

The North Seas Countries' Offshore Grid initiative (NSCOGI)

- Cost allocation for hybrid infrastructures -

Deliverable 3 – Final version

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Working Group 2 – Market and Regulatory issues

28 July 2014

1. INTRODUCTION

1.1 Statement of aims and objectives of the NSCOGI

The aim of the North Seas Countries' Offshore Grid Initiative (NSCOGI) is to establish a strategic and cooperative approach to improve current and future energy infrastructure development in the North Seas. The initiative seeks to identify ways to facilitate coordinated development of a possible offshore network that maximizes the cost-effective use of renewable energy and infrastructure investments in the North Seas.

The Memorandum of Understanding between the ten countries around the North Seas, signed on 3 December 2010, breaks down the overarching objective into a set of deliverables, which are grouped into Grid Configuration and Integration issues (Working Group 1 - WG1), Market and Regulatory issues (WG2) and Permitting and Authorization issues (WG3).

Working group 2 was assigned a set of 5 deliverables:

1. Identification of incompatibilities of national markets and regulatory regimes which act as barriers to coordinated offshore grid development.
2. Proposal to address these barriers so that national regimes are sufficiently compatible to facilitate cross-border investment.
3. Proposal on efficient cost-benefit sharing and investment incentives.
4. Proposal for a common regulatory approach to anticipatory investments (including the sharing of technological risk) to achieve a cost efficient grid development.
5. Proposal for market mechanisms to facilitate the increased penetration of variable renewable generation and combination of offshore wind farms with interconnection, taking into account national renewables support schemes, to contribute to the elaboration of codes and guidelines under the Third Package.

WG2 has already published several documents:

- Regulatory Benchmark report (January 2012)
- Recommendations for guiding principles for the development of integrated offshore cross border infrastructure (November 2012)
- Possible Market Arrangements for Integrated Offshore Networks (March 2013)

A second market arrangements paper – Discussion Paper 2: Integrated Offshore Networks and the Electricity Target Model – is to be published shortly. This will expand on the issues discussed in the first market arrangements paper and consider how offshore renewable generation would operate under the different timeframes of the Target Model.

Further studies are yet to be carried out, including further work on power trading in different timeframes (intra-day, forward), the impact of renewable support schemes and anticipatory investment.

1.2 Aims and objectives of the present paper

In order to meet our third deliverable, WG2 has developed proposals for identifying how the costs and benefits of projects combining cross-border infrastructure and renewable generation may be shared fairly between multiple stakeholders and with due regard to investment incentives.

1.3 Context

In 2010, the European Commission published its Energy Infrastructure Priorities for 2020 and 2030 which identified the offshore grid in the North Seas as a priority corridor for the transport of electricity. In this context, the NSCOGI was set up to facilitate coordinated development of offshore grids in the North Seas.

Since then, the development of an interconnected offshore grid in the North Seas has been intensively discussed by governments, Transmission System Operators (TSOs) and National Regulatory Authorities (NRAs) in the NSCOGI, together with the European Commission. Several studies have investigated the benefits of an integrated offshore grid and have come to the same conclusion: a meshed grid design could under certain circumstances bring financial, technical and environmental benefits at the European level but the size of these benefits is very dependent on,

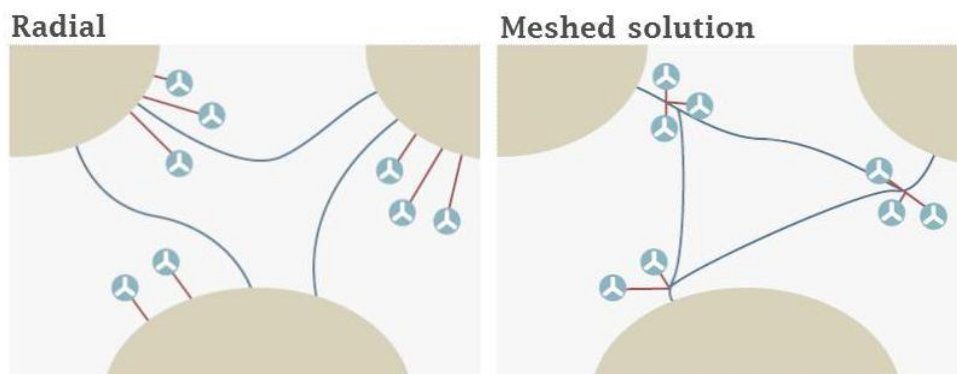


Figure 1 - Possible offshore grid development

inter alia, the volume and location of offshore renewable generation.

Today, offshore renewable generators are individually connected to national transmission grids via a radial connection to shore. Interconnectors generally link together two onshore grids. However, hybrid structures combining interconnectors and renewable energy sources (RES) could, in some situations, be a more efficient alternative. This would represent the first step towards an offshore meshed grid.

The NSCOGI study on future grid development¹ established that, with 55GW of offshore RES, a meshed grid design would generate 77M€ of additional annual net benefits compared to a radial design. This represents a slight gain of 3%. However, with higher volumes of renewables, the saving would be more significant: 7% cost reduction with 117 GW of RES in 2030². In addition to these cost savings, a meshed grid would enhance security of supply, enable integration of greater volumes of RES, increase operational flexibility and reduce environmental impacts owing to their being fewer cables and landing points (thereby facilitating authorisation procedures). It should, however, be noted that the choice between radial and meshed solutions must be made on a case-by-case basis – no general conclusion on the “best” solution can be drawn.

A coordinated approach raises several issues: interaction of national RES support mechanisms, compatibility of national regulatory regimes and legal frameworks, governance issues, market arrangements. Moreover, the connection of a different kind of asset between multiple countries would need to be facilitated and allowed by national connection regimes (e.g. offshore wind farms combined in a hub, connection of an ORG to an interconnector, interconnection between three countries). Finally, a coordinated approach involving several stakeholders would raise particular costs issues, including who would pay for common components of a meshed offshore grid interconnecting several offshore wind farms from different countries.

Hybrid projects could reduce the overall cost of infrastructure, mainly thanks to fewer or shorter cables to shore. However, efficient cost-benefit allocation is essential to incentivize the development of hybrid assets where this solution is more efficient than interconnectors and radial generator connections being developed separately. This paper investigates different cost allocation methods which might be used to encourage hybrid asset development.

The study is based on a basic model where an Offshore Renewable Generator (ORG) is connected to two bidding zones located in different countries.

1.4 Complementarity with ACER’s work on cross-border cost allocation (CBCA)

The NSCOGI study on cost allocation was undertaken at the same time as the Agency for the Cooperation of Energy Regulators (ACER) was developing a cross-border cost allocation (CBCA) methodology as required by Regulation (EU) No 347/2013. The aim of this Regulation is to facilitate priority infrastructure projects with cross-border impacts. In September 2013, ACER published Recommendation No 07/2013 regarding the cross-border cost allocation requests submitted in the

¹ NSCOGI, The North Seas Grid study, Initial findings, November 2012, <http://www.benelux.int/NSCOGI/>

² Under a slightly more ambitious scenario - 126GW of offshore wind capacity installed in the North and Baltic Sea by 2030 - a similar conclusion is reached: connecting wind farms in close proximity together (forming a hub), instead of individually to shore, could save up to €14bn. The report assumes 321 wind farm projects will be developed by 2030 and that 114 of them can be clustered into hubs.

OffshoreGrid, 2011. Offshore Electricity Grid Infrastructure in Europe: a Techno-Economic Assessment. 3E (coordinator), dena, EWEA, ForWind, IEO, NTUA, Senergy, SINTEF, Final Report, October 2011. <http://www.offshoregrid.eu/>

framework of the first Union list of electricity and gas projects of common interest (PCIs)³. Cross-border cost allocation (CBCA) is necessary in order to facilitate projects which have a negative effect on at least one hosting country (i.e. a hosting country with a negative cost benefit analysis (CBA) at national level, on the assumption that the hosting country is charged with the cost of the part of the project located in its territory). Such projects would not be built without an appropriate cost allocation, so positively impacted third countries might need to contribute to make the project viable⁴. This method, which is based on a cost benefit analysis (CBA), may be applied to PCIs as soon as they have reached sufficient maturity and when the project promoters have not been able to solve the problem of a negative CBA.

NSCOGI has closely followed ACER's work, to make sure that our proposal for cost allocation is compatible with the CBCA recommendations. However, the scope and objective of ACER's CBCA and NSCOGI's cost allocation work are different. In that sense, this paper is complementary to ACER's recommendations on CBCA.

One difference concerns the parties involved in cost allocation. Our paper focuses on cost allocation between promoters of a hybrid asset, i.e. ORGs and hosting TSOs, without the involvement of any other parties. Conversely, the CBCA exclusively concentrates on allocating part of the costs to the TSO of a positively affected third country, when the CBA of one hosting country is negative. As for the scope, the NSCOGI work studies cost allocation mechanisms for hybrid assets, combining renewable production and cross-border trade, while the CBCA work is dedicated to PCIs.

The NSCOGI and ACER work aim to solve rather different cost issues. In the NSCOGI case, hybrid assets may decrease investment costs (due to fewer and/or shorter cables) but may also reduce cross-border electricity trade, thus the related social and commercial benefits. However, NSCOGI assumes that, for the case studied, hybrid assets are beneficial from a global perspective (the net benefit of the project is positive and higher than the net benefit of a radial solution). Thus, the main objective of our work is to allocate costs properly between project promoters so as to incentivize them to develop a hybrid solution, when this is more beneficial from a global perspective. Conversely, a PCI is by definition beneficial from a European perspective. However, when a hosting country has a negative cost benefit analysis, the national TSO may be reluctant to develop the PCI. CBCA allows for a contribution from positively impacted countries to the cost of a PCI that would not be realized otherwise, e.g. in cases where a country hosting (part of) the infrastructure would incur a net loss if costs were allocated according to the traditional approach that each country pays for the cost of infrastructure located in its territory.

³http://www.acer.europa.eu/Official_documents/Acts_of_the_Agency/Recommendations/ACER%20Recommendation%2007-2013.pdf

⁴ Initially, only countries incurring at least 10% of the total net benefits should contribute towards the compensation. This 10% threshold (and the whole ACER Recommendation) is not mandatory for NRAs; a lower significance threshold may be considered, in particular if the net benefits above the threshold of the contributing countries are not sufficient to cover the compensation required or if the amount of compensation places an unreasonable burden on a contributing country.

Table 1 : comparison of cross-border cost allocation for PCIs, as recommended by ACER, and the NSCOGI cost allocation study

	CBCA	NSCOGI
Scope	PCIs	Hybrid projects
Application criterion	CBA < 0 for at least one hosting member state/TSO	CBA Hybrid solution > CBA radial solution
Parties involved ⁵	TSOs in hosting member state TSOs in other member state	TSOs in hosting country ORG
Financial flows	TSO in other member state → hosting TSO	ORG ↔ hosting TSO

To conclude, the scope and objective of ACER’s CBCA and NSCOGI’s cost allocation work are different and complementary. However, we have followed ACER’s work closely to make sure that our proposal for cost allocation is compatible with ACER’s CBCA methodology.

⁵ It should be noted that in this case, the “TSO” is considered as representing the interests of grid users (producers and consumers) in its own country.

2. MODEL AND FRAMEWORK

2.1 Model

This study is based on a basic model for illustrative purposes: a hybrid asset linking two bidding zones in two different countries A and B and an Offshore Renewable Generator (ORG). This infrastructure is used both for transporting cross-border flows (like a conventional interconnector between two bidding zones) and renewable production.

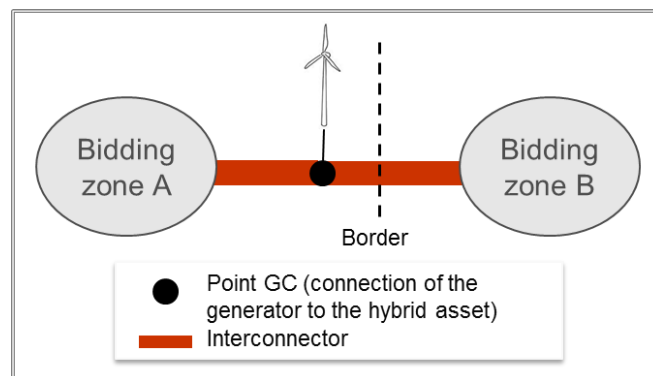


Figure 2 - Model of hybrid asset

Throughout this paper, this type of asset - connecting an offshore renewable generator to an interconnector - will either be referred as a T-in connection or a hybrid asset.

Other connection concepts could also be used, such as:

- **Wind farm hub:** wind farms close to one another are connected together, forming a hub with only one transmission line to shore.
- **Hub-to-hub connection:** wind farm hubs connected to several countries are connected together, forming a cross border transmission line.

These concepts are not studied in detail in the present paper.

2.2 Market arrangements and asset classification

Cost allocation depends on access to assets and the use of infrastructures. Today, ORGs pay for (or contribute to) individual radial connections to which they have exclusive access, thus priority. An ORG may be reluctant to pay for a grid asset if it does not have priority access to it and thus sometimes may not be able to use it. In the case of a hybrid asset, the interaction of two principles needs to be clarified:

- **Priority Access and Priority Dispatch for RES** as per the Renewables Directive.
- **Congestion Management Guidelines and EU Target Model** as per the Third Energy Package legislation (in particular Regulation 714/2009, Framework Guidelines and Network Codes).

The first principle gives priority access for renewable energy sources. The second establishes that electricity should flow according to price differentials through the use of market-based capacity auctions, and that cross-border flows should not be reduced in order to solve a country’s internal congestion. In the case of a hybrid asset, used both for transporting offshore renewable generation and cross-border trade, it is important to first define who has priority of access when congestions occur (i.e. when demand for flows exceed the capacity of the asset).

These issues were studied in a previous NSCOGI discussion paper: *Possible Market Arrangements for Integrated Offshore Networks*⁶. WG2 used “Virtual Case Studies” to consider a number of options. Four different options were investigated:

- **Option 1:** ORG in fixed bidding zone with virtual case 1 (VC1).
- **Option 2:** ORG in a floating bidding zone.
- **Option 3:** ORG in its own bidding zone.
- **Option 4:** ORG in fixed bidding zone with virtual case 2 (VC2).

In both options 1 and 4, the ORG bids in a fixed bidding zone (its national bidding zone): they have the same effect on the market, and in case of congestion, may apply the same solutions. They only differ in the way the assets are classified.

In this paper, only the day-ahead timeframe was considered. The conclusions are subject to a number of hypotheses, in particular that interconnection capacity is allocated through implicit auctions via a single price coupling algorithm⁷. Criteria such as social welfare, stability of and compatibility with the legal framework and the incentive value were taken into account in the analysis in general qualitative terms.

The paper concluded that an ORG connected to several bidding zones should only be allowed to bid into one of them. Options 1 and 4 (ORG always bidding into a fixed bidding zone) seemed to represent the best solution for market arrangements.

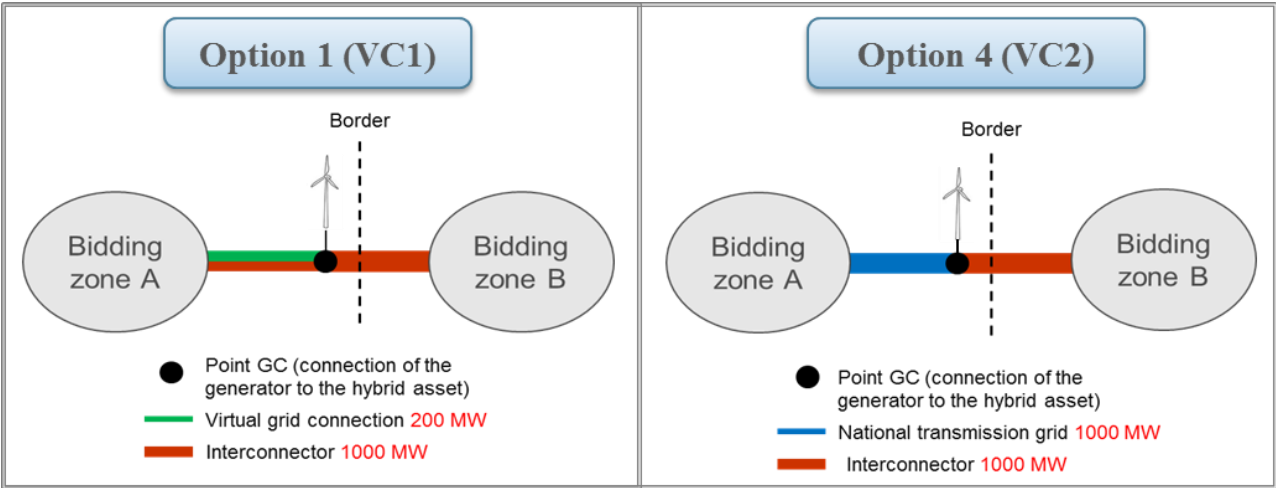


Figure 3 - Market arrangement and asset classifications

⁶ <http://www.benelux.int/NSCOGI/>

⁷ Single price coupling has been applied between all NSCOGI countries except Ireland since 5 February 2014.

This paper will focus on this market arrangement with the two asset classifications: VC1 and VC2.

2.2.1 Asset classification

In **VC1**, the portion of the interconnector between the ORG and bidding zone A is classified partly as a “virtual” grid connection, partly as an interconnector. The capacity of the “virtual” grid connection equals the forecast generation of the ORG at each hour. If the renewable generator is not producing, the entire connection is an interconnector.

In **VC2**, the link from the country of bidding zone A to the ORG is defined as part of the national transmission system. The connection between the ORG and the country of bidding zone B is classified as an interconnector.

2.2.2 Congestion management

With this market arrangement – ORG bidding in its national bidding zone - issues may arise when the prevailing flow is from bidding zone B to bidding zone A. In this case, there is a conflict between cross-border flows and transmission of the ORG production to bidding zone A, as both need access to a congested asset (cf. Figure 4).

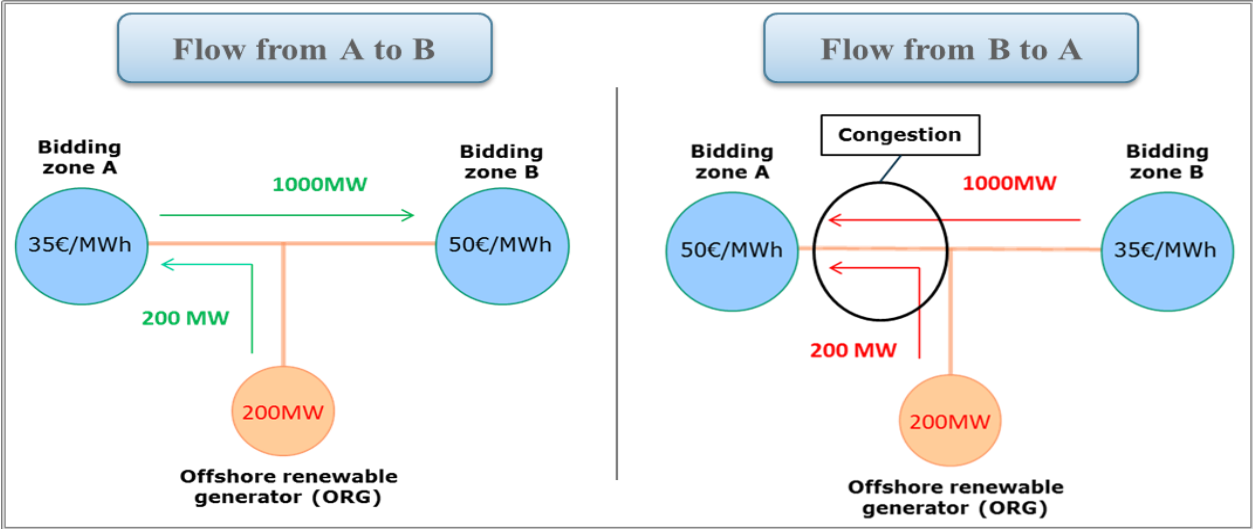


Figure 4 - Congestion management

NSCOGI concluded that it would be preferable to give priority to the ORG over cross-border flows even when this leads to decreased day-ahead interconnection capacities. In this paper, we assume that the ORG production will always be sold in its national bidding zone and prioritized in the case of congestion.

2.3 Current framework: connection regimes and financing

Responsibilities for the financing, construction and operation of assets vary across the NSCOGI countries. However, in most countries, TSOs have a significant role. This section analyses the current

role of different stakeholders either for cross-border infrastructure or offshore generators' connections in NSCOGI countries.

2.3.1 Interconnection without renewable production connected

In almost all NSCOGI countries, the national TSO is in charge of financing, building and operating regulated interconnections (both on- and offshore). Financing of the infrastructure and reinforcement of the onshore grid are then socialized through the grid access tariff. Reinforcement costs arise from upgrades to the existing grid caused by the integration of new infrastructure. Reinforcement costs for cross-border infrastructures are generally not shared between TSOs; each TSO pays for the reinforcement of its own grid.

Interconnections in the UK⁸ or exempted interconnections are financed and developed by private investors.

Regulated interconnectors are generally planned and built on a bilateral basis between national TSOs of connected countries (except in the UK). Direct costs (interconnector's costs) and benefits (congestion revenue) are usually split 50:50. Otherwise, each operator finances, builds and operates the section of the infrastructure located on its own territorial waters and benefits are allocated proportionally to their costs.

2.3.2 Offshore renewable generation with radial grid connection

Currently, renewable offshore generators are built in territorial waters and individually connected back to shore. At present, under national connection regimes the competent authority (generally a TSO) is obliged to connect any offshore renewable generators installed on its territory to the transmission grid. However, legal uncertainties remain concerning the connection of ORGs to the grid of another state, or to an interconnector. Development of a meshed grid may require this principle to be more flexible. In particular, connection regimes might need to allow connection of an ORG located on another state's territory when it is more cost efficient. But this would require further analysis and possibly changes to legislation.

The responsibilities for building and financing the connection of offshore wind farms to the grid vary throughout NSCOGI countries. In almost all the NSCOGI countries, the wind farm developer (partially⁹) finances its radial connection to its national transmission grid. After its completion, the connecting cable will either become a component of the national transmission grid operated by the TSO or a component of the generation installation (Belgium). An exception to this is the specific role of the TSO in Denmark and Germany; the radial connection is built, financed and operated by the TSO, and the costs are socialized to all users via the transmission charge.

⁸ A regulated 'cap and floor' regime has recently been developed.

⁹ In Belgium, the wind farm's connection is subsidised with a maximum of €25M per Offshore generator.

In the UK, the connection of ORGs to the onshore transmission grid is delivered by a third party, an Offshore Transmission Owner (OFTO). OFTO licences are awarded through a competitive tender process. Transmission lines to connect offshore generators can either be built by licensed OFTOs or by generator developers. In both cases, the connection is financed by the generator and operated by the OFTO.

In all cases, any reinforcement of the grid is managed by the TSO and the cost socialized through the tariff.

2.4 Cost issues raised by a hybrid asset

Development of hybrid solutions has just started. Some pilot projects are currently under consideration that could be developed in the North Seas. For example, the COBRA cable - interconnection between the Netherlands and Denmark with possible integration of an offshore wind farm - should be commissioned in 2016. The Kriegers Flak project aims at creating a combined grid solution connecting wind farms in the Kriegers Flak area to the German and Danish national grids. Its construction has already started, with the two German wind farms, Baltic 1 (48MW) and Baltic 2 (288MW), operational since 2011 and 2013, and should be achieved by 2018. The FAB project (France Alderney Britain) – an interconnector linking France and Britain and tidal generation of Alderney - is currently under consideration.

Currently, there is no specific legal framework and regulatory regime for such assets. When an ORG is connected to an interconnector, forming a hybrid asset, the use of the interconnector is altered which raises cost issues.

If the ORG is prioritised over cross-border flows in the direction of imports, as defined by the previous NSCOGI paper on Market Arrangements, its renewable production is always sold in its national bidding zone; it will receive the same benefits as with a radial connection to shore. Without an appropriate allocation, its costs may be lower than a radial connection, for instance if it only pays incremental costs, i.e. the T-in connection to the interconnector (shorter cable than connection to shore).

Conversely, the interconnector's benefits (congestion rent and social surplus) may be reduced by the ORG's connection limiting the capacity available for cross-border flows. Since the ORG gets priority of access, cross-border flows will possibly be constrained when the ORG is producing and the direction of the prevailing flows is the same as that of the renewable generation. In compensation, the country where the ORG is located (bidding zone A), receives all the benefits in terms of contribution to renewable targets and additional generating capacity. Its national TSO might also save reinforcement costs on its onshore grid, compared to the case where the ORG is radially connected to shore. This may increase the surplus of country A and limit, or in some cases compensate for, the loss of surplus resulting from the T-in connection of the ORG.

The other interconnected country and TSO receive no additional benefits from the ORG's connection to compensate for its potential loss (reduced congestion rent and surplus). Without an appropriate

allocation, it might not benefit from the cost savings generated by the hybrid infrastructure, which would be entirely caught by the ORG (and potentially by TSO A).

Therefore, with a conventional cost allocation, the other country has no immediate interest in accepting the ORG’s connection and developing a hybrid infrastructure, even though it represents the most beneficial project from a global perspective. An efficient cost allocation method is required to send the right signal to all stakeholders and incentivize the development of a hybrid asset when and where it is more efficient than individual development. In particular, the ORG could pay for its priority access and its used/reserved capacity on the interconnector. In this way, the ORG contributes to the financing of the common part of the hybrid asset.

This paper investigates various cost allocation methods and recommends how these issues may be handled. It also analyses the level of the ORG contribution so as to guarantee that the hybrid asset is beneficial for all stakeholders.

2.5 Impact of order of development

A hybrid asset can be developed in different ways; and the order of development might impact the cost allocation methods. For example, the order of development raises potential problems of free-riding and first mover disadvantage. Without appropriate cost allocation, those arriving late would possibly only pay for incremental costs while incumbent parties have already paid for common infrastructure. Depending on the order in which projects are developed, the cost allocated to stakeholders may be different. In the case of a T-in interconnection, three scenarios can be assessed:

- a) A radially connected ORG (or hub) is converted into an interconnector (to connect to another country).
- b) An ORG (or offshore hub) connects to an existing interconnector.
- c) Both the interconnector and the ORG are built or planned at the same time.

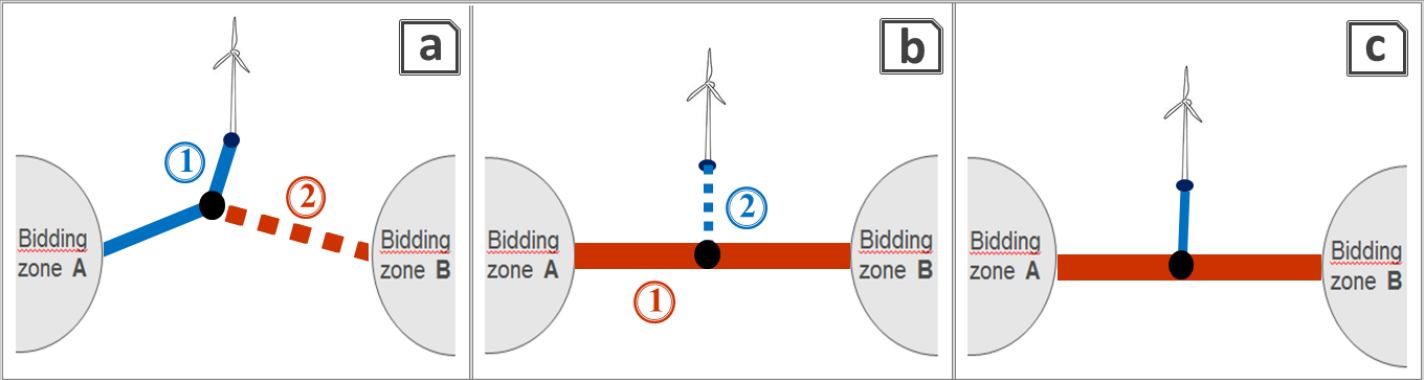


Figure 5 - Possible order of development for a hybrid asset

Different orders of development of a hybrid infrastructure may raise different cost issues.

- Scenario Ⓐ: A radially connected ORG converted into an interconnector

This scenario does not seem to raise particular cost issues as asset classification and access are well defined and are not likely to be contested. The ORG is treated exactly as any other ORG radially connected to shore. Besides, in this scenario, TSOs benefit from lower investment costs (shorter cables), which compensate for the reduction of benefits caused by the presence of the ORG. TSOs will undertake the hybrid project only when their cost benefit analyses are better than the same shore-to-shore interconnector with no renewable production connected; i.e. when cost savings from using the existing cable outweigh the possible limitation of benefits when the ORG is generating.

If the access conditions of the ORG are not modified when it becomes a hybrid asset (the same conditions as a radially connected ORG whatever the timeframe), no transfer between TSOs and the ORG seems to be needed. The sensitive issue is who will be responsible for financing the reinforcement of the cable between TSO A's onshore grid and the ORG's connection. This cost could either be shared between the TSOs or be entirely borne by TSO A, when the cable is classified as its offshore transmission grid (VC2).

This scenario is similar to the current development of the onshore grid. Onshore, the cable connecting a generator to the transmission grid becomes part of the national grid, operated by the national TSO. When using this new part of the onshore grid, the TSO does not pay the generator. If the ORG is not affected by the development of a new interconnector, it may not be considered necessary to reallocate the costs between the three stakeholders, since this principle is functioning onshore and is generally accepted.

- **Scenario ⑥: An ORG (or offshore hub) connecting to an existing interconnector**

In this scenario, a conventional interconnector is first built on a bilateral basis between national TSOs. When an ORG connects to the existing interconnector, this partially changes the role of the interconnector and modifies its business plan, i.e. the congestion rent and generated social surplus.

This scenario also raises free-rider issues. Without an appropriate allocation – i.e. if the ORG only pays incremental costs - the ORG could be tempted to connect to the existing interconnector even when it does not represent the optimal solution. For this reason, interconnector owners should be allowed to refuse a T-in connection and require a radial connection to shore when a hybrid asset is less efficient than individual development, in particular where a cost allocation method with perfect incentive value cannot be found.

Besides, the status of the interconnector would change: the part of the interconnector between the T-in connection point and bidding zone A would become either a virtual grid connection (VC1) or the national transmission grid of country A (VC2). This might raise legal issues – which are not studied in this paper.

It should also be noted that, even though connecting an ORG to an interconnector after it is operational is technically possible, it might be expensive and might lead to additional loss of interconnector revenues due to the downtime needed to install and test T-connections.

- Scenario ©: Both Interconnector and ORG built/planned at the same time

This scenario raises issues similar to scenario ⑥. However, cost allocation is decided ex-ante, during the planning stage, so as to guarantee higher net benefits and profitability for every stakeholder. The hybrid asset will be planned only if the cost allocation satisfies every stakeholder. As all assets are built at the same time, no change of status is required.

The order of development also affects the risk borne by different stakeholders. In scenario ⑥, since the ORG is built first, it will bear similar risks to any other radially connected ORG. As for scenario ⑦, the ORG's risks are reduced as the interconnector is already functioning: the ORG will be able to sell its production immediately and will not need to wait for the TSO to reinforce the grid. When the entire project is planned at the same time (scenario ©), the risk of stakeholders dropping out or the project being delayed are greater. The risk borne by the ORG is higher, as if the interconnector construction is delayed, the ORG will not be able to sell its production as soon as it is commissioned. Similarly, the risks for the TSOs are increased. If the ORG withdraws from the project, the TSOs might bear stranded costs (e.g. the technology used or the optimal capacity may have been different for the project without the ORG connected).

More generally, the development of such hybrid assets implies higher risks than conventional assets: several stakeholders, innovative technology, risk of withdrawal and delay.

In this paper, we will focus on scenario ⑥ and © as scenario ⑦ does not seem to raise the same costs issues.

3. ASSUMPTIONS AND CRITERIA

3.1 Assumptions

The conclusions of the present paper are subject to the following assumptions.

- **Regulated interconnector.**

This paper focuses on regulated interconnectors (merchant interconnectors are not considered).

- **An offshore renewable generator always bids in its national bidding zone and its production is prioritized over cross-border flows (c.f. 2.2).**

This assumption derives from the conclusion of the first NSCOGI paper on Market Arrangements. As a consequence, this study is based on the assumptions used in that paper i.e.:

- **Positive market prices.**
- Interconnection capacity is allocated through implicit auctions via a single price coupling algorithm.
- **ORG sensitive to market price**

The first market arrangements paper assumed that even though some support schemes are still needed the ORG is sensitive to the market price, i.e. that it is an active market player. In this paper, this last assumption has been slightly modified. For simplicity we assume that support schemes are harmonized in the North Seas countries, even though this is not currently the case, and the ORG is sensitive to market price.

- **Hybrid asset is more profitable than individual development.**

In the study we assume that a hybrid asset is the most profitable project; the global cost-benefit analysis (CBA) is better than the CBA of the ORG radially connected to shore (ORG radial) independently from the interconnector (IC). This means that the difference between the costs and benefits (in terms of generated social surplus and congestion rent) is higher for a hybrid asset. This implies higher profitability and net benefit of the hybrid project. Otherwise, a hybrid asset should not be considered by project promoters and cost allocation is no longer an issue.

$$\begin{aligned} - & B_{\text{hybrid asset}} - c_{\text{hybrid asset}} \geq (B_{\text{ORG radial}} - c_{\text{ORG radial}}) + (B_{\text{IC}} - c_{\text{IC}}) \\ - & \frac{B_{\text{hybrid asset}}}{c_{\text{hybrid asset}}} \geq \frac{B_{\text{ORG radial}} + B_{\text{IC}}}{c_{\text{ORG radial}} + c_{\text{IC}}} \end{aligned}$$

Whether connecting an offshore renewable generator to an interconnector is beneficial depends on various factors: distance of the wind farm to shore, distance from the interconnector, wind farm capacity, price difference between connected countries...

Generally, a T-in connection would be preferable when costs savings due to the reduced costs of infrastructure will outweigh the loss of benefits from trade constraints. Cost savings mainly result from a reduction of the ORG's connection length: the cable length to connect the ORG to the T-in joint is shorter than the cable to connect the ORG to shore.

When deciding on the final design of the assets to be constructed, it should be kept in mind that the assets will be functioning for over 30 years; it should be economically and socially relevant and useful for the entire time span.

- **Combined assets lead to infrastructure cost reduction.**

The costs of a hybrid project are lower than the costs of two distinct projects:

$$- C_{hybrid\ asset} \leq C_{ORG\ radial} + C_{IC}$$

- **The congestion rent and surplus generated by a hybrid asset are lower than those of two separate projects.**

In the present paper, we assume that the connection of the ORG triggers a loss of congestion rent and surplus compared to a radial solution plus an interconnector of the same capacity. We assume that the global benefit of an interconnector increases as trading volumes increase (this seems reasonable as long as more trading capacity is needed in Europe: each new interconnector increases European welfare)¹⁰. More specifically, we assume that when an ORG connects to an interconnector, the potential reduction of the volume traded outweighs the possible increase of the spread (price difference between interconnected countries) and reduces congestion rent. Then, we can infer that the benefits of a hybrid asset are lower than the benefits of two distinct projects:

$$- B_{hybrid\ asset} \leq B_{ORG\ radial} + B_{IC}$$

It should, however, be noted that the loss of surplus of TSO A may be partially or entirely compensated: when the ORG connects to the interconnector, TSO A may save reinforcement costs compared to a radial connection, thereby increasing its surplus.

- **Operation costs are negligible.** Only the allocation of investment costs is discussed in this study.
- **Reinforcement costs** of the countries involved should be integrated into the cost allocation methods. However, this study does not deal with the reinforcement costs of or any impact on a third country (which might be involved in the interconnection project or the offshore renewable generation connection).

¹⁰ This assumption seems reasonable. However, trading volumes are not the only way to value an interconnection, and might not be truly representative of the value of some interconnectors. Indeed, an interconnector may have much added value when used in emergency or exceptional situations.

3.2 Criteria

An ideal cost allocation method should fulfill the following criteria. The criteria are not in order of importance and some can be more relevant than others.

1. **Incentive value (net benefit)** – cost allocation methods should incentivize every stakeholder to prefer the most efficient project (a combined project or a radial connection of the ORG to shore) from a global perspective. A method should guarantee a higher net benefit for all stakeholders compared to an individual project.
2. **Cost-incentive:** a method should guarantee acceptable costs for all stakeholders and especially be **compliant with the individual rationality principle:** no one pays more than its stand-alone costs¹¹.
3. **No unfair discrimination:** an ORG connected to a hybrid asset should be treated in a similar way to any other renewable generator and should not bear higher costs.
4. **Horizontal/vertical consistency**¹²: Two stakeholders imposing similar infrastructure costs (or similar cost savings) should be allocated a similar contribution. An individual who imposes larger costs should be charged more than one imposing less.
5. **Compatibility** with current European and national legal frameworks as far as possible (whenever such frameworks exist) – or at least as close as possible.
Cost allocation methods should also be in line with the CBCA methods currently being developed by ACER.
6. **Reinforcement cost allocation:** a desirable method should allow for allocation of reinforcement costs between TSOs. In all NSCOGI countries, ORGs are never charged for necessary reinforcement costs.
7. **Complexity and feasibility of the method:** the method should be straightforward to implement. A method using parameters and data that are easy to define and determine would be preferred. The number of money transfers between stakeholders should also be taken into account.
8. **Adaptability:** a good method would be applicable or extendable to more complicated projects (three-leg interconnectors, hub to hub interconnection...).
9. **Allocation between stakeholders:** An ideal method should be able to allocate costs between all stakeholders. It should allow for the costs paid by each TSO to be differentiated, rather than considering the two TSOs involved as a whole, as opposed to the ORG.

Throughout this paper, these criteria will be used to evaluate and compare different cost allocation methods.

¹¹Stand-alone costs: costs that would be supported by an actor if it decides to develop a project alone (i.e. a radial connection or a conventional interconnector).

¹² Milligan, M., Ela, E., Hodge, B.M., Kirby, B., Lew, D., Clark, C., DeCesaro, J., Lynn, K., (2011). Cost-causation and integration cost analysis for variable generation, National Renewable Energy Laboratory (NREL), U.S. Department of Energy, June 2011, p.16-18. <http://www.nrel.gov/docs/fy11osti/51860.pdf>

4. COST ALLOCATION METHODS FOR INFRASTRUCTURE COSTS

This section focuses on different cost allocation methods to share costs of a hybrid infrastructure. Each method is applied to our basic model of T-in interconnection and illustrated through a virtual example of a T-in interconnection.

4.1 Notation and example

4.1.1 Notation

The same notation is used throughout this paper.

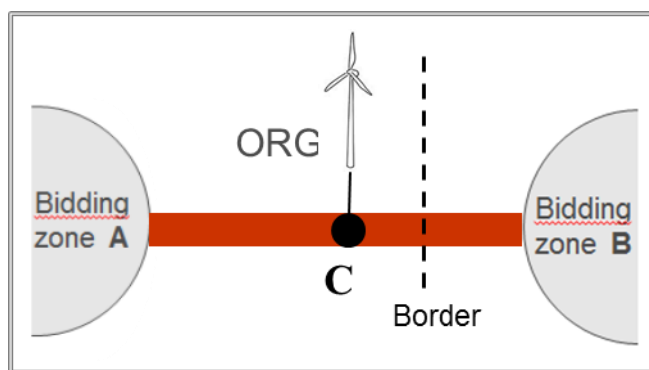


Figure 6 - Hybrid asset model

- **Hybrid project:**
 - c_{hybrid} : Total hybrid asset's cost (T-in connection of ORG plus interconnection costs). Reinforcement costs are not included.
 - x_{ORG}, x_A, x_B : Costs respectively allocated to the ORG, TSO A and TSO B.
 - $x_{IC} = x_A + x_B$
 - $x_{ORG} + x_A + x_B = c_{hybrid}$
- **Distinct projects:**
 - $c_{ORGradial}$: Costs for a radial connection of the renewable generator to shore.
 - c_A, c_B : Interconnector's cost allocated to TSO A and B (reinforcement costs not included).
 - $c_{IC} = c_A + c_B$: Interconnector cost.
 - $c_{reinftA}, c_{reinftB}$: Reinforcement costs of A and B's onshore grids as a result of the interconnector.
 - $c_{reinftIC} = c_{reinftA} + c_{reinftB}$: Total reinforcement costs for the interconnector.

4.1.2 Example of T-in interconnection

The example used throughout this study is a virtual T-in interconnection between a 1400MW interconnector between Great Britain and Norway and Dogger Bank A (1000MW offshore wind

farm). The data come from an OffshoreGrid¹³ study. This T-in interconnection is **hypothetical** and has never been considered even though both projects are currently being studied. The Britain-Norway interconnector project is part of the 2012 TYNDP and is planned to be commissioned in 2020. The Dogger Bank A connection is planned for 2016-2017.

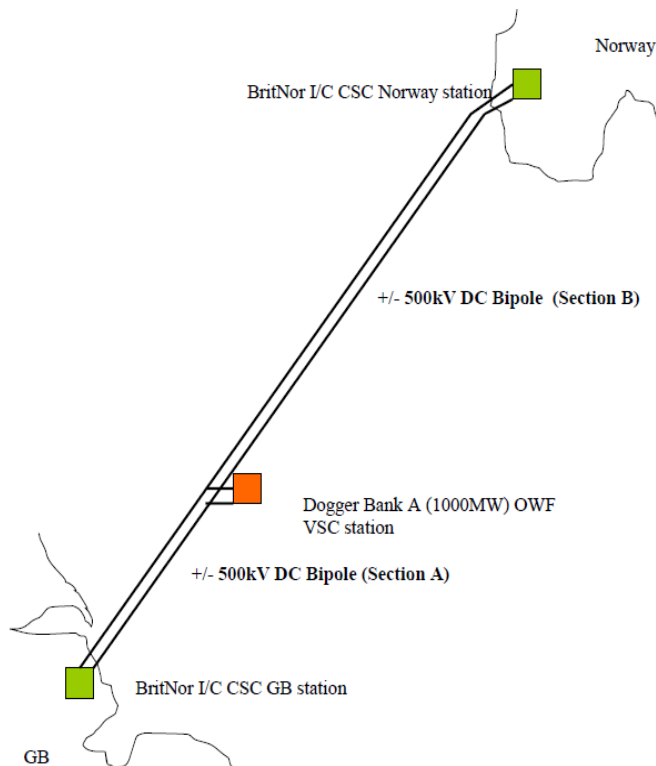


Figure 7 - Virtual T-in interconnection
Source: OffshoreGrid, October 2011¹

Infrastructure costs (m€):

- Distinct projects:

- Radial connection of the ORG : **€587**
- Interconnector costs: **€1446**

- Hybrid project: **€1743**

- T-in connection of the ORG: **€296**
- Interconnection costs : **€1447**

Cost allocation between GB-Norway:

- 50/50 or;
- Each TSO/OFTO pays the costs of the interconnector in its territorial waters – benefits are proportional to costs. We assume that this results in a **60-40 (GB-NO)** distribution.

Assumptions :

- Distance Dogger Bank – GB: $\frac{1}{4}$ of interconnector length.
- Costs are linear (e.g. cost of asset part between GB and Dogger Bank is equal to $\frac{1}{4}$ of total interconnector cost).

This example will be used throughout the paper for illustrative purposes. It should be noted that the results obtained using this example would be different if another example were used. General conclusions about the efficiency of different methods therefore cannot be drawn from this example.

¹³ OffshoreGrid, 2010. McGarley, P., Cowdroy, S., D5.1 - European OffshoreGrid Site Requirements and Connection Report. Senergy Econnect Project, July 2010, p.33-42.
<http://www.offshoregrid.eu/index.php/results>

4.2 Proportional to stand-alone costs

4.2.1 Principle

This solution is a general cost allocation method. It applies when a common project is more beneficial than two separate projects. In that case, a simple way to allocate costs of a common project is to distribute the total cost between stakeholders proportionally to the cost they would have paid if they had decided to set up the project alone.

We assume that two countries A and B have both identified a national project to improve their system efficiency, respectively at cost (A) and cost (B). However, a common transnational project would address their problem more cost efficiently. Thus, they decide to develop this common infrastructure at cost (T) lower than the sum of both projects' costs.

Cost allocated to country A is defined by:

$$x_A = \frac{\text{cost}(A)}{\text{cost}(A)+\text{cost}(B)} * \text{cost (T)}$$

NB: Costs borne by an actor that has decided to start its project alone, instead of as a common infrastructure are called **stand-alone costs**.

This method has been suggested by the Northeast Independent System Operators (ISO) and Regional Transmission Organizations (RTO) of the United States to solve interregional transmission cost allocation issues¹⁴.

4.2.2 Properties

- A larger share of the common infrastructure is allocated to actors with higher stand-alone costs.
- Rationality principle: all stakeholders are charged lower costs for the common project than their stand-alone costs, as long as the common project is less expensive than two distinct projects.
- Symmetry: two actors with similar stand-alone costs would pay the same amount for the common infrastructure.

4.2.3 Application

In the NSCOGI case study, three stakeholders are involved, the ORG and TSOs from both countries. The common project represents the hybrid asset, replacing the radial connection of the ORG to shore and the conventional interconnector.

Cost allocated to the ORG with this method is:

$$x_{ORG} = \frac{c_{ORG\ radial}}{c_{ORG\ radial}+c_A+c_B} c_{hybrid}$$

¹⁴ Buechler, J.P., (2013). FERC Order 1000 : Transmission Planning and Cost allocation Interregional Issues Update, ISO New England, NYISO, PJM, January 2013.

Cost allocated to TSOs:

$$x_A = \frac{c_A}{c_{ORGradial} + c_A + c_B} c_{hybrid} \quad \text{and} \quad x_B = \frac{c_B}{c_{ORGradial} + c_A + c_B} c_{hybrid}$$

Example:

Virtual T-in connection between Britain-Norway interconnector and Dogger Bank A (c.f. paragraph 4.1.2):

- Radial connection of the ORG : €587 Million
- Interconnector cost: €1446 Million with a 60:40 or 50:50 distribution between A and B.
- Hybrid project cost €1743 Million

Then cost allocated to the **ORG** = $587/(587+1446)*1743 = \mathbf{€503 \text{ Million}}$

Cost allocated to **A** = $0.6*1446/(587+1446)*1743 = \mathbf{€744 \text{ Million}}$ (with a 60:40 distribution)

Cost allocated to **B** = $0.4*1446/(587+1446)*1743 = \mathbf{€496 \text{ Million}}$

When costs and benefits are equally shared between TSOs (50:50 distribution), they pay €620 Million each.

4.2.3.1 Reinforcement costs

This method offers various possibilities to deal with reinforcement costs. Reinforcement costs could either be allocated between the three stakeholders, exclusively between TSOs or not shared at all. This section will investigate the three different ways of allocating reinforcement costs.

- **Allocation between all stakeholders**

In this case, reinforcement costs should be integrated into the investment cost (i.e. stand-alone costs paid by TSOs for building the interconnector- c_A , c_B - and total hybrid asset's costs c_{hybrid}).

As this method allocates costs proportionally to stand-alone costs, a larger share of reinforcement costs would be allocated to the TSO with higher stand-alone costs – and a smaller part will be distributed to other stakeholders.

This method guarantees lower costs for every stakeholder compared to stand-alone costs as long as the total hybrid cost is lower than the costs of distinct projects. Including reinforcement costs will not alter this property: each stakeholder would still bear lower costs than its stand-alone costs.

- **Allocation between TSOs**

Reinforcement costs could be shared only between the TSOs (with the ORG not contributing) by using this method in two steps. First, costs are allocated between the ORG and the interconnector (without reinforcement costs). Then, the remaining interconnector costs plus reinforcement costs are shared between the TSOs.

$$x_{IC} = \frac{c_{IC}}{c_{ORG\ radial} + c_{IC}} c_{hybrid} \quad \text{then} \quad x_A = \frac{c_A + c_{reinft A}}{c_{IC} + c_{reinft A} + c_{reinft B}} (x_{IC} + c_{reinft IC})$$

Cost distribution between TSOs (second step of this method) could also be carried out using other approaches, taking into account benefits (e.g. cost shared proportionally to each TSO's benefits, c.f. 4.6).

- **Territorial approach**

Finally, reinforcement costs could be entirely paid by the TSO of the country where they are required. In this case, reinforcement costs should not be integrated into investment costs. Each TSO pays the reinforcement costs on its own territory. This is currently the case in most interconnection projects.

The example below illustrates these different solutions, when the connection of hybrid asset generates a €100 million reinforcement cost in zone A and no reinforcement cost in zone B (with a 50:50 distribution between A and B).

Table 2- Example: Different ways to allocate reinforcement costs with proportional method

		ORG	A	B
Reinforcement costs separately paid by TSOs		503	720	620
Reinforcement costs allocated	between TSOs ¹⁵	503	713	627
	between all stakeholders	507	711	625

In the first case, costs are not allocated between stakeholders: TSO A pays its entire reinforcement costs. In the second case, costs are shared only between TSOs, TSO A pays 93M€ out of 100M€ for its reinforcement, TSO B contributes to the required reinforcement of grid A by paying 7M€; this represents a 1% increase of its costs.

In the 3rd case, reinforcement costs of grid A are shared between all stakeholders, this slightly increases the ORG and TSO B's costs compared to case 1. In all cases, TSO A supports the greatest part of the reinforcement costs and each stakeholder pays less than with separate projects.

4.2.3.2 Asset classification

Asset classification does not affect this method as it is based on stand-alone costs; Costs to build two separate assets - the interconnector alone and the radial connection of the ORG - are independent of the hybrid asset's cost and classification. Then the costs allocated to the ORG and to the interconnector would be the same with both asset classifications (VC1 and VC2). However, the distribution between TSOs might be different according to the asset classification. In VC2 where a shorter section of the hybrid asset is defined as an interconnector, the stand-alone costs of A might

¹⁵ $x_{IC} = 1446 / (1446 + 587) * 1743 = 1240$, $x_A = (723 + 100) / (1446 + 100) * (1240 + 100) = 713$

be higher than with VC1; equal to the costs of its national offshore transmission grid plus a share of the interconnector cost.

4.2.3.3 Assessment against predefined criteria

1. **Incentive value (Net Benefit):** This method does not guarantee higher net benefits for TSOs compared to an interconnector without an ORG.
2. **Cost-incentive:** It guarantees each stakeholder a lower cost than the stand-alone cost when the hybrid project is more cost-efficient.
3. **No unfair discrimination:** The ORG would bear lower or equal costs compared to a radial connection.
4. **Horizontal/vertical consistency:** Two actors with similar stand-alone costs would be allocated the same share of the hybrid infrastructure. If one actor has higher stand-alone costs, it would pay a greater share of the hybrid asset
5. **Compatibility with current legal framework:** This method seems to be compatible with the current framework even though it is quite different from the present allocation for an ORG.
6. **Complexity:** This method is straightforward to implement. Stand-alone costs are rather easy to determine and would normally be assessed in order to decide whether to choose a hybrid or two separate infrastructures.
7. **Adaptability:** This method could be applied to any project as long as the stand-alone cost may be assessed.
8. **Reinforcement:** This method allows for the allocation of reinforcement costs. They can be shared between all stakeholders or just between TSOs. In the second case, the ORG is not affected by the reinforcement needs and will not finance them.
9. **Allocation between stakeholders:** This method allows for distribution of the costs between all stakeholders; especially it differentiates the costs between TSOs A and B.

4.3 Louderback's method

4.3.1 Principle

Louderback's method is a proportional method suggested by an accounting professor, Louderback, in 1976. Proportional methods consist of defining a direct contribution by every actor i and allocating residual costs of the global project - once all contributions have been subtracted - between all stakeholder, proportionally to one variable.

Louderback's method distinguishes different costs:

- ca_i : direct or attributable costs (costs that can be directly allocated to stakeholder i)
- cc : common costs
- c_i : stand-alone costs : costs that would be supported by an actor if it decides not to collaborate.

In this method, each stakeholder pays his attributable costs (direct contribution). Common costs are shared proportionally to the difference between stand-alone costs and attributable costs ($c_i - ca_i$). This difference is also called the Alternate Cost Avoided¹⁶.

Louderback assumed that $c_i \geq ca_i$, attributable costs are always lower than or equal to stand-alone costs.

Louderback distribution for agent i is given by:

$$x_i = ca_i + \frac{c_i - ca_i}{\sum_{j=1}^n (c_j - ca_j)} cc$$

The complexity of this method lies in defining attributable and common costs. The definition of these different costs for each stakeholder directly affects their share of total costs and could be contested.

This method is also known as the Alternate Cost Avoided Method (ACA).

A slightly modified method based on the same principles, the Separable Cost Remaining Benefits (SCRB)¹⁷, has been widely used by civil engineers for water resources issues and is still in use.

4.3.2 Properties

- A larger share of common costs is allocated to stakeholders who benefit the most from implementing a combined infrastructure.
- No one has an interest in excluding another stakeholder from the project.
- Individual rationality principle: all stakeholders bear lower costs than their stand-alone costs if these two conditions are satisfied:
 - Attributable costs are lower than stand-alone costs for every stakeholder.
 - Total cost of a combined project is lower than the sum of stand-alone costs.

If one of these conditions is not satisfied, it is likely that the combined solution would not be chosen.

- Every actor pays higher costs than its attributable costs.

4.3.3 Application

In the example, stand-alone costs represent the cost of a radial connection of the ORG and the cost of the interconnector with no renewable production, allocated to each TSO. The contribution of the ORG and TSOs are given by:

¹⁶ Parrachino, I., Dinar, A., Patrone, F., Fioravante (2006). "Cooperative game theory and its application to natural, environmental and water resource issues", Basic Theory. World Bank Policy Research Working Paper.

¹⁷ In this method c_i is replaced by $\min[ci, bi]$ where b_i represents the benefit received by i from realizing a project by itself. When $b_i \geq c_i$, it corresponds to the ACA method.

$$x_{ORG} = ca_{ORG} + \left[\frac{c_{ORG\text{radial}} - ca_{ORG}}{c_{ORG\text{radial}} + c_{IC} - (ca_{ORG} + ca_{IC})} \right] * CC$$

$$x_{A/B} = ca_{A/B} + \left[\frac{c_{IC\ A/B} - ca_{A/B}}{c_{ORG\text{radial}} + c_{IC} - (ca_{ORG} + ca_{IC})} \right] * CC$$

4.3.3.1 Common and attributable costs definition

Different definitions of attributable and common costs could be assessed. Market arrangements and asset classification might affect the definition.

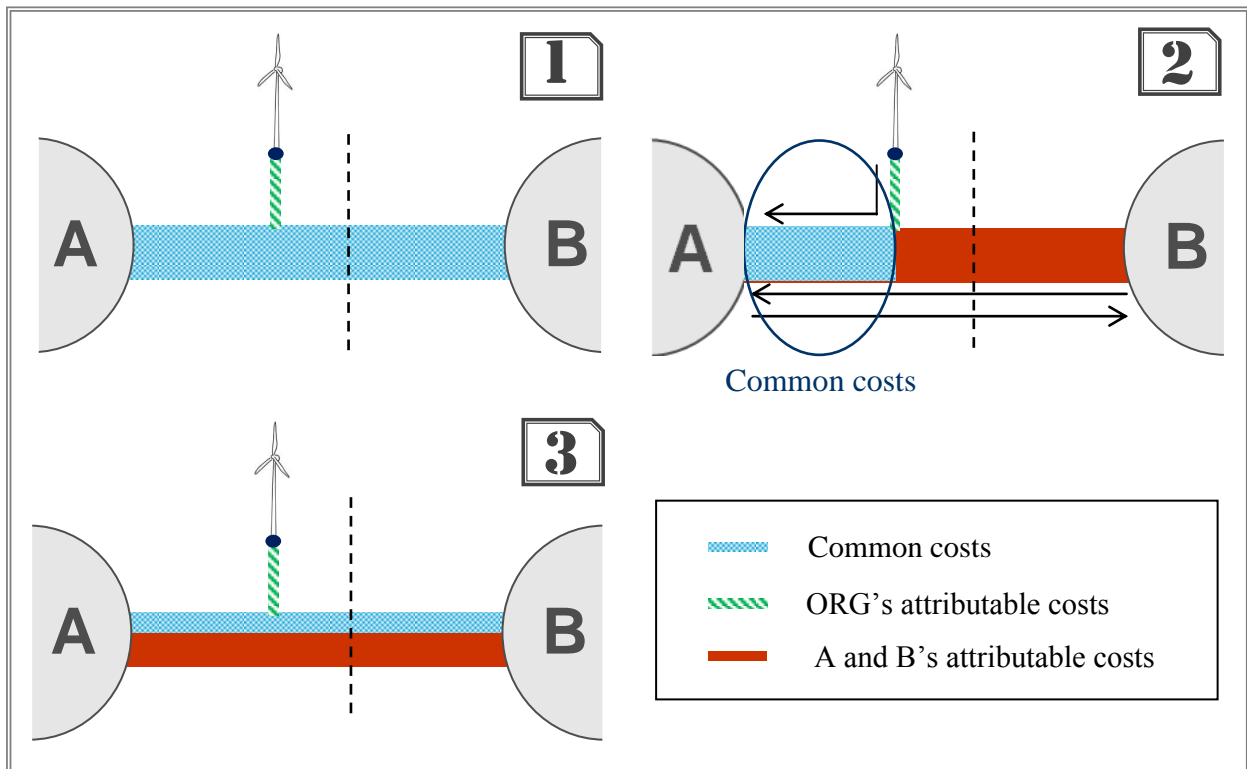


Figure 8- Possible costs definitions

In all cases, the ORG's attributable costs represent the cost of the T-in connection from the wind farm to the interconnector.

In case 1, TSOs have no attributable costs (except possibly the reinforcement cost of their onshore grid). Common costs cover the entire interconnector. This definition considers that the interconnector is a common asset as its functioning is modified by the presence of the ORG: it is used both for transporting cross-border flows and renewable production.

In case 2, the part of the asset classified as common infrastructure is reduced: it represents only the part of the interconnector between bidding zone A and the T-in connection of the ORG. This definition matches the commercial flow of the hybrid asset: this part of the interconnector is both used for transporting renewable production (which is always sold to bidding zone A) and for cross-

border flow between bidding zones A and B. The rest of the interconnector costs represent the TSOs' attributable costs.

Finally in case 3, the common infrastructure is proportional to the ORG's use of the interconnector over the entire interconnection. The part of the interconnector classified as common infrastructure could either depend on the maximum or average power of the ORG. This definition is based on physical flow: when the price in bidding zone A is lower than in bidding zone B, the flow goes from A to B. Even though the ORG always bids and receives the price of zone A, its production might be physically sent to B. Besides, the connection of the ORG might decrease the use and value of this section of the interconnector (lower or no available capacity for cross-border flows). Then, as the ORG affects this part of the interconnector too, sharing its costs might compensate TSOs for their lost benefits.

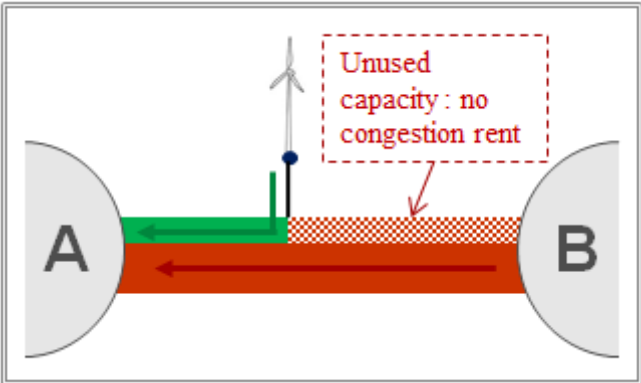


Figure 9 - Loss of congestion rent

Case 2 seems to better fit the market arrangements with both asset classifications (VC1 and VC2). The ORG may bear a higher cost in case 1 than in cases 2 and 3 – as common costs are higher. However, the ORG's costs are always lower than radial connection costs, whatever the definition of attributable and common costs, as far as the two previously mentioned conditions are satisfied (cf. 2.2).

Example:

Same example as in 4.1.2: T-in connection between Britain-Norway Interconnector and Dogger Bank A wind farm:

- Radial connection of the ORG : €587 Million
- Interconnector costs: €1446 Million with a 50:50 or a 60:40 distribution between A and B.
- Hybrid project worth €1743 Million
- Assume that the ORG is located at one-fourth of the interconnector (closer to A)

Table 3- Example: Cost allocation with Louderback's method

	ORG	IC	
	ORG total infrastructure costs	IC costs	A;B (50:50) / A;B (60:40)
Dinstinct projects	587	1446	723 / 868 / 578
Case 1	538	1205	602 / 723 / 482

Case 2	458	1285	643	771 / 514
Case 3 (Pnom)	523	1220	610	732 / 488

In this example, case 2 leads to the lowest contribution of the ORG. However, in this example, the ORG is close to shore A. When the renewable generator is further from shore A, the ORG's contribution in case 2 increases and gets closer to case 1 and 3 (e.g. ORG at 1/3 : 477 m€, ½: 503 m€). Besides, the ORG represents 71% of the total interconnector capacity: the ORG's contribution would be reduced with a lower share.

4.3.3.2 Reinforcement costs

If onshore grid reinforcement costs are included in attributable costs, each country pays their own reinforcement costs. However, Louderback's method could distribute reinforcement costs between stakeholders by including them in common costs.

In that case, a TSO which needs to reinforce its own grid will pay higher costs, but will not pay the whole cost: a share of its reinforcement cost will be allocated to the other TSO and to the ORG.

For example, connection of hybrid asset generates a €100 million reinforcement cost in zone A and no reinforcement cost in zone B. If reinforcement costs are included in common costs, Louderback's method gives the following allocation:

Table 4 - Example: Reinforcement costs allocation - Louderback's method

	ORG	IC		
	x_{ORG}	x_{IC}	$x_A (+100m€ \text{ reinf}^t)$	x_B
Dinstinct projects	587 (+0)	1546	823 (+100)	723 (+0)
Case 1	541 (+3)	1302 (+97)	693 (+91)	609 (+7)
Case 2	475 (+17)	1368 (+83)	715 (+72)	653 (+11)
Case 3 (Pnom)	528 (+5)	1315 (+95)	697 (+88)	618 (+8)

Red parentheses represent additional costs borne by each stakeholder when a €100 million reinforcement is required in zone A compared to a situation where no reinforcement is needed.

In this example, reinforcement costs are mainly assumed by TSO A (TSO of the grid affected). According to the different cases, the share of reinforcement costs borne by TSO A varies between 72 and 91%.

A small part of TSO A's reinforcement costs are redistributed to the ORG and TSO B. In case 2, the allocation is more affected by including reinforcement costs into common costs, as in this case, common costs are lower. Adding reinforcement costs would have a more significant relative effect on common costs. However, the ORG's contribution remains lower than its contribution in case 2 and 3 with reinforcement costs included in TSO A's attributable costs.

When reinforcement costs are not supposed to be financed by the ORG, this method could be used in two steps, in a similar way to the proportional method (cf.4.2.3.1). First, costs are allocated between the ORG and the interconnector (without reinforcement cost). Then, the remaining

interconnector costs plus reinforcement costs are shared between TSOs (by including them in common costs). In this case, the reinforcement costs are shared but only between TSOs.

4.3.3.3 Asset classification

Asset classification might affect attributable and common costs definition.

Louderback's method is less suitable for VC2. With this asset classification, it is less obvious why TSO B should contribute to the national offshore transmission grid reinforcement of TSO A (included in common costs). When these costs are not classified as common costs, there is no more common infrastructure shared by all three stakeholders; a part of TSO A's national offshore grid is common to TSO A and the ORG, the interconnector costs are shared by TSOs. In this case, Louderback's method loses interest.

One possible solution would be for TSO B to contribute when the hybrid asset is globally more efficient but TSO A has a negative cost-benefit analysis without an appropriate allocation. However, its contribution could be lower than with VC1, as this part of the asset is no longer an interconnector: TSO A entirely owns this part of the asset, and could develop, or connect other infrastructures on it, without planning it with TSO B.

4.3.3.4 Assessment against predefined criteria

1. **Incentive value (Net Benefit):** This method does not guarantee higher net benefits for TSOs than with two distinct projects.
2. **Cost-incentive:** It guarantees each stakeholder a lower cost than stand-alone costs when the two previously cited hypotheses are verified (cf. 4.3.2).
3. **No unfair discrimination:** The ORG would bear lower or equal costs compared to a radially connected generator (under 2 conditions, cf. 4.3.2).
4. **Horizontal/vertical consistency:** Two actors with similar stand-alone and attributable costs would pay the same share of the hybrid infrastructure. If one actor has higher stand-alone and attributable costs, it would pay a greater share of the hybrid asset. A larger share of common costs is allocated to stakeholders who benefit the most from implementing a combined infrastructure
5. **Compatibility with current legal framework:** this method seems compatible with the current framework. Case 2 is closer to the current framework than cases 1 and 3¹⁸.
6. **Complexity:** The complexity of this method lies in defining attributable and common costs.
7. **Adaptability:** This method could be applied to any project as long as common costs and attributable costs could be well defined.
8. **Reinforcement:** This method allows for allocating reinforcement costs. They can be shared between all stakeholders or just between TSOs. In the second case, this has no impact on the costs allocated to the ORG.

¹⁸ Except in Denmark and Germany, where ORGs do not pay for their connections to the grid, which are entirely financed by TSOs.

9. **Allocation between stakeholders:** this method allows for distributing costs between all stakeholders, especially between TSOs A and B.

4.4 Shapley value

4.4.1 Principle

The Shapley value (1953) is a solution concept in cooperative game theory. For a coalition of several players, the Shapley value assigns a unique distribution of the total gain generated by this cooperation. This method applied to cost allocation is called the Shapley-Shubik method. In this case, the Shapley value could be applied when cooperation between agents produces economies of scale; it allocates the resulting benefits among the actors.

Imagine a coalition being formed by one actor at a time. The first player will bear the entire investment costs and each following actor will only pay for incremental costs. In that case the order of arrival is important; each actor's cost depends on how many actors there already are in the coalition. It affects the costs of each stakeholder and could be contested.

Shapley's method consists in assigning to each actor the average marginal contribution over all the possible sequences in which the coalition can be formed.

The Shapley value of a player i , given a coalitional game (v, N) is:

$$\phi_i(c) = \sum_{S \subseteq N-i} \frac{|S|!(|N-S|-1)!}{|N|!} [c(S+i) - c(S)]$$

- N : total number of players
- S : represents a coalition of s players ($s \in [2;N]$).
- $c(S)$: cost function or cost-sharing game : costs paid by the coalition while cooperating.
- $c(S+i) - c(S)$ represents incremental cost paid by i while joining coalition S .

Example for a 3-actors cooperative project:

There are $2^3 = 6$ possible orders of development: $\{1,2,3\}$, $\{1,3,2\}$, $\{2,1,3\}$, $\{3,1,2\}$, $\{2,3,1\}$ and $\{3,2,1\}$. The probability for 1 to enter first or last into the coalition is $1/3$ (order of arrival of 2 and 3 do not matter in these cases). Actor 1 has a $1/6$ probability to enter in the second place after 2 and $1/6$ after 3.

Then, contribution of actor 1 to the coalition is equal to:

$$x_1 = \frac{1}{3} c(1) + \frac{1}{3} [c(1,2,3) - c(2,3)] + \frac{1}{6} [c(1,2) - c(2)] + \frac{1}{6} [c(1,3) - c(3)]$$

Many empirical studies have shown the efficiency of the Shapley value in several fields. The World Bank, for example, has led several studies on the application of cooperative game theory to environmental and natural resources issues. These studies demonstrate the value of using Shapley's

method to allocate common costs in many projects such as the Dchar El Oued dam in Morocco, pipeline usage in Canada or a hydroelectric power station in India¹⁹.

4.4.2 Properties

The Shapley value is the unique function value that satisfies the four following properties:

- **Total cost-sharing:** players distribute among themselves the total costs of the coalition.
- **Symmetry:** two symmetric agents (equal marginal contribution) pay an equal share of the coalition cost. The Shapley value respects the horizontal consistency principle.
- **Dummy:** no cost is allocated to players whose marginal contribution is null.
- **Additivity:** The Shapley value is linear: if we combine two coalition games described by cost functions v and w , then the distributed cost should correspond to the costs derived from v and the costs derived from w .

Besides, the Shapley value is a **fair distribution**: all stakeholders bear lower costs than their stand-alone costs - when there are economies of scale (coalition costs are lower than the sum of stand-alone costs) - and pay higher costs than their incremental costs.

Moreover, the Shapley value integrates the order of development to allocate costs: it gives the same contribution to every stakeholder whatever is the order of arrival of the stakeholder.

4.4.3 Application

In the case of a hybrid asset, the order of development affects costs allocated to each stakeholder - when stakeholders arriving late only pay their incremental costs.

For instance, if an ORG wants to connect to an existing interconnector (scenario b):

- The TSOs would finance the entire interconnector and distribute investment costs accordingly.
- The ORG would only pay for the T-in connection between its wind farm and the interconnector.

Conversely, if the ORG is built first, it would pay for its radial connection to shore. Then, if two TSOs want to transform the hub into an interconnector, they would need to finance the incremental part: interconnector from the hub to shore.

According to the order of development, costs borne by each stakeholder are completely different - if this is not corrected by an appropriate cost sharing method.

The Shapley value could be applied to a hybrid infrastructure. However, only two stakeholders could be distinguished: the ORG and the interconnector. With this method, all the possible orders of entering into the coalition (i.e. hybrid asset project) are considered. TSOs cannot be differentiated, as

¹⁹ Parrachino, I., Dinar, A., Patrone, F., Fioravante (2006). "Cooperative game theory and its application to natural, environmental and water resource issues", World Bank Policy Research Working Paper.

they cannot join the coalition at different stages: both parts of the interconnector should be built or planned at the same time. Building half an interconnector is not realistic.

The distribution of the ORG is given by:

$$c_{ORG} = \frac{1}{2} * c_{ORGradial} + \frac{1}{2} * [c_{hybrid} - c_{IC}]$$

$$c_{A+B} = \frac{1}{2} * c_{IC} + \frac{1}{2} * [c_{hybrid} - c_{ORGradial}]$$

Example:

Cost allocated to the **ORG** = $0.5 * 587 + 0.5 * (1743 - 1446) = \text{€}442 \text{ Million}$

Cost allocated to **TSOs** = $0.5 * 1446 + 0.5 * (1743 - 587) = \text{€}1301 \text{ Million}$

4.4.3.1 Reinforcement costs

Shapley's method doesn't allocate costs between TSOs. Any method could then be used to distribute infrastructure and reinforcement costs between TSOs A and B.

With this method, the ORG cannot be allocated a share of reinforcement costs. It pays its average incremental costs over the different possible orders of implementation of the project. Reinforcement costs are never included in its incremental costs (except maybe reinforcement costs entailed by its radial connection to shore, but these are currently not supported by the ORG but by the TSO).

4.4.3.2 Asset classification

The Shapley-Shubick method is not altered by different asset classifications, as it doesn't differentiate costs between TSOs.

4.4.3.3 Assessment against predefined criteria

1. **Incentive value (Net Benefit):** This method does not guarantee higher net benefits for TSOs compared to two distinct projects.
2. **Cost-incentive:** This method guarantees each stakeholder lower costs than stand-alone costs as long as the total hybrid cost is lower than the sum of the costs of distinct projects (economies of scale).
3. **No unfair discrimination:** The ORG would bear lower or equal costs compared to a radially connected generator.
4. **Horizontal/vertical consistency:** two symmetric agents (equal stand-alone costs) receive an equal share of the hybrid infrastructure's cost. If an actor imposes higher stand-alone costs, it would be allocated a higher share of the hybrid infrastructure's cost.
5. **Compatibility with current legal framework:** this method seems compatible with the current framework even though the present allocation of ORGs' costs is quite different.

6. **Complexity:** this method is straightforward to apply to this case study where only three stakeholders are involved. It could become more complicated when a hybrid project involves many stakeholders and possible orders of development, as the formula becomes more complex.
7. **Adaptability:** This method could be applied to a more complicated project (three-legged interconnector, two wind-farm hubs interconnected) but it does not allow for the contribution of two TSOs involved in a two-legged interconnector to be differentiated.
8. **Reinforcement:** This method does not allocate reinforcement costs.
9. **Allocation between stakeholders:** The Shapley value is not able to allocate costs between the two TSOs. The contribution of the interconnector to the hybrid infrastructure has still to be allocated between both TSOs. The costs could be allocated according to conventional methods for interconnectors: 50:50, proportional to costs, or any other methods.

4.5 Min/max contribution

4.5.1 Principle

With this method, the ORG finances its connection costs to the interconnector (attributable costs) and pays a contribution for its use of the shared infrastructure costs. The principle is similar to Louderback's method but with a different allocation of residual costs. Besides, it only focuses on how to define the ORG's contribution to the interconnector costs; it does not deal with cost allocation between TSOs.

The contribution could be proportional to different variables :

- Capacity actually used by the ORG : **average load factor of the ORG** (ALF)
- Reserved capacity for the ORG : **Nominal power of the ORG** (NP)

This factor could be applied to the part of the interconnector actually used by the ORG (interconnector between A and T-in connection of the ORG) or over the entire interconnector, considering that its connection affects this section of the interconnector too even though it is not directly using it.

The second solution could be really expensive and negative for the ORG, and for this reason it will not be studied in this paper. The ORG's total cost (sum of this contribution and its attributable costs) should be inferior to its radial connection costs. As this criterion will not necessarily be verified, the ORG contribution should be limited by a maximum value: the difference between radial connection costs and attributable costs ($C_{ORG\ radial} - C_{A\ ORG}$).

4.5.2 Properties

- This method focuses on how to define the ORG's contribution to the interconnection costs; it does not deal with cost allocation between TSOs.
- This method does not guarantee lower costs for the ORG.

4.5.3 Application

The contribution could be defined by:

$$\text{Contribution} \geq \text{Interconnector cost (from A to T-in junction)} \times \text{average load factor of the ORG}$$

$$\frac{P_{nom\ ORG}}{P_{interco}} \times \text{Interconnector cost (from A to T-in junction)} \leq \text{Contribution}$$

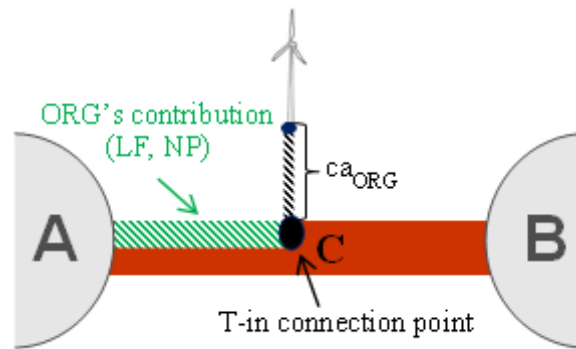


Figure 10 - Cost allocation - Min/max contribution

The contribution given by the average load factor method could be a minimal contribution for financing the interconnector infrastructure.

The nominal power method could define a maximum contribution for the ORG. It gives a contribution close to the radial connection costs. It could be more expensive than radial connection; for example, when the ORG is not that close to the interconnector: it may be less expensive to build a direct line to shore than to connect to the interconnector and pay the contribution. In that case, the nominal power contribution should be removed. Indeed, if the ORG is close to the interconnector and that combined project generates costs savings thanks to large economies of scale, the total cost of the ORG with this method should be lower than the radial connection cost.

Example:

Table 5- Example: Cost allocation with Min/Max contribution

	ORG		IC	
	ORG's contribution to A	ORG total costs	IC costs	A;B (50/50)
Distinct projects	0	587	1446	723
ALF	124	420	1323	662
Pnom	258	554	1189	594

4.5.3.1 Reinforcement costs

These methods do not deal with reinforcement costs and cost allocation between TSOs. A share of reinforcement costs could be attributed to the ORG, if they're counted in the interconnector's investment costs.

4.5.3.2 Asset classification

These methods are suitable for both asset classifications VC1 and VC2. In VC1, the contribution represents the financing of the virtual grid connection. These methods are rather similar to the current connection and access arrangements for wind farms in most NSCOGI countries: the ORG finances its connection to the grid (based on its nominal power), the connection is then managed by the TSO (or OFTO), except in Denmark and Germany where the connection is entirely financed by TSOs, so the costs are socialized and shared by all grid users.

4.5.3.3 Assessment against predefined criteria

1. **Incentive value (Net Benefit):** These methods do not deal with benefits. A minimal contribution might not give a good signal to the ORG: it might be tempted to connect to an interconnector even when the global project is not the optimal solution (as connection proportional to load factor is really advantageous for the ORG). None of the methods guarantees higher net benefits for TSOs compared to distinct projects. However, as the nominal power method imposes higher costs on the ORG, it is more likely to be an incentive for TSOs.
2. **Cost-incentive:** These methods do not always guarantee lower costs for the ORG. However, it should be true in almost all cases (especially with average load factors).
3. **No unfair discrimination:** The ORG would bear lower (load factor) or similar (nominal power) costs compared to a radially connected generator.
4. **Horizontal/vertical consistency:** this criterion is not relevant for this method.
5. **Compatibility with current legal framework:** this method seems compatible with the current framework and really similar to what is currently applied. With this method, the ORG pays for its connection based on load factor or nominal power. The ORG's charge for its connection to the grid is currently based on its maximal power.
6. **Complexity:** This method is straightforward to implement.
7. **Adaptability:** This method could easily be applied to a more complicated project, with the same market arrangements (ORG bidding in its national bidding zone).
8. **Reinforcement:** This method is not able to allocate reinforcement costs.
9. **Allocation between stakeholders:** This method does not allocate costs between TSOs. As for the Shapley value, the cost between TSOs could be allocated according to conventional methods for interconnectors: 50:50, proportional to costs, or any other methods.

4.6 Proportional to benefits

4.6.1 Principle

This method consists in allocating costs proportionally to stakeholders' benefits. For each project, each actor pays its proportional share of the project's benefits. Every actor will have the same ratio between benefits and costs. When actors are able to choose between different projects, they will select the most cost efficient.

Let's call:

- b_i : benefit received by i
- c_{tot} : total cost of a project

Then the cost allocated to i is defined by:

$$x_i = \frac{b_i}{\sum_j b_j} c_{tot}$$

The complexity of this method lies in assessing the benefits of all stakeholders. The definition of benefits is often uncertain and based on multiple assumptions. As the estimated benefits of one actor have a direct effect on all stakeholders' costs they could be sharply contested. Each actor has an interest to minimize its estimated benefits so as to reduce its contribution.

4.6.2 Properties

- A larger share of the total costs is allocated to actors who receive higher benefits.
- **Cost efficient**: this method leads to the optimal decision: it incentivizes the most efficient project.
- **Efficient distribution**: the ratio between benefits and costs is equal for each stakeholder.
- **Symmetry**: two actors with similar benefits would be charged the same costs.

4.6.3 Application

With this method, each stakeholder's benefit from the hybrid project should be assessed.

Let's call:

- b_{ORG} : Benefits received by the ORG from selling its renewable production in bidding zone A.
- b_{IC} : Benefits from cross-border electricity trades in terms of congestion rent and social surplus, with the hybrid infrastructure.

The ORG's contribution is given by:

$$x_{ORG} = \frac{b_{ORG}}{b_{ORG} + b_{IC}} c_{hybrid}$$

In this case, c_{hybrid} must include the entire costs of the ORG i.e. costs to produce, transport and install the farm. Other methods (except the proportional to stand-alone costs method), give the same cost sharing distribution whether these costs are integrated in the total costs of the hybrid project and the radial connection costs, or not (only the connection costs are considered).

The benefits of an ORG are difficult to assess. They arise from the selling of its production on the electricity market. Renewable energy production is variable and generally dependent on weather conditions.

Currently, in all NSCOGI countries, support schemes guarantee ORGs minimum or fixed revenues. However, when offshore renewables become competitive, their revenues will depend on the price

on the electricity market, which may be highly volatile. This would increase uncertainty in assessing the ORGs' revenues.

Assessing an interconnection's benefit is also a tough task. Benefits are estimated over a long time span, and could be heavily affected by the construction of new interconnectors, grid upgrades or changes in the energy mix. The connection of an ORG makes it even more difficult to estimate the interconnector benefits, as another variable is added: the intermittent renewable production.

Thus, benefits might be contested. Besides, this approach is really different from what is currently done; a radially connected ORG pays its connection costs to shore, whatever its benefits are. Nonetheless, with this method an ORG will decide to connect to an interconnector only when it is more cost-efficient (higher benefits/costs ratio). As the ORG's benefits are the same whether it is connected to shore or to an interconnector (with the NSCOGI market arrangements cf. 2.2), and the hybrid project's ratio benefits/costs is supposed to be higher, this method will guarantee to the ORG lower costs than radial connection costs. From an economic perspective, this method leads to the optimal project.

4.6.3.1 Reinforcement

As with the first method (proportional to the costs of distinct projects) reinforcement costs could either be shared between all stakeholders, TSOs or separately paid by each TSO. This depends on whether they are integrated into total hybrid costs.

4.6.3.2 Asset classification

This method is compatible with both asset classifications VC1/2. Asset classification will not change the stakeholders' benefits and, as a consequence, will not affect the cost allocation.

4.6.3.3 Assessment against predefined criteria

1. **Incentive value (Net Benefit):** this method guarantees the same ratio between benefits and costs for all stakeholders, corresponding to the global profitability of the project. However, it does not ensure higher net benefits for TSOs compared to an interconnector without an ORG.
2. **Cost-Incentive:** this method guarantees lower costs for all stakeholders as long as the hybrid asset is more efficient than individual development (interconnector and radial connection developed separately).-
3. **No unfair discrimination:** an ORG connected to a hybrid asset will not be treated similarly to a radially connected ORG. The higher benefits, the higher its contribution will be. However, there is no unfair discrimination in the sense that the ORG would bear lower or equal costs compared to a radially connected generator.
4. **Horizontal/vertical consistency:** this method does not respect this principle. Two actors generating similar costs will not pay the same contribution if their benefits are different.

5. **Compatibility with current legal framework:** This approach seems rather different from current practice. Currently ORGs' costs are independent from their benefits.
6. **Complexity:** In theory, this method is straightforward to implement. However, the difficulty of this method relies on the contestability of stakeholders benefits. Benefits are difficult to assess. It could seem hazardous to base a cost allocation method on estimated benefits, in particular those of the ORG.
7. **Adaptability:** Easy to apply to more complicated projects, if benefits can be assessed.
8. **Reinforcement:** This method allows for allocating reinforcement costs. They can be shared between all stakeholders or just between TSOs. In the second case, the ORG is not affected by reinforcement needs and will not finance them.
9. **Allocation between stakeholders:** This method allows for distributing costs between all stakeholders; in particular, it differentiates between the costs of TSOs A and B.

4.7 Comparison of different cost allocation methods

4.7.1 Analysis of criteria

The table below summarizes and compares the different cost allocation methods previously described according to criteria developed in section 3.2. The criteria are not in order of importance and some can be more relevant than others. **Therefore, the best method may not be the one with the most smiling faces.**

Table 6 - Comparison of costs allocation methods

	Proportional to stand-alone costs	Louderback	Shapley	Min	Max	Proportional to benefits
1. Incentive value (Net Benefit)						
2. Cost-incentive						
3. No unfair discrimination						
4. Horizontal /vertical consistency				--	--	
5. Compatibility						
6. Reinforcement cost allocation						
7. Complexity and feasibility						
8. Adaptability						
9. Allocation between stakeholders						

Adapted to both
asset classifications
(VC1/VC2)



4.7.2 Illustration

In order to compare suggested cost allocation methods, the chart below sums up the results obtained with the illustrative example of a T-in interconnector. The last method, proportional to benefits, has not been integrated in this comparison, as the benefits have not been assessed.

The results obtained with this example are illustrative and would be different with another example. General conclusions about the efficiency of different methods cannot be drawn from this example.

Reinforcement costs have not been integrated into investment costs. A 50:50 distribution between TSO A and B has been suggested for the interconnector's costs.

Table 7 - T-in interconnector - comparison of cost allocation methods

		ORG Total costs	IC	A, B (50:50 distribution)
Distinct projects		587	1446	723
Proportional to stand-alone costs		503	1240	620
Louderback	Case 1	538	1205	602
	Case 2	458	1285	643
	Case 3	523	1220	610
Shapley		442	1301	651
Load Factor method		420	1323	662
Nominal power method		554	1189	594

We can first notice that all methods guarantee lower costs for the ORG and TSOs compared to two distinct projects. The ORG's costs are always higher than its attributable costs – the costs of its T-in connection to the interconnector (296 m€). Besides, the lowest and highest contributions of the ORG are respectively given by the load factor method and the nominal power method, previously defined as the minimal and maximal contribution.

The ORG's contribution fixed by the nominal power method is below the radial connection costs. There are two possible reasons: economies of scale reducing the connection costs, and the two assumptions we have made in this example - ORG located at one-fourth of the interconnector, (which might not be its exact location) and linear costs ($\frac{1}{4}$ of the interconnector costs $\frac{1}{4}$ of interconnector total cost).

In this example, the Shapley value represents one of the lowest contributions for the ORG. So does Louderback's method with the 2nd definition of attributable costs (Figure 8- Possible costs definitions). Conversely, Louderback's method with cost definition 1 and 3 gives a closer contribution for the ORG to its radial connection costs. However, these results might be different with another example.

5. ALLOCATION OF BENEFITS

In the last section, different methods for allocating infrastructure costs have been studied. These methods partially solve the cost-benefit distortion by distributing costs savings between stakeholders. Only one of them (method 4.6, proportional to benefits) deals with benefits. Indeed, other methods do not take benefits into account while sharing costs; they only ensure lower costs for every stakeholder than individual projects.

Since the benefits of TSOs may be reduced by the connection of the ORG, lower investment costs might not be sufficient to guarantee higher or even positive net benefits to both TSOs.

Thus, allocation of benefits between stakeholders has yet to be studied. Unlike costs that may be shared between the three stakeholders, benefits can only be shared between equivalent parties. Congestion rent may only be shared between TSOs; an ORG cannot obtain a share of congestion rent. Conversely, one cannot ask the ORG to share the benefit resulting from selling its generation with one or both TSOs. Besides, surplus (considered as part of the TSOs' benefit as these work on behalf of the grid users) cannot be shared.

This section will focus on different ways of sharing benefits between all stakeholders or between TSOs. Then, it will analyze the extent to which these methods combined with the cost allocation methods studied provide incentives for all stakeholders.

5.1 Allocation of benefits between all stakeholders: benefits proportional to costs

Once infrastructure costs have been allocated between stakeholders - using one of the methods described in section 4 (except method n°5) – it could be tempting to allocate a hybrid asset's benefits proportionally to each actor's share of the total cost. Even though this method seems efficient from a theoretical economic perspective, it raises several issues and could be difficult to apply in the current legal framework.

Benefit allocation guarantees the same ratio between benefits and costs and the same profitability for every stakeholder. In that sense, this is an efficient method; it gives an appropriate incentive to all stakeholders and leads to the optimal decision making from an economic perspective.

However, this approach seems really different from what is currently applied to radial ORG and interconnectors. An ORG does not share the revenues from selling its production on the electricity market. Besides, with this method, a share of the ORG's risk, resulting from its variable production, is transferred to TSOs. It also seems fairly difficult distributing benefits from two different sources between stakeholders. Most of all, this approach raises serious regulatory issues:

- First, a share of congestion rent might be allocated to the ORG. Usually, congestion rent revenues of regulated interconnectors are shared between the two TSOs operating the interconnector.

- Then, the congestion rent must be used as defined by art. 16.6 of Regulation (EC) N° 714/2009 :“Any revenues resulting from the allocation of interconnection shall be used for the following purposes:
 - (a) guaranteeing the actual availability of the allocated capacity; and/or
 - (b) maintaining or increasing interconnection capacities through network investments, in particular in new interconnectors.”

Allocating congestion rent to the ORG is thus not compatible with the current European legal framework.

Besides, the ORG receiving a share of congestion rent could be tempted to manipulate the market in order to increase its revenues; all the more so as it is directly using the interconnector. This solution raises unbundling issues and should not be used.

5.2 Allocation between TSOs

In the case study, the ORG is allowed to bid only into its national bidding zone. Usually an ORG radially connected to shore will pay its charges and access to its national TSO. Then, the ORG may pay a contribution for its use of the infrastructure to TSO A – TSO of the country where it is selling its production. In that case, the contribution of the ORG will reduce the investment costs for TSO A. Conversely, TSO B would pay the same cost as for an interconnector with no renewable production connected - even though it would not receive any benefits from the ORG’s connection and would potentially lose a part of its congestion rent and surplus. The connection of the ORG may decrease TSO B’s net benefits and they may even turn negative. In order to incentivize TSO B to participate in a hybrid project or to accept the connection of the ORG, an agreement should be found between both TSOs. Different solutions have been considered:

- An appropriate congestion rent allocation (or reallocation) between TSOs or;
- TSO A could pay compensation to TSO B.

This section will focus on different allocations between TSOs, to incentivize TSO B to undertake a hybrid project. Then, it will study the incentive value of these solutions.

5.2.1 (Re)allocation of benefits proportionally to costs

This solution consists in allocating (or reallocating when the interconnector is functioning prior to the ORG’s connection - scenario ⑥, cf. section 2.5) congestion rent proportionally to the effective costs borne by each TSO. Each TSO receives a share of congestion rent commensurate to its effective costs once the ORG’s contribution has been deducted from TSO A’s costs.

TSO A’s benefits could be determined as follow:

$$B'_A = \frac{c'_A}{c'_A + c'_B} RC'$$

Where:

- **CR** : Congestion rent received by TSOs when no renewable generator is connected to the interconnector (before the connection of the ORG)
- **CR'**: Congestion rent earned by the hybrid asset (after the ORG's connection).
- **c_A, c_B** : interconnector costs respectively borne by TSO A and B before the connection of the ORG.
- **c'_A, c'_B** : TSO A and B 's costs after the ORG connection (once the ORG has paid its contribution to TSO A for its access and use of the interconnector).
- In this approach: $c'_A = c_A - \text{contribution}_{\text{ORG} \rightarrow \text{A}}$ and $c'_B = c_B$
-
- Prime stands for hybrid asset.

This solution guarantees the same rate of return for both TSOs even though it would probably be different from the one for the interconnector without or before the ORG connection. It will depend on the costs saved and the congestion rent reduced as a result of building the hybrid asset as well as the amount of the ORG's contribution to A (defined by one method of section 4). Section 5.3 will study under which conditions the TSOs profitability will be higher when undertaking a hybrid project.

Example:

In order to illustrate the different methods to deal with the allocation of benefits between TSOs, we will use the same example of a T-in interconnector.

Assumptions:

- 50:50 distribution between TSOs (for the "classic" interconnector)
- Contribution of the ORG to TSO A given by Louderback's method (case 2) : 162M€
- 10% loss of congestion rent between hybrid asset and interconnector (1663 vs. 1497M€)
- **c'_A, c'_B** represent share of hybrid asset's costs borne by TSO A and B
- **B'_A, B'_B**: benefits received by TSOs from cross-border trade (congestion rent)
- **R'_A, R'_B**: ratio between benefits and costs

	c'_A	B'_A	R'_A	c'_B	B'_B	R'_B
Reallocation of benefits between TSOs	561	654	1.17	723	843	1.17

5.2.2 Compensation from TSO A to TSO B

Another solution consists in assessing compensation between TSOs either based on costs or benefits.

5.2.2.1 Costs compensation

The amount of compensation could simply represent a share of the ORG's contribution paid to TSO A. This share could be proportional to the distribution of benefits between TSOs that would accrue if the interconnector was not connected to an ORG (or, in scenario ⑥, to the distribution used before the ORG's connection).

If β represents the ratio of benefit received by B before or without the connection of the ORG, the compensation could be defined by:

$$compensation_{A \rightarrow B} = \beta \cdot contribution_{ORG \rightarrow A}$$

This method is equivalent to directly sharing costs between the three stakeholders and commensurate benefits with costs. It guarantees an equal rate of return for both TSOs.

This method leads to the same ratio between costs and benefits as the reallocation of benefits (cf. 5.2.1).

5.2.2.2 Congestion rent compensation

The compensation could be based on congestion rent. In this case, the idea is to compensate TSO B for its lower profitability as a result of the potential reduction of congestion rent. Considering that TSO B pays the same costs as for a classic interconnector and that zone B does not receive renewable production or its related benefits, TSO B should not be affected by the ORG's connection.

The principle is to fix the compensation so as to guarantee the same profitability for TSO B as before or without an ORG connected to the interconnector.

The compensation could be set as follow:

$$compensation_{A \rightarrow B} = \sum_t \beta (P_{ORG,t} \cdot \Delta_t) = \beta (RC - RC')$$

- β : share of benefits received by TSO B when no renewable generator is connected to the interconnector (or before the connection of the ORG)
- $P_{ORG,t}$: Production of the ORG at any given moment t.
- Δ : spread, price difference between bidding zone A and B at any given moment t. When there is no congestion on the interconnector, the spread is null.
- RC, RC' : Congestion rent generated by the interconnection respectively without and with an ORG.

This compensation could be an ex-post or ex-ante (based on estimated loss of benefits) compensation. However, it is felt that an ex-ante (one-shot) compensation would be a better idea. It would have the advantage of enhancing the visibility for TSOs and might be easier to implement than ex-post compensation.

In this case, the profitability of TSOs would be different. TSO B's rate of return would be the same as the one of the interconnector; TSO A's return might be either lower or higher depending on the ORGs contribution to A.

Example:

Data used in this example are the same as in part 5.2.1

	C_A^i	B_A^i	R_A^i	C_B^i	B_B^i	R_B^i
Cost compensation	642	748	1,17	642	748	1,17
Benefit compensation	561	665	1,19	723	831	1,15

5.2.3 Remarks

All these methods only share congestion rent revenues. Although an ORG connected to an interconnector may also reduce consumer and producer surplus in connected countries, it seems more appropriate not to include a surplus compensation. It is felt that surplus, which is difficult to assess, may hamper the implementation of this method in practice.

TSOs are in charge of financing, building and upgrading their national transmission grid. In the VC2 case, the cost of the national transmission grid of TSO A might represent a great share of the hybrid asset's costs. Then, with a conventional allocation, the project might be profitable overall but provide no incentive for the TSO to connect the ORG. When the hybrid asset is the best solution from a global perspective, but TSO A has a negative cost benefit analysis (CBA), TSO B might contribute to the financing of TSO A's national offshore transmission grid. But in that case, TSO B should have a say on any project affecting its profitability and be compensated accordingly by TSO A when its benefits are endangered.

5.3 Incentive value of cost allocation methods

A hybrid asset is the best option when:

$$\text{cost savings} \geq \text{lost benefits (in terms of congestion rent and surplus)}$$

in comparison with individual development (i.e. radial connection of the ORG and conventional interconnector). In this paper we assumed that this condition is always met. Otherwise, a hybrid project will not be considered anyway and cost allocation will no longer be an issue.

A cost allocation method is an incentive when it guarantees that this condition is true for every stakeholder. The ORG benefits are the same as for a radial connection to shore since its production is prioritized. All cost allocation methods ensure lower costs compared to a radial connection. Then, its net benefit and its profitability will necessarily increase with the hybrid project.

The difficulty lies in ensuring higher net benefit for both TSOs. Indeed, benefits from cross-border exchanges decrease when the ORG connects to the interconnector. Even though their costs are also reduced, their profitability will increase only when costs savings are higher than benefits lost.

In scenario ⑥, the reduction in the TSOs' investment costs results from the contribution of the ORG. Thus, the higher the contribution of the ORG, the better is the TSOs' profitability.

When the contribution of the ORG is higher than the estimated loss of congestion rent caused by the ORG's connection, methods one and two guarantee a higher net benefit for both TSOs, while the

third method guarantees an equal net benefit to TSO B and a higher net benefit for TSO A (compared to their benefits with the conventional interconnector).

6. CONCLUSIONS

Scope and objective

This paper investigates different cost allocation methods for a hybrid asset combining renewable generation and cross-border trade. It sets out the assumptions on which the study is based, and a list of different criteria that an ideal allocation method should meet. Several methods are then tested against these criteria. In order to make the study more concrete, the methods are tested using the example of a small hybrid asset, consisting of an interconnector with an ORG connected to it with a tee-in connection. The example involves three stakeholders: two TSOs and one ORG. An important assumption is that the hybrid asset is a better solution than developing individual assets (i.e. a regular interconnector and a radial connection of the ORG to its national onshore transmission grid). A fictitious example has been used as a quantitative illustration.

This paper does not aim to define a method for cost allocation to be applied to all future hybrid structures between NSCOGI countries, but focusses on investigating the pros and cons of different methods. In order to choose a cost allocation method for a particular project or, where relevant, define a general framework for hybrid projects in a particular country the weight given to each criterion would need to be considered. In particular, the particularities of the national legal framework as regards interconnectors and ORGs would need to be taken into account. The aim of this paper is therefore to help the cost allocation question to be resolved, whether by the relevant authorities or through negotiation between the stakeholders involved.

Key conclusions

It should be noted that the results of the study presented in this paper are subject to a number of assumptions and would require further analysis and adaptation in other scenarios. Nevertheless, some general thoughts have emerged.

- ➔ **Different cost allocation methods have different strengths and weaknesses:** When assessing the different methods against the criteria, no one method stood out as the strongest. Each fulfilled the criteria to a different extent, with strengths in one area but weaknesses in another. The situation where costs need to be allocated may also call for more weight to be given to some criteria and less to others, indicating that some methods may be more suitable in certain circumstances. This shows that cost allocation does not necessarily need to follow a prescribed method, but approaching it with some flexibility could have its advantages.
- ➔ **Incentive value:** The majority of the methods studied ensure lower costs for all stakeholders compared to the costs they would have paid if they had decided to develop separate projects (a radial connection of the ORG to shore and a conventional interconnector). However, no

method guarantees higher net benefits²⁰ for TSOs in every possible case. As a consequence, this may only be evaluated on a case-by-case basis.

- **Enhancing the incentive value by basing cost allocation on benefits:** Basing cost allocation on benefits is challenging. Benefits for ORGs are difficult to assess (*ex ante*) as they are highly dependent on weather conditions, *inter alia*. Furthermore, allocating costs proportionally to each stakeholder's benefits could be difficult to implement as it is very different from the current framework²¹. However, this method could be used to share costs between TSOs if the Cost Benefit Analysis (CBA) methodology, developed by ENTSO-E to assess benefits for all Ten-Year Network Development Plan projects, is used as a standardised methodology.
- **Enhancing the incentive value by reallocation of benefits:** Another solution based on benefits that has shown to be challenging is the allocation of benefits proportionally to each stakeholder's costs. Allocating congestion rent to an ORG or sharing the ORG's benefits with the TSOs may be in conflict with the unbundling obligation under the Third Package so may not be compatible with the current legal framework.
- **Allocation of costs and benefits between TSOs:** The connection of an ORG possibly decreases both the congestion rent and economic surplus generated by cross-border flows. This is particularly the case for the TSO which is not in the country hosting the ORG. In order to rebalance the costs and benefits of the two TSOs, it is worth considering allocating benefits differently than for a regular interconnector. For hybrid projects, only basing reallocation on congestion rent could be more suitable than basing reallocation also on surplus. Economic surplus is difficult to assess and sharing it may be difficult to implement in practice. In addition, ex-ante compensation is preferred to ex-post compensation, as this would have the advantage of enhancing visibility for TSOs.
- **Reinforcement costs:** Some of the cost allocation methods covered in this paper could be applied when allocating reinforcement costs between TSOs. It was felt that ORGs should not contribute to reinforcement costs since ORGs are not charged for reinforcement costs in any NSCOGI country.

²⁰ In our case, benefits for TSOs are considered to be the sum of the congestion rent and grid users' (producers' and consumers') surplus.

²¹ In all NSCOGI countries, connection costs for ORGs are based on real costs and not on benefits (note that in Denmark and Germany, connection costs for ORGs are socialized).

7. FURTHER ANALYSIS

This paper explores cost allocation methods from the point of view of achieving a fair distribution of the costs of a hybrid asset involving three stakeholders: two TSOs operating a cross-border project and an ORG. However, a number of other issues have not been studied so far and would need to be explored before validating our conclusions.

- ➔ **Compatibility with legal framework:** Several cost allocation methods presented in the paper at first sight seem compatible with the current legal framework. However, the legal feasibility of the solutions has not been studied in detail, so further work should be carried out to validate the feasibility of implementing the suggested cost allocation methods. In addition, legal issues that could possibly arise with the change of status of an asset have not been studied in this paper. In particular, when an ORG connects to an existing interconnector, a part of the interconnector will either become a virtual grid connection (VC1) or part of the national transmission grid (VC2).
- ➔ **Applicability to more complex assets:** The study focuses on a T-in connection of an ORG to an interconnector. The compatibility of the methods developed in this paper with more complex assets was one of the criteria used in the assessment but has not been studied in detail. The application of the various methods to other types of hybrid assets could therefore be usefully explored further (e.g. hybrid projects involving three countries, hybrid assets linked together).
- ➔ **Age of assets in the case of incremental development:** In scenario ⑥ of this paper, where the ORG connects to an existing interconnector we have not taken into account the age of the interconnector and its remaining life expectancy when the ORG connects. The question of how to integrate this parameter into the cost allocation has still to be developed. Besides, the possible loss of interconnector revenue induced by downtime during the installation of the T-in connection has not been taken into account.
- ➔ **Impact of market arrangements:** In this paper we focused on the scenario where the ORG is only allowed to bid into its national bidding zone. This assumption derives from the conclusions of the first NSCOGI paper on market arrangements, focusing on the day-ahead timeframe. However, NSCOGI has also investigated possible market arrangements for the intraday timeframe, which could be different. Any effect this might have on cost allocation and the compatibility of the different methods should be explored further.
- ➔ **Conditions for preferring a hybrid asset to individual development:** This study assumes that a hybrid asset is a better solution than separate developments (radial connection of the ORG). However, it does not investigate in which cases and conditions a hybrid solution is a better solution. This issue could be explored further.

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8. LIST OF ABBREVIATIONS

ACER	Agency for the Cooperation of Energy Regulators
CBA	Cost Benefit Analysis
CBCA	Cross-Border Cost Allocation
EC	European Commission
ENTSO-E	European Network of Transmission System Operators for Electricity
NSCOGI	North Seas Countries' Offshore Grid Initiative
OFTO	Offshore Transmission Owner
ORG	Offshore Renewable Generator
PCI	Project of Common Interest [COM/2011/658]
RES	Renewable Energy Sources
TSO	Transmission System Operator
TYNDP	Ten-Year National Development Plan

9. GLOSSARY

Congestion	Grid bottlenecks resulting from a demand for flow that exceed the available commercial capacity of an interconnection. Congestion leads to price differentials between two bidding zones (or markets) resulting in a congestion rent perceived by the interconnection's operators (TSOs for regulated interconnection). This revenue must be used to improve available capacity of interconnections, increase exchange capacities (particularly through new investments) and possibly to decrease the tariff for grid users.
Hub-to-hub interconnection	Wind farm hubs connected to several countries connected together, forming a cross border transmission line.
Hybrid asset	Asset combining renewable energy sources and interconnection. A hybrid asset is both used for transporting renewable generation and cross-border flows.
Market coupling	Market Coupling matches bids and offers from two or several national markets (or bidding zones), after book closure, and automatically allocates the available cross-border transmission capacity. The available cross-border transmission capacity is used to minimize the price difference between two or more areas, letting electricity flows from the lowest price area to the highest price area. Market coupling optimizes the selection of accepted offers within the scope of the coupled markets, leading to an optimized use of available production plants.
T-in interconnection	Direct connection of an offshore renewable generator to an interconnector.
TYNDP	<p>The TYNDP presents a forward-looking proposal for electricity transmission infrastructure investments across 34 European countries. It is a non-binding plan, to be updated every two years by ENTSO-E, as required by the 3rd energy Package.</p> <p>It aims at ensuring transparency regarding the electricity transmission network and to support decision-making processes at regional and European level.</p>
Wind farm hub	Cluster of wind farms close to one another, connected to shore by only one transmission line.