North Sea
Wind Power Hub
Programme

Cost & benefits

CBA framework for hub-and-spoke projects

Discussion paper

#1

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About this paper

Why read this report

To facilitate development and implementation of hybrid projects, clarity is required on the Cost and Benefit topic. A Cost and Benefit Analysis (CBA) is a generally accepted approach for reviewing energy infrastructure projects. Having a CBA is required to provide insights into the relevance of a project and to show decision- and policy makers the added value for society of a project. This discussion paper aims to show the CBA options that the North Sea Wind Power Hub (NSWPH) consortium partners have, their shortcomings and the decisions the NSWPH still needs to take with regard to the CBA framework for the hub-and-spoke concept. The discussion paper also provides insights into discussions that still need to take place between policy makers. While this discussion paper is focussing on providing an adequate application of a CBA framework for a hub-and-spoke project, the considerations included in this discussion paper are valid in case projects cover more than just a single functionality (unlike conventional projects).

Highlights

CBA is one of the key topics that must be addressed on time to meet key development milestones of a hub-and-spoke project.

Adjustment of the CBA methodology is required to assess all characteristics and to capture the full benefits of a hub-and-spoke project.

Discussion and clarity is required on how the counterfactual of a huband-spoke project will be defined to facilitate a fair comparison and what the scope of the impact assessment needs to be to enable an adequate cost-benefit analysis.

Structure of the discussion paper

1. Introduction
2. CBA discussion
3. NSWPH perspective
4. NSWPH suggestions
5. CBA execution
6. Next steps

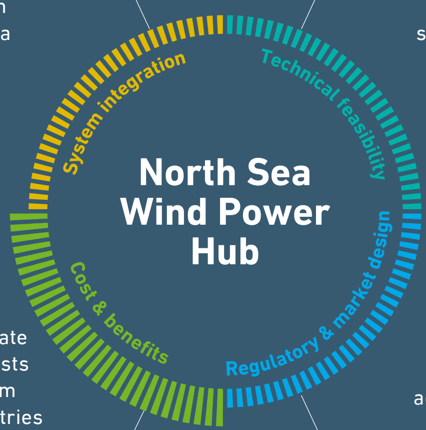
The big picture

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

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

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

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



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

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

Executive summary

The deployment of renewable energy sources in Europe will increase significantly to support the goal of net zero greenhouse gas emissions by 2050. Energy scenarios consider offshore wind as a major renewable energy source in the future European energy system. To support the development of offshore wind in the North Sea region, the North Sea Wind Power Hub (NSWPH) consortium has developed a vision of an international, cross-energy sector hub-and-spoke concept.

To ensure sound decision-making for the development of these type of projects, it is necessary to adequately assess the costs and benefits of such projects. In light of the new and innovative hub-and-spoke concept, where various infrastructure functionalities are combined, an appropriate approach to Cost-Benefit Analysis (CBA) is one of the topics that should be discussed. This discussion paper aims to show the options that the NSWPH consortium partners have and the decisions the NSWPH still needs to take with regard to the CBA framework for the hub-and-spoke concept.

As a main finding, it is assessed that, in principle, the ENTSO-E and ENTSO-G CBA guidelines can be used to assess the costs and benefits of the hub-and-spoke concept. However, some adjustments to the application of the CBA guidelines would be required to account for the international, cross-energy sector character of the hub-and-spoke concept.

Three main issues arise when applying the CBA framework to the hub-and-spoke concept:

1. The definition of scope. It is to be decided what region and what costs are taken into account in the CBA, since the large scale of the project and the amount of installed offshore wind capacity will impact not only the coastal regions, but will also reach far inland.

2. The decision on the baseline scenario, where one could either choose a business as usual scenario or a business as usual plus concrete plans scenario. To account for the steps towards meeting the 2030 energy targets NSWPH suggests to use the business as usual plus concrete plans scenario as a baseline scenario.

3. The decision on the factual and the counterfactual. The exact configuration of the hub-and-spoke project is not yet determined, therefore there are many different plausible factuals. Also, it is still to be determined how the counterfactual needs to be defined and what it should include in terms of functionality. Given the fact that there are still various factuals possible, it is also necessary to define an individual counterfactual per factual. It is expected that a decision on the factuals, their individual counterfactuals and their relationship to the baseline drives the observable value of the project in a CBA. Therefore, it is intended to discuss these options transparently with policymakers before taking a decision on this topic.

A hub-and-spoke project impacts the electricity system on a bidding-zone level, the grid within a bidding zone, as well as the gas/hydrogen grid due to the inclusion of Power-to-Gas (PtG). When focusing on the impact of the project on the electricity grid, there is already a wide range of tools (or so-called studies) that can be used to identify the costs and benefits of a project in the electricity system. Separately, due to the inclusion of PtG in the overall project scope, a CBA for a hub-and-spoke project should also assess the impact on the hydrogen market and infrastructure on a socio-economic level. A possible approach to quantify the effects of energy sector coupling is to model PtG conversion as additional demand on the electricity market and additional supply on the hydrogen market. In principle these effects in the electricity and hydrogen market need to be assessed in conjunction.

The NSWPH is planning to start the first regional CBA analysis in the second half of 2021. In this analysis the NSWPH intends to apply the CBA framework as suggested in this discussion paper, while engaging with policy makers to decide on key aspects, such as the counterfactual. Here, the NSWPH is open to amend the framework based on the outcome of discussions that arise from this discussion paper.

1 Introduction

The deployment of renewable energy sources in Europe will increase significantly to support the goal of net zero greenhouse gas emissions by 2050. Energy scenarios consider offshore wind as a major renewable energy source in the future European energy system. The European Commission stated in its offshore renewable energy strategy that a target of 300 GW is realistic and achievable. To enable this rapid acceleration in deployment and integration of large-scale offshore wind, with maximum socio-economic benefit, there is an urgent need for international coordination, long-term policy targets and an enabling framework.

To support the development of offshore wind in the North Sea region, the North Sea Wind Power Hub (NSWPH) consortium has developed a vision of an international, cross-energy sector hub-and-spoke concept. The hub-and-spoke concept ensures cost-effective, modular deployment by combining offshore wind assets and interconnectors, and facilitating the integration of gas, electricity systems through Power-to-Gas (PtG) conversion.

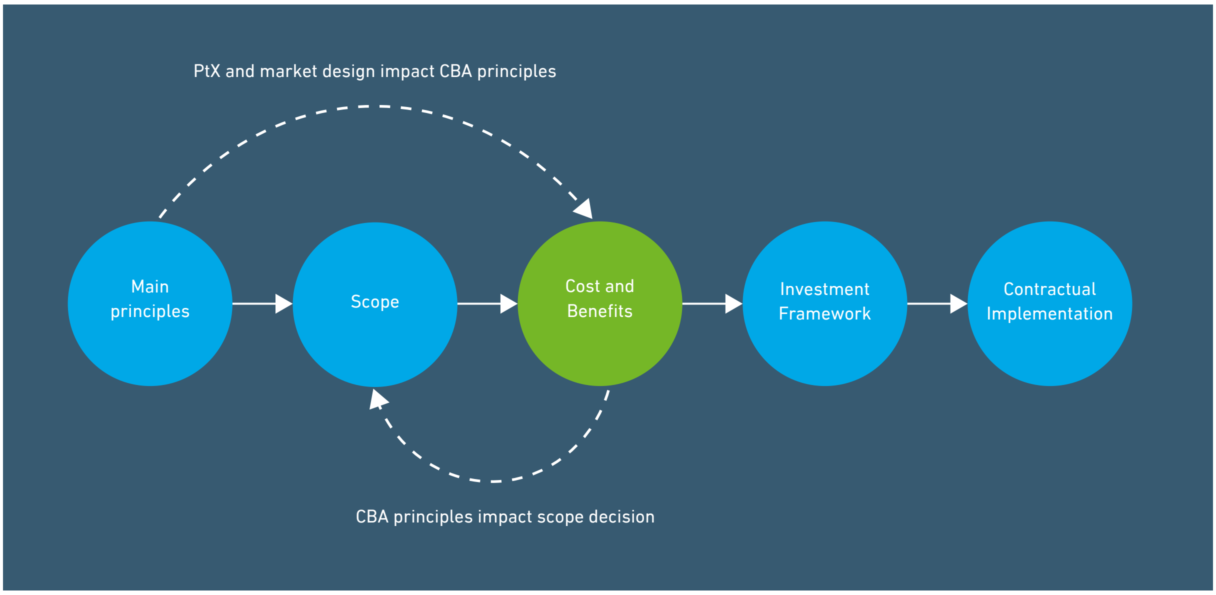
Highlight
CBA is one of the key topics that must be addressed on time to meet key development milestones.

To ensure that the chosen solution maximises benefits for society and climate while minimising costs and distributing them fairly between countries and stakeholders, an appropriate approach to Cost-Benefit Analysis (CBA) is one of the topics that should be discussed.

In an earlier discussion paper the NSWPH introduced the Topical Agenda. The Topical Agenda identifies the five key regulatory topics that must be addressed to ultimately arrive at a full enabling framework that can provide sufficient investment certainty to project stakeholders. The third topic is about costs and benefits, and will cover two subtopics, namely agreement on CBA framework and agreement on cross border cost sharing. Discussions to define the principles of a cost benefit assessment and cost sharing methodology are still at an early stage in all North Sea countries, as well as on EU level. The costs and benefits topic also has interdependencies with other topics. The relation of the costs and benefits topic with the other topics is shown in the figure below.

[1] European Commission, Communication from the commission to the European parliament, the council, the European Economic and Social Committee and the Committee of regions – An EU Strategy to harness the potential of offshore renewable energy for a climate neutral future, November 2020.
[2] The umbrella term Power-to-Gas (PtG) is often used to describe conversion of renewable power via electrolysis into different chemical compounds.
[3] https://northseawindpowerhub.eu/discussion-paper-topical-agenda/

Figure 1: The relation of the cost and benefit topic with other topics



In this figure, the five key topics are depicted which must be tackled and addressed so decisions can be made on time to meet key development milestones. Main principles addresses the principles of a CBA and cost sharing methodology and therefore directly impact Cost and Benefit. The Cost and Benefit topic serves the purpose of ensuring final alignment among North Sea countries on the outcome of the cost benefit assessment of the first hub-and-spoke project. Disagreement might require adjustment of the project scope.

This discussion paper aims to show the options that the NSWPH consortium partners have and the decisions the NSWPH still needs to take with regard to the CBA framework for the hub-and-spoke concept. The discussion paper also provides insights into discussions that still need to take place between policy makers. While this discussion paper is focussing on providing an adequate application of a CBA framework for a hub-and-spoke project, the considerations included in this discussion paper are valid in case projects cover more than just a single functionality (unlike conventional projects).

2 CBA framework discussion

When discussing a CBA[4] framework, it is important to first reflect on the overall purpose of executing a CBA. The primary purpose of a CBA is to capture all costs and benefits of an investment project on society. The impacts are measured by a set of objectively defined costs and benefits indicators that are used to quantify and monetize the impacts. Different project alternatives (factuals) can be assessed in a CBA by comparing their effects on the society as a whole. A CBA shows whether the societal benefits of the investment outweigh the societal costs and which investment alternative has the highest expected societal value. The best investment alternative is the one that maximises societal value measured by the net present value of the investment. As such, a CBA can inform project developers and stakeholders in order to optimise the overall configuration of the project.

A CBA is a generally accepted approach for reviewing energy infrastructure projects[5]. Having a CBA is required to provide insights into the relevance of a project and to show decision- and policy makers the added value for society of a project. It will give an ex-ante indication of the project costs and benefits. The hub-and-spoke concept will therefore also be assessed using a CBA[6].

Highlight
A CBA gives insight in the relevance and the add value of energy infrastructure projects.

Separately, an adequate CBA can also provide policymakers to a certain extent ex-ante insight into how costs and benefits are allocated across project stakeholders (OWF developers, infrastructure developers and producers and consumers at large). In doing so, a CBA can therefore play an informative role in subsequent political discussions on how costs and benefits potentially need to be re-allocated (cross-border cost allocation [CBCA]). This paper will, however, focus on providing an insight into the development of an appropriate CBA framework for international, cross-sector hub-and-spoke projects and will therefore not dive into the political considerations of how costs and benefits might need to be re-allocated.

In addition, the CBA can also help to understand the impact and use of a project as input in dialogues with EU institutions. In principle a CBA is able to provide insights into the wider impact of a project, beyond e.g. the directly involved countries. By providing insights into the project impact on other EU countries, it enables project stakeholders to enter discussions to utilise EU funds that are meant for exactly this purpose.

Highlight
A CBA determines how cost and benefits are allocation across project stakeholders and how other EU countries are impacted.

[4] When referring to CBA in this discussion paper, it is assumed that it has a socio-economic welfare perspective, i.e. a societal cost benefit analysis is meant.
[5] ENTSO-E 2nd and 3rd ENTSO-E guidelines, and ENTSOG 2nd methodology report.
[6] As part of the ENTSO-E TYNDP process NSWPH obtained PCI status after undergoing a CBA. However, this was not a full and adequate CBA, as did not capture the full costs and benefits of the hub-and-spoke concept.

3 NSWPH perspective on CBA

In the energy sector, CBA guidelines have been developed for transmission infrastructure development projects in the electricity sector ("ENTSO-E Guideline for Cost Benefit Analysis of Grid Development Projects" and its 2nd and 3rd editions) and the gas sector (ENTSOG 2nd methodology report). These guidelines are enhanced and reviewed every two years under extensive stakeholder consultation, and are subject to an official opinion by the Agency for the Cooperation of Energy Regulators (ACER) and approval by the European Commission. Also, these guidelines and the used terminology are known to policymakers. Therefore, the NSWPH aims to be consistent with these guidelines wherever possible to ensure wide applicability and usage of the results of the CBAs that the NSWPH program will execute.

From a fundamental principles perspective, the currently developed CBA methodologies (by both ENTSOs), are applicable to the hub-and-spoke concept. In other words, in principle the ENTSO-E CBA methodology can be used to assess the costs and benefits of the hub-and-spoke concept. However, the ENTSO-E and ENTSOG guidelines are developed primarily for the assessment of conventional investment projects (e.g. a single interconnection cable or pipeline), for single sector projects (only electricity or only gas) and for infrastructure or storage projects, not for generation assets or grid connection infrastructure. The latter assets are part of the hub-and-spoke concept, since the hub-and-spoke concept incorporates three features:

Highlight
The current CBA guidelines were developed for conventional electricity and gas infrastructure or storage projects.

1. **Hybrid |** Hybrid projects combine offshore wind transmission and interconnection capacity;

2. **Energy sector coupling |** Facilitating the integration of gas, electricity and heat sectors through e.g. Power-to-Gas (PtG) conversion, renewable gas and liquid fuels storage and Gas to Power;

3. **Multinational |** Strong cross-border nature by linking not only two, but multiple individual energy markets.

Text box 1: Defining hybrid

The term "hybrid projects" as used by the European Commission, North Sea Energy Cooperation, ENTSO-E and Roland Berger, refers to projects in which the development and implementation of offshore wind and interconnection capacity is combined.

Hence, the hub-and-spoke concept will include interconnectors to bordering North Sea countries and will enable sector coupling and re-use of existing gas infrastructure through PtG conversion (either on- or offshore). As a result, some adjustments to the application of the CBA guidelines would be required to account for the characteristics of a hub-and-spoke project. In tailoring the CBA framework the NSWPH aims to be in line with the CBA requirements from the – soon to be revised – TEN-E regulation.

Highlight
Adjustment of the CBA methodology is required to assess all characteristics of a hub-and-spoke project.

4 Practical applications CBA and NSWPH suggestions

When looking into the application of an adequate CBA framework, three main issues arise when applying the CBA framework to the hub-and-spoke concept. The issues relate to the definition of scope, the baseline scenario and the factual and counterfactual respectively.

Definition of scope

The first issue concerns the definition of the scope. Due to the large scale of the project and the amount of installed offshore wind capacity, the impact of bringing this capacity onshore can impact not only the coastal regions but will also reach far inland. The scope will depend on how the baseline scenario and counterfactual are defined. Ultimately, the CBA result of the specified hub-and-spoke project considers net effects relative to the defined counterfactual. Hence, if the counterfactual has the same impact on the onshore grid and hence lead to the same need for grid reinforcements, this will not impact the net result.

The question here is to what extent this should be taken into account in the CBA. The ENTSO-E and ENTSOG guidelines prescribe a geographical region that covers (1) the countries on whose territory the project shall be built, all directly neighboring member states and other member states significantly impacted by the project and (2) at least Europe respectively. It is still open whether that should also be the region that is taken into account in the CBA for the hub-and-spoke concept. And to what level of detail this region should be taken into account (e.g. NUTS-1 or NUTS-2, see Figure 2). Also, it is still to be decided whether for example the costs of onshore grid reinforcements (for the electricity grid) and the costs for adjusting the gas grid to accommodate hydrogen transport should be taken into account as well. Alternatively, if we leave out these costs, we may decide on a project without considering the wider impacts to the energy system. This will increase the risk of deciding to invest in a project with a negative (or too low) net present value when all costs are taken into account.

Highlight

A CBA with a too small scope and level of detail risks overlooking the wider impact on the energy system.

Figure 2: Considered NUTS levels

NUTS 1 | Major socio-economic regions

NUTS 2 | Basic regions for the application of regional policies

NUTS 3 | Small regions for specific diagnoses

Baseline scenario

The second issue has to do with the decision on the baseline scenario, which is in essence defining the (local) demand, supply and reference grid that needs to be taken into account when assessing the project. Two possibilities are foreseen to serve as the baseline scenario, namely (i) a business as usual scenario, or (ii) a business as usual scenario plus concrete plans.

Highlight
Two baseline scenario options exists which define the considered demand, supply and reference grid in the project assessment.

In the first option, the business as usual scenario consists of currently active and commissioned offshore wind parks and interconnector capacity projects, as well as current facilities for PtG conversion. An advantage of this approach is that the comparison is not so difficult, because the information on current capacities is readily available. However, the business as usual scenario is a less realistic scenario as currently active and commissioned projects do not meet the energy targets set by the governments.

The second option is a business as usual plus concrete plans scenario. Here, next to currently active and commissioned projects for offshore wind capacity, interconnection capacity and current facilities for PtG conversion, also concrete plans that have not yet been commissioned are taken into account. The advantage of this option is that it leads to a more realistic counterfactual, because it includes the steps towards meeting the 2030 energy targets. However, it is unclear which projects are concrete enough to be included in the scenario. As a comparison, this type of scenario approach is in line with the scenario approach that is used within the ENTSOs for assessing projects as part of the bi-annually TYNDPs.

Highlight
NSWPH suggests using the business as usual plus concrete plans scenario since it provides insights in delivered social welfare in addition to other North Sea area investments.

Taking into account the advantages and disadvantages of the two possibilities, NSWPH suggests to use the business as usual plus concrete plans scenario as a baseline scenario. As such, it can be assessed whether the hub-and-spoke concept contributes to social welfare in comparison to a scenario in which there are other investments in the North Sea area, though only those that are already planned or very likely to take place. In the future, it is more beneficial to have clear boundary conditions for developments to be seen as "concrete", therefore more discussion on this on a EU level could be required. On the short-term, as part of ministerial discussions, the NSWPH program will align with the directly involved countries on the chosen option for the scenarios and will align as much as possible with the ENTSOs guiding scenarios.

Table 1: Baseline scenarios

Elements	1. Business as usual	2. Business as usual + concrete plans
Offshore wind capacity	Currently active and commissioned offshore wind parks. Includes wind parks with an integrated approach such as Kriegers Flak.	Commisioned projects as well as projects in an advanced stage of planning. Includes allocated capacity which has not yet been commissioned (Energy Plans).
Interconnector capacity	Currently active and commissioned projects.	Currently active and commissioned projects. Projects in an advanced stage of planning according to ENTSO-E TYNDP and National Energy Plans.
P2X conversion	Current facilities.	Current facilities and concrete plans.
Comments	The comparison is easier as current capacities are readily available and make for a clear contribution on the NSWPH. However, currently commissioned projects are not a realistic counterfactual as they do not meet the energy targets set by the governments (i.e. meeting the Paris Agreement)	More realistic counterfactual because it includes the steps takes towards meeting the 2030 targets. The outlook of various North Sea countries explicitly states cooperation with other countries. Unclear what projects are 'concrete' enough to be included in the scenario.

Factual and Counterfactual

Aside from deciding on the baseline scenario, another decision is required on the factual, which is the third issue. In the NSWPH hub-and-spoke vision, the factual describes an internationally coordinated and integrated project alternative. It therefore aims to provide an efficient solution to connect and integrate the offshore wind generation capacity to the wider onshore system to satisfy energy demand.

If the configurations of the hub-and-spoke concept was only compared with the baseline scenario it would be possible that there is an alternative to the hub-and-spoke concept that would lead to an even larger societal return. Therefore, it is good practice in CBA analyses to consider different factuals. As the exact configuration of the hub-and-spoke project is not yet determined, there are many different plausible factuals, based on e.g. hub location, offshore wind farm capacity connected to the hub and the hub configuration type (all-electric, all-hydrogen, combined).

Highlight
Uncertainty around how to define the factual and counterfactual exists.

Moreover, to adequately capture the costs and benefits of a hub-and-spoke project and thereby doing justice to the possible economies of scale and scope that such a project can bring, it is necessary to define a counterfactual to which the hub-and-spoke project (factual) is compared. However, how the counterfactual needs to be defined and what it should include, in terms of functionality, is still to be determined.

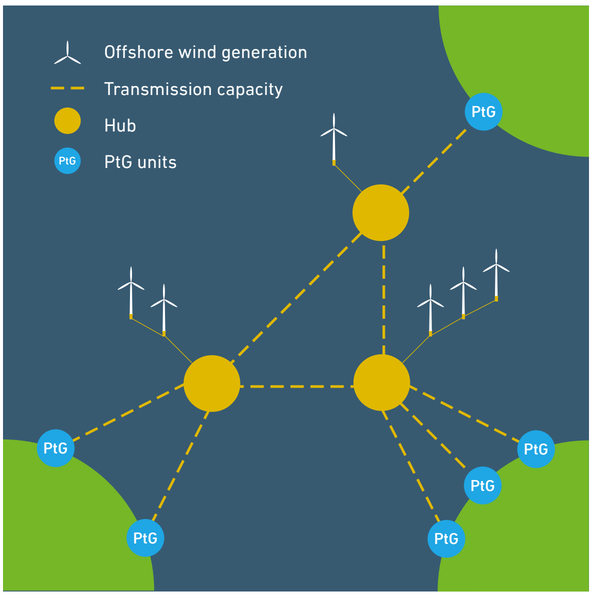
Currently, various approaches to define the counterfactual have been identified to reflect a less integrated, less internationally coordinated alternative to the hub-and-spoke project. As such, a decision on the approach for the counterfactual is required to enable the execution of a CBA for a hub-and-spoke project. In principle, the counterfactual should also be tailored towards ultimately reaching the climate targets. Figure 3 shows one of these options, where the NSWPH factual presents an internationally coordinated solution, where transmission capacities from the "hub-to-shore" and interconnection capacities from "hub-to-hub" are pre-optimized. The counterfactual represents an alternative solution to connecting and integrating the same amount of offshore wind to the wider energy system (i.e. the gas and electricity systems). Annex 1 provides a broader overview of alternative counterfactuals.

Highlight

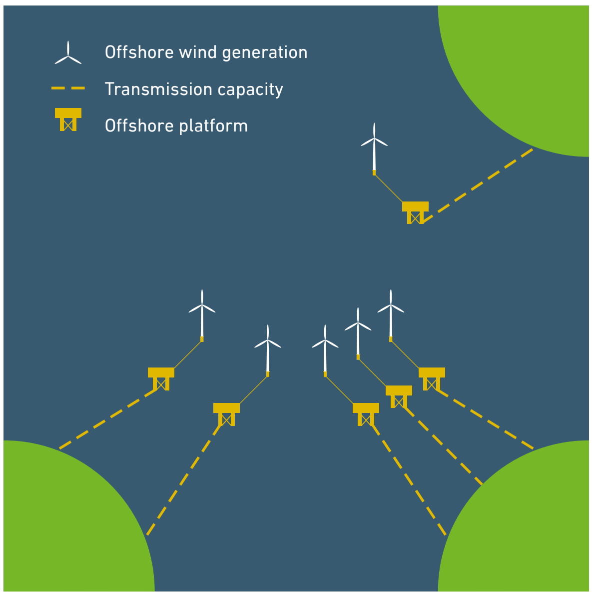
A decision on the counterfactual approach is required to enable CBAs for hub-and-spoke projects.

Figure 3: Factual and Counterfactual option 1

Factual



Counterfactual option 1



Counterfactual option 1 is a less internationally coordinated and less integrated alternative to the hub-and-spoke project where similar levels of offshore wind capacity are connected to the same onshore connection points. However, the connections are radially to their national connection points and without additional PtG capacity to efficiently integrate the offshore wind energy.

Pros | This option provides the most distinct differences between the conventional approach of connecting and integrating offshore wind and the internationally coordinated and integrated approach through a hub-and-spoke project for similar levels of offshore wind capacities.

Cons | From a functionality and a cost perspective the factual and the counterfactual are very different. Thereby determining the drivers in the differences of the factual and the counterfactual is more difficult.

Given the fact that various factuals are still possible, it is also necessary to define an individual counterfactual per factual, thereby enabling a fair comparison between the alternative solutions to connect and integrate the envisioned offshore wind capacities. The risk of this approach is that it may impair the consistency of the CBA assessment, as it complicates the comparison of different factuals.

It is expected that a decision on the factuals, their individual counterfactuals and their relationship to the baseline drives the observable value of the project in a CBA. Therefore, it is intended to discuss these options transparently with policymakers before taking a decision on this topic.

Text box 2: Definitions

Baseline scenario | A description of possible European energy futures, including both supply and demand of energy across the electricity and gas systems and a reference grid that describes the already developed infrastructure.

Factual | This is the project, in the NSWPH view this is a possible internationally coordinated and integrated hub-and-spoke project that defines project characteristics in terms of hub structure and size, connection capacities (also between hubs and to shore) and way of grid integration (e.g. including PtG).

Counterfactual | This is the reference case to which the hub-and-spoke project is compared with. It should therefore reflect a less internationally coordinated and less integrated alternative to the factual.

Quantification and monetisation of benefits

Here, it is explained in more detail how the three different project elements (hybrid, energy sector coupling and multinational) relate to the benefit indicators. Not all expected benefits from the hub-and-spoke concept and alternatives can be meaningfully quantified and monetised. Nonetheless, several important expected benefits can be quantified. In our view, an exact understanding of the nature of the benefits of the hub-and-spoke concept is very important. This conceptual clarity will guide further choices regarding the quantification and monetisation of the benefits and helps to understand the consequences of certain modelling assumptions.

Table 2: CBA indicators

Indicator	Explanation	Quantification and monetization
B1. Socio-economic welfare	Direct impact on total welfare as measured by consumer and producer surplus. This is impacted by changes in the supply curve (production costs).	Δ Consumer surplus (€) , Δ Producer surplus (producers) (€) and Δ Congestion rents (€) (TSO's). Output from market simulations
B2. CO2 variation	The additional societal value of reduction in CO2(eq) emissions not covered in B1 (through energy taxation).	Δ CO2 emission * (Societal value CO2 emission reduction – ETS price). Output from market simulations.
B3. RES integration	Impact on meeting RES targets, international agreements, etc. Additional value not covered in B1 and B2	No objective approach for monetization. Reduction in curtailment (MWh) and MWRES-connected can be reported.
B4. Non-CO2 emissions	Reduction in non-direct greenhouse emissions, such as CO, NO2, SO2 and particulate.	Δ emissions in tonnes per year. Quantification based on post process based on market (redispatch) simulations. No approach for monetization is suggested.
B5. Grid losses	Thermal losses in the grid due to investment. Could be positive if average transport distances increase	Δ thermal losses in the grid. Monetized using yearly average electricity price per zone. Output from network simulations.
B6. System adequacy	Contribution of project to lowering EENS or creating additional adequacy margin.	Δ EENS * VOLL or spare capacity that doesn't need to be installed based on costs of peaking units. Output from monte carlo simulations
B7. System flexibility	Transmission capacity provides flexibility to share flexible units to accommodate fast and deep changes in net demand	% of GTC increase in relation to remaining maximum hourly ramp. No approach for monetization is suggested in ENTSO-E guidelines.
B8 System stability	Ability to regain a state of operation equilibrium after being subject to a physical disturbance.	Hard to quantify. Studies are by their nature complex an time consuming. ENTSO-E (3rd) suggests qualitative scoring.
B9. Avoidance of the Renewal/Replacement costs of Infrastructure	The benefit a project can bring by avoiding or deferring replacing or upgrading existing infrastructure	One-off incremental benefit in EUR million for the avoided or deferred investment costs
B10. Redispatch Reserves	Impact of a project on needed contracted redispatch reserve power plants. This captures the benefits of reducing internal congestions.	Reduction of the maximum amount of necessary redispatch in MW. Can be quantified using redispatch simulations.
S1-3. Residual impacts	Residual social or environmental impacts. E.g. impact on nature and biodiversity.	Residual impact is hard to quantify. Mitigation costs can be monetized but should be included in costs.

The impact of the project on socio-economic welfare, CO2 emissions and parts of security of supply can be quantified using market simulation studies. In terms of the quantification of CO2 emissions, it is relevant to ask: What is the societal value of CO2 emission reductions? How CO2 emissions are priced differs between countries. Some have adopted a national carbon tax, some rely on energy taxation, some rely on the CO2 quota price, etc. This is not as straightforward, as we don't have a unilateral price at EU-level. If we had EU-level carbon taxation, we would have such a price. As one of the primary objectives of hub-and-spoke projects is the effective deployment of clean, renewable energy to cut carbon emissions, this is an important issue for policy makers and project partners to discuss.

Highlight
One societal value of CO2 reductions at EU-level is helpful to capture hub-and-spoke project benefits.

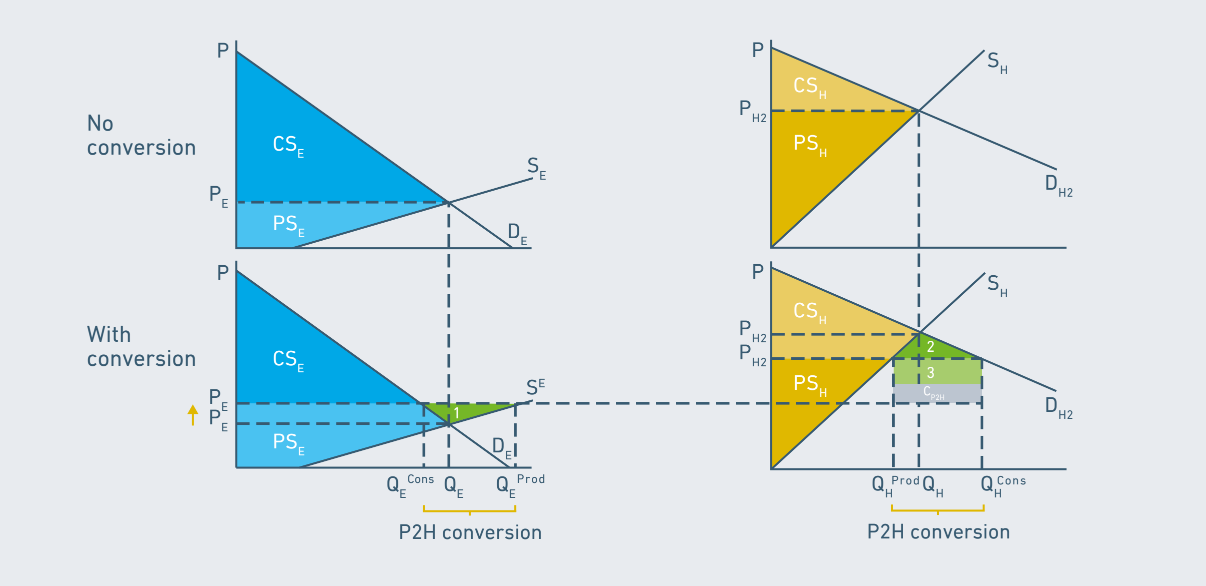
The ENTSO-E 3rd guideline mentions the generation cost approach to calculating the socio-economic welfare impact of a project in case of inelastic demand. The generation cost approach does not provide insight in the distribution of benefits between different stakeholders (countries, OWF, TSOs). This detailed insight is necessary to enable in a next stage whether a compensation between countries or stakeholders within a country is needed. Therefore, we suggest using the total surplus approach to determine the socio-economic welfare indicator. This approach is also mentioned in the ENTSO-E guideline, in which the impact on the socio-economic welfare is measured through the delta in consumer surplus, producer surplus and congestion rents. In case of inelastic demand both approaches deliver the same results.

To quantify the benefits of energy sector coupling it is necessary to simultaneously model supply and demand on the market for electricity and hydrogen. A possible approach to quantify the effects of energy sector coupling is to model PtG conversion as additional demand on the electricity market and additional supply on the hydrogen market. The additional demand for electricity (and therefore supply on the hydrogen market) is dependent on the difference between the electricity price and hydrogen price. Using this approach, different uses of PtG conversion (storage and end usage) are simultaneously captured (see Figure 4).

Highlight
To quantify the benefits of energy sector coupling, supply and demand of electricity and hydrogen should be modeled simultaneously.

Figure 4: Total socio-economic welfare across markets

Electricity market **Hydrogen market**



In the example above, the increase in total welfare is equal to:

1 Increased producer surplus eletricity market
Total welfare in the electricity market increases because of additional producer surplus for converted energy.

2 Increased consumer surplus hydrogen market
Consumers in the hydrogen market benefit from lower prices. Total welfare increases because of additional consumer surplus for newly served demand.

3 Conversion rent
The owner of the P2X conversion assets earns additional surplus. This is equal to the quantity of converted energy multiplied by the price difference between markets (PH - PE), minus the variable cost of conversion (CP2H)1.

Welfare is drawn in the figure for the hydrogen market, but in reality this can be additional surplus for both electricity market or hydrogen market depending on who owns the P2H conversion assets.

The increase in total welfare =

$$(CS_{E,\text{ with project}} + CS_{H,\text{ with project}} + PS_{E,\text{ with project}} + PS_{H,\text{ with project}} + \text{Conversion rent}_{\text{with project}}) - (CS_{E,\text{ without project}} + CS_{H,\text{ without project}} + PS_{E,\text{ without project}} + PS_{H,\text{ without project}} + \text{Conversion rent}_{\text{without project}})$$

The ENTSOG 2nd CBA methodology guideline might be used to identify and quantify the benefits related to PtG conversion. However, since PtG conversion is not a transmission infrastructure project in the gas sector as it is a new source of supply, not all indicators might be relevant.

Due to the large scale of the project and the amount of installed offshore wind capacity, the impact of bringing this capacity onshore can impact not only the coastal regions but will also reach far inland. The geographical perimeter of the model that is used for the quantification should therefore be the pan-European approach. This is in line with the ENTSO-E and ENTSOG guidelines, which prescribe a geographical region that covers (1) the countries on whose territory the project shall be built, all directly neighbouring member states and other member states significantly impacted by the project and (2) at least Europe respectively.

Highlight
Monetisation of some costs and benefits is not straightforward or even impossible, which risks quantification of the full value of a project.

More generally speaking, in theory when performing a CBA both costs and benefits are ideally to be fully monetised. Full and unambiguous monetisation of all costs and benefits enables quantitative project comparison while using only one indicator. However, in practice, this is not straightforward and practically impossible for some costs and benefits. This complicates the execution of the CBA and also does not allow for a quantification of the full value of a project in monetary terms, especially when looking into the long-term future. Current projections show e.g. a decrease in monetary value (in particular socio-economic welfare: indicator B1 of table 2) of interconnection capacity between the various electricity markets and therefore other indicators such as System Adequacy (indicator B6), System Flexibility (indicator B7) and System Stability should be playing a more dominant role in the overall value of additional interconnection capacity. As such, it could be envisioned that in the actual CBA these indicators will need to be valued more significantly when deciding upon the initiation of specific projects. These considerations are especially relevant for a hub-and-spoke project, as a hub-and-spoke project can provide these benefits through adding interconnection functionality.

Highlight
For a hub-and-spoke project indicators as System Adequacy, System Flexibility and System Stability should be playing a more dominant role.

Direct and indirect Costs

The direct costs of the project can be estimated through an estimation of capital expenditures (CAPEX) and operational expenditures (OPEX) of the project. CAPEX includes the costs of the initial investment (e.g. land, buildings, plants, machinery, equipment) and, if applicable, replacement costs. OPEX includes the costs to operate and maintain the new project, such as labor costs, materials, fuel, energy and other consumables. Many different sources can be used as an input for estimating the costs in the factual and counterfactual based on previous CBA studies.

With respect to the scope of the cost estimation, there are two important decisions on indirect cost:

1. The first is whether to in-or exclude the costs of onshore grid reinforcements. Promotion (2018) considers that it might not be necessary to include the onshore grid reinforcement, as the reinforcement need of the onshore grid is expected to be significant regardless of project alternative. We follow the logic that the need for onshore grid reinforcement is likely to be similar for different project alternatives. However, the costs for reinforcements of onshore transmission grids (for electricity and gas) could be expected to be different for the factuals and counterfactual. The coordination between countries in the factual seems to have some large benefits that relate to the need for onshore grid enforcement by reducing congestions. This however could lead to higher costs for the offshore transmission infrastructure. Consequently, this means that when one would fully incorporate the additional costs for offshore grid development, excluding the onshore grid in the CBA might lead to an underestimation of the benefits in the factual. Conceptually, the impact of hub-and-spoke concept on the onshore grid should therefore be included. A relevant question in this regard is: What will the scope be for these grid reinforcements? Should only costs for reinforcements in the countries that are directly affected be included, or also in neighboring countries? Which grid reinforcement needs can be isolated to be caused by the hub-and-spoke project specifically, and which cannot?

Highlight
Not including onshore grid reinforcements costs into the direct projects costs might result in an underestimation of the hub-and-spoke project benefits.

2. The second decision is to in-or exclude the costs of the offshore wind park. A CBA in the energy sector traditionally focuses only on the transmission infrastructure or only on generation. However, for the hub-and-spoke concept there might be important interdependencies between the design of transmission infrastructure and the costs of offshore wind parks. As such, it is important to capture these interdependencies in the costs and benefits. For example, in the factual scenario it is likely that the offshore wind parks are built further from shore, which will have an impact on both construction and operating costs (and other factors such as utilization). The CBA should be able to take into account the impact of the transmission network design (e.g. using hubs or a radial approach) on offshore wind park locations and the costs. This would lead to a more comprehensive CBA, but also increases complexity. It is however not an explicit goal of the CBA to research different project alternatives based on different offshore wind park designs, as is the case for different hub designs.

Highlight
The CBA should be able to consider the impact of the transmission network design of the project on offshore wind park locations and the costs.

Evaluation methods

As mentioned, not all expected costs and benefits can be monetised or quantified. In other cases, a quantification may be the more accurate solution, however, requires many resources and much effort. Here it may be a more pragmatic approach to also use a qualitative assessment approach. Ultimately, the quantified costs and benefits should be integrated into a Net Present Value (NPV) calculation.

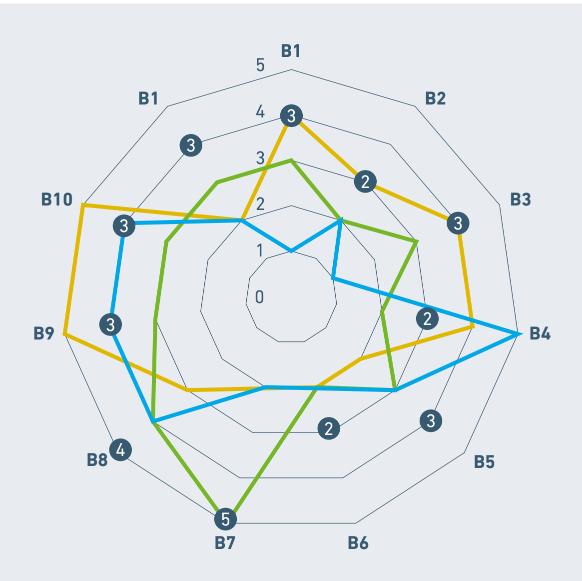
Qualitative assessment approaches can be combined with quantified and monetised costs and benefits in multi-criteria analysis. The main drawback of the qualitative assessment is that it may be difficult to argue that the assessment is totally objective. At least, some objective scoring criteria must be agreed upon between project partners. As such, the methodology for the qualitative assessment can be based on an objective scoring system (e.g. 1-5) based on objectively defined criteria.

The qualitative assessment can be conceptualized through e.g. a spider chart. While the multi-criteria approach assigns subjective weighting factors to Key Performance Indicators (KPIs), the spider chart allows for a comparison of specific KPIs, which are from a project perspective most important. The figure below illustrates how a spider chart could look like. A full list of indicators that needs to be assessed for the factual and the counterfactual can be found in Annex 2.

Highlight

Since not all costs and benefits can be monetised, qualitative assessments can be combined with quantified and monetised costs and benefits in multi-criteria analysis.

Figure 4: Qualitative assessment spider



An example of a conceptualisation of a qualitative assessment based on a scoring systems from 1-5 for 10 KPIs in a spider chart.

5 How can such a CBA be executed?

After a decision on the specific counterfactual is made, it is important to consider the alternatives of actually executing the costs and benefits analysis and simulating the costs and benefits in the various systems that are impacted.

As described, a hub-and-spoke project impacts the electricity system on a bidding-zone level, the grid within a bidding zone as well as the gas/hydrogen grid due to the inclusion of PtG. When focusing on the impact of the project on the electricity grid, we already see a wide range of tools (or so-called studies) that can be used to identify the costs and benefits of a project in the electricity system (see ENTSOE text-box).

Text box 3: ENTSOE

Market studies

Market studies results allow the computation of some of the CBA indicators, such as socio-economic welfare (SEW), CO2 emissions, RES integration and the adequacy component of security of supply. The output of market simulations will be used as an input for defining the generation, consumption and power flows in the grid, allowing load flow calculations to be performed.

NTC | Using a simplified (NTC) model of the physical grid, the bidding areas are represented as a network of interconnected nodes connected by a transport capacity that is available for market exchanges (NTC).

Flow-based | Flow-based market simulations thus use (a representation of) the physical grid capacities to define the constraints for market exchanges rather than a set of independent NTC values.

Network studies | Network studies allow bottlenecks in the grid corresponding to the power flows resulting from the market exchanges to be identified.

Re-dispatch studies

Re-dispatch simulations assist in the computation of the CBA indicators (the same as for market simulations) when it concerns the evaluation of internal projects using the initial generation dispatch from NTC-based market simulations as a starting point.

Flow-based market simulations can offer an alternative approach to compute the CBA indicators for internal projects.

Separately, due to the inclusion of PtG in the overall project scope, a CBA for a hub-and-spoke project the impact on the hydrogen market and infrastructure needs to be assessed on a socio-economic level. As mentioned before, a possible approach to quantify the effects of energy sector coupling is to model PtG conversion as additional demand on the electricity market and additional supply on the hydrogen market. In principle these effects in the electricity and hydrogen market need to be assessed in conjunction.

Finally, the long-term perspective must be considered in the CBA as well, as the SEW result for the one specific hub-and-spoke project may not be stable over time, as the offshore grid can will probably develop step by step. Policy makers therefore need to be aware that the decision to build one specific project may be subject to subsequent investment decisions on the next steps.

To enable more robust decision-making taking into account also these uncertainties, it is good practice to do various sensitivity analysis, thereby getting a better insight into value-drivers and robustness of the overall project.

6 What to expect from the NSWPH consortium?

The NSWPH is planning to start the first regional CBA analysis for the next funneling phase in the second half of 2021, during which NSWPH aims to select and prioritise the best configuration options. In this analysis the NSWPH intends to apply the CBA framework as suggested in this discussion paper, while engaging with policy makers to decide on key aspects such as the counterfactual. The NSWPH is open to amend the framework based on the outcome of discussions that arise from this discussion paper. More specifically, based on this assessment the NSWPH consortium expects that the following elements on the CBA framework require a more in-depth discussion:

- How will the counterfactual be defined? In essence, what is the reference case to which individual hub-and-spoke projects are going to be compared with?
- What is the scope of the impact that needs to be assessed? How deep into the grid does the impact need to be assessed?
- How to ensure fair valuation of indicators that are (currently) non-monetisable?

On a more political level, hub-and-spoke projects are expected to bring benefits to North Sea countries, neighbouring countries and the rest of Europe. A potential problem for the hub-and-spoke concept is that the benefits and costs might not be evenly distributed between different (participating) countries and stakeholders within a country. Providing an enhanced insight into the costs and benefits these types of projects can bring, can facilitate or initiate discussions on cost sharing.

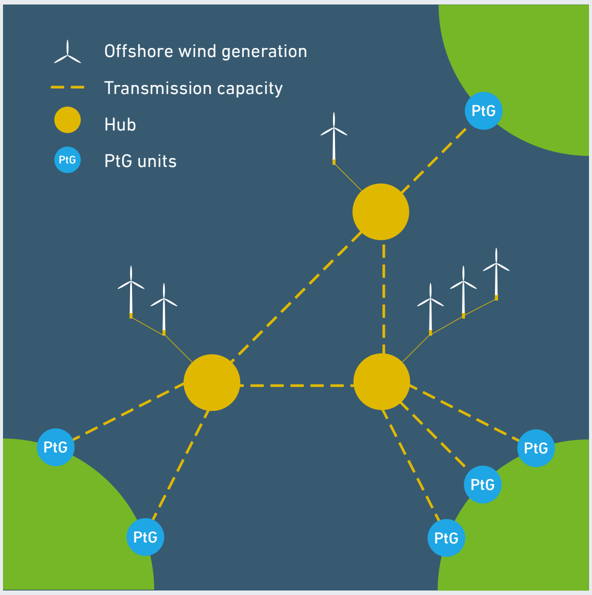
With regard to the envisioned CBA framework by the NSWPH consortium, it is aimed at adequately capturing the costs and benefits of hub-and-spoke projects. However, for policy makers other aspects are expected to be relevant as well, such as RES credits, in light of CO2 reduction targets and obligations. The CBA framework by the NSWPH consortium does not intent to value these credits, but rather expect that by e.g. providing insights into the amount of RES integration in the system through hub-and-spoke projects it can help facilitate possible negotiations between Member States on the sharing of RES credits.

Finally, as previously described, the NSWPH consortium sees a need to further dive into CBA indicators that are currently difficult to quantify or monetise, to enable adequate valuation of additional interconnection capacity between electricity markets. As such, the NSWPH will explore these knowledge gaps in future analysis.

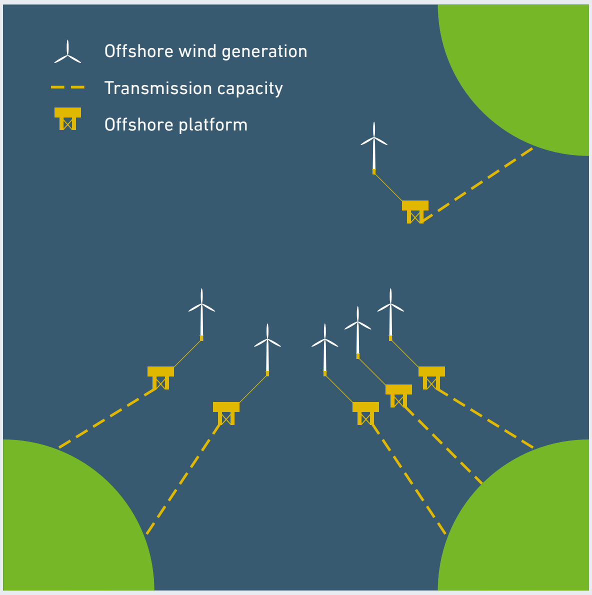
Annex 1 : Optional Counterfactuals

Figure: Counterfactual option 1

Factual



Counterfactual option 1



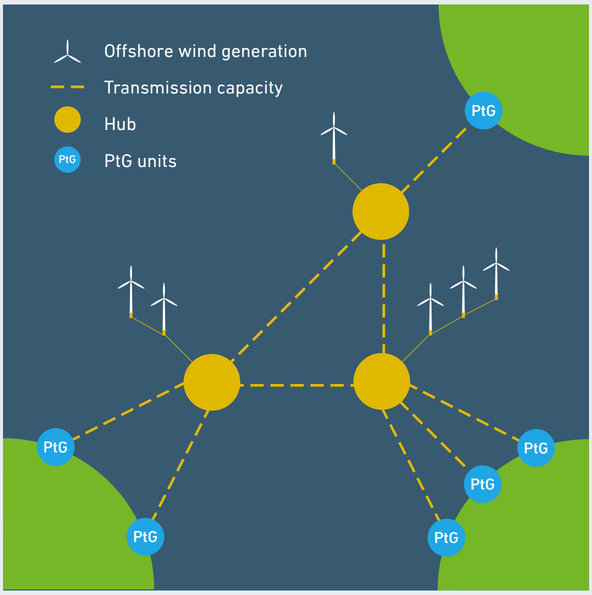
Counterfactual option 1 is a less internationally coordinated and less integrated alternative to the hub-and-spoke project where similar levels of offshore wind capacity are connected to the same onshore connection points. However, the connections are radially to their national connection points and without additional PtG capacity to efficiently integrate the offshore wind energy.

Pros | This option provides the most distinct differences between the conventional approach of connecting and integrating offshore wind and the internationally coordinated and integrated approach through a hub-and-spoke project for similar levels of offshore wind capacities.

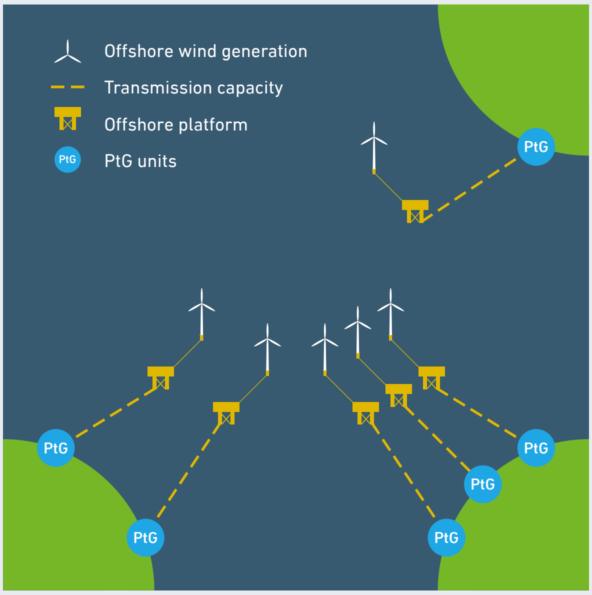
Cons | From a functionality and a cost perspective the factual and the counterfactual are very different. Thereby determining the drivers in the differences of the factual and the counterfactual is more difficult.

Figure: Counterfactual option 2

Factual



Counterfactual option 2



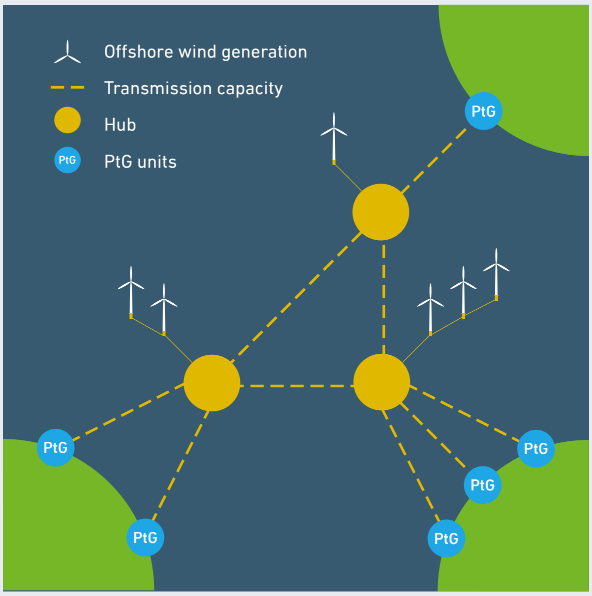
Counterfactual option 2 is similar to counterfactual option 1 in terms of the connected offshore wind capacity, however this option also includes a similar amount of PtG capacity in it's radial alternative to efficiently integrate the offshore wind energy.

Pros | From an integration perspective, the functionality of the factual and counterfactual are more similar, making the overall costs of the factual and counterfactual more comparable. From a functionality perspective there's still a difference, especially on interconnection functionality

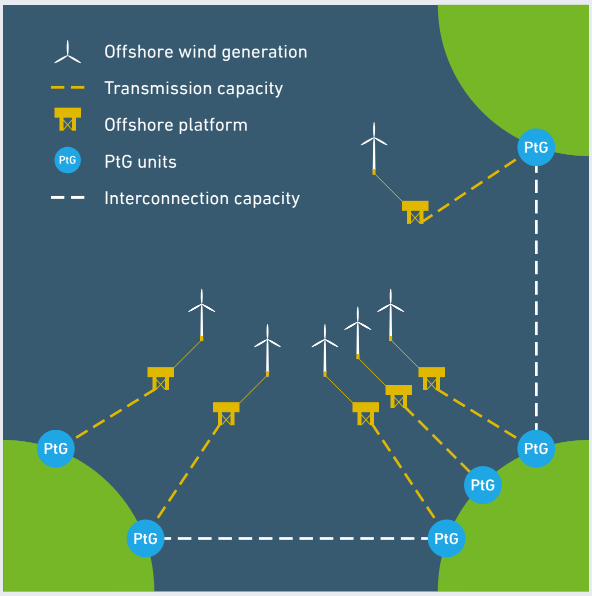
Cons | The amount of PtG capacity in the counterfactual is the same as in the factual. From an integration perspective these capacities could be subject to optimization, which is not included in this option.

Figure: Counterfactual option 3

Factual



Counterfactual option 3



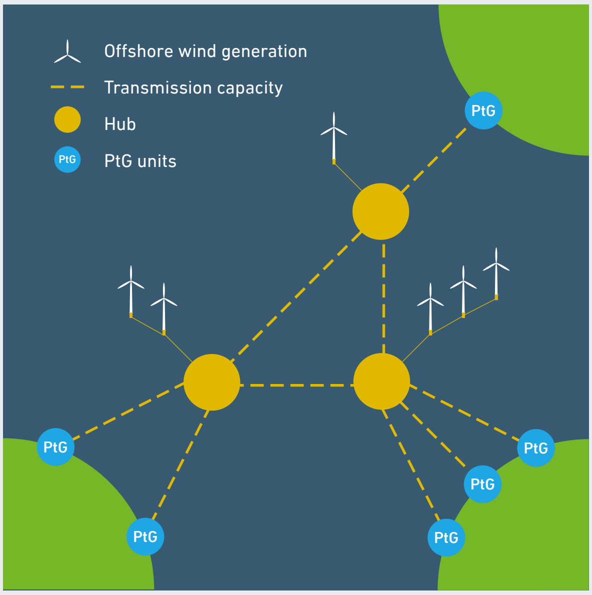
Counterfactual option 3 is similar to option 2, meaning also onshore PtG is part of the offshore wind integration. However additionally, to “match” the functionality of the factual, additional Interconnection capacity is envisioned that have a similar functionality as the factual.

Pros | Theoretically, this factual enables a fair comparison on the overall costs of the required infrastructure, as the functionality of the factual and the counterfactual are (in theory) identical.

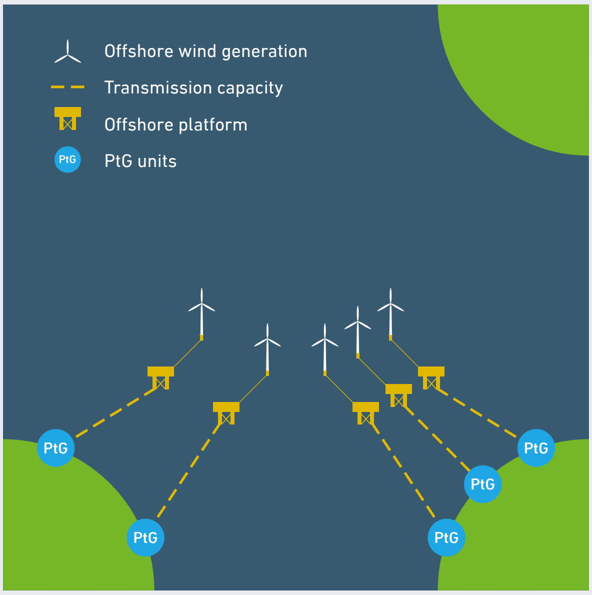
Cons | Defining the counterfactual is very complex (possible impossible) as the impact of a hub-and-spoke goes well beyond providing additional Interconnection capacity in the connected countries. As it provides a by-pass for onshore transmission, it can unlock additional interconnection capacity elsewhere in the pan-European grid. These effects would need to be defined in capacities for the counterfactual, which is a complex exercise.

Figure: Counterfactual option 4

Factual



Counterfactual option 4



Counterfactual option 4 is identical to counterfactual option 1, however in this option it is assumed that overall less offshore wind can be deployed due to lacking "local demand or need" to enable integration and deployment of offshore wind and lacking local capabilities to deploy offshore wind (e.g. due to local spatial constraints).

Pros | Includes fundamental benefits for the assessment of an internationally coordinated approach as it allows you to show that an internationally coordinated approach enables more (efficient) deployment of offshore wind.

Cons | Inherently changing scenario assumptions, therefore factual and counterfactual are actually a comparison of scenarios. Additionally, determining the drivers in the differences of the factual and the counterfactual is more difficult.

Annex 2

Table: Cost Benefit indicators

Benefit indicators:	Socio-economic welfare (both E and G system) CO2 variation RES integration Non-CO2 emissions Grid losses System adequacy System flexibility System stability Avoidance of Renewal/replacement costs of infrastructure Redispatch reserves Residual impacts
Direct project costs:	Infrastructure Investment Costs Infrastructure Operational Costs
Indirect costs:	Onshore grid reinforcements (electricity grid) Onshore grid adaptation costs (gas grid)

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