TYNDP 2022

System Needs Study

Identification of offshore hybrid needs in the TYNDP's identification of system needs phase – methodology

Final Version · May 2023

ENTSO-E Mission Statement

Who we are

ENTSO-E, the European Network of Transmission System Operators for Electricity, is the **association for the cooperation of the European transmission system operators (TSOs)**. The 39 member TSOs, representing 35 countries, are responsible for the **secure and coordinated operation** of Europe's electricity system, the largest interconnected electrical grid in the world. In addition to its core, historical role in technical cooperation, ENTSO-E is also the common voice of TSOs.

ENTSO-E **brings together the unique expertise of TSOs for the benefit of European citizens** by keeping the lights on, enabling the energy transition, and promoting the completion and optimal functioning of the internal electricity market, including via the fulfilment of the mandates given to ENTSO-E based on EU legislation.

Our mission

ENTSO-E and its members, as the European TSO community, fulfil a common mission: Ensuring the **security of the interconnected power system in all time frames at pan-European level** and the **optimal functioning and development of the European interconnected electricity markets**, while enabling the integration of electricity generated from renewable energy sources and of emerging technologies.

Our vision

ENTSO-E plays a central role in enabling Europe to become the first **climate-neutral continent by 2050** by creating a system that is secure, sustainable and affordable, and that integrates the expected amount of renewable energy, thereby offering an essential contribution to the European Green Deal. This endeavour requires **sector integration** and close cooperation among all actors.

Europe is moving towards a sustainable, digitalised, integrated and electrified energy system with a combination of centralised and distributed resources.

ENTSO-E acts to ensure that this energy system **keeps consumers at its centre** and is operated and developed with **climate objectives** and **social welfare** in mind.

ENTSO-E is committed to use its unique expertise and system-wide view – supported by a responsibility to maintain the system's security – to deliver a comprehensive roadmap of how a climate-neutral Europe looks.

Our values

ENTSO-E acts in **solidarity** as a community of TSOs united by a shared **responsibility.**

As the professional association of independent and neutral regulated entities acting under a clear legal mandate, ENTSO-E serves the interests of society by **optimising social welfare** in its dimensions of safety, economy, environment, and performance.

ENTSO-E is committed to working with the highest technical rigour as well as developing sustainable and **innovative responses to prepare for the future** and overcoming the challenges of keeping the power system secure in a climate-neutral Europe. In all its activities, ENTSO-E acts with **transparency** and in a trustworthy dialogue with legislative and regulatory decision makers and stakeholders.

Our contributions

ENTSO-E supports the cooperation among its members at European and regional levels. Over the past decades, TSOs have undertaken initiatives to increase their cooperation in network planning, operation and market integration, thereby successfully contributing to meeting EU climate and energy targets.

To carry out its **legally mandated tasks**, ENTSO-E's key responsibilities include the following:

- Development and implementation of standards, network codes, platforms and tools to ensure secure system and market operation as well as integration of renewable energy;
- Assessment of the adequacy of the system in different timeframes;
- Coordination of the planning and development of infrastructures at the European level (Ten-Year Network Development Plans, TYNDPs);
- Coordination of research, development and innovation activities of TSOs;
- Development of platforms to enable the transparent sharing of data with market participants.

ENTSO-E supports its members in the **implementation and monitoring** of the agreed common rules.

ENTSO-E is the common voice of European TSOs and provides expert contributions and a constructive view to energy debates to support policymakers in making informed decisions.

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Ten-Year Network Development Plan 2022

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ENTSO-E System needs visualisation platform
https://needs.entsoe.eu

Questions?

Contact us as at **tyndp@entsoe.eu**

Contents

1 Aim of the study

1.1 Context and Background

The System Needs Study aims to show where action is required to ensure access to electricity throughout Europe for the 2030 and 2040 time horizons. In general, the study identifies opportunities for capacity increases over corridors and not single projects. The needs can be satisfied by infrastructure or other means (see the Ten-Year Network Development Plan [TYNDP] 2022 System Needs Study).

In parallel to the TYNDP 2020 cycle, the public debate and focus on offshore developments intensified and was further triggered by the European offshore Renewable Energy Sources (RES) strategy. External discussions recognised that further offshore development is key to enabling the pathway towards EU decarbonisation in line with EU Climate Law targets, for which both hybrids and radial / traditional point to point interconnectors will have a key role to play. Hybrid projects are solutions that serve dual purposes[1]: i) connection function of offshore RES to demand centres[2] and ii) interconnecting countries or bidding zones to facilitate trade, which then enables price convergence and indirect RES connection.

ENTSO-E received and acknowledged comments that opportunities for these types of potential solutions to satisfy European needs are not covered by the system needs studies as these types of needs had so far been out of scope of the system needs exercise.

ENTSO-E agreed to set up an innovation process in parallel to the TYNDP 2022 process and to develop a respective methodology.

A positive proof-of-concept has been developed and tested on an example region. This report describes the way of working and presents the results of the test runs. The methodology will be further detailed in view of its implementation in the TYNDP 2024 process.

1.2 Approach

The current System Needs Study investigates if new corridors or the reinforcement of existing ones would be beneficial. This is tested by an economic analysis of the concrete and conceptual expansion of corridors.

The TYNDP 2020 showed that 93 GW of direct interconnection corridors were identified between 2025 and 2040 (see Figure 1).

Nevertheless, offshore hybrid assets (interconnector plus offshore RES) were not in the scope of the system needs study 2020 nor of the system needs study 2022, whereas this kind of project can represent, in some situations, a good opportunity to gather and optimise interconnector and RES integration.

The questions to be investigated are as follows:

- 1) Are there systemic needs for hybrids and other solutions to facilitate achieving the necessary price convergence, CO_2 targets, RES integration levels and security of supply criteria?
- 2) Can offshore hybrid projects offer higher benefits to the system compared to single purpose solutions such as direct interconnectors and a separate offshore RES connection?

Hence, the methodology to be developed needs to facilitate the respective investigations and provide related answers.

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[1] This can be “multi-purpose” as well, meaning crossing energy sectors.

[2] Demand centres could also be offshore, e. g. P2X units. During the methodology development discussed in this document, the sector crossing aspect has not yet been considered.

This document presents the proposed methodology and describes the example study, including a list of minimum requirements related to input information necessary to identify offshore hybrid opportunities during the system needs process.

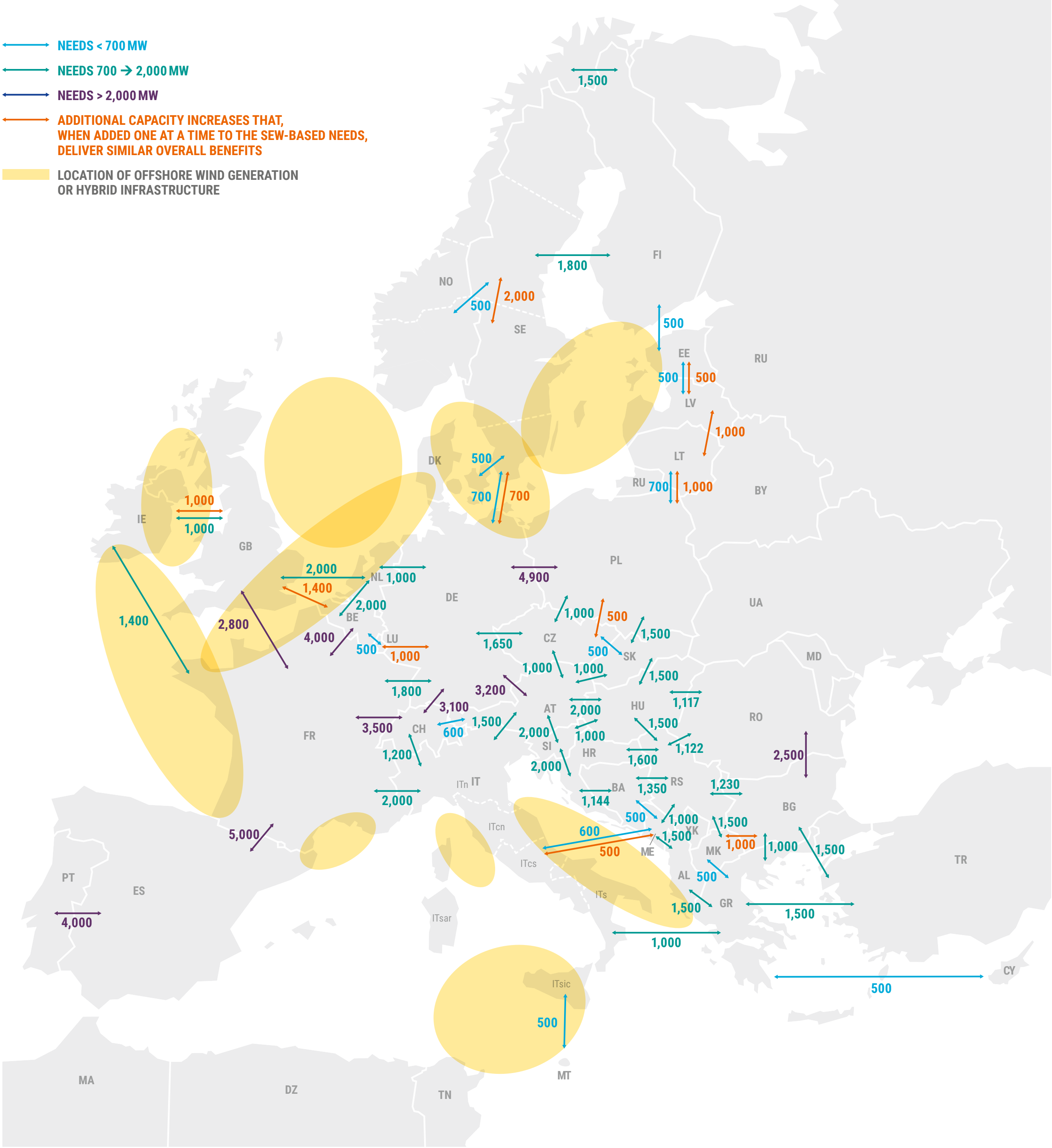

Figure 1 – Map from the TYNDP 2020 Identification of Needs Study on SEW based needs 2040 and location of potential hybrid offshore infrastructure

2 Methodology & main assumptions

Methodology

The System Needs Study aims to identify opportunities for the expansion of existing or new connections between bidding zones / countries. The areas assessed are the North Sea and the Baltic Sea market zones.

The offshore RES capacity is assumed to already be part of the scenario. However, to identify the need for potential offshore hybrid assets for modelling purposes, the offshore RES capacity needs to be in a separate zone rather than being part of a country's or an onshore zone's production portfolio, as is the case in TYNDP 2022, TYNDP 2020 and earlier studies. Existing models need to be adjusted respectively, with new zones being added. This is necessary to better consider locational offshore RES profiles (timeseries). The offshore RES zone is radially connected to one market zone M1 as a starting condition as the aim of the proposed methodology is to check whether it is more valuable to implement a direct interconnection solution or a hybrid configuration from one Offshore Wind Farm (OWF) already connected to one Transmission System Operator (TSO).

A network expansion study is then executed, during which the optimiser compares a pair of candidates. This comparison delivers information if a connection from the offshore RES zone to another market zone M2 is more beneficial to the overall system than a direct connection between zones M1 and M2 (via offshore interconnection or even onshore if possible). Direct connections between the new offshore RES can also be included (see Figure 2). The optimisation criterium is the sum of CAPEX and OPEX, (i. e. overall generation costs for the whole area). The variant with lowest overall costs is selected by the optimiser and a new economic opportunity is identified.

Stability of the methodology

As connections usually have a mutual impact on their benefits, a question that came up was whether the number of candidates impacts the results. To test this, several variants were compared during the example study: one model run with only one pair of candidates per zone and another model run including multiple pairs of candidates per zone.

Sensitivities related to CAPEX variations have also been executed.

Input information

All candidates, i. e. potential new connections between zones, are inputs to the network expansion study. The offshore RES locations is also new input information. The complete list of input information is specified later in this report (see Chapter 6).

3 Test of the methodology on an example region

To test the methodology, an example test environment was set up. First, exemplary hybrid candidates were defined. The main assumptions are described in the following.

3.1 Model

The study is based on the NTC model used during the System Needs Study of TYNDP 2020 for the National Trends 2040 scenario. The example area for this study is the North Sea and Baltic Sea. For the market areas bordering the North and/or Baltic Sea, the wind offshore generation capacities in the model have been updated according to the values from the Pan-European Market Modelling Database (PEMMDB) for the TYNDP 2022, finally including 197 GW offshore wind in the investigated area.

Furthermore, to consider an expansion of the onshore network until 2040 compared to the Mid-term Adequacy Forecast (MAF) 2025 reference grid, the onshore Net Transfer Capacities (NTCs) have been adapted according to the results of the System Needs Study of the TYNDP 2020 for the 2030 time horizon (NT scenario).

3.2 Candidates

The first step during the System Needs Study Process is the definition of which candidates the optimiser can select.

In this study, it is assumed that for hybrid projects, the offshore RES is already radially connected to one market area in the reference case (red lines). To assess the benefits of hybrid infrastructure compared to point-to-point interconnectors (green lines), an alternative interconnector candidate between the offshore RES and the second market area (purple line) is defined for each border.

There are two different types of hybrid assets considered in this study. The first one describes the case where an already radially connected OWF is connected to another market area (Type 1). The second type represents the case where two already radially connected OWFs can be connected by a line in between (Type 2). Both types are displayed in the following figure.

As a standard capacity for offshore RES, a capacity of 2 GW is assumed. To put it simply, the respective capacity for transmission assets included in the analysis, such as cable lines and converter stations, is assumed at the same level of 2 GW. A 2 GW capacity is assumed for all data regarding costs and technical possibilities.

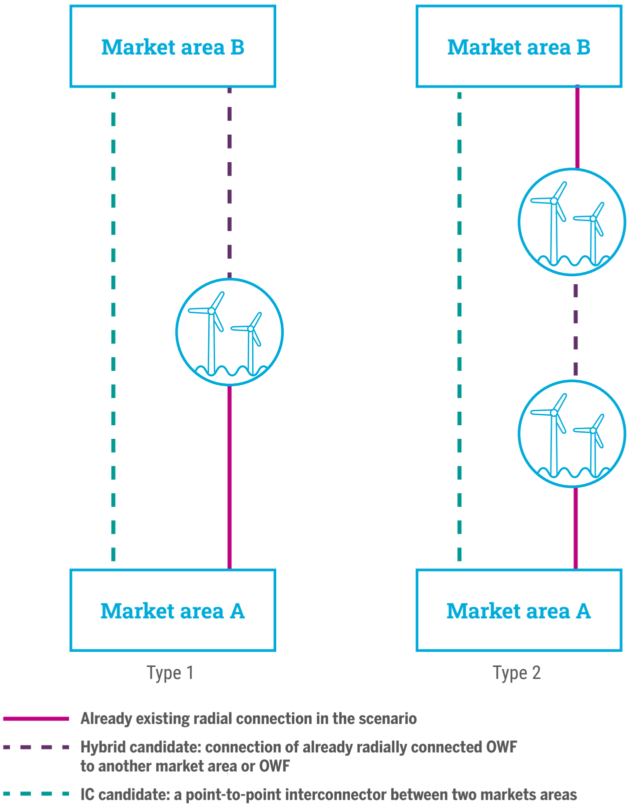

Figure 2 – Example candidates

If, according to the scenario data of the TYNDP 2022, the offshore wind capacity in a market area is sufficiently high to create more than one offshore bidding zone (e. g. > 4 GW)[3], it is also possible to consider separate additional connections to different countries / market nodes (see Figure 2 – Example candidates). These can be either hybrid candidates of type 1 or type 2 (see figure 1). Moreover, the same offshore node can also be used to add candidates to more than one other market node, thereby allowing the possibility of offshore hubs with more than two "legs" (see Figure 3).

In each of the configurations shown above, the capacity of all lines is assumed to be 2 GW. The offshore RES is always assumed to be 2 GW.

In the event one wants to include a hub project in the study where, different from the case in Figure 3, the OWF connections will either be built as a hub or as radial connections to each of the involved market areas, the following modelling approach shown in Figure 4 can be used. Two dummy market node areas are created: "dummy_imp" and "dummy_exp", which have zero load and zero generation capacity. Flows to or from these dummy areas are only possible in one direction (blue and orange lines are uni-directional). The bi-directional red line between the two dummy areas represents the single candidate for the whole project. By adding the red line, flows between the three market areas A, B and C become possible. Without the red line, each offshore zone can only feed in its respective "home country", and flows between the different market areas are not possible. In the example shown, the overall capacity of the offshore hub is 6 GW (3 x 2 GW).

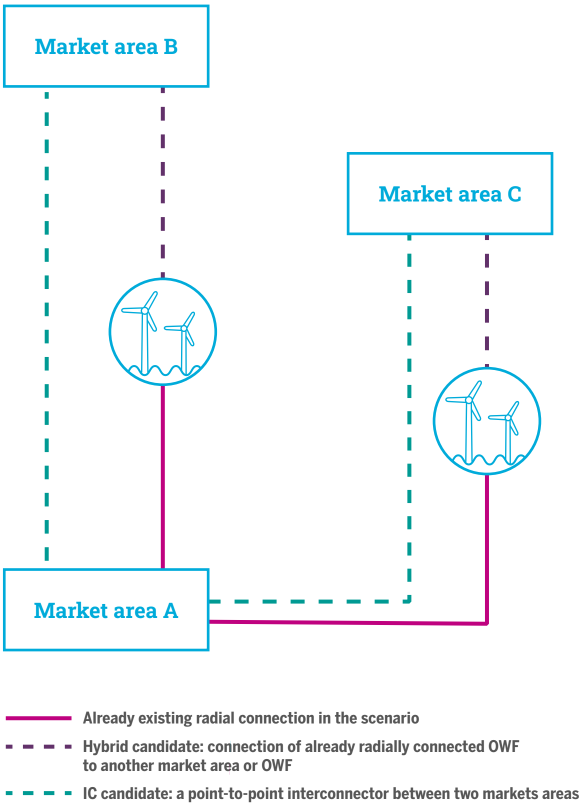

Figure 3 – Multiple OWF candidates

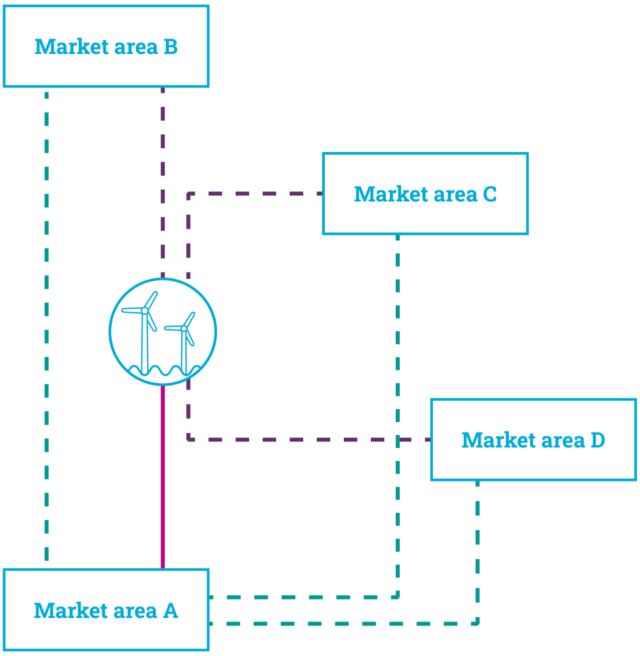

Figure 4 – Single OWF with multiple candidates

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[3] This is an assumption as the granularity and the size of the offshore bidding zones will be a choice made by the single Member States, likely linked to distances between offshore RES and hence input profiles as well as reflecting the status of the grid congestions.

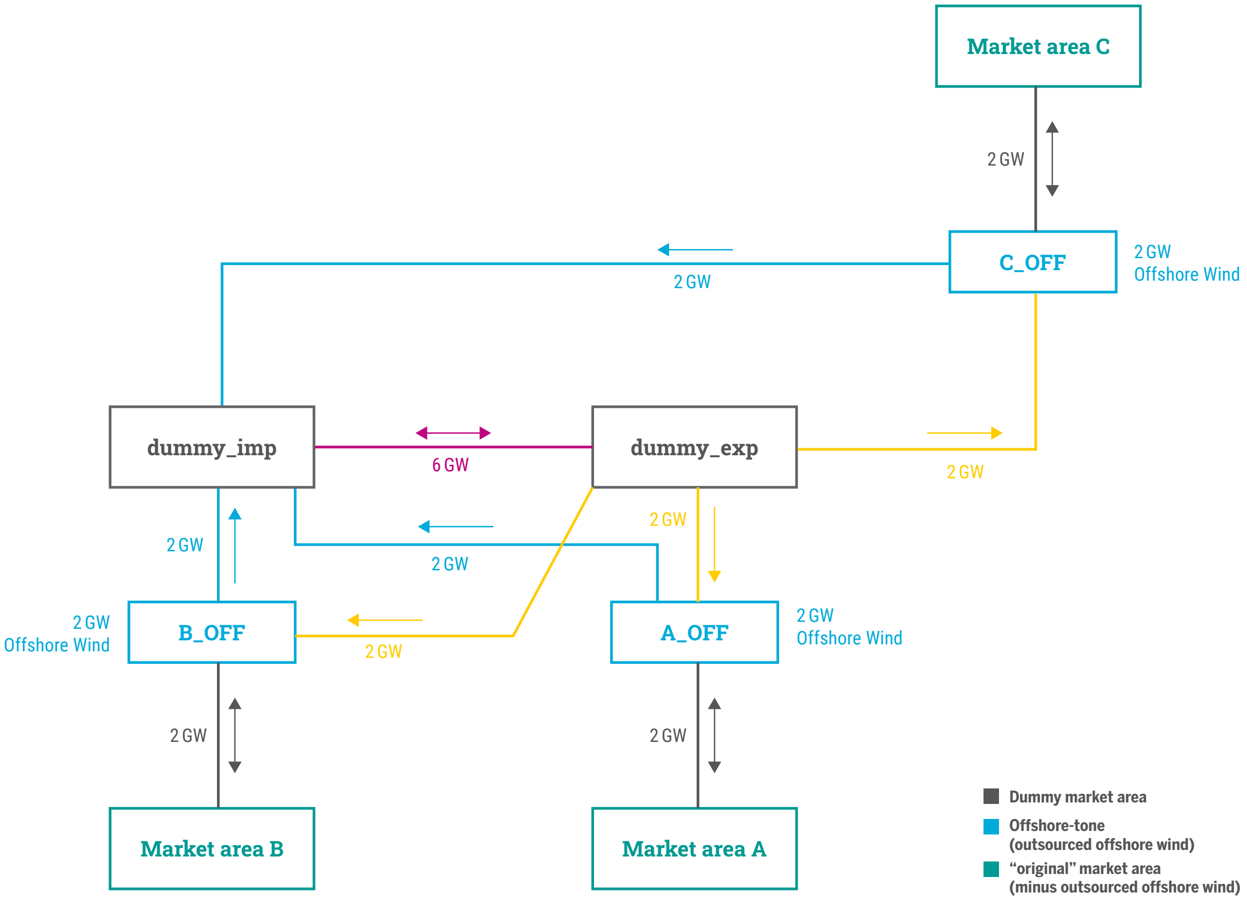

Figure 5 – Configuration when adding a hub

For the optimisation, the following information is required for the definition of a candidate:

- **Name:** unique name of the candidate
- **Link**: between two existing market areas in the model
- **Annual cost** per MW
- **Unit size** of the link in MW
- **Max. number** of units

Next to the definition of the link (e. g. market area A – market area B) and the name (e. g. IC_A_B), additional information on the assumed costs, unit size and maximum number of buildable units is required for each candidate. In this study, the maximum number of units is set to 1 for each hybrid candidate and a non-limiting number (e. g. 10) is set for point-to-point interconnector projects in order to identify at which point a hybrid is selected rather than an interconnector. As described before, the capacity of the offshore RES in hybrid project candidates is assumed to be 2 GW. This also affects the cost assumptions, which are based on the assumption of 2 GW transmission assets. The details on the cost assumptions are described in the next section.

For this study, a number of example candidates were collected from several TSOs in the North Sea and Baltic Sea area. These are not intended to represent an exhaustive planning scenario but only to test a methodology in the context of this innovation study.

Only some of the candidates, rather than the whole scope, are represented in the Figure 6 – Candidates in order to ease the readability.

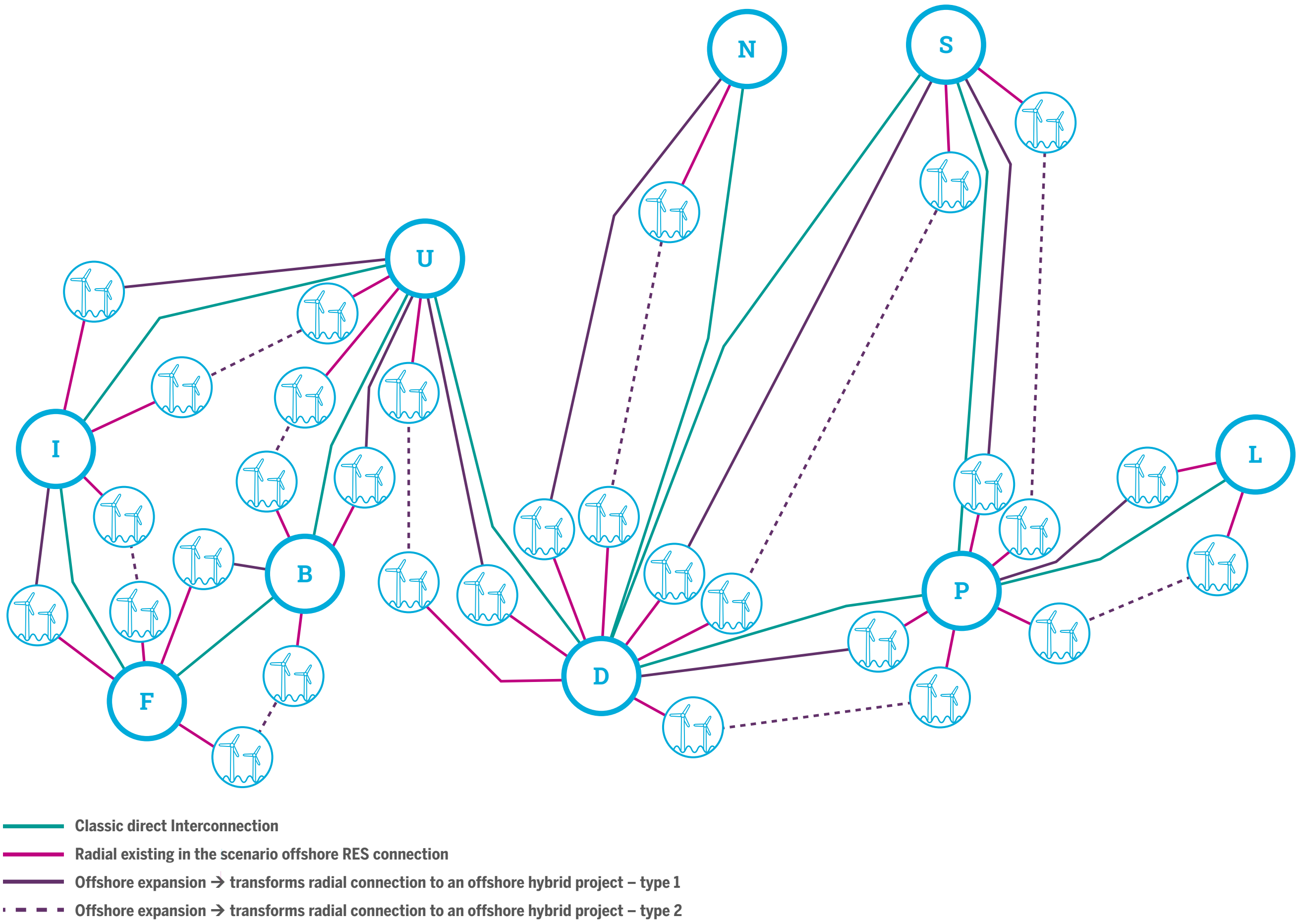

Figure 6 – Candidates

3.3 Costs

As part of the optimisation task, the candidates are both direct sea connections between price zones as well as hybrid connections using the existing network infrastructure of offshore RES.

As described in Section 3.2 Candidates, different types of hybrid candidates were distinguished. For hybrid candidates of type 1, two possible assumptions regarding the technical possibilities are considered. By adding a second leg to an existing OWF, it has been assumed that it is technically possible to add the second leg without requiring an additional offshore converter but with some additional costs, e. g. for platform extensions (option A). The second option is to assume that an additional offshore converter is needed (option B), which usually results in higher costs.

The main components of the costs include the cost of sea and land cable lines, land and sea HVDC converting stations and costs resulting from the expansion of the offshore station due to the connection of additional cable lines. The following overview shows the assumed investments needed for each type of candidate:

- **Direct point-to-point interconnector (IC):** two onshore converters, sea and land cable lines;
- **Hybrid candidate type 1 option A:** one onshore converter, sea and land cable lines, expansion of the offshore station;
- **Hybrid candidate type 1 option B:** one onshore converter, one offshore converter, sea and land cable lines;
- **Hybrid candidate type 2:** sea cable line, expansion of sea stations; (type 1 & 2 refer to Figure 2 – Example candidates)

The assumed costs of these components are presented in Figure 7 below.

Regarding converter stations and the costs resulting from the expansion of the offshore station due to the connection of additional cable lines, the cost of these components are presented in Figure 7 below.

Components of CAPEX	value
Sea cable line [M€/km]	4
Land cable line [M€/km]	4
Offshore AC/DC converter station [M€]	1000
Onshore AC/DC converter station [M€]	600
Expanding the platform per single new cable connection [M€]	100

Figure 7 – Costs used

4 Tools

4.1 Tools applied for the Test

To develop and verify the developed methodology, simulations were carried out in two independent simulation tools: Antares and PLEXOS.

In both tools, the simulations were conducted on the basis of the same model of the European energy market. Thus, it was possible to check whether the methodology, while using the same input data and using two different tools, enables convergent results of the analysis to be achieved.

4.2 Optimisation

The potential for the construction of offshore hybrid projects was tested by conducting a grid expansion analysis. This type of analysis comprises solving an optimisation task in which a network structure is searched for, ensuring the minimum total cost of covering the demand. The development of the network structure is carried out based on defined new connections between individual price zones, the network candidates. The optimisation itself is carried out in the annual horizon for the year 2040 with an hourly granulation of 8,760 hours. The network candidates need to be offered to the model as input information data.

5 Results and sensivity tests

The result of the optimisation is a list of candidates to be invested in that minimises the overall generation costs. Looking at each border, different results are possible. Either only the interconnector project or only the hybrid project were selected by the optimiser, or both were selected or none of them.

The list will not be published due to the testing character of this study which only allows a limited view. After the inclusion of the methodology in the System Needs Study, the onshore and offshore grid will be optimised at the same time. Furthermore, an extensive data collection process will precede the analysis, which was only possible to a limited extent in this study.

In addition, as part of the analysis, the sensitivity of the final result to the change in the cost assumptions of individual elements of the network infrastructure was checked. Assumptions regarding sensitivity are presented in the following Table.

Components of CAPEX	CAPEX sensitivity					
Scenario	base	sens1	sens2	sens2a	sens3	sens4
Sea cable line [M€/km]	4	1.8	4	4	−10 %	+10 %
Land cable line [M€/km]	4	1.8	4	4		
Offshore AC/DC converter station [M€]	1000	1000	1000	1000		
Onshore AC/DC converter station [M€]	600	600	600	600		
Expanding the platform per single new cable connection [M€]	100	100	200	300		

For individual price zones, a list of network candidates has been developed. Each candidate has been assigned with: connection type, starting node, end node, link length, number of AC/DC converter stations on land, number of AC/DC converter stations at sea and annuity. In total, the number of candidates exceeded 60. Figure 9 – Results of sensitivities shows the results of the simulations. It can be seen that the built network candidates are hybrid connections of the type HA.3 and HA.1. The results were presented for the baseline scenario and additional sensitivities at the cost of the investment.

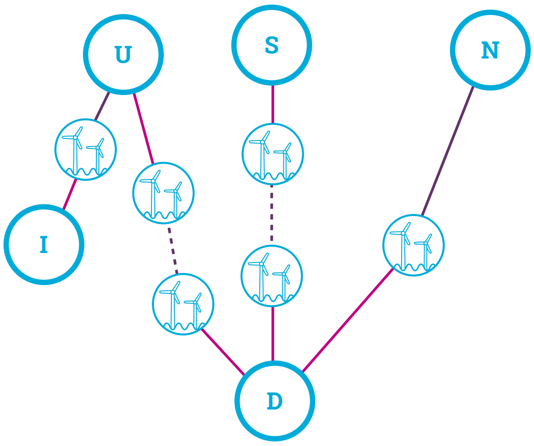

Figure 8 – Results

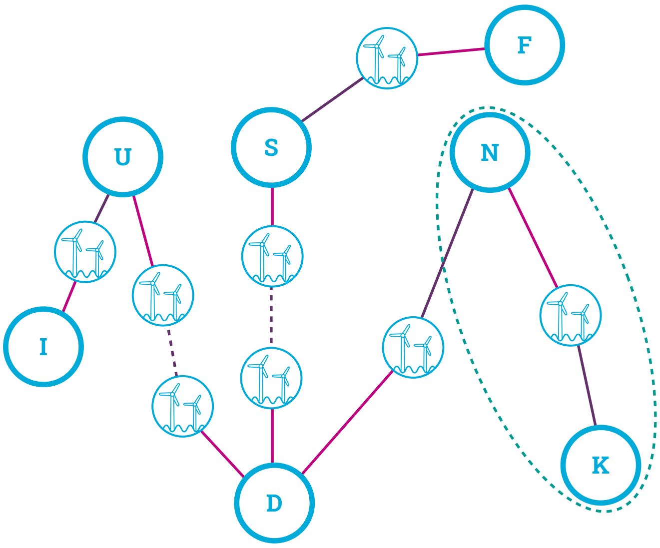

Figure 9 – Results of sensitivities

Built candidate	Type	Sensitivity scenario						Number of occurrences
		base	sens 1	sens 2	sens 2a	sens 3	sens4	
OFF_Doff – S_Off	HA.3	1	1	1	1	1	1	6
OFF_Doff – U_Off	HA.3	1	1	1	1	1	1	6
OFF_D-N	HA.1	1	1	1	1	1	1	6
OFF_I-U	HA.1	1	0	1	1	1	1	5
OFF_K-N	HA.1	0	1	0	0	0	0	1
OFF_F-S	HA.1	0	1	0	0	1	0	2

Table 1 – Sensitivity results

Base case is still found (except one in case 1)

Base case is equal to case 4, case 2 and case 2a. Therefore, we can conclude that an increase of 10 % of CAPEX or +20 %/30 % additional converter cost had no effect.

Moreover, case 3 and case 1 provide one more project compared to base case. Therefore, a decrease of 10 % allows one more project. These results mean that even if the costs are not well known, it will not jeopardise the results.

The common core is still the same; the needs remain regardless of the fluctuations in prices. The results of the optimiser are stable, whatever the price.

6 Input data requirements

Anticipating the identification of potential offshore hybrid needs in future analyses, a table of necessary input data for their modelling has been developed, as shown in the table below:

Project location	Name	
	Type (HA/IC)	
	Interzone	
	start node	
	end node	
Offshore RES	Capacity	[MW]
Transmission Cables	Technology (AC/DC)	
	Capacity	[MW]
	length offshore	[km]
	CAPEX offshore	[MEUR/km]
	length onshore	[km]
	CAPEX onshore	[MEUR/km]
	Total cables CAPEX	[MEUR]
On/Offshore substations	Technology (AC/DC)	
	Capacity	[MW]
	CAPEX onshore substation (without converter if DC)	[MEUR]
	CAPEX onshore AC/DC converter	[MEUR]
	CAPEX offshore substation (without converter if DC)	[MEUR]
	CAPEX offshore AC/DC converter	[MEUR]
	Total substations CAPEX	[MEUR]
Project costs	Total CAPEX	[MEUR]
	OPEX	[MEUR/a]

Appendix

Assumptions on model region

Market node	Installed offshore wind capacity TYNDP 2022 [MW]
BE00	6,000
DE00	39,680
DEKF	330
DKE1	3,490
DKKF	600
DKW1	7,487
FI00	5,000
FR00	26,900
IE00	4,700
LT00	1,400
LV00	1,000
NL00	30,000
NOS0	400
PL00	9,590
SE03	0
SE04	3,031
UK00	56,370
UKNI	500

Table 2 – Installed offshore capacities in the example region

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