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Abstract

Onshore, generators are connected to the transmission grid by TSOs. This regulatory model could simply be extended to offshore (i.e. Germany), but the connection of offshore wind farms to shore is also an opportunity to test alternatives, i.e. the third party model (i.e. the UK) or the generator model (i.e. Sweden). In this paper, we argue that the third party and generator models are indeed better suited to support the evolution towards larger scale offshore wind farms that are increasingly developed farther out to sea, while the TSO model is better suited to support the evolution towards cross-border offshore grid projects. In other words, an important trade-off needs to be made because none of the existing regulatory models can fulfill all the expectations in the current context in Europe. And, the trade-off has to be made at the regional or EU level because the different national regulatory frameworks are incompatible when applied to a cross-border offshore grid project.

Keywords

Renewable energy, offshore wind, grid connection, transmission, regulation

Introduction[*]

Offshore wind technology is increasingly used to achieve the renewable energy ambitions in different parts of the world. In Europe, the National Renewable Energy Action Plans that member states submitted to the European Commission, show that the installed capacity of offshore wind farms is expected to increase from the existing 3 GW to about 40 GW by 2020.[1] In this context, there are two important evolutions.

There is an evolution towards larger scale offshore wind farms that are developed deeper into the sea so that more significant infrastructure investments need to be made to connect these wind farms. These so-called farm-to-shore investments are already between 15% and 25% of the total project cost, compared to 5 to 10% for onshore wind farms (Swider et al., 2008; and Weißensteiner et al., 2011). Farm-to-shore investments are also expected to become a relevant share of the total regulated transmission asset base in some member states. Connecting 19 GW of offshore wind in the UK would, for instance, imply a total offshore transmission investment between 6 and 10 billion pound, which is a value of the same order of magnitude as the existing onshore transmission system (Green and Vasilakos, 2011). Tennet is also currently already investing 6 billion euro to connect offshore wind farms in the north of Germany.

There is also an evolution towards cross-border offshore grid projects. Indeed, a meshed electricity grid requires fewer physical components with higher transmission capacity, which is beneficial due to the economies of scale present in transmission systems. This has also been the case onshore, where the grid approach has been favored for a long time now, especially since the introduction of both technology and operational standards in the previous century. Several studies have compared the costs of a meshed and non-meshed solution to connect offshore wind farms in the North Sea, starting from different scenarios for 2030, concluding that the meshed solution would indeed be cheaper, especially in scenarios with more offshore wind (OffshoreGrid, 2011; NSCOGI, 2012).

Offshore pioneering member states have started to test novel regulatory frameworks for the connection of offshore wind farms. There are already three alternative models: Germany relies on its TSOs, extending the grid model we know from onshore to offshore; Sweden has used a "generator model" in some projects, whereby the offshore wind farm developers are responsible for their own connection to shore; and the UK relies on tendering to third parties to design and develop the connection of offshore wind farms. The main contribution of this paper is to discuss the ability of these three alternative models to support the two ongoing offshore evolutions, i.e. the evolution towards larger scale offshore wind farms that are developed deeper into sea, and the evolution towards cross-border offshore grid projects. The article is therefore organized in two sections. Section 1 evaluates the ability of the alternative regulatory models to support the evolution towards larger scale offshore wind farms that are increasingly developed deeper into sea. Section 2 discusses the ability of the alternative regulatory models to support the evolution towards offshore grid projects across borders.

[*] The research for this article was conducted with François Lévêque, Marcelo Saguan, Isabel Azevedo and Jean-Michel Glachant in the context of the EU FP7 funded project THINK. The author deeply thanks his colleagues and the reviewers for their feedback on an earlier version of this article. All errors remain the authors' own responsibility.

[1] COM(2011) 31 final: Renewable Energy: Progressing towards 2020.

1. Ability to support the evolution towards large-scale offshore wind farms increasingly developed farther out to sea

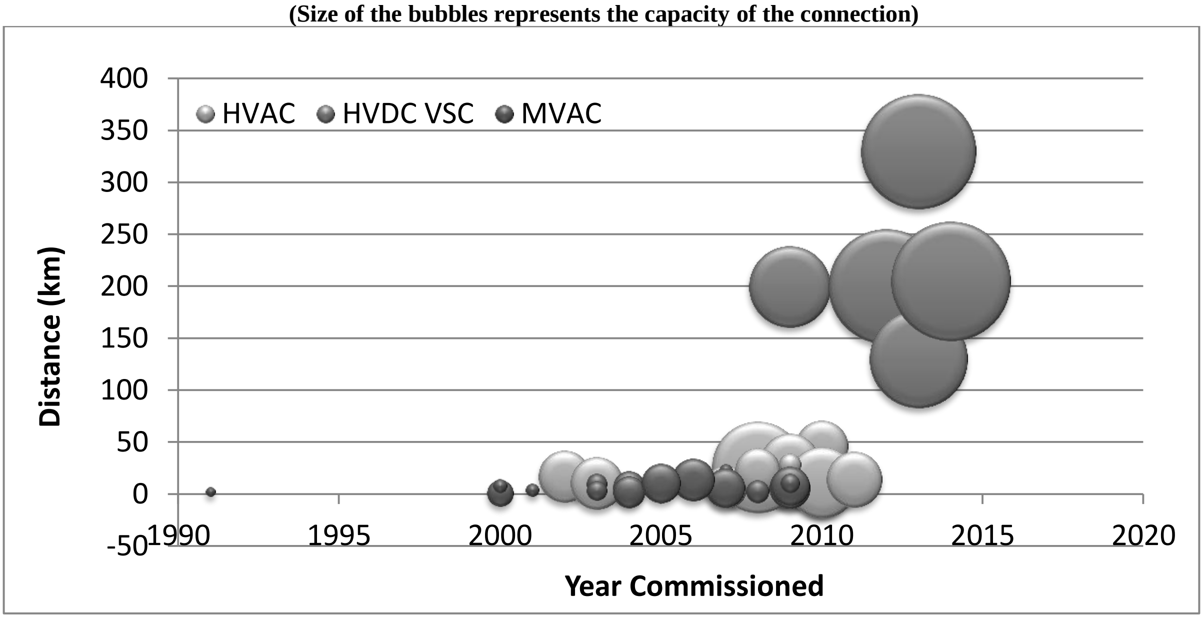
We first discuss the economic features of farm to shore investments (section 1.1), which then allows us to propose regulatory criteria (section 1.2) to assess the alternative regulatory models for their ability to support the evolution towards large-scale offshore wind farms that are increasingly developed deeper into sea (section 1.3).

1.1 Economic features of farm to shore investments

In Europe, farm-to-shore investments are characterized by an evolution towards larger-scale offshore wind farms that are developed farther out to sea, as illustrated in Figure 1.

The early projects are indeed very close to shore (from 10 meter to 50 km from shore). They have an installed capacity between 4 and 504 MW, and are connected to the onshore electricity grid with Medium or High Alternative Current (MVAC or HVAC) transmission systems. However, the five newer projects in the figure are relatively larger-scale with an installed capacity between 400 and 864 MW, and they are developed farther out to sea at distances between 130 and 330 km from shore. This new type of offshore wind project is also connected to shore with a different technology, i.e. High Voltage Direct Current Voltage Source Converter (HVDC VSC) transmission systems. They are being developed in Germany, but also expected in other EU member states, such as the UK where concessions to develop this type of projects have recently been allocated, totaling almost 20 GW.

Figure 1 – Mapping of the 53 farm-to-shore projects[2]
(Size of the bubbles represents the capacity of the connection)



These new projects have stronger economic features than typical investments needed to connect generation onshore. In what follows, we present the reasoning for this statement and illustrate it with the example of a recent project in Germany, i.e. Borwin. This project includes three offshore wind farms located about 200 km from shore, totaling 1200 MW (i.e. 400 MW in phase 1 in 2009 and 800 MW in phase 2 in 2012) and its connection cost has been estimated at 1200 million Euros.

The first issue is that the network externalities are stronger for farm to shore investments than for typical onshore connections. Most generators onshore are located near the existing transmission grid

[2] For more detailed information about these projects, see Meeus et al. (2012).

and can be relatively easily connected: there is only a marginal impact on other users and they do not create strong externalities. Indeed, onshore grids are normally well-developed and well-meshed. Moreover, new conventional generators onshore are often thermal gas power plants, and they have a certain flexibility concerning the choice of their location. Exceptions onshore can be large hydro or onshore wind farms located far away from the existing onshore transmission grid. Offshore, these exceptions are, however, becoming the rule. For instance, in the case of Borwin, there is a strong impact on the existing grid because a capacity of 1200 MW needs to be connected close to shore where the existing grid is weak and already congested. The integration of offshore wind farms in the existing transmission grid therefore typically requires strong grid reinforcements, i.e. strong network externalities among users.

The second issue is that the cost and technology uncertainties are stronger for farm-to-shore investments than for typical onshore connections. As previously stated, most generators can be connected relatively easily onshore. A typical connection is relatively cheap onshore, and uses well-known AC transmission systems. In the case of Borwin, the offshore wind farms have been connected using the lesser-known HVDC VSC systems because of the large distance to shore. Offshore, transmission systems are also built from scratch so that there are more degrees of freedom in the investment decision that could be explored, i.e. greenfield investment. Moreover, the experience with the installation, operation and maintenance of transmission assets offshore is much more limited than onshore. Note finally that these additional cost and technology uncertainties offshore imply that there is more information asymmetry between the regulatory authority approving the investments and the company implementing the investments.

The third issue is that the economies of scale are stronger for farm to shore investments than for typical onshore connections. Onshore, it is less likely that several generators are asking to be connected in the same area, located far from the existing grid, and around the same time, while this is typically the case offshore. Therefore, there are more opportunities offshore to coordinate these connections to capture economies of scale. In the case of Borwin, three offshore wind farms have been developed in a period of 3 years in the same area. The HVDC VSC systems to connect them consist of a DC cable with two converter stations, one to convert the AC output of the wind turbine into DC, and one to reconvert the DC output of the cable into the AC of the onshore grid. By coordinating the connection of the two wind farms in Borwin in first phase, only 4 converter stations and 2 cables to shore need to be used, instead of 6 stations and 3 cables. Note that this is referred to as wind farm clustering, i.e. having offshore wind farms share their connection to shore.

1.2 Regulatory criteria

The regulatory criteria that are important for farm to shore investments follow from the above discussed economic features of these investments: 1) advanced connection planning (to deal with the strong network externalities and strong economies of scale); 2) an element of competition (to deal with the strong cost and the strong technology uncertainties); and 3) price signal (to make sure that offshore wind farm developers have an incentive to actively participate in the connection planning).

Advanced connection planning

The current model in most EU member states is that the TSOs deal with connection requests by generators on a first-come-first-serve basis. The participation of generators in this process is limited. Such a reactive connection planning strategy whereby transmission follows generation is increasingly problematic because most plants that are currently constructed, such as gas plants and renewable energy plants, are relatively quick to market, while transmission is facing increasing opposition so that its reaction comes too late, if it continues to follow generation.

A more planned approach for the connection of generators would imply that TSOs coordinate the requests, and possibly also anticipate certain investments (Rious et al., 2010; and Sauma and Oren, 2006). They could already do early project development work with a limited cost, like applying for permits, so that once a project is fully approved, it can be implemented quicker. TSOs would then need to be encouraged to incur such costs for projects that are not yet sure to be developed. The participation of generators in this planning process is therefore also essential because they have the best information about their demand for transmission services (Littlechild and Cornwall, 2009), which could be achieved by organizing group connection procedures, or auctioning of connection slots. Such an advanced connection planning approach is especially important offshore due to the stronger economies of scale and network externalities of farm to shore investments.

Element of competition

The current model in most EU member states is that only TSOs can connect generators, so that they cannot be contested either in the design or in the development of connections. This was not necessarily a problem because up until recently the connection of a generator was standardized and low cost.
In the transition towards a low carbon energy system, new generation technologies will however have to be connected, and they will be connected with new transmission technologies, which is especially true offshore. The information asymmetry between the regulatory authority and the regulated TSO regarding the costs of the transmission investments to connect generators is indeed increasing so that it becomes opportune to introduce elements of competition, like tendering for the design and development of these connections, which can then also encourage innovation.

Price signal

The current models in EU member states to allocate the network costs to generators are very diverse. Finland, Czech Republic and Luxembourg apply deep connection charging whereby the generators pay for the costs of their connection and for the reinforcements that are needed to remedy congestion in the grid caused by the newly added generation capacity. Other member states apply shallow connection charging whereby generators only pay for the costs of their connection, not for the reinforcements that might be needed. Note finally that in the UK, generators do not pay directly for their connection (i.e. super shallow connection charging), but they pay indirectly because part of the network costs are recovered from generators with locational signals reflecting the cost of providing transmission services in different parts of the network.

What matters is that generators receive a price signal so that they internalize the cost of their demand for transmission services in the total investment, and this signal can come from connection charges, or from transmission tariffs (Baldick et al., 2011; Lévêque, 2003; and Ruester et al., 2012). The problem is that renewable generators often do not pay, or pay only part of their connection costs, and special rules that often apply in Europe, such as connection priority or access and dispatch priorities, can further distort their investment decisions. As for instance discussed in Hiroux and Saguan (2010), it would be better to include the cost of connection in the support mechanisms for renewable energy. This would increase transparency regarding the cost of renewable energy, and imply that also these generators take grid connection costs into account in their investment decisions. Especially offshore this is important to make sure that offshore wind farm developers are incentivized to participate in advanced connection planning.

1.3 Assessing the alternative regulatory approaches

In what follows, we use the regulatory criteria proposed in the previous section to assess the three alternative regulatory models to connect offshore wind farms to shore.

TSO model

The first model has been implemented in Germany, and simply extends the responsibility of TSOs to connect generators from onshore to offshore. Actually, TSOs in Germany are obliged to connect offshore wind farms by the time they are commissioned. The Borwin project, referred to in section 1, illustrates that this encourages connection planning for farm-to-shore investments. In this project, two offshore wind farms have indeed shared a connection to shore. Therefore, the German implementation of this model already includes an element of advanced connection planning, but currently lacks competition, and the price signal towards offshore wind farm developers is also missing.

Generator model

The second model has been used in Sweden for some projects, and relies on the offshore wind farm developers to connect to shore.[3] This is one way of introducing an element of competition in farm-to-shore investments, and it also implies that the necessary price signals are given to offshore wind farm developers. The Swedish implementation of this model, however, does not currently include advanced connection planning.

Third party model

The third model has been implemented in the UK, and includes tendering for farm-to-shore investments so that third parties can enter to invest in the grid. In the UK, these third parties are referred to as Offshore Electricity Transmission Owners (OFTOs). The first OFTO license was awarded in 2010, which was to transfer the ownership and operation of the transmission assets of the Robin Rigg project from the generator to a third party. Note that the UK implementation of this model also allows generators to become the OFTO. In any case, it means there is an element of competition and also a price signal, but advanced connection planning will only be implemented for future tendering rounds. Note finally that the regulatory authority Ofgem is positive about the experience with the first round, estimating the benefits in the range of 350 million GBP to a total value of 1.1 billion GBP.

Assessment summary

Table 1 summarizes the above assessment. Each of three models could be improved. For instance, the TSO model could easily include a price signal, and the generator and third party model could include advanced connection planning, which the UK also intends to do. However, the TSO model cannot include an element of competition. In conclusion, the generator and the third party model are better suited than the TSO model to support the first offshore evolution towards larger scale offshore wind farms that are developed deeper into sea.

Table 1: Comparison of the three alternative regulatory models, as currently implemented in Germany, Sweden and the UK

Alternative Models	TSO	Generator	Third party
As currently implemented in	Germany	Sweden	UK
Advanced connection planning	Yes	No	Not yet
Element of competition	No	Yes	Yes
Price signal	No	Yes	Yes

[3] Note that some offshore wind farms in Sweden have been connected with the TSO model, but in other cases, like Kriegers Flak, the generator model has been applied (Energinet.dk, 2009).

2. Ability to support the evolution towards cross-border offshore grid projects

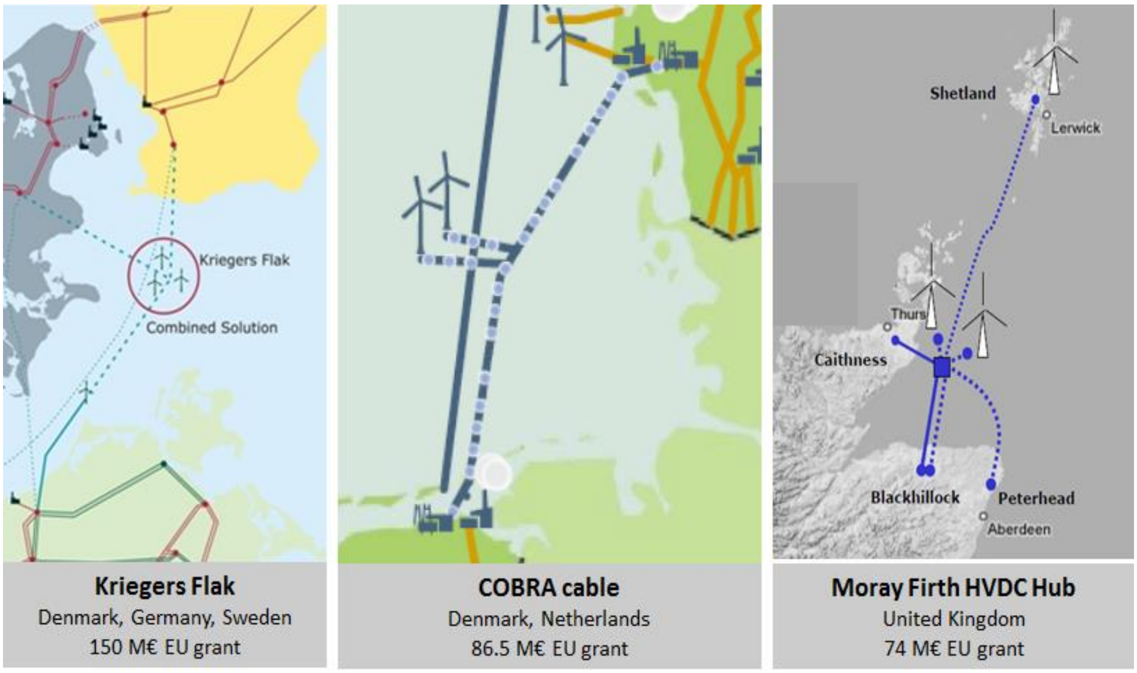
We first revisit the economic features of offshore infrastructure investments for the specific case of cross-border offshore grid projects (section 2.1). We then also revisit the regulatory criteria (section 2.2), so that we can finally re-asses the three alternative regulatory models, focusing on their ability to support the evolution towards cross-border offshore grid projects (section 2.3).

2.1 Revisiting the economic features of offshore infrastructure investments

The European Economic Recovery Program provided EU funding to three ongoing offshore grid projects, as illustrated in Figure 2.

The first project is Kriegers Flak (EU grant of €150 M). Planned by the Danish TSO (Energinet.dk), a German TSO (50-Hertz), and the Swedish TSO (Svenska Kraftnätt), the project combines the connection of up to 1600 MW of offshore wind farms in Danish, German, and Swedish waters with the creation of interconnection capacity (Jørgensen, 2011; Meeus and Saguan, 2011). The second project is the Cobra cable (EU grant of €86.5 M). Planned by the Dutch TSO (Tennet) and the Danish TSO (Energinet.dk), the project is to interconnect Denmark with the Netherlands with a capacity of about 700 MW, with an option to also connect offshore wind farms at a second stage (Van Dijk and Vilhelmsen, 2011). Third project is Moray Firth HVDC Hub (EU grant of €86.5 M). Planned by the Scottish TSO (Scottish and Southern Energy), the project is to connect 2500 MW existing and planned offshore wind farms to shore, and simultaneously interconnect the onshore grid of the Scottish mainland to the grid of the Shetland Islands (Neilson, 2011).

Figure 2 – Kriegers Flak, Cobra cable and Moray Firth



Offshore grid projects have economic features that are at least as strong as the features of farm to shore investments. In comparison with the Borwin project (section 1.1), the projects Kriegers Flak, Corbra Cable, and Moray Firth have similar network externalities, similar cost and technology uncertainty, and similar economies of scale. They, however, face an additional uncertainty related to the cost and the operation of HVDC systems. With current technology, the whole infrastructure stops working if a fault occurs in one of the physical components of the infrastructure, i.e. one of the converter stations or cables. This is manageable in relatively small-scale infrastructures like Borwin, and even in integrated solutions like Kriegers Flak, Cobra Cable, and Morray Firth, but not in a larger-scale grid. The hardware (HVDC circuit breakers) and software (HVDC control systems) that is needed to allow for a more sophisticated operation of HVDC systems, like we already have in HVAC systems, is under development, and it remains to be seen at what cost it will become available.

2.2 Revisiting the regulatory criteria

The Kriegers Flak project illustrates that in the specific case of cross-border offshore grid projects, it is problematic that different Member States use different regulatory models for offshore transmission infrastructure investments.

The Kriegers Flak project is about connecting up to 1600 MW of offshore wind farms in Danish, German, and Swedish waters in combination with increasing the interconnection capacity between these countries. On the Danish and German side, the TSO model applies, while on the Swedish side, the generator model has been used for this project. It has been difficult to coordinate the involved parties because of the incompatibilities between the regulatory models (Meeus and Saguan, 2011). This has also been confirmed in the work of the North Seas Countries' Offshore Grid Initiative (NSCOGI, 2013)[4].

It is therefore important to harmonize the national regulatory models for the connection of offshore wind farms at the regional or EU level. In order to achieve this, the involved Member States need to agree on a regional or EU regulatory target model that they would then harmonize with.

2.3 Re-assessing the alternative regulatory approaches

In what follows, we re-assess the three alternative regulatory approaches, focusing on their suitability to become the regional or EU regulatory target model.

TSO model

The TSO model is the dominant model onshore, and several countries already extended this model to offshore, including Belgium, Denmark, France, Germany, Ireland, Netherlands, and Norway (NSCOGI, 2012). The cooperation of TSOs has been institutionalized by the third energy liberalization package[5] with the creation of the European Network of Transmission System Operators for electricity (ENTSO-E). ENTSO-E is an EU body that executes tasks on behalf of TSOs, which could include the development of offshore grids.

Generator and third party models

The generator and third party models involve an increasing number of entities in the design and development of offshore transmission assets. This implies that integrating these assets in a meshed offshore grid across borders becomes more difficult, especially for the incremental investments that will need to be made in the future to integrate different cross-border offshore grid projects.

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[4] The Energy Ministers of in a total 10 countries in this region signed a Memorandum of Understanding in December 2010, supported by their TSOs, their regulators and the European Commission.

[5] The third package consists of five legislative texts: (1) a Directive (2009/72/EC) revisiting the internal market for electricity; (2) a Directive (2009/73/EC) revisiting the internal market for natural gas; (3) a Regulation (715/2009) on conditions for access to the natural gas transmission networks; (4) a Regulation (714/2009) revisiting the conditions for access to the network for cross-border exchanges in electricity; and (5) a Regulation (713/2009) establishing an Agency for the Cooperation of Energy Regulators.

Re-assessment summary

As the TSO model is already the dominant model in Europe, it would be institutionally more feasible to select this model as the regional or EU target model for the connection of offshore wind farms in the North Seas. If all Member States would harmonize with this model rather than with the generator or third party models, this would also simplify coordination between the involved parties, simply because less parties would be involved. Therefore, the TSO model is better able to support the evolution towards cross-border offshore grid projects, than the generator or third party models.

Conclusion

We are expecting a lot from the regulatory framework for the connection of offshore wind farms in the current context in Europe.

The regulatory framework is expected to support the evolution towards larger scale offshore wind farms that are increasingly developed deeper into sea. We discussed that this implies that the framework should include advanced connection planning, an element of competition, and an adequate price signal to deal with the strong economic features of these offshore infrastructure investments.

Three alternative regulatory models already exist in Europe, i.e. the TSO model, the generator model, and the third party model. We discussed that the way Germany, Sweden, and the UK have implemented these models can be improved. We also noted that the TSO model couldn't include an element of competition so that it is less suited than the generator and third party models to support the evolution towards larger scale offshore wind farms deeper into sea.

The regulatory framework is, however, also expected to support the evolution towards cross-border offshore grid projects, such as Kriegers Flak. The experience is that the different national regulatory frameworks are incompatible when they are applied to such a cross-border project. It is therefore important to harmonize the regulatory framework at the regional or EU level. In order to achieve this, the involved Member States need to agree on a regional or EU target model that they would then harmonize into. We discussed that for this purpose, the TSO model is more suitable than the generator model or the third party model.

In other words, none of the three existing regulatory models can fulfill all the expectations in the current context in Europe. We therefore need to make an important trade-off between the generator or third party models that are more suitable to support the evolution towards larger scale offshore wind farms that are increasingly developed farther out to sea, and a TSO model that is more suitable to support the evolution towards cross-border offshore grid projects. Also, the trade-off needs to be made at the regional or EU level.

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