices (first to BZ 3, then to BZ 2). The OBZs, therefore, have a price equal to the onshore bidding zone with the middle price (BZ 2). For the high wind scenario (higher than 1000 MW), the interconnector towards BZ 2 is also congested; therefore, the price of the OBZs equals the price of the onshore bidding zone with the lowest price (BZ 1).

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