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The impact of hybrid layout in North Seas electricity projects in a 2030 European scenario

Assessment of system benefits for the pan-European power system through METIS

CARERI F

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Joint Research Centre

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Executive summary

With the ratification of the Paris Agreement in September 2016, the European Union aims to lead global efforts to put the world on track to avoid dangerous climate change consequences. This will has been further confirmed in the European Commission's long term strategy to reach climate-neutrality by 2050. The implementation of an effective long term decarbonisation strategy cannot be separated by the deployment of renewable energy sources and the realisation of cross-border electricity projects: this is particular relevant for the North Sea area, where governments of the relevant countries have opted for an energy cooperation strategy creating suitable conditions for the development of offshore wind energy.

As European Commission's science and knowledge service, the JRC has been requested to perform modelling and analytical support to identify EU-wide potential benefits in the operation of selected generation and transmission assets in the North Seas as they were realised in hybrid configuration (i.e. synergic planning and commissioning of both generation and transmission assets) by 2030. In order to perform this task, the METIS tool – able to simulate the operation of energy systems and markets on an hourly basis over a year – has been used. The base scenario in mainly based on the European Commission's EUCO30 2030 scenario: some study-specific modifications concern the update of expected transmission capacities in 2030 as well as in the installed capacity values for offshore wind power. In the context of the analysis, the benefit indicators considered are consistent with the ones identified by the European Network of Transmission System Operators (ENTSO-E) in its cost-benefit analysis guidelines.

The following infrastructure projects have been analysed:

- COBRAcable
- DE OWF connected to NL
- Nautilus
- NeuConnect
- IJmuiden Ver OWF to GB
- CGS IJmuiden Ver - Norfolk

In the study, it is important to keep in mind the underlying assumption behind it, and that the hybrid configuration (coordinated development of offshore wind power capacity and offshore grids) for this purpose is compared to a reference configuration (offshore wind power capacity, grids connecting them to shore and interconnectors developed separately): in other words, **hybrid assets are not compared with a no-development option** (zero-alternative). **The impact of the coordinated realisation of transmission and generation assets has only been analysed in terms of operational performances**: in addition, **the benefits related to hybrid assets in relation to spatial planning are not assessed**. The approach in calculating benefits in electricity infrastructure development is in line with the methodology used by ENTSO-E in the Ten Year Network Development Plan (TYNDP).

Looking at the results it can be noted how the values of the system level indicators in the hybrid configuration, compared to its specific reference configuration, involve a small reduction of system social welfare. This expected result relates to the fact that, in the hybrid configuration, offshore wind power has to be conveyed from generators to the rest of the system using the interconnector, resulting in reduced available transmission interconnection capacity for the regular power exchange between the pertinent countries. On the other hand, in the reference configuration, offshore wind generation is directly connected to one bidding zone, without the need to use any cross-border transmission infrastructure to convey the production to that bidding zone.

Analysing the breakdown of the system social welfare into its components, it can be noted an overall increase in the congestion rent, an overall increase in the consumer

surplus and an overall decrease in producer surplus; however, as already mentioned, the assessment in this study considers only the operational performances of hybrid assets compared with their respective reference configurations, so this result should not be interpreted as an overall negative performance of hybrid configuration with respect the reference one. **The results of this study should therefore be used in a wider cost-benefit analysis, also taking into account additional cost-benefit indicators such as CAPEX and OPEX savings in realising hybrid electricity projects in the North Seas area**.

1 Introduction

The European Union played a key role in the definition of the world's first universal, legally binding climate deal in Paris in December 2015. With its ratification of the Agreement in September 2016, the EU aimed to lead global efforts to put the world on track to avoid dangerous climate change consequences. On 28 November 2018, the European Commission presented its strategic long-term vision[1] for a prosperous, modern, competitive and climate-neutral economy by 2050. The strategy shows how Europe can lead the way to climate neutrality by investing into realistic technological solutions, empowering citizens, and aligning action in key areas such as industrial policy, finance, or research – while ensuring social fairness for a just transition. Following the invitations by the European Parliament and the European Council, the Commission's vision for a climate-neutral future covers nearly all EU policies and is in line with the Paris Agreement objective to keep the global temperature increase to well below 2°C and pursue efforts to keep it to 1.5°C.

The effective implementation of a European long term decarbonisation strategy has at its core the deployment of renewable energy sources and the realisation of cross-border electricity projects: a synergic planning of renewable energy sources and transmission asset can identify possible benefits that could not be exploited if the two activities are performed separated.

This is particular relevant for the North Seas area: with the political declaration on energy cooperation between North Seas Countries[2] of June 2016, Belgium, Denmark, Germany, Ireland, Luxembourg, the Netherlands and Sweden and Norway have agreed to further strengthen their energy cooperation, creating suitable conditions for the development of offshore wind energy in order to ensure a sustainable, secure and affordable energy supply in the North Seas countries.

Energy cooperation between the North Seas countries focuses on four main areas:

- Spatial planning will aim at optimising the use of limited space in this intensively used sea. This will include data sharing, finding common approaches to environmental impacts, and the coordination of permitting procedures
- The electricity grid has to be developed so that it is able to accommodate large scale offshore wind energy. Markets should be well connected to allow electricity to flow when and where it is needed. The regional work in this field should include coordinated grid planning and development, but also exploring potential synergies with the offshore oil and gas sectors
- In future, participating countries have to share information about their individual offshore infrastructure needs, helping plan the investments as well as align support schemes and mobilise investment capital for joint projects
- Identify best practices and ways to harmonise technical rules and standards across the region. The cooperation also aims to reduce costs throughout the lifecycle of generation facilities. To achieve this, the participating countries will work towards mutual recognition of national standards

The cooperation between North Seas countries is ensured by four Support Groups[3] focusing on different work streams: as European Commission's science and knowledge service, the JRC has been requested to perform modelling and analytical activities to support the "Development and regulation of offshore grids and other offshore infrastructure" Support Group, with the aim to **identify EU-wide potential benefits in the operation of selected generation and transmission assets in the North Seas as they were realised in hybrid configuration by 2030** (i.e. synergic planning and commissioning of both generation and transmission assets).

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(1) https://ec.europa.eu/clima/policies/strategies/2050_en

(2) http://europa.eu/rapid/press-release_IP-16-2029_en.htm

(3) https://ec.europa.eu/energy/sites/ener/files/documents/energy_cluster_paper_-_final_with_date.pdf

The goal of this JRC study is to analyse the operational performances of selected offshore wind power and electricity interconnection projects in the hybrid configuration with respect to a reference one where the planning and the realisation of the generation and transmission projects are independent. To perform this task, the JRC used METIS (a zonal tool used by the European Commission to further support its evidence-based policy making, for electricity and gas), having built in the last years significant modelling capabilities on it.

The operational performances have been measured by defining a set of benefit indicators that are consistent, with reference to the scope of the analysis, with the "Guidelines for cost-benefit analysis of grid development projects" developed by the European Network of Transmission System Operators (ENTSO-E) and approved by the European Commission in September 2018 [1].

The report is structured as follows:

- Section 2 describes the modelling approach, in terms of adopted tool, scenario definition, modelling assumptions and considered benefit indicators
- Section 3 described the cases analysed on hybrid and reference configuration
- Section 4 provides the results of the METIS analyses at system level.

2 Modelling approach

This section shortly describes the modelling approach followed to analyse the impact of the synergic deployment of generation and transmission assets in the North Seas area. After a brief description of the METIS tool, used to carry out the analyses, the modelled scenario – with its main drivers – is presented. The section ends with a discussion of the modelling assumptions enforced in the analytical approach and presenting the benefit indicators that have been calculated through the simulations.

2.1 Description of the METIS tool

METIS is a mathematical model providing analysis of the European energy system for electricity, gas and heat. Originally developed by Artelys with the support of IEAW (RWTH Aachen University), ConGas and Frontier Economics as part of Horizon 2020 and closely followed by DG ENER, it simulates the operation of energy systems and markets on an hourly basis over a year, while also factoring in uncertainties like weather variations analysing, for example, the hour-by-hour impact of using more renewable energy: the model can be used at national or regional level.

The METIS power system module used in this study includes models of the European power system, representing power production, consumption and transmission assets. It takes as input data for production capacities, annual demand, annual renewable power generation, NTCs as well as fuel and CO_2 prices for all 28 EU Member States (plus complementary data for the 6 non-EU countries Switzerland, Norway, Serbia, former Yugoslav Republic of Macedonia, Montenegro and Bosnia-Herzegovina from external sources).

The goal of the tool is simulating the power system operation at hourly time steps in order to minimise operation costs, assuming an inelastic load. Results are provided for each element of the model (generation, fuel consumption, CO_2 emissions). The power system module embeds a model for reserve (*Frequency Containment Reserve*, FCR; *automatic Frequency Restoration Reserve*, aFRR; *manual Frequency Restoration Reserve*, mFRR) whose allocation could be optimised simultaneously with the power dispatch. The power system module can be used to conduct system studies such as generation adequacy analysis, impact of RES integration on operations, cost-benefit analysis of infrastructure projects, etc. All deliverables related to METIS, including all technical specifications documents and studies are published on the METIS European Commission website [1].

2.2 Scenario definition

The starting point in developing a scenario suitable to analyse the role of hybrid electricity projects in the North Seas area is represented by the European Commission EUCO30 scenario [3] where the European Union meets the following 2030 targets: 40% GHG emissions reduction, 27% share of RES on final energy consumption and 30% of energy efficient target.

The choice to model this particular scenario encompassing the aforementioned targets with respect to a scenario including the recently approved one by the European Parliament[4] is motivated by the fact that this scenario was already successfully implemented as a METIS *context*: this allowed saving considerable amount of time in the implementation from scratch of the modelling framework for the analyses. Moreover, it must be pointed out that the results of the analysis are provided, for each analysed project, as differences between two cases:

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(4) In November 2018 the European Parliament approved a 32% EU-wide binding target for RES by 2030 and 32.5% efficiency.

- a **reference case**, where the interconnector projects are developed in a configuration without exploiting synergies between transmission and offshore wind generation deployment;
- a **hybrid case**, where it is investigated a possible generation-transmission synergy.

Since there is scenario coherence between the cases, it is expected that the sensitivity of the provided results with respect to variations in the boundary condition of the scenario are small: therefore, it can be concluded that the resilience of the results for what concerns the scenario is, in the context of the analysis, sufficiently robust.

Assuming the EUCO30 as starting point, the transmission network capacities for the target year have been modified to characterise the scenario accordingly to the goal of the study. The values for *Net Transfer Capacity* (NTC) in the 2030 scenario used in this study are reported in Table 3 in the Annex: in particular, they have been obtained considering:

- 2030 values from ENTSO-E *Ten Tear Network Development Plan* (TYNDP) 2016 [4]
- 2027 values from ENTSO-E TYNDP 2018 [5]
- expected timeline of the projects from ENTSO-E TYNDP 2018 [5]

When not specified otherwise, the reference case is coincident with the scenario described: in fact, the interest of the study is to analyse the specificity of each project in its hybrid configuration. This, however, does not allow having one common reference case suitable for all as the PINT (*Put IN one at the Time*) or TOOT (*Take Out One at the Time*) approaches in ENTSO-E TYNDPs.

2.3 Modelling assumptions

The power system modelled in the study is represented by a network in which each node represents a country that can be linked to others with power transmission links, modelled through the *Net Transfer Capacity* (NTC) approach. This means that no detailed representation of the transmission network inside a country is included: moreover, the distribution of the power flows as a function of the impedances of the transmission network system is discarder. Finally, the zonal approach implies also the *Direct Current* approximation: therefore transmission losses are not accounted.

As described in section 2.1, METIS is able to model the effect of climatic conditions on power system operation by means of the definition of *climatic years* as a combination of pertinent time series, as example, for RES production (i.e. solar PV, onshore and offshore wind, hydropower, etc.) and electricity demand (dependant on temperature time series): this, however, requires to sequentially run a configuration of the power system resulting for each climatic year, resulting in a higher computational burden.

Since the goal of the study is to assess the impact of deploying in a synergic way electricity interconnectors and offshore wind farms and the effect it has on the operation of the power system (in terms of variation of benefit indicators resulting from power system simulations), the METIS tool has been used in a differential way[5]: considering this, it is expected that the variability in the outputs resulting from different climatic conditions would be sufficiently small. Since the aforementioned hypothesis is considered reasonable, it has been decided to run METIS only in the average climatic year: this is expected to be an acceptable trade-off between accuracy and resources.

For similar reasons, it has been decided to not run the reserve module in METIS: the variation of the reserve requirements would be exclusively related to the shift of part of

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(5) As explained in section 2.4, benefits are assessed as difference of each indicator between a hybrid case and a reference case: this implies, as described in section 3, only a variation of the connection point of offshore wind capacity and topology of the electricity interconnector. Therefore, benefit indicators are always presented in relative terms.

the offshore wind power from a zone to another one (see section 3) and this is expected to have a small impact on the (relative) benefit indicators.

2.4 Benefit indicators

This section describes the system level benefit indicators computed as difference of the METIS output between the hybrid case and the reference case (see section 3).

Some of the benefits showed are provided as monetised indicators, while some are not monetised: concerning the latter, an explanation on how the pertinent variable is treated in the cost minimisation objective function in METIS is provided. Considering the extent of the study, this set of indicator is consistent with the ones defined by ENTSO-E in [1].

2.4.1 Monetised benefit indicators

2.4.1.1 Variation of producer surplus

The variation of system level producer surplus for offshore wind power generators[6] (ΔPS_{OWF}) and for the rest of the generation mix (ΔPS_{other}) is computed according to the following equations: it is assumed that generators bids at their marginal cost of generation.

$$\Delta PS_{OWF} = \left. \sum_{h=1}^{8760} \sum_{z=1}^{N_Z} \sum_{\substack{g=1 \\ g\in\alpha_z \\ g\in\Pi_{OWF}}}^{N_{G,z}} \left(MP_{z,h} - PC_{g,h}\right) \cdot P_{g,h} \right|_{hybrid} - \left. \sum_{h=1}^{8760} \sum_{z=1}^{N_Z} \sum_{\substack{g=1 \\ g\in\alpha_z \\ g\in\Pi_{OWF}}}^{N_{G,z}} \left(MP_{z,h} - PC_{g,h}\right) \cdot P_{g,h} \right|_{reference}$$

$$\Delta PS_{other} = \left. \sum_{h=1}^{8760} \sum_{z=1}^{N_Z} \sum_{\substack{g=1 \\ g\in\alpha_z \\ g\in\Pi_{other}}}^{N_{G,z}} \left(MP_{z,h} - PC_{g,h}\right) \cdot P_{g,h} \right|_{hybrid} - \left. \sum_{h=1}^{8760} \sum_{z=1}^{N_Z} \sum_{\substack{g=1 \\ g\in\alpha_z \\ g\in\Pi_{other}}}^{N_{G,z}} \left(MP_{z,h} - PC_{g,h}\right) \cdot P_{g,h} \right|_{reference}$$

where:

- *h* is the index enumerating the hours of the simulated time window (one year of simulation);
- *z* is the index enumerating the METIS modelled zones (N_Z is the total number of zones);
- *g* is the index enumerating the generators belonging to the *z*-th zone (α_z is the set of generators belonging to the *z*-th zone);
- Π_{OWF} is the set of generators that are offshore wind farms in the *z*-th zone;
- Π_{other} is the set of generators that are not offshore wind farms in the *z*-th zone;
- $MP_{z,h}$ is the marginal price in the *z*-th zone at the *h*-th hour [€/MWh];
- $PC_{g,h}$ is the marginal cost of production for the *g*-th generator at the *h*-th hour [€/MWh];
- $P_{g,h}$ is the generation output for the *g*-th generator at the *h*-th hour [MW];

2.4.1.2 Variation of consumer surplus

The variation of system level consumer surplus ΔCS is computed according to the following equation: it is assumed that the maximum *willingness-to-pay* of the aggregated (inelastic) load is equal to the *Value of Lost Load* (VoLL).

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(6) This refers to the variation of Producer Surplus for all offshore wind power generators, not just for the amount of installed capacity that is shifted in the hybrid configuration.

$$\Delta CS = \left.\sum_{h=1}^{8760}\sum_{z=1}^{N_Z}\left(VoLL_{z,h} - MP_{z,h}\right)\cdot D_{z,h}\right|_{hybrid} - \left.\sum_{h=1}^{8760}\sum_{z=1}^{N_Z}\left(VoLL_{z,h} - MP_{z,h}\right)\cdot D_{z,h}\right|_{reference}$$

where:

- *h* is the index enumerating the hours of the simulated time window (one year of simulation);
- *z* is the index enumerating the METIS modelled zones (N_Z is the total number of zones);
- $\mathrm{VoLL}_{z,h}$ is the VoLL for the *z*-th zone at the *h*-th hour: the METIS default constant and system-wide value of 15000 €/MWh has been used in the optimisation procedure;
- $MP_{z,h}$ is the marginal price in the *z*-th zone at the *h*-th hour [€/MWh];
- $D_{z,h}$ is the system (inelastic) load for the *z*-th zone at the *h*-th hour [MW].

It can be easily noted how the variation of consumer surplus is not a function of the chosen VoLL.

2.4.1.3 Variation of congestion rent

The variation of system level congestion rent – or merchandise surplus – (ΔCR) is computed according to the following equations:

$$\Delta CR = \left.\sum_{h=1}^{8760}\sum_{m=1}^{N_Z}\sum_{\substack{n=1\\ n\in\beta_m}}^{N_Z}\left(MP_{m,h} - MP_{n,h}\right)\cdot T_{m,n}\right|_{hybrid} - \left.\sum_{h=1}^{8760}\sum_{m=1}^{N_Z}\sum_{\substack{n=1\\ n\in\beta_m}}^{N_Z}\left(MP_{m,h} - MP_{n,h}\right)\cdot T_{m,n}\right|_{reference}$$

where:

- *h* is the index enumerating the hours of the simulated time window (one year of simulation);
- *m* is the index enumerating the METIS modelled zones (N_Z is the total number of zones);
- *n* is the index enumerating the METIS modelled zones connected to the *m*-th zone (β_m is the set of zones connected to the *m*-th zone);
- $MP_{m,h}$ is the marginal price in the *m*-th zone at the *h*-th hour [€/MWh];
- $MP_{n,h}$ is the marginal price in the *n*-th zone at the *h*-th hour [€/MWh];
- $T_{m,n}$ is the power flow from the *m*-th to the *n*-th zone.

2.4.1.4 Variation of social welfare

The variation of system social welfare ΔSW is computed as the sum of producer surplus (both components), consumer surplus and congestion rent:

$$\Delta SW = \Delta PS_{OWF} + \Delta PS_{other} + \Delta CS + \Delta CR$$

2.4.2 Not monetised benefit indicators

2.4.2.1 Variation of Energy Not Served

The variation of (expected) system *Energy Not Served* (ENS) is provided in MWh/a; it is computed according to the following equation:

$$\Delta ENS = \sum_{h=1}^{8760}\sum_{z=1}^{N_Z} ENS_{z,h}\Bigg|_{hybrid} - \sum_{h=1}^{8760}\sum_{z=1}^{N_Z} ENS_{z,h}\Bigg|_{reference}$$

where:

- h is the index enumerating the hours of the simulated time window (one year of simulation);
- z is the index enumerating the METIS modelled zones (N_Z is the total number of zones);
- $\mathrm{ENS}_{z,h}$ is the (expected) ENS computed by METIS for the z-th zone at the h-th hour.

As shown in section 2.4.1.2, it has been assumed in METIS a system-wide VoLL corresponding to 15000 €/MWh. This penalty factor has not to be intended as the economic value of ENS but as a sufficiently high mathematical parameter used to minimise it.

2.4.2.2 Variation of CO_2 emissions

The variation of system CO_2 emissions is reported in kt/a; it is computed according to the following equation:

$$\Delta EmiCO_2 = \sum_{h=1}^{8760}\sum_{z=1}^{N_Z}\sum_{\substack{g=1\\ g\in\alpha_z}}^{N_{G,z}} \chi_g \cdot P_{g,h}\Bigg|_{hybrid} - \sum_{h=1}^{8760}\sum_{z=1}^{N_Z}\sum_{\substack{g=1\\ g\in\alpha_z}}^{N_{G,z}} \chi_g \cdot P_{g,h}\Bigg|_{reference}$$

where:

- h is the index enumerating the hours of the simulated time window (one year of simulation);
- z is the index enumerating the METIS modelled zones (N_Z is the total number of zones);
- g is the index enumerating the generators belonging to the z-th zone (α_z is the set of generators belonging to the z-th zone);
- χ_g is the emission factor [t/$MWh_{electric}$] for the g-th generator;
- $P_{g,h}$ is the generation output for the g-th generator at the h-th hour [MW].

The economic value of CO_2 emission is already internalised in producer costs. The value considered for CO_2 emission price, consistent with EUCO30 scenario [3], is 27 €/t; according to this, "coal is before gas" in the merit order curve.

2.4.2.3 Variation of RES curtailment

The variation of RES curtailment is provided in MWh/a; it is computed according to the following equation:

$$\Delta ResCurt = \sum_{h=1}^{8760}\sum_{z=1}^{N_Z} ResCurt_{z,h}\Bigg|_{hybrid} - \sum_{h=1}^{8760}\sum_{z=1}^{N_Z} ResCurt_{z,h}\Bigg|_{reference}$$

where:

- h is the index enumerating the hours of the simulated time window (one year of simulation);
- z is the index enumerating the METIS modelled zones (N_Z is the total number of zones);

- $ResCurt_{z,h}$ is the RES curtailment computed by METIS for the z-th zone at the h-th hour.

METIS minimises RES curtailment in the objective function using a penalty factor equal to 0.5 €/MWh. This penalty factor has not to be intended as the economic value of RES curtailment but as a mathematical parameter used to minimise it.

3 Description of the cases

This section describes in detail how the following cases have been modelled in METIS in both hybrid and reference configurations:

- COBRAcable
- DE OWF connected to NL
- Nautilus
- NeuConnect
- IJmuiden Ver OWF to GB
- CGS IJmuiden Ver - Norfolk

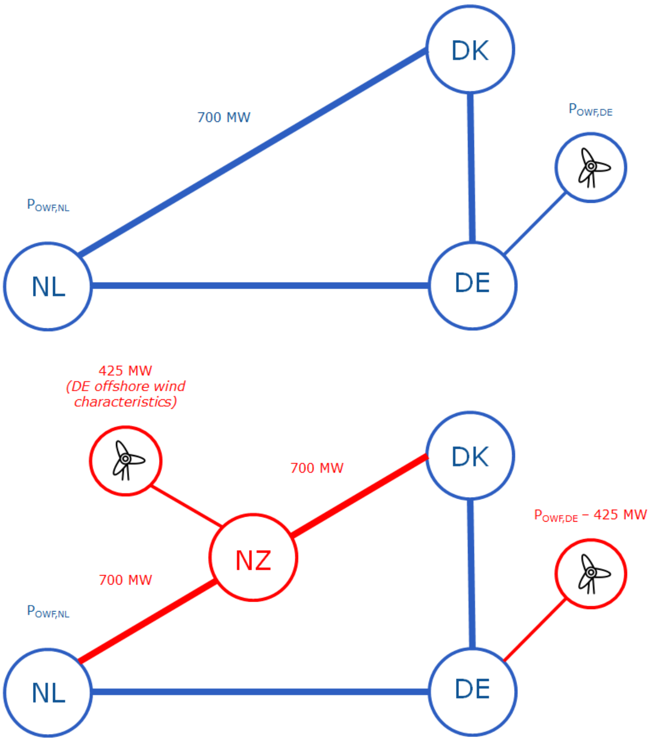
For each case, the system layout in the reference and in the hybrid case is presented.

3.1 COBRAcable

COBRAcable is an interconnection project between Endrup (Denmark) and Eemshaven (Netherlands) consisting of 320 kV DC subsea cable and related substations on both ends, with a length of 325 km, applying *Voltage Source Converter Direct Current* (VSC-DC) technology: at the time of writing (December 2018) the project is under construction and, according to Energinet and ENTSO-E estimates, it will be commissioned in the third quarter of 2019 (labelled as "investment in time" in [5]). The project has been included in the third list of *Projects of Common Interest* (PCIs) released in November 2017.

Figure 1 shows the configuration of the COBRAcable interconnector project in the reference and in the hybrid configurations: the variations of the latter with respect to the former are shown in red.

Figure 1. System layout in reference (upper part) and hybrid case (lower part) for COBRAcable



Source: JRC, DG ENER, Roland Berger, 2019.

For what concerns the analysis in this study, the project is already included in the 2030 scenario in its reference point-to-point configuration: in order to investigate possible synergies between with the deployment of offshore wind power in the area and the development of the electricity interconnector, the hybrid configuration in METIS has been implemented as follows:

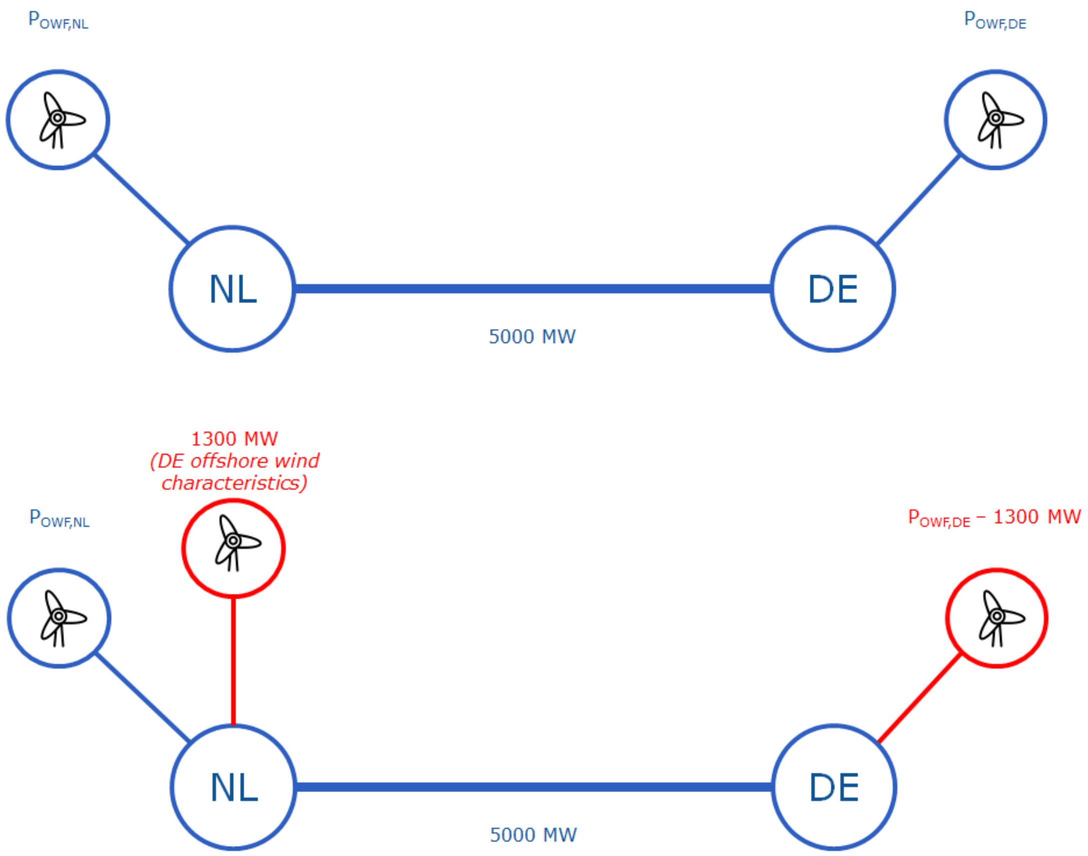
- the COBRAcable interconnector has been split in two halves and an additional fictitious zone NZ (*New Zone*) has been introduced in the METIS model;
- 425 MW of offshore wind power (with German offshore wind characteristics) has been connected in NZ. This capacity has been removed from German total offshore wind installed capacity.

3.2 DE OWF connected to NL

This case does not involve any variation of the cross-border transmission system layout: compared with the reference configuration (coincident with the 2030 scenario), the hybrid configuration in METIS consists in the shift of 1300 MW of German offshore wind capacity that has to be connected in Netherlands.

Figure 2 shows the configuration of this case in the reference and in the hybrid configurations: the variations of the latter with respect to the former are shown in red.

Figure 2. System layout in reference (upper part) and hybrid case (lower part) for DE OWF connected to NL



Source: JRC, DG ENER, Roland Berger, 2019.

3.3 Nautilus

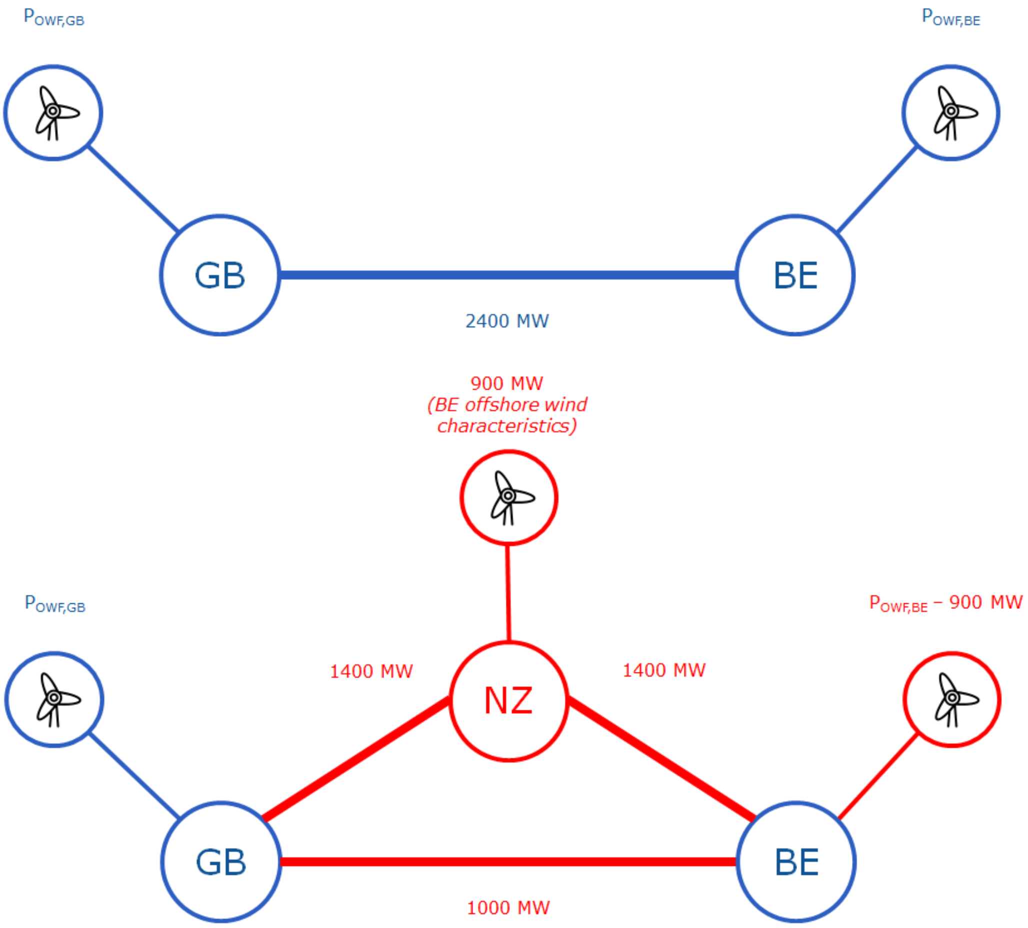
The Nautilus project is a future 1000÷1400 MW HVDC connection between South-Eastern England and Belgium, which is expected to be commissioning the earliest by 2028 (indicative timing declared by ENTSO-E). The project is currently labelled by ENTSO-E as "Under consideration" in [5], so timing, location, routing, capacity are subject to further studies. The reference TSOs, Elia and NGIHL, are currently conducting a bilateral feasibility study. The project has been included in the third list of *Projects of Common Interest* (PCI) released in November 2017.

For what concerns the analysis in this study, the project is already included in the 2030 scenario in its reference point-to-point configuration: in order to investigate possible synergies between the development of the offshore wind power in the area and the electricity interconnector, the hybrid configuration has been implemented in METIS as follows:

- the 1400 MW Nautilus interconnector has been split in two halves and an additional fictitious zone NZ (*New Zone*) has been introduced in the METIS model;
- 900 MW of offshore wind power (with Belgian offshore wind characteristics) has been connected in NZ. This capacity has been removed from Belgian total offshore wind installed capacity.

Figure 3 shows the configuration of the Nautilus project in the reference and in the hybrid configurations: the variations of the latter with respect to the former are shown in red.

Figure 3. System layout in reference (upper part) and hybrid case (lower part) for Nautilus



Source: JRC, DG ENER, Roland Berger, 2019.

3.4 NeuConnect

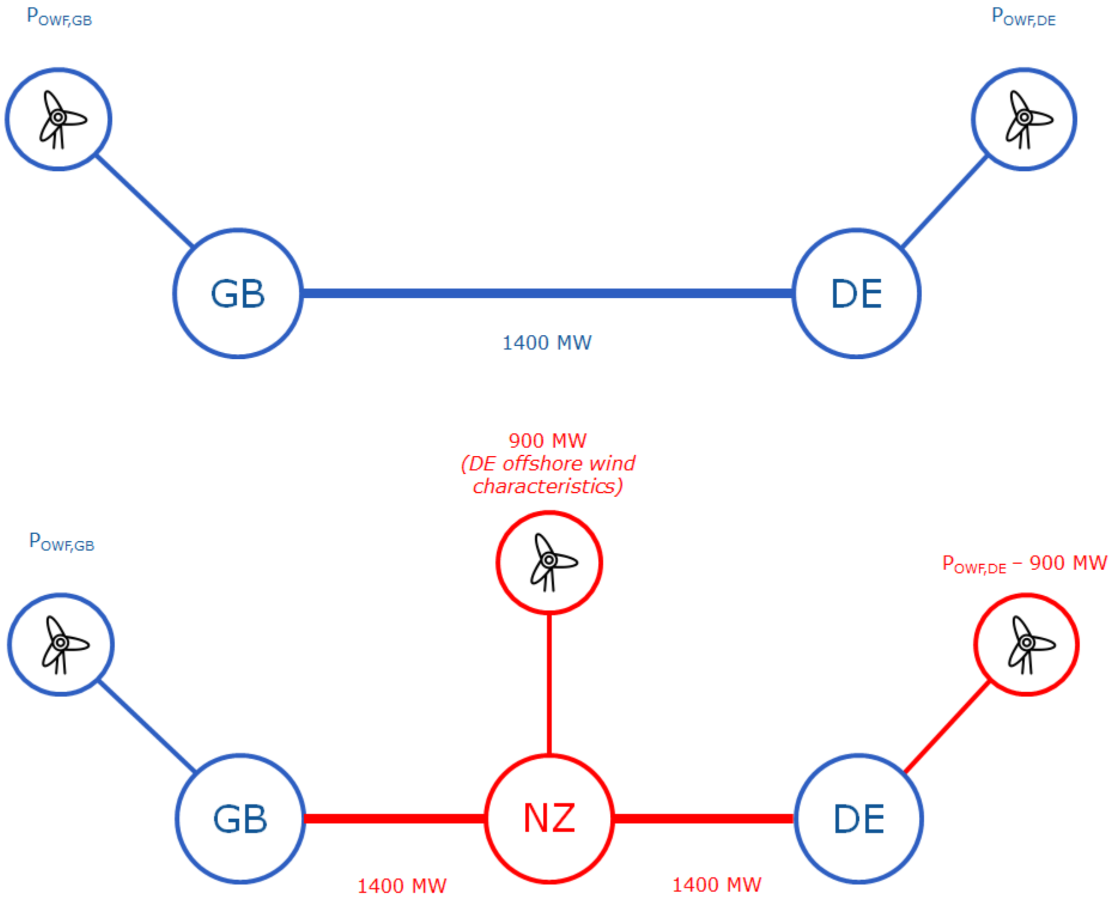
This NeuConnect is expected to be the first subsea HVDC electricity interconnector linking Great Britain (Grain 400 kV substation in Kent) and Germany (Fedderwarden 380 kV substation). With a length of approximately 700 km, the project is currently in permitting phase and, as declared by ENTSO-E in [5], it should be commissioned by 2022. The project promoter (NeuConnect Britain Limited) will consider applying to the PCI process after inclusion in the TYNDP due to permitting implications.

For what concerns the analysis in this study, the project is already included in the 2030 scenario in its reference point-to-point configuration: in order to investigate possible synergies between the development of the offshore wind power in the area and the electricity interconnector, the hybrid configuration has been implemented in METIS as follows:

- the 1400 MW NeuConnect interconnector has been split in two halves and an additional fictitious zone NZ (*New Zone*) has been introduced in the METIS model;
- 900 MW of offshore wind power (with German offshore wind characteristics) has been connected in NZ. This capacity has been removed from German total offshore wind installed capacity.

Figure 4 shows the configuration of the NeuConnect project in the reference and in the hybrid configurations: the variations of the latter with respect to the former are shown in red.

Figure 4. System layout in reference (upper part) and hybrid case (lower part) for NeuConnect



Source: JRC, DG ENER, Roland Berger, 2019.

3.5 IJmuiden Ver OWF to GB

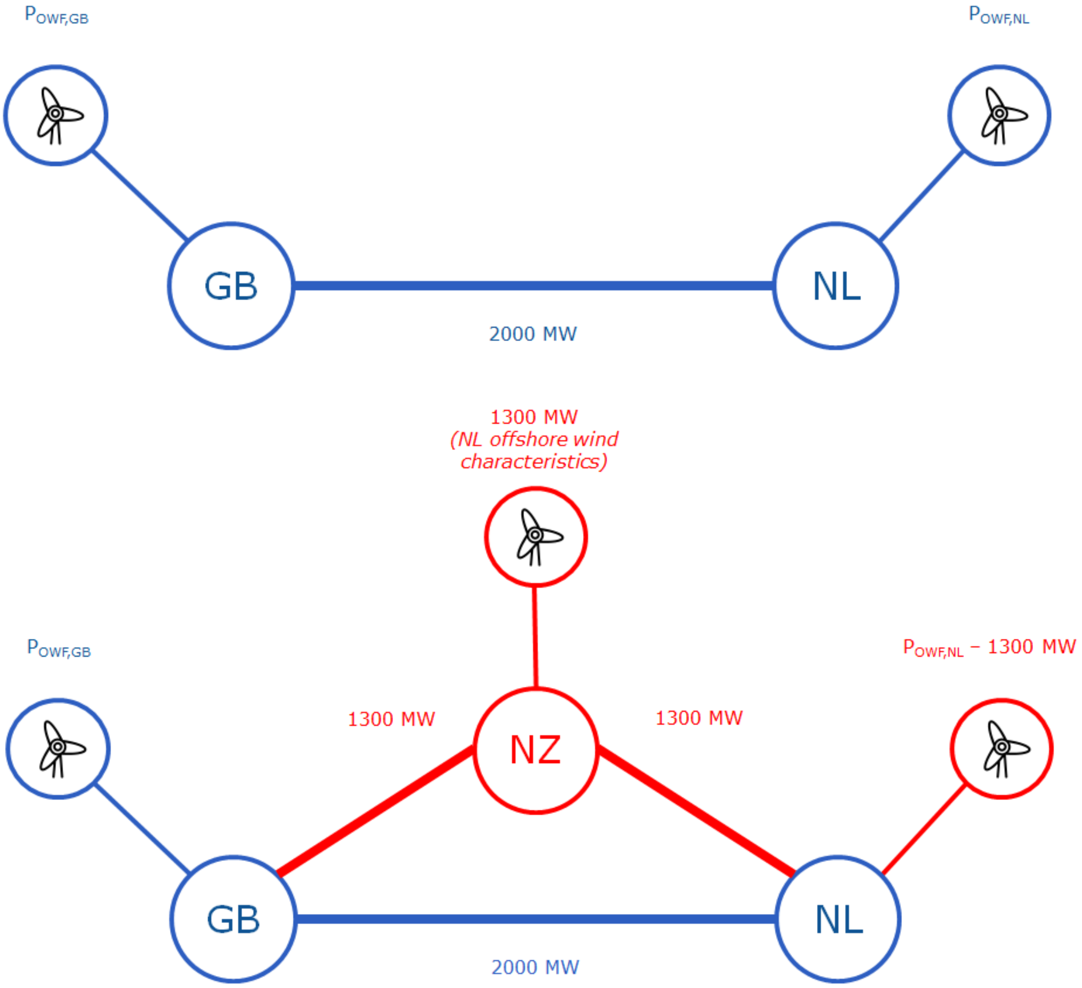
The case considers a future 1300 MW HVDC connection between South-Eastern England and Netherlands, to be commissioned before 2030.

For what concerns the reference configuration analysis in this study, it considers a slightly different transmission system layout in terms of total interconnection capacity between Great Britain and Netherlands (2300 MW instead of 2000 MW as in scenario 2030): in order to investigate possible synergies between the development of the offshore wind power in the area and the electricity interconnector, the hybrid configuration has been implemented in METIS as follows:

- the 1300 MW point-to-point interconnector has been split in two halves and an additional fictitious zone NZ (*New Zone*) has been introduced in the METIS model;
- 1300 MW of offshore wind power (with Dutch offshore wind characteristics) has been connected in NZ. This capacity has been removed from Dutch total offshore wind installed capacity.

Figure 5 shows the configuration of this case in the reference and in the hybrid configurations: the variations of the latter with respect to the former are shown in red.

Figure 5. System layout in reference (upper part) and hybrid case (lower part) for IJmuiden Ver OWF to GB



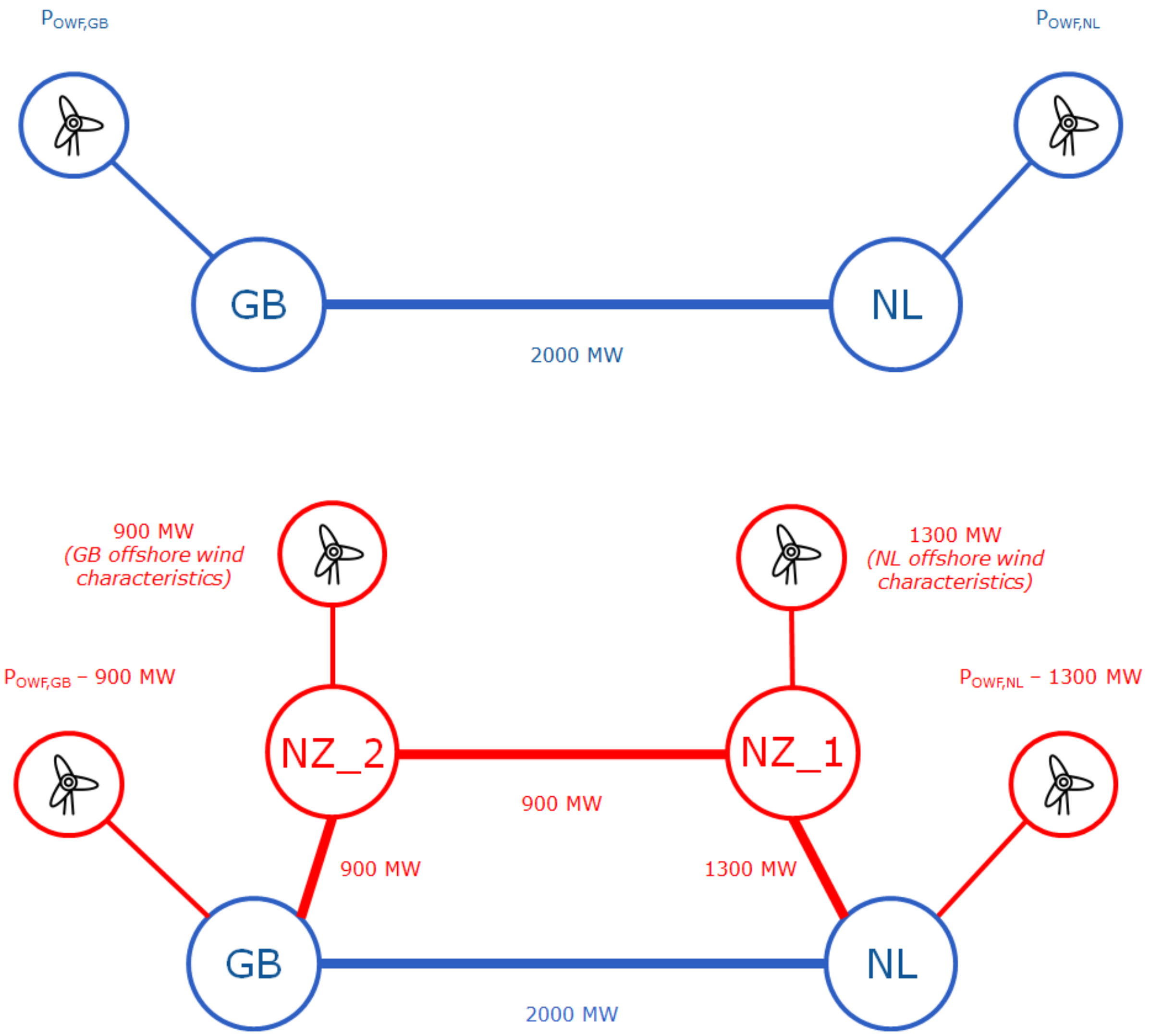
Source: JRC, DG ENER, Roland Berger, 2019.

3.6 CGS IJmuiden Ver - Norfolk

The case considers a future 900 MW HVDC interconnection between South-Eastern England and Netherlands, to be commissioning before 2030.

For what concerns the reference configuration analysis in this study, it considers a slightly different transmission system layout in terms of total interconnection capacity between Great Britain and Netherlands (1900 MW instead of 2000 MW as in scenario 2030). Figure 6 shows the configuration of this case in the reference and in the hybrid configurations: the variations of the latter with respect to the former are shown in red.

Figure 6. System layout in reference (upper part) and hybrid case (lower part) for CGS IJmuiden Ver - Norfolk



Source: JRC, DG ENER, Roland Berger, 2019.

In order to investigate possible synergies between the development of the offshore wind power in the area and the electricity interconnector, the hybrid configuration has been implemented in METIS as follows:

- the 900 MW pint-to-point new interconnector has been split in three sections and two additional fictitious zone NZ_1 and NZ_2 have been introduced in the METIS model;

- 1300 MW of offshore wind power (with Dutch offshore wind characteristics) has been connected in NZ_1. This capacity has been removed from Dutch total offshore wind installed capacity;
- 900 MW of offshore wind power (with British offshore wind characteristics) has been connected in NZ_2. This capacity has been removed from British total offshore wind installed capacity;
- NL and NZ_1 are connected by means of a 1300 MW interconnector: the fact that the size of this link is higher with respect to the 900 MW point-to-point interconnector in the reference configuration is related to the peak generation capacity of offshore wind power installed in NZ_1, which is higher than the transmission capacity of the original 900 MW interconnector in the reference configuration;
- GB and NZ_2 are connected through a 900 MW interconnector: it represents the original 900 MW interconnector in the reference configuration;
- NZ_1 and NZ_2 through a 900 MW interconnector: it represents the original 900 MW interconnector in the reference configuration.

4 System level results

Table 1 and Table 2 show the values of monetised and not monetised benefit indicators, as defined in section 2.4, for the six analysed cases.

Table 1. Monetised benefit indicator (difference between hybrid and reference configuration) – system level

Case	**ΔPS_{OWF} [M€/a]**	**ΔPS_{other} [M€/a]**	**ΔCS [M€/a]**	**ΔCR [M€/a]**	**ΔSW [M€/a]**
COBRAcable	-5.98	-2.77	3.25	2.96	-2.54
DE OWF connected to NL	-22.27	-17.38	31.18	5.22	-3.26
Nautilus	-4.43	-19.82	14.22	6.13	-3.91
NeuConnect	-16.14	-18.49	20.93	8.34	-5.36
IJmuiden Ver OWF to GB	-8.91	-37.66	27.81	13.80	-4.95
CGS IJmuiden Ver - Norfolk	-5.18	-10.91	3.37	8.53	-4.19

Source: JRC, 2019.

Table 2. Not monetised benefit indicator (difference between hybrid and reference configuration) – system level

Case	**ΔENS_{OWF} [MWh/a]**	**$\Delta EmiCO_2$ [kt/a]**	**$\Delta ResCurt$ [GWh/a]**
COBRAcable	0	45.56	2.06
DE OWF connected to NL	0	192.2	-0.87
Nautilus	0	55.59	0.98
NeuConnect	0	99.85	1.71
IJmuiden Ver OWF to GB	0	76.69	-1.48
CGS IJmuiden Ver - Norfolk	0	-13.48	-3.33

Source: JRC, 2019.

Looking at the values of the indicators in Table 1, it can be noted how the hybrid configuration (compared to its specific reference configuration) involves a small reduction of system social welfare[7] (between -5.36 and -2.54 M€/a): this expected result is motivated by the fact that, in the hybrid configuration, offshore wind power has to be conveyed from generator to the transmission system using the pertinent interconnector, with a reduction of usable transmission interconnection capacity for the rest of the system; on the other hand, in the reference configuration, offshore wind generation is directly connected to the zone representing the connection country, without the need of use on any cross-border transmission infrastructure to convey the production to the pertinent zone.

The breakdown of the decrease of system social welfare generally results in:

- an increased congestion rent (from +2.96 to +13.80 M€/a) because of the mentioned increased use of cross-border transmission infrastructure resulting in the hybrid configuration;
- an increased consumer surplus (from +3.25 to +31.18 M€/a) and a contextual decreased producer surplus for offshore wind power producer[8] (from -22.27 to -4.43 M€/a) and the rest of the generator mix (from -37.66 to -2.27 M€/a). The transmission and generation layout in the hybrid configuration results in a different power dispatch for generation units and, as a consequence, to a different power flow distribution: according to this, some countries will increase (or decrease) their net imports. Moreover, as already explained, the different power

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(7) It must be pointed out that it is negative *variation* of social welfare between hybrid and reference configuration: with reference to *absolute* values, social welfare is always positive in each case.

(8) As already explained, this refers to the variation of producer surplus for all offshore wind power generators, not just for the amount of installed capacity that is shifted in the hybrid configuration.

flow distribution increases in general congestions, resulting in market split and marginal price differential at the extreme of the congested cross-border transmission corridor. The combination of different net import/export profiles together with the arise of price differentials results a) for countries with higher net imports in the hybrid configuration, in an increase of the local consumer surplus (and a decrease of local producer surplus) and b) for countries with higher net export in the hybrid configuration, in a decrease of the local consumer surplus (and an increase of local producer surplus).

Looking at the values of the not monetised benefit indicators in Table 2, it can be noted how the hybrid configuration (compared to its specific reference configuration) does not bring to any change[9] in the ENS values: this means that, in the methodological boundary conditions of the zonal analysis, the level of security of supply in the hybrid and reference case is the same.

For what concerns the variation of CO_2, in five of the six cases there is a limited increase of the emissions (from 45.56 to 99.85 kt/a) while in the sixth case (CGS IJmuiden Ver - Norfolk) there is a small decrease of the emissions (-13.48 kt/a): these variations are a consequence of the different power dispatch resulting in the hybrid configuration with respect to the reference one. While there is a difference on reference cases transmission capacity values between GB and NL for the "IJmuiden Ver OWF to GB" and "CGS IJmuiden Ver - Norfolk" cases (see sections 3.5 and 3.6), possibly affecting the variation between the operating points in hybrid and reference configurations, it is interesting to note how the system reaches slightly lower levels of the emissions only in the case where two additional zones have been in included in the METIS model to analyse the relevant hybrid configuration: this confirms how a more flexible transmission system could allow a better utilisation of the power system assets.

In general, it can be concluded how the hybrid configuration of the analysed North Seas projects results in a small decrease of social welfare: however, the goal of the study was to show the impact of the synergic realisation of transmission and generation assets in terms of *operational performances*. This information should be used in a wider cost-benefit analysis, also taking into account additional cost-benefit indicators as CAPEX and OPEX savings in realising hybrid electricity projects in the North Seas area.

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(9) Again, the reported indicator is a *variation* between hybrid and reference case: however, looking at the absolute values of each case separate, METIS have detected no (expected) ENS as results of the simulations in both configurations in all the six cases.

5 Conclusions

The European Union is fully committed to fight climate change: in this context, the implementation of an effective long term decarbonisation strategy cannot be separated by the deployment of renewable energy sources and the realisation of cross-border electricity projects: this is particular relevant for the North Sea area, where governments of the relevant countries have opted for an energy cooperation strategy creating suitable conditions for the development of offshore wind energy.

As European Commission's science and knowledge service, the JRC provided modelling and analytical support to identify EU-wide potential benefits in the operation of selected generation and transmission assets in the North Seas as they were realised in hybrid configuration (i.e. synergic planning and commissioning of both generation and transmission assets) in a 2030 year scenario using the tool METIS.

The values of the system level results shows how the hybrid configuration (compared to its specific reference configuration) involves a small reduction of system social welfare: in particular, the results show a total increase of the congestion rent, a total increase of the consumer surplus and a total decrease of the producer surplus. Since the goal of the study was to show the impact of the synergic realisation of transmission and generation assets in terms of operational performances, the results of this study should be used in a wider cost-benefit analysis, also taking into account additional cost-benefit indicators as CAPEX and OPEX savings in realising hybrid electricity projects in the North Seas area.

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Annex

Table 3. NTC values in 2030 scenario

Border	NTC [MW]	Border	NTC [MW]	Border	NTC [MW]	Border	NTC [MW]
AT-CH	1700	DE-SE	1315	HU-HR	2000	NO-DE	1400
AT-CZ	1000	DK-DE	4000	HU-RO	1300	NO-DK	1640
AT-DE	7500	DK-NL	700	HU-RS	600	NO-FI	0
AT-HU	1200	DK-NO	1700	HU-SI	1700	NO-GB	3400
AT-IT	1655	DK-SE	2440	HU-SK	2000	NO-NL	700
AT-SI	1200	EE-FI	1016	IE-FR	700	NO-SE	3695
BA-HR	1844	EE-LV	1600	IE-GB	500	PL-CZ	600
BA-ME	800	ES-FR	8000	IS-GB	1000	PL-DE	3000
BA-RS	1100	ES-PT	4200	IT-AT	1385	PL-LT	1000
BE-FR	2800	FI-EE	1016	IT-CH	3860	PL-SE	600
BE-GB	2400	FI-NO	0	IT-FR	2160	PL-SK	990
BE-LU	1080	FI-SE	3200	IT-GR	500	PT-ES	3500
BE-NL	3400	FR-BE	4300	IT-HR	0	RO-BG	1500
BG-GR	1728	FR-CH	3700	IT-ME	1200	RO-HU	1400
BG-MK	530	FR-DE	4800	IT-MT	200	RO-RS	1450
BG-RO	1400	FR-ES	8000	IT-SI	1640	RS-BA	1200
BG-RS	600	FR-GB	6900	LT-LV	2100	RS-BG	350
CH-AT	1700	FR-IE	700	LT-PL	1000	RS-HR	600
CH-DE	5600	FR-IT	4350	LT-SE	700	RS-HU	600
CH-FR	1300	GB-BE	2400	LU-BE	700	RS-ME	1100
CH-IT	6240	GB-DE	1400	LU-DE	2300	RS-MK	950
CZ-AT	1200	GB-FR	6900	LV-EE	1600	RS-RO	1300
CZ-DE	2600	GB-IE	500	LV-LT	1800	SE-DE	1315
CZ-PL	600	GB-IS	1000	ME-BA	750	SE-DK	1980
CZ-SK	2100	GB-NL	2000	ME-IT	1200	SE-FI	3200
DE-AT	7500	GB-NO	3400	ME-RS	1000	SE-LT	700
DE-CH	3300	GR-BG	1032	MK-BG	500	SE-NO	3995
DE-CZ	2000	GR-IT	500	MK-GR	1200	SE-PL	600
DE-DK	4000	GR-MK	1200	MK-RS	1050	SI-AT	1200
DE-FR	4800	HR-BA	1812	MT-IT	200	SI-HR	2000
DE-GB	1400	HR-HU	2000	NL-BE	3400	SI-HU	2000
DE-LU	2300	HR-IT	0	NL-DE	5000	SI-IT	1895
DE-NL	5000	HR-RS	600	NL-DK	700	SK-CZ	1100
DE-NO	1400	HR-SI	2000	NL-GB	2000	SK-HU	2000
DE-PL	2000	HU-AT	800	NL-NO	700	SK-PL	990

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