TYNDP 2024

Offshore Network Development Plans

Methodology

January 2024

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ELECTRIFYING EUROPE

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 **40 member TSOs**, representing 36 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 inter-connected 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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ENTSO-E ONDP interactive data visualisation platform

Questions?

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

Contents

1 Methodology for Infrastructure Development

The Offshore Network Development Plans (ONDP) deliver information on the needs to connect the offshore Renewable Energy Sources (RES) generation capacities in line with the **MS non-binding agreements** and the potential additional expansion of the transmission infrastructure between aggregated offshore generation nodes.

The result of this assessment is a high-level and strategic overview of required offshore transmission capacity, connecting offshore RES and/or interconnecting different zones of the European electricity system. The ONDPs will deliver the following information for each time horizon (2030, 2040, 2050) and sea basin:

- Overview of the offshore RES capacities foreseen to be located in each sea basin; and
- Possible configurations of the transmission infrastructure that could connect the different RES to each other and/or the onshore systems, including the potential needs for interconnectors, hybrid projects, radial connections, reinforcements and hydrogen infrastructures.

This document explains the methodology through which the 2024 ONDPs have been developed. The methodology specifies the process behind the data gathering, the modelling and the post processing in support of the definition of the offshore transmission corridors and, in general, in the analysis of the offshore transmission infrastructure strategic needs in 2030, 2040 and 2050.

The present methodology is applicable for the delivery of the 2024 ONDPs, which are formally part of the Ten-Year Network Development Plan (TYNDP) 2024 package. Further development of the process is expected for the future editions of the ONDP.

The reinforcements required onshore are out of scope of the 2024 ONDPs. However, the ONDPs will feed the TYNDP 2024 Identification of System Needs (IoSN) process the necessary information to optimise the overall electricity system.

The 2024 ONDPs are built on the following set of data:

- The **offshore RES capacities** data gathered by the Transmission System Operators (TSOs), in line with the (upper bandwidth) of the 2023 non-binding agreements signed by the respective Member States (MSs) or the national strategies; and
- The **offshore transmission infrastructure**, existing, planned and expected (meaning not yet included in the plans but in the advanced stage of studying), based on input from TSOs in the 2030, 2040 and 2050 time horizons. This infrastructure is then expanded via centrally executed simulations; the results are post-processed by ENTSO-E Regional Groups, for the 2040 and 2050 time horizons.

The 2030-time horizon will not be modelled as in network infrastructure planning terms; the expansion situation is already more or less clear at present. The 2040- and 2050-time horizons will be based on the TYNDP2022 edition of the DE2040-and DE2050[1] simulation models and scenario results, additionally applying the endogenously defined MS- offshore data[2].

1 Applying the DE instead of the NT scenario was considered to be the best solution as the 2050NT scenario is collected on a voluntary basis from TSOs, thus the data show gaps. In addition, the 2050- time horizon is not foreseen for the NT scenario.

2 When discussing the connection between the ONDP and the TYNDP, two options have been discussed: i) an extra model-run in addition to the regular DE 2050 scenario ("DE2050ONDP") or accepting the data-locking is part of the regular DE2050 scenario. As this means that the optimiser is not allowed to change offshore RES production capacities, this requires an agreement with ENTSOG. Due to the resource situation, the second option has been preferred in the Program Management. WG SB commented that the optimiser cannot freely select to build additional offshore RES to satisfy the H_2 demand. (In an unlocked situation, the optimiser can decide to build electricity infrastructure, H_2 infrastructure to potential electrolysers and storage or to upgrade the RES generation to satisfy all needs in the most economic efficient manner.) This is no longer possible for the first edition of the ONDP as offshore RES is pre-defined.

The models which are developed for this first edition of the ONDP are not suited to adequately identifying onshore reinforcement needs as they are derived from the TYNDP 2022 Scenarios, and these will be identified in the TYNDP 2024 infrastructure gap identification study[3], i.e. the IoSN[4].

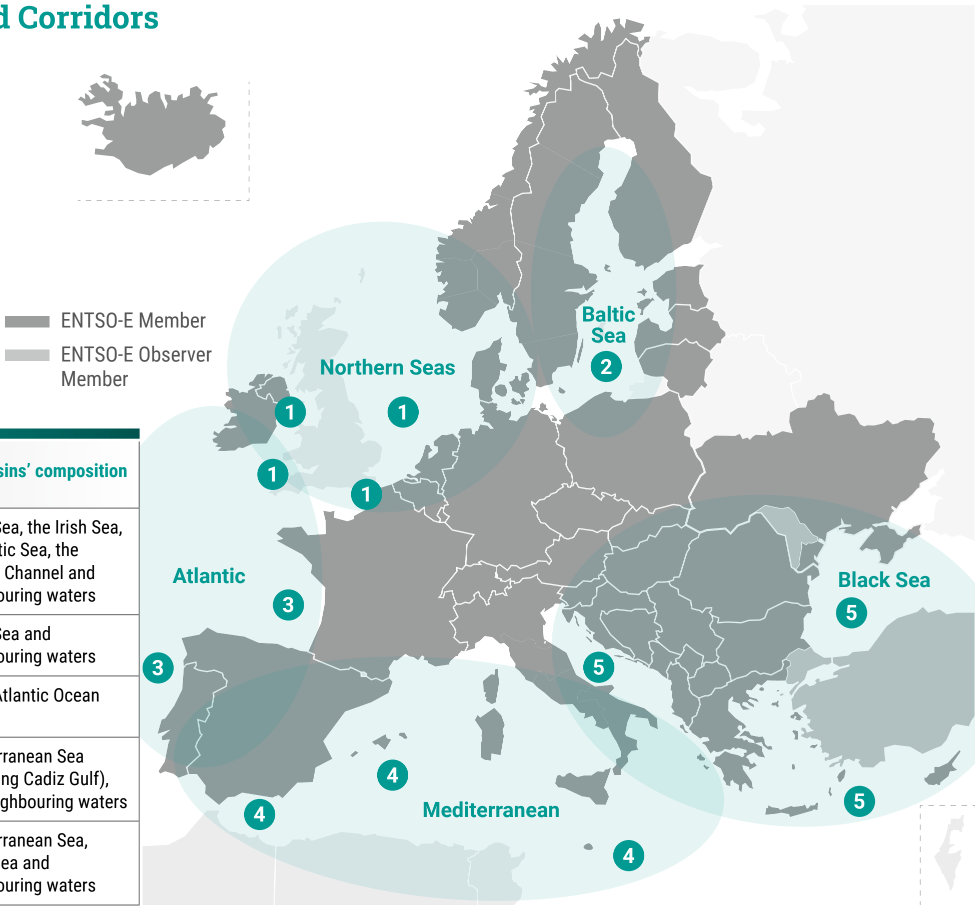
Sea basins and TEN-E corridors

The priority offshore grid corridors are specified in the TEN-E regulation:

- **Northern Seas Offshore Grids (NSOG)**, including North Sea, the Irish Sea, the Celtic Sea, the English Channel and neighbouring waters;
- **Baltic Energy Market Interconnection Plan offshore grids (BEMIP offshore)**, including the Baltic Sea and neighbouring waters;
- **South and West offshore grids (SW offshore)**, including the Mediterranean Sea, including the Cadiz Gulf, and neighbouring waters;
- **South and East offshore grids (SE offshore)**, including the Mediterranean Sea, Black Sea and neighbouring waters;
- **Atlantic offshore grids (AOG)**, including the North Atlantic Ocean waters.

Priority Offshore Grid Corridors

1 Northern Seas Offshore Grids (NSOG)
2 Baltic Energy Market Interconnection Plan (BEMIP offshore)
3 Atlantic Offshore Grids (AOG)
4 South and West Offshore Grids (SW offshore)
5 South and East Offshore Grids (SE offshore)



Priority Offshore Grid Corridors	Sea basins' composition
1. NSOG (BE, DK, FR, DE, IE, LU, NL, SE)*	North Sea, the Irish Sea, the Celtic Sea, the English Channel and neighbouring waters
2. BEMIP offshore (DK, EE, FI, DE, LT, LV, PL, SE)	Baltic Sea and neighbouring waters
3. AOG (FR, IE, PT, ES)	North Atlantic Ocean waters
4. SW offshore (FR, GR, IT, MT, PT, ES)	Mediterranean Sea (including Cadiz Gulf), and neighbouring waters
5. SE offshore (BG, CY, HR, GR, IT, RO, SI)	Mediterranean Sea, Black Sea and neighbouring waters

(* Norway is included in RGNS. Great Britain will be included as soon as a cooperation agreement has been fixed both between NSEC/NSOG and the EU and ENTSO-E and the British Government. An MoU between NSEC and UK has been signed (link). Based on this background, the GB TSO will be invited to RGNS meetings again. Northern Ireland is part of the All Island and is thus part of the Irish synchronous system.)

Figure 1 – Priority Offshore Grid Corridors from (EU) 2022/869.

3 The "infrastructure gap identification study" is the new terminology including more requirements for what is known as "Identification of System Needs (IoSN)". Thus, in this document the old abbreviation "IoSN" might still appear.

4 The distinct methodologies for modelling the onshore and offshore transmission first imply a risk of inconsistencies between the two exercises. This risk of inconsistencies is related to, among others, a difference in model granularity; a difference in the models used (T22 vs. T24), including differences in the starting grid; and the identification of new or different point-to-point interconnectors or hybrid systems. This risk will be addressed by feeding ONDP results into the IoSN process and by close coordination between both processes. In addition, adequate disclaimers related to onshore development in the first edition of the ONDPs might be included.

Cost input assumptions

The following cost assumptions have been applied when simulating the potential extension of the offshore network infrastructure:

Element	Symbol	CAPEX/OPEX	Unit	Cost Set 1	Cost Set 2	Cost Set 3
Onshore HVDC cable	———	CAPEX	MEUR/MW*km	0.00168	0.00274	0.0038
Offshore HVDC cable	———	CAPEX	MEUR/MW*km	0.00168	0.00234	0.003
Offshore HVDC converter (including platform)	P+C	CAPEX	MEUR/MW	0.55	0.625	0.7
Onshore HVDC converter	C	CAPEX	MEUR/MW	0.25	0.275	0.3
Offshore node expansion	NE	CAPEX	MEUR/MW	0.165	0.18575	0.21
Offshore AC Substation		CAPEX	MEUR/MW	0.441	0.5005	0.56
Onshore AC Substation		CAPEX	MEUR/MW	0.189	0.2145	0.24
Offshore = Onshore AC cable		CAPEX	MEUR/MW*km	0.00135	0.0012	0.00105
Onshore HVDC cable	———	OPEX	% of CAPEX/year	2.50 %	2.50 %	2.50 %
Offshore HVDC cable	———	OPEX	% of CAPEX/year	2.50 %	2.50 %	2.50 %
Offshore HVDC converter (including platform)	P+C	OPEX	% of CAPEX/year	1.50 %	1.50 %	1.50 %
Onshore HVDC converter	C	OPEX	% of CAPEX/year	1.50 %	1.50 %	1.50 %
Offshore node expansion	NE	OPEX	% of CAPEX/year	1.50 %	1.50 %	1.50 %
Offshore AC Substation		OPEX	% of CAPEX/year	1.50 %	1.50 %	1.50 %
Onshore AC Substation		OPEX	% of CAPEX/year	1.50 %	1.50 %	1.50 %
Offshore = Onshore AC cable		OPEX	% of CAPEX/year	2.50 %	2.50 %	2.50 %

Table 1 – Cost Assumptions.

The onshore High Voltage Direct Current (HVDC) cable covers the route of the offshore-to-onshore connection happening on land. It does not cover any internal reinforcement.

Sensitivity assumptions are based on numbers which have been sent for external consultation by the ENTSO-E Scenario building process, the German offshore network development plan (page 119 and 120) and an average of both. They have been used to develop different cost configurations for the expansion loops described in the following chapters.

It is important to note that assumptions on asset prices are very uncertain due to at least three reasons:

- The ONDPs deal with a long-term development that falls under the “class 5” category of AACE International’s classification system, usually performed during the conceptual stage of a project. This translates into an additional uncertainty range of -20 to + 100 % around the sensitivities found;
- Current uncertainties due to inflation and tensions on the supply chain add substantially to the above. TSOs experience substantial short term price increases compared to only one year ago; and
- Uncertainties-related technology evolution are a third dimension usually covered in the above-mentioned AACE standard, but should be specially highlighted here as the political push offshore development might speed up HVDC technology developments that would evolve later without that push.

2 ONDP Development Steps

To build the first edition of the high-level strategic ONDPs for each sea basin, the following three steps have been executed. These steps are illustrated in Figure 2 and are further elaborated upon in the next section and in Figure 3.

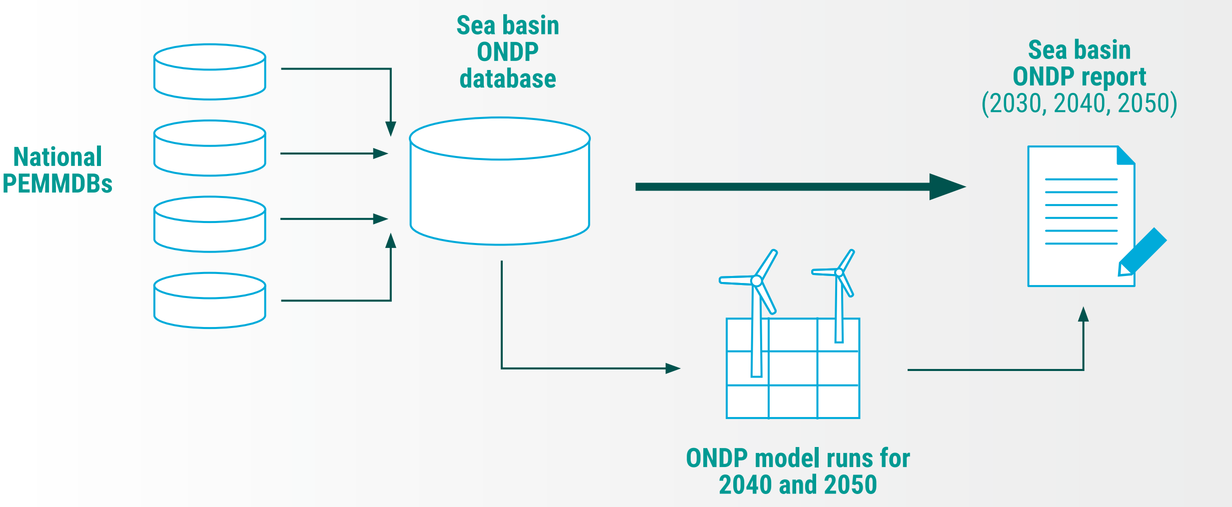


Figure 2 – Development steps of the ONDP. PEMMDB stands for Pan-European market Modelling Database, and it is the central database used by ENTSO-E to develop all planning products. Each TSO develop a dedicated database, including data from their own countries.

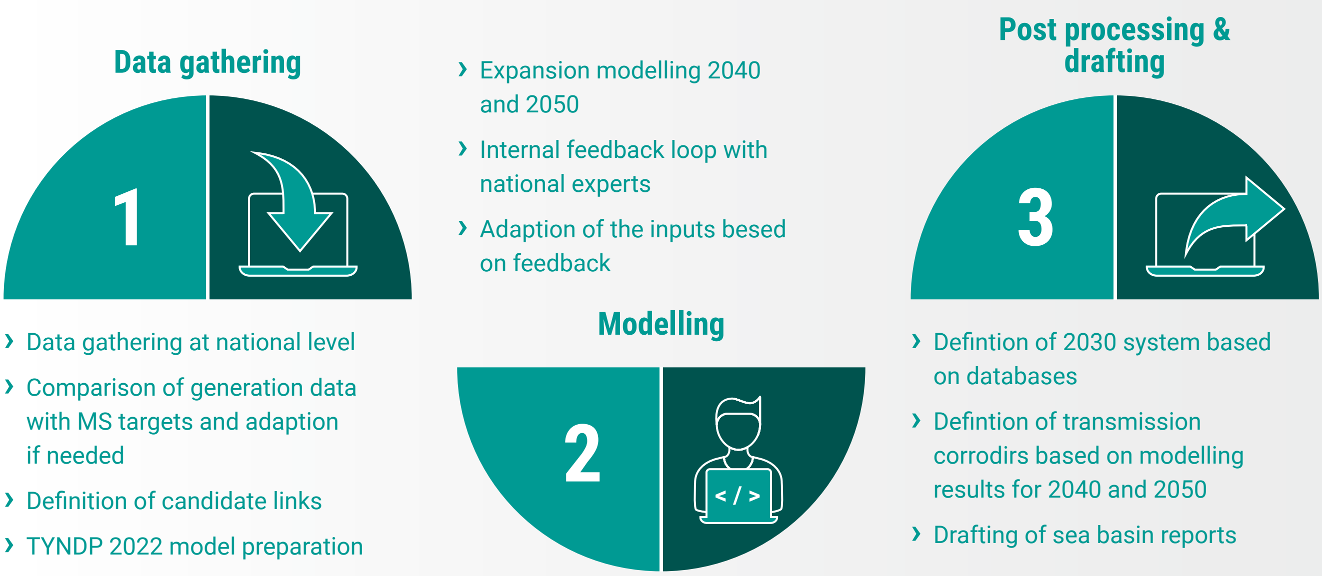


Figure 3: ONDP Development Steps.

Step 1: Data gathering and preparation of ONDP models. During this phases, the following has been specified:

- The offshore RES generation clusters (capacity and location) within each sea basin, based on the Non-binding agreements and other information from the MSs;
- The starting transmission infrastructure to connect wind parks and clusters/hubs of wind parks. The standard assumption is that all offshore RES is at least connected to the country belonging to the Exclusive Economic Zone (EEZ) – or several countries, in the event it is already considered in known plans (TYNDP, National development plans) and ambition to do otherwise (e.g. offshore hybrid projects); and
- Possible ideas of initial connection options to further expand the offshore transmission infrastructure, if not considered in Step 2.

Step 2: Modeling – Central high-level model runs for 2040 and 2050, specific to the ONDPs, to specify offshore hybrid transmission corridors, including:

- Opportunities for expansion of the offshore transmission infrastructure, connecting two or more offshore nodes to each other; and
- Opportunities for expansion of the offshore transmission infrastructure, connecting an offshore node to (an) additional onshore node(s).

Step 3: Post-processing of modelling outcomes and opportunities by the ENTSO-E Regional Groups. Regional Groups are to use the findings from the model run to further detail the offshore configuration[5] by:

- Defining the potential infrastructural asset needs to realise the offshore transmission corridors identified in the model run (e.g. number of substations, km of cables).

Figure 4 provides a more detailed breakdown of the ONDP preparation process.

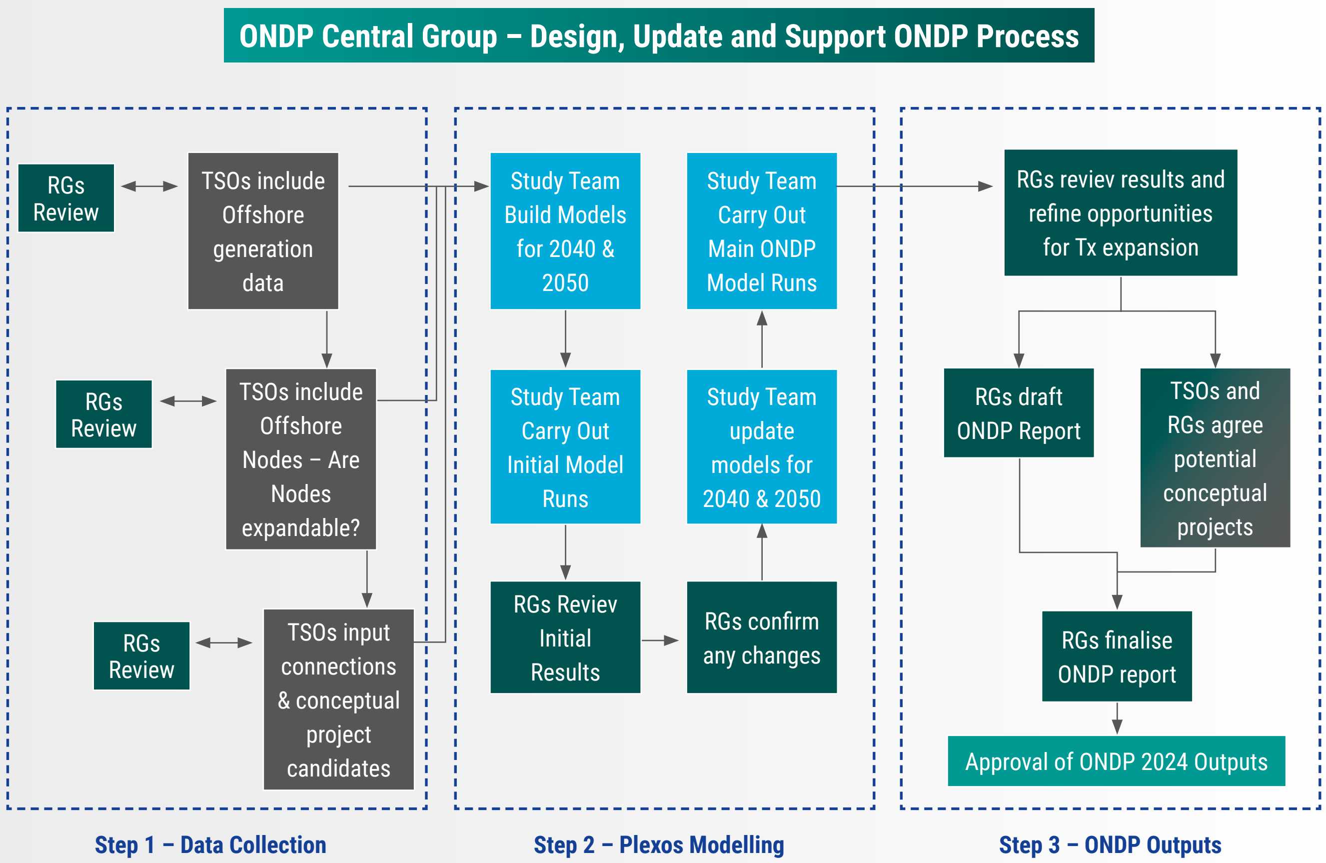


Figure 4 – ENTSO-E Development process & responsibilities behind the ONDP.

5 The results of the ONDP will be used as an input to the TYNDP 2024 IGIS to identify onshore reinforcement needs.

ENTSO-E runs a linear expansion model, applying information submitted by the Member States (offshore capacities, locations) and TSOs (Em, potential links). For practical reasons, the TYNDP2022 "Distributed Energy" scenario model has been used and the new MSs' offshore capacities have been mounted on it. ENTSO-E runs simulations for the 2040- and 2050- time horizons. Simulations are then post-processed by ENTSO-E's Regional Groups (RG), doing plausibility checks and refining the results.

The 2030- time horizon is known (please refer to TYNDP 2022); thus no expansion-model-run has been executed. The onshore system expansion is investigated in the TYNDP24 context in late 2024 as part of the IoSN phase of the TYNDP.

Overall, an entire process for the expansion process can be visualised, as shown in Figure 5.

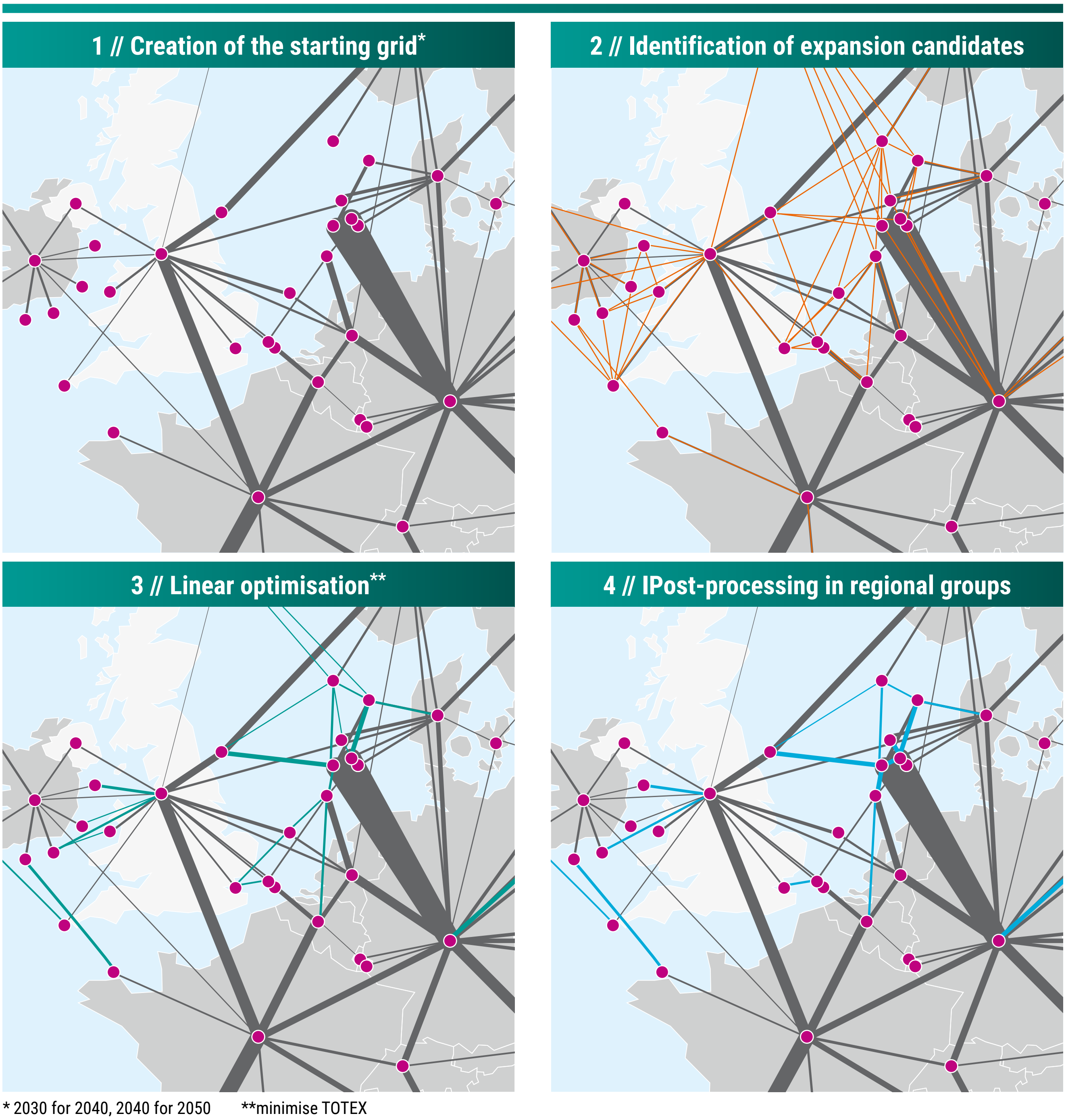


Figure 5 – Schematic Visualisation of the ONDP expansion loops.

2.1 Starting Conditions for the ONDP modelling

Step 1 – Data gathering and preparation of ONDP Models

For the 2040- and 2050- time horizons, the ONDP is based on the **TYNDP22 DE model**, using the TYNDP2022 results as a starting point, integrated with the updated offshore RES capacities aligned with the MS non-binding goals. The models aggregate the generation (installed MW) and transmission (NTC) information to create a starting grid, shown in Figure 6. This starting grid is then expanded through a linear optimisation algorithm, with the goal of identifying additional transmission corridors between the offshore nodes, and between the offshore and onshore nodes.

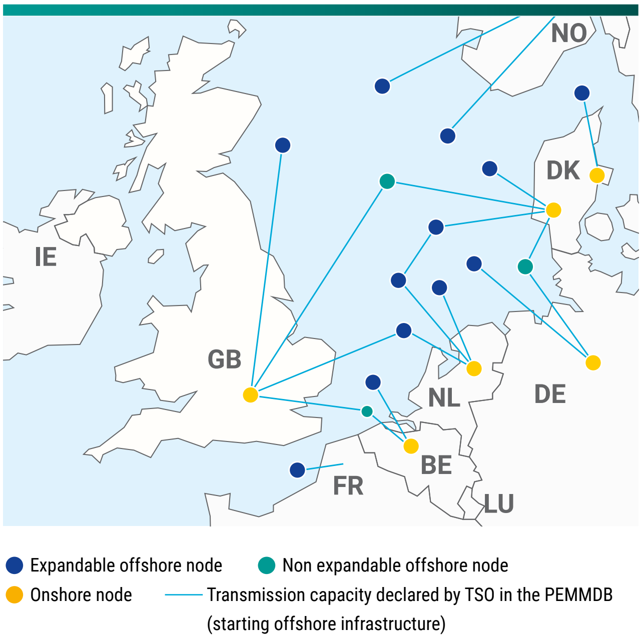


Figure 6 – Output of Step 1 (illustrative).

The preparation of the model will enable a starting offshore grid to be "drawn", composed by the offshore generation nodes, the planned hybrid projects and the radial connections which are available to hybrid expansion.[6]

The original offshore generation capacities resulted from the TYNDP2022 DE Scenario, summed up to 127 GW, 260 GW and 407 GW in 2030, 2040 and 2050 respectively. These capacities has been updated to the updated ambitions of the EU Member States, Norway and UK.

Once the capacities were set, the offshore generation nodes in each country have been defined, in 2040 and 2050 models. The generation nodes have been defined by aggregating offshore RES generation capacities available for hybrid transmission interconnection to reduce the overall system costs when connecting the offshore RES to the system. Aggregation criteria are:

i. the offshore RES are located fairly close to each other and located within the same Pan-European Climate Database (PECD) zone, sharing a similar production pattern (see Figure 6);

ii. is fully comprehended in the same national waters; and

iii. is characterised by the same of the following node-connection-options (see Figure 8):

   a) Radially connected, not ready to be expanded[7]

   b) Radially connected but ready to be expanded

   c) Hybrid transmission, not ready to be expanded

   d) Hybrid transmission, ready to be expanded.

The location of the offshore nodes included in the 2040 and 2050 simulation-models is defined in compliance with the national Maritime Spatial Plans (MSPs) (where available) or equivalent national spatial planning for the maritime areas (see also chapter 3).

The candidate links for the 2040 and 2050 modelling run have been individuated, mainly through 2 criteria:

- Direct TSO–TSO coordination on potential interesting (from a technical or economical perspective) links; and
- Geographical proximity of the offshore nodes.
- The total candidates considered are 109 and 269 for 2040 and 2050 respectively.

6 The map is a qualitative representation of the potential structure of the offshore model in the North Sea, not based on the real data under gathering.

7 From a modelling perspective, these nodes will not have to be included as separate nodes. However, it is important that this information is gathered in the RG.

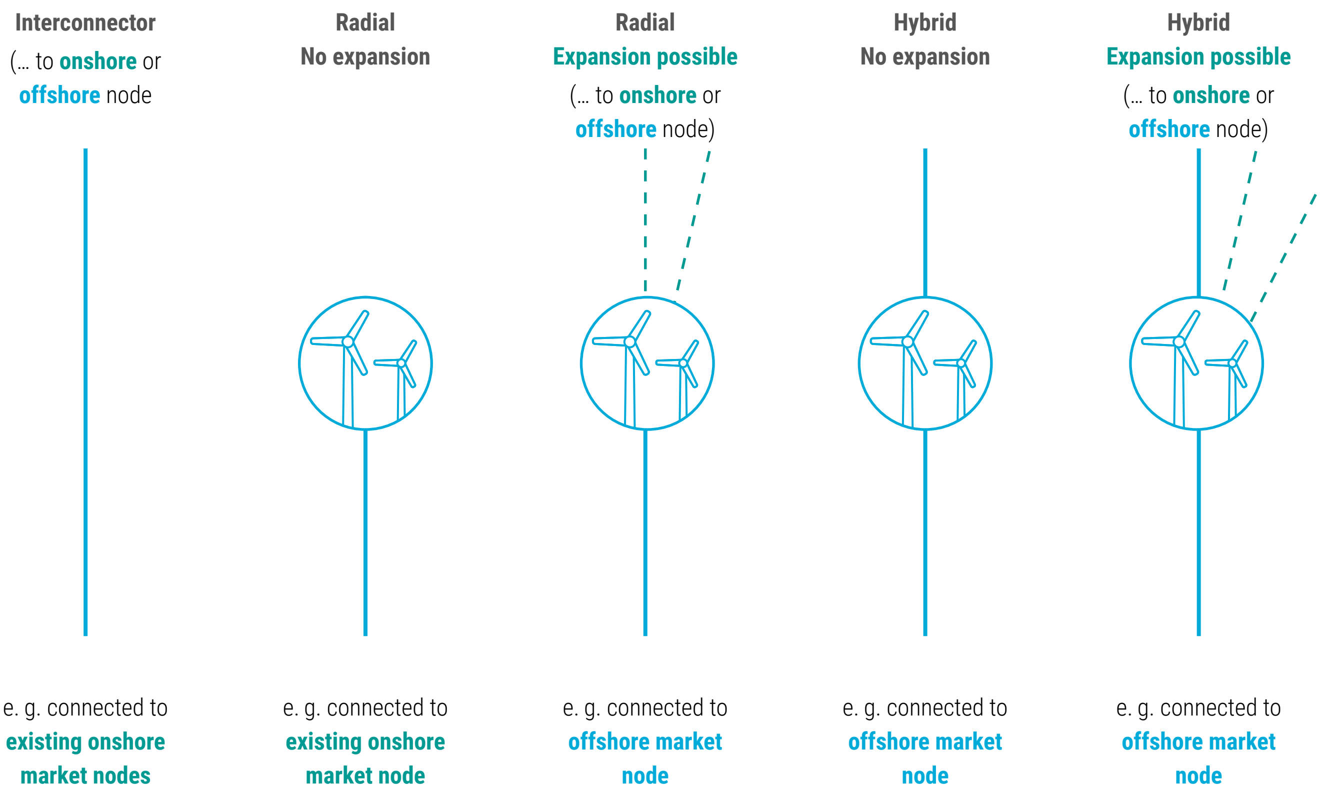


Figure 8 – Representation of node-connection-options (to be specified by the RGs).

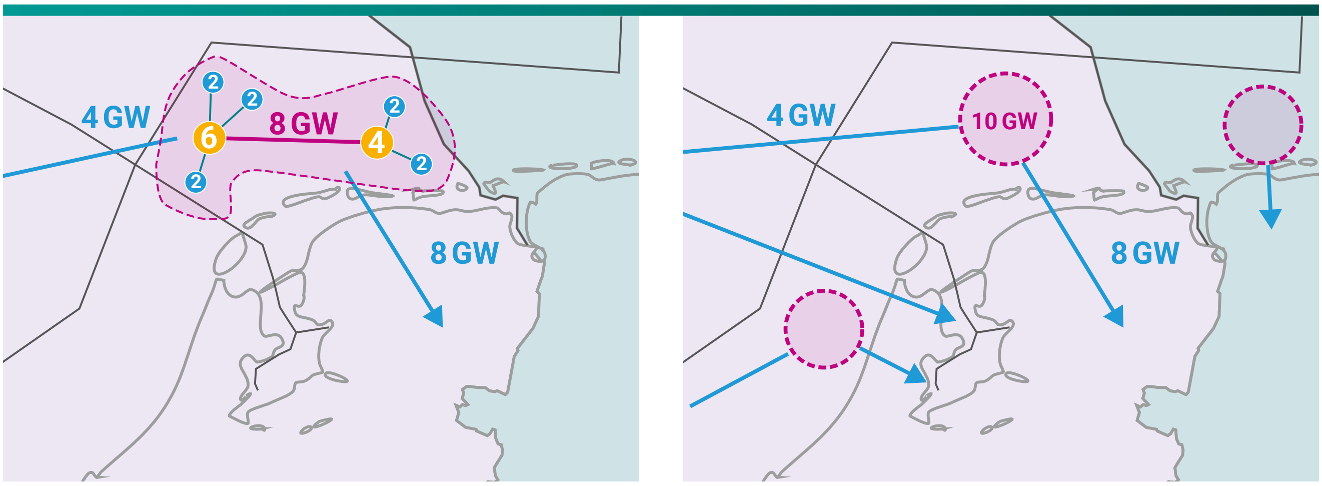


Figure 9 – Step 1 – Aggregation of offshore RES Clusters into nodes in the model. The ONDP will give the details about the distribution of the generation capacities and transmission infrastructure inside the modelling nodes in step 3.

To capture the future trend of increased electrification in the European energy system, the electrical demand from TYNDP 2022 models has been increased by 8 %. This value has been judged as a reasonable compromise between the early figures from the Scenarios 2024 and the estimations provided by the European Commission. The increase of 8 % of the electrical demand has been performed by updating the values of the single national electrical demands.

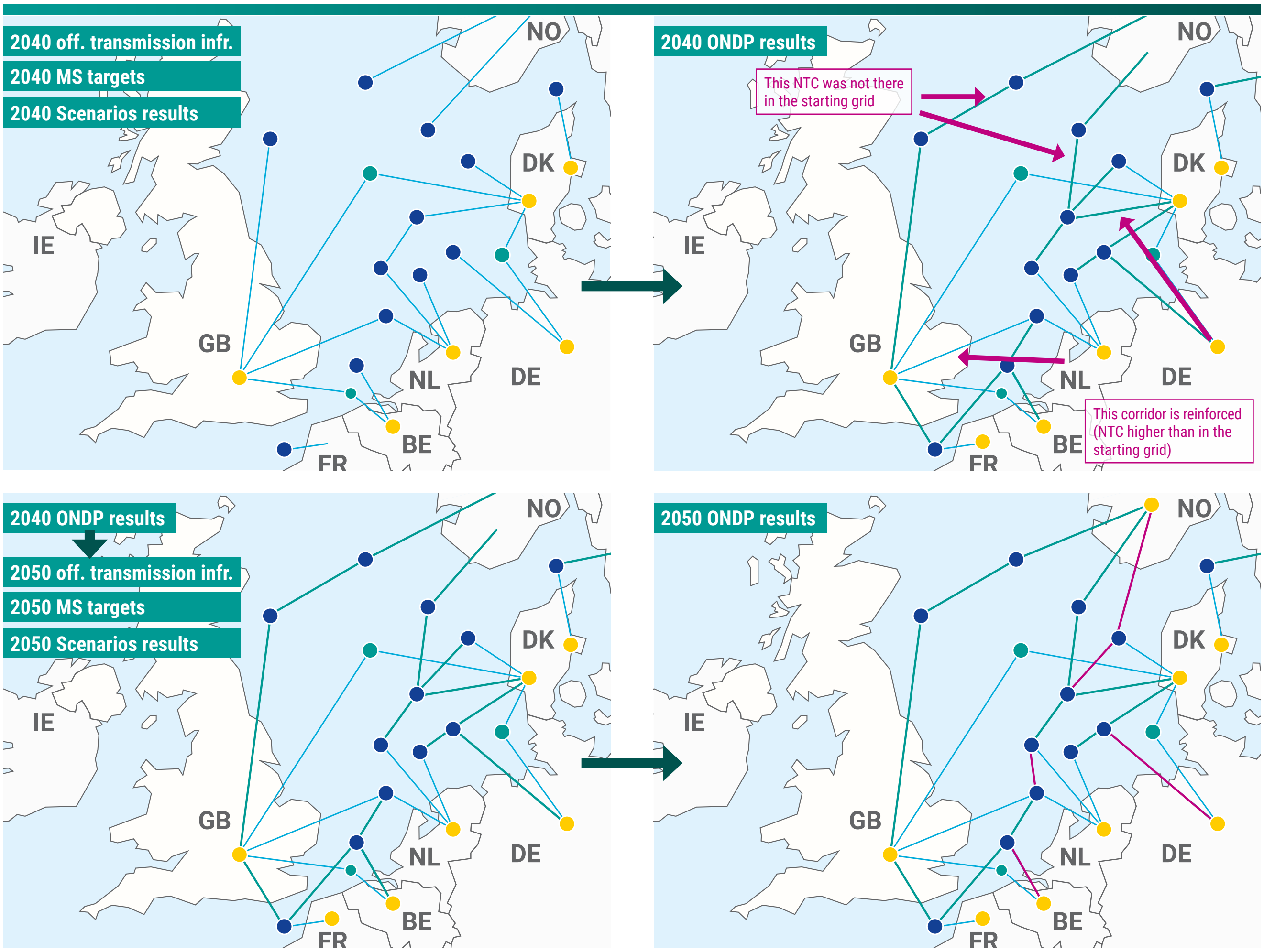
Step 2 – Central model run for 2040 and 2050, specific to the ONDP

As more than 90 % of the generation targets are not yet realised, there is a need to investigate the potential configuration of the transmission system connecting them. The expansion of the transmission infrastructure considers investment options to neighbouring nodes that could be available for expansion to hybrid configuration, in compliance with the location and specification of the offshore generation nodes.

- As mentioned earlier, for the first ONDP edition, no expansion will be run on the onshore system. Related investigations will be done in the TYNDP24 exercise, considering the outcome of this first edition;
- No expansion will be run on the offshore generation capacities as these are fixed in line with the MS goals;
- The starting grid includes the transmission capacity connecting the generation capacity radially to the respective country, and any hybrid infrastructure already planned; and
- The additional transmission capacity corridors identified during the expansion simulation represent aggregated information and not single projects.

The grid model is expanded through a linear optimisation problem, meaning that the size of the candidates is not priorly defined, but individuated by applying the standard costs of the infrastructure to the distances of each candidate, with the objective of minimising the target function. The additional transmission capacity connects the offshore nodes to neighbouring market zones, allowing the increase in the dispatched energy and decrease in overall system emission due to thermal generation powered by fossil fuels.

The results obtained through the model runs have been checked, clustered and the size of the corridors set to a meaningful value, while keeping the identified transmission corridors in place.



The maps are a qualitative representation of the offshore model in the North Sea, not based on the real data gathered.

Expandable offshore node · Non expandable offshore node · Onshore node · Transmission capacity declared by TSO in the PEMMDB (starting offshore infrastructure) · Transmission capacity obtained through the model in 2040 · Transmission capacity obtained through the model in 2050

Figure 10 – Step 2 – The optimiser expands NTCs of existing links between nodes and creates new links.

Simulation method

The expansion loop of the simulations is based on linear optimisation, i.e. costs grow linearly with the size/length of the project, and the target function finds a minimal total system cost in terms of Capital Expenditure + Operating Expenditure (CAPEX+OPEX).

As the linear programming approach is not constrained by the obligation to find integer results for the expansion links, it is much faster and enables the adaptation of the inputs to explore different configurations. As the ONDP is a strategic high level exercise that should avoid the assessment of single projects and investigating transmission corridors, the linear programming approach offers a good compromise between speed of simulation and level of detail of the outcomes.

In particular, the problem is set-up by implementing the following approximations:

- Variables representing investments are continuous variables;
- Power flows in the network lines obey Kirchhoff's first law (i.e. DC load flow); and
- Only uncertainties related to the consumption and availability of generation units are considered.

The optimiser does not define a set of projects but the overall transmission capacity (NTC) pursuing the same target function, defined as:

$$\min\left(\sum CAPEX + \sum fixed\ OPEX + \sum variable\ OPEX\right)$$

The variable OPEX value includes the amount of unserved energy during the dispatch and the value of lost load, together with fuel costs and other variable OPEX.

The standard transmission technology considered for the expansion candidates is HVDC, with VSC converter technology. It is assumed that all technology is interoperable. To cope with the uncertainties related to the technical evolution of the connection solutions, two main configurations have been considered when calculating the costs related to the expansion of the offshore transmission corridors:

- A "With DC breakers" technical configuration, in which the different corridors are connected through DC hubs including DC breakers; and
- A "Without DC breakers" technical configuration, in which the different corridors are connected through the use of AC hubs, and each link has a dedicated AC/DC converter.

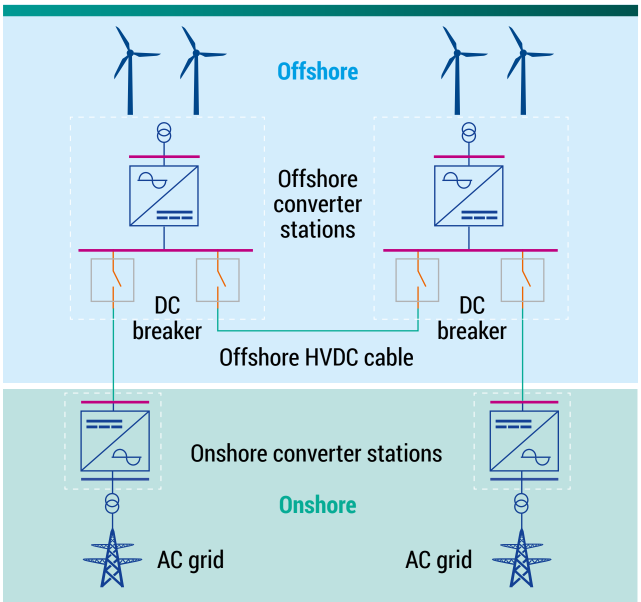


Figure 11 – Example of a hybrid configuration using DC breakers, with only one converter per offshore substation, and DC breakers protecting the HVDC links.

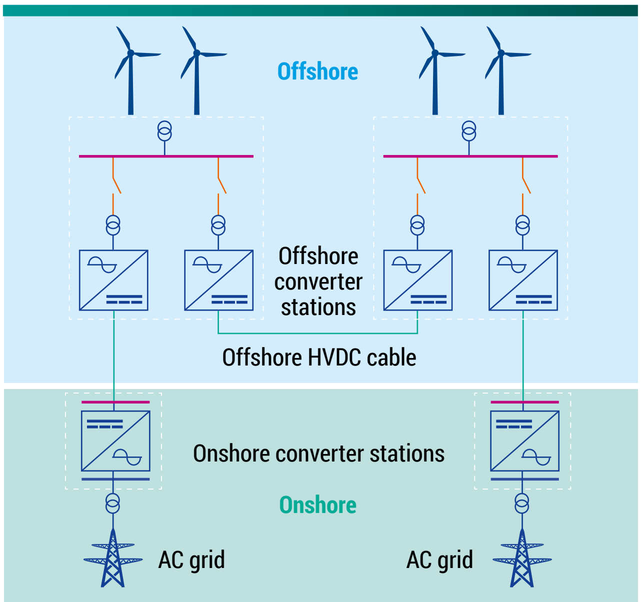


Figure 12 – Example of a hybrid configuration without using DC breakers, with one converter per each HVDC link.

For both of the above technical configurations, three cost sets have been defined, to cope with the impact of the cost of infrastructure on the expansion of transmission assets.

- Cost set 1: cost values equal to the ones considered in **Scenarios 2024**, this cost set considered the lowest costs of infrastructure;
- Cost set 2 – and average of cost sets 1 and 3; and
- Cost set 3 – costs equal to the German National Development plan, this costs set included the highest costs of infrastructure

The table with the values considered can be found in chapter 1 of this document.

The linear expansion algorithm assesses, for each technical configuration and costs set, the amount of additional transmission infrastructure to decrease the system costs (CAPEX+OPEX), also assessing the increase in the energy dispatched and the reduction in CO_2 emissions.

The linear results are the basis for the definition of the transmission corridors. However, as they come in the form of continuous values of transmission capacity, these results need to be assessed to find the reasonable discrete technical sizes allowing the evaluation of the potential infrastructural needs.

Step 3 – Post processing of the modelling results, drafting of the sea basin reports.

In step 3, the regions translate the linear results of the simulation into discrete transmission corridors, sized through the technical assumptions listed above. The information on the size (expressed in transmission capacity) of the corridors is translated into potential needs for transmission assets, in terms of km cable, number of substations etc..

This post-processing and translation of the modelling results begins with two basic activities:

- The assessment of which new connections make sense (from a technical perspective); and
- The assessment/adjustment of the corridors' size to discrete values.

The criteria for the consideration of a corridor is its appearance under different technical configurations and cost sets and/or importance for national offshore strategies.

Once the final discrete transmission corridors have been identified and the total amount of transmission capacity connecting the generation capacities is defined, a theoretical assessment of equipment needs is executed, based on a set of technical assumptions and the location of the assets.

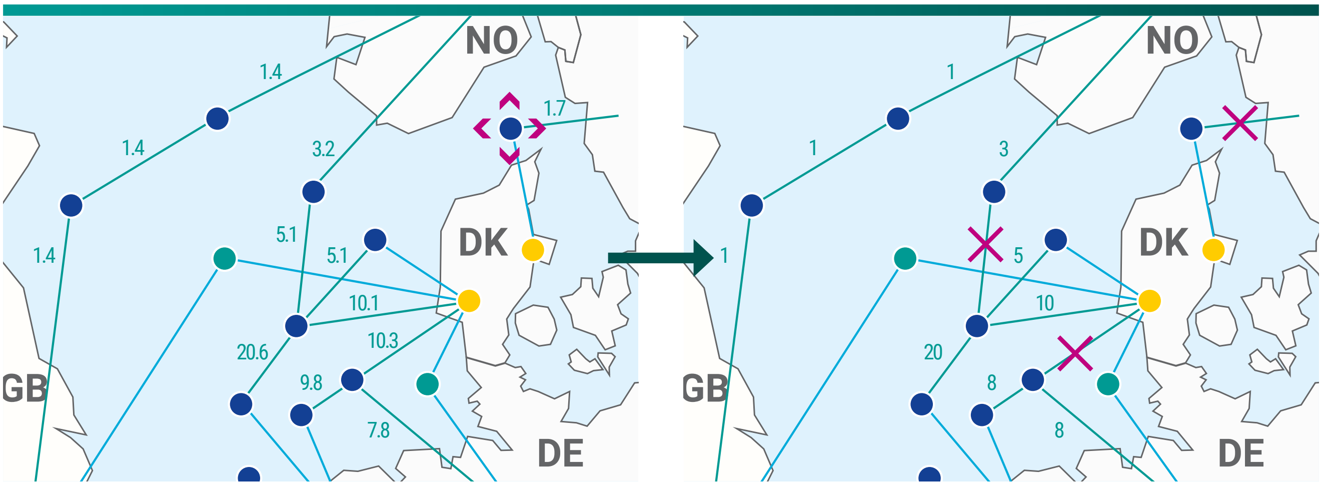


Figure 13 – Step 2 – example of the post-processing of step 2 results (green lines).

The following criteria will be used to select the most suitable transmission technology for the connection of offshore clusters:

Zone \ Size of the RES cluster	Up to 1 GW	Between 1 and 2 GW	Above 2 GW
Zone I 0–22.2 km	HVAC	Single HVDC	Multiple HVDC (max size per connection, 2 GW
Zone II 22.2–50 km	HVAC	Single HVDC	Multiple HVDC (max size per connection, 2 GW
Zone III 51 km – EEZ border	Single HVDC	Single HVDC	Multiple HVDC (max size per connection, 2 GW

Table 2 – Criteria for choosing the transmission technology to connect an Offshore RES cluster. Zones consider the distance-to-shore, while related cable lengths include the assumption of an additional 30 km onshore connection to a standard node.

- Zone I – Offshore RES clusters will be radially connected by high voltage alternating current (HVAC; standard power and voltage levels if possible). In rare cases, RES clusters will be connected with HVDC if these clusters are or will be connected to other RES clusters or their capacities are equal or larger than 1 GW. The possibility to foresee installations within area I should be cross-checked against national regulations;
- Zone II – Offshore RES clusters will be radially connected to shore by HVAC[8] or HVDC if the capacity is equal or beyond 1 GW. HVDC will also be applied when the RES clusters are or will be connected to other RES clusters; and
- Zone III – Offshore RES clusters in area III will be connected to shore and other clusters by HVDC.

The approach is summarised in Table 2. For 2030, 2040 and 2050, HVDC connections will be sized up to 2 GW 525 kV.

For the list of investment options and related costs, please refer to the material in the annexes.

8 The threshold of 50 km has been applied HVDC projects start appearing at these distances. This assumes that the connection includes a maximum 30 km distance from shore to a theoretical standard onshore connection point. Together with the application of the TYNDP 2022 NTC-model with one node per onshore market zone, this implies that "deep" connections to the onshore system just like onshore expansion in general will not be reflected in the first edition of the ONDP. This is part of the IoSN-24 process of the classic TYNDP 2024.

3 Spatial Planning

This chapter specifies how the spatial information coming from the MSP, or any equivalent deliverable from the Member States, is used and provides methodologies for the offshore transmission and generation planning. The MSP data can be applied as a basis for the definition of the offshore generation nodes and the post processing of the modelling outcomes.

As mentioned in chapter 2, MSP data have been considered both during Step 1 (data gathering) and in Step 3 (Post processing) of the ONDP development. In Step 1, MSP data have been used to define the location of offshore generation capacities, while in Step 3 the spatial information on the potential conflict between usage of the maritime areas has been considered to investigate solutions to accommodate the ONDP results.

3.1 Maritime areas for planning of offshore RES generation and transmission

The MSP delivered by every MS should indicate which areas are assigned to host offshore generation and transmission. The majority of MSP information is available for a time frame up to approximately 2030. Whenever information was not available on the 2040 and 2050 time horizons, the applicability of the available data for all the relevant timeframes (2030, 2040, 2050) has been assumed.

The following information concerning offshore energy planning has been in the MSPs, whenever available:

- Maritime areas assigned to offshore RES generation;
- Maritime areas assigned to offshore transmission infrastructure;
- Maritime areas assigned to P2X infrastructure; and
- Coastal areas assigned to energy infrastructure.

The main information about European MSPs is available at The European Maritime Spatial Planning Platform. The level of development (see Figure 14) and more detailed information on the MSPs per sea basin as defined by the EC can be found at the corresponding websites:

1) Baltic Sea basin;

2) North Sea basin;

3) Atlantic Ocean sea basin;

4) East Mediterranean sea basin;

5) West Mediterranean sea basin;

6) Black Sea basin;

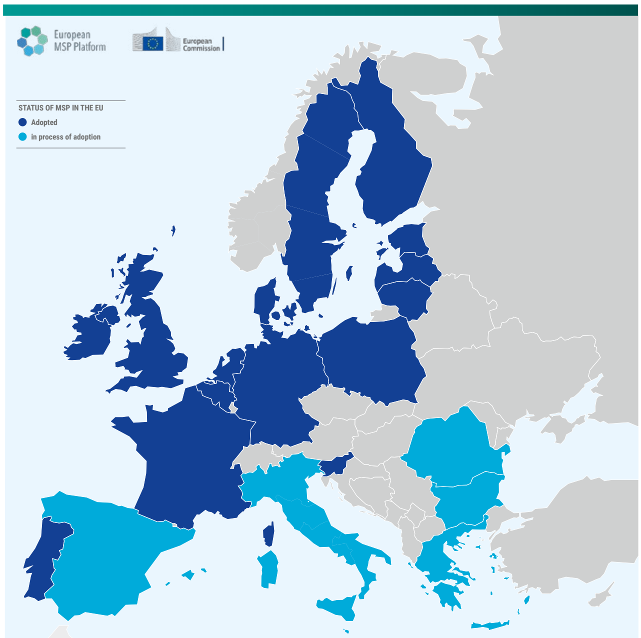


Figure 14 – Comparison of the adoption of MSP plans in Europe[9].

The MSP information has been used during Step 1 of the ONDP development to define the position of the offshore nodes considered in the 2040 and 2050 models, and in Step 3, during the post processing of the modelling results and the assessment of the infrastructural needs.

In Step 1, the available information on the position of the maritime areas assigned to offshore RES generation has been used to define the coordinates of the generation capacities considered in the study. For radial connections, this enables the more precise definition of the distances to be considered when assessing the potential equipment needs to connect the aggregated units. In the setup of the 2040 and 2050 models, the MSP information has been used to define the coordinates of the offshore nodes connected through hybrid infrastructure.

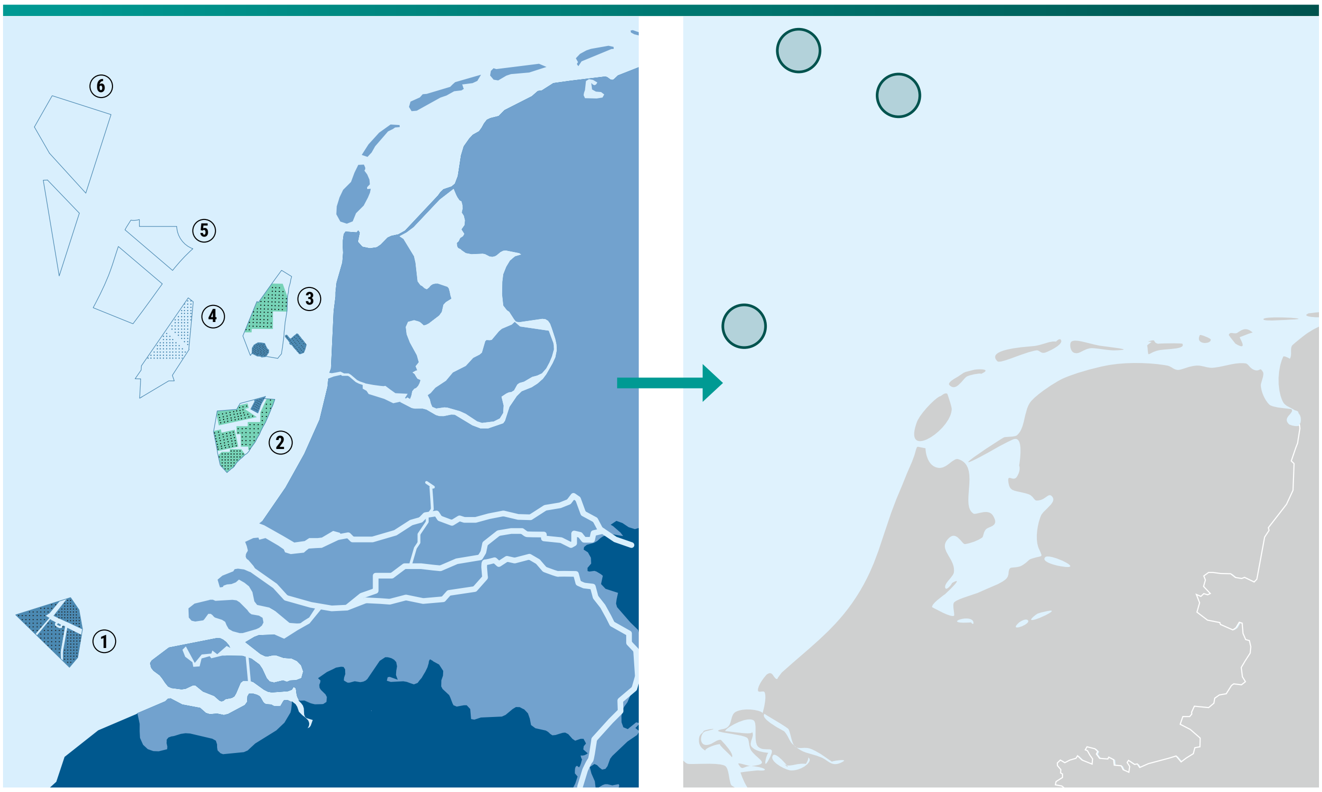


Figure 15 – Example of the use of MSP information for the definition of the nodes considered in the expansion of the NL hybrid infrastructure. The image on the right is the representation of the NL maritime areas assigned to offshore RES generation, and on the left is the position of the nodes considered in the ONDP24 expansion models for the NL waters.

9 Source: Countries | The European Maritime Spatial Planning Platform (europa.eu)

In step 3, during the post processing, possible conflicts between the different sectors should be considered when assessing the routing of the identified transmission corridors. Potential conflicts with the maritime areas listed below have been considered:

1. Military restricted area;
2. Environmental protected area;
3. Area required for maritime usage
   a. Marine aquacultures,
   b. Extraction of marine aggregates,
   c. Mooring areas,
   d. Dense shipping lanes.

When precise sets of rules for the coexistence of the assets of different sectors have not been defined in the MSPs, the following rules have been applied:

Generation allocation and transmission routes:

- Attempt to avoid the allocation of generation infrastructure in military areas and shipping lanes;
- You can cross shipping lanes with transmission assets if necessary, but you should not run in the same trench;
- Attempt to avoid transmission routes in military areas (see also chapter 3.2); and
- Only use environmental protected areas if absolutely necessary and only in allowed areas, e.g. in the event there is insufficient space in national EEZ to allocate envisaged offshore generation. Transmission routes should also use the minimum possible environmental protected area.

So far, Member states have expressed that there are no joint international rules in terms of "go-to" or "don't-go-to" areas offshore. Thus, ENTSO-E's approach is to apply common sense for its high level ONDPs, knowing that these rules might be more strict or loose in different areas.

The treatment of reservation areas might differ nationally. For creating the ONDPs, the working assumption is that reservation areas can be used for the allocation of RES generation. This simplifying instruction is given with the knowledge that it might violate national rules in some Member States but not in others.

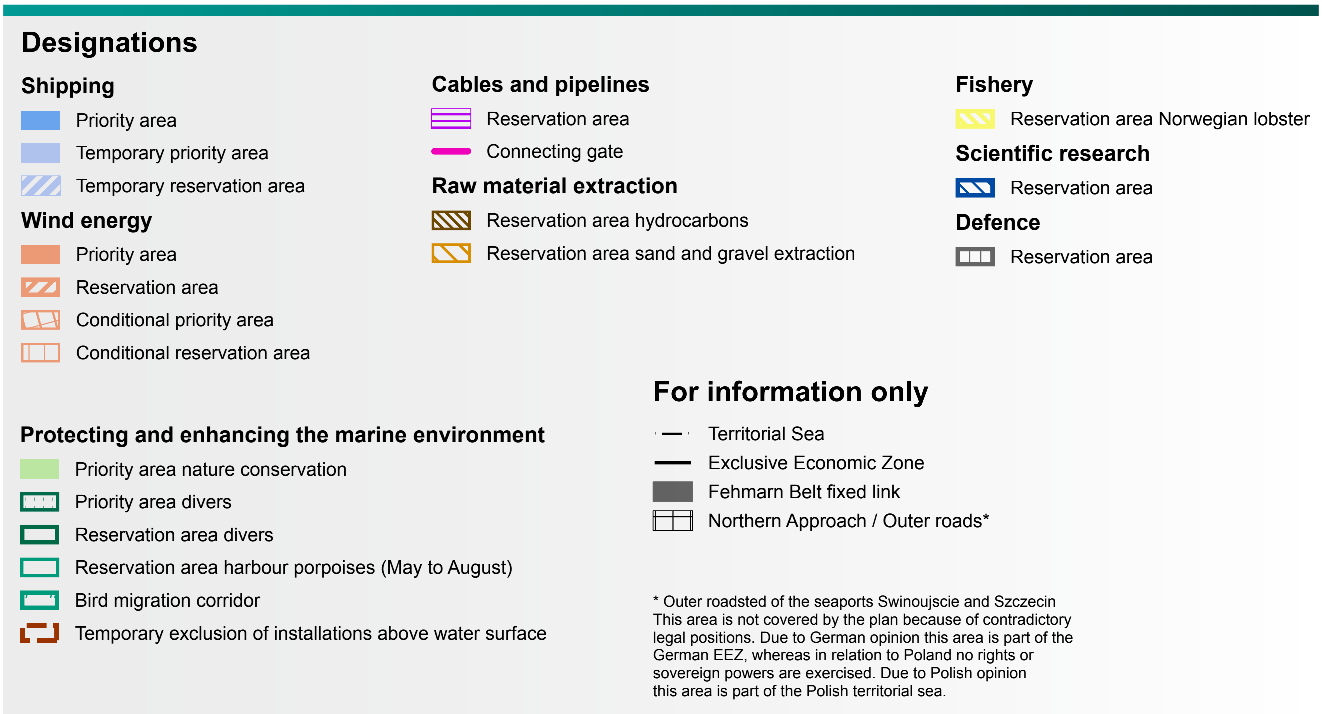


Figure 16: Example of MSP with multiple usages (Germany North Seas and Baltic Sea 2021).

Source: BSH - Maritime Spatial Planning

3.2 Space requirements for offshore transmission infrastructure

When defining the length of a cable route, a +15 % to the straight line distance has been considered to take into account the deviations occurring due to obstacles or restricted zones.

The following maximum widths for the transmission corridors are assumed:

- **HVDC – 200 m corridor** can be wide enough for a HVDC ± 525 kV 2 GW transmission asset (two or three cables); and
- **HVAC** 225 kV, up to 1.4 GW (maximum capacity of the offshore substation; the power is assumed to be transmitted over different circuits) – three links are necessary with a sufficient distance between the links to repair it if the cable is damaged (depending on the water depth), leading approximately to a **600 m corridor**.

Therefore, the widths of the corridor should be well dimensioned to identify which maritime area it can cross and which landfall can be acceptable.

Other existing or planned uses of the sea should be analysed in the MSP to check that the transmission assets are compatible with it and to define the best possible route. Depth gradient of the waters should be checked to avoid hindering conditions for the installation of the submarine cables.

For the methodology of the MSP information application in the ONDP 2024 regrading offshore transmission, please use the methodology description regarding RES generation as described in chapter 3.1.

Figure 17 – Cable route of OWF Nederwiek VS straight point-to-point line, an example of the adaptations considered in the 15 % addition mentioned above.

4 How the ONDP 2024 links to the TYNDP 2024

The ONDP 2024, although it is a separate product, remains part of the TYNDP, in line with the mandate of the 2022/869 EU Reg Art 14.2. This means that the results of its analysis are considered in the rest of the TYNDP products.

In particular, the ONDP capacities and transmission infrastructure are fed into the process behind the development of the IoSN 2024. The IoSN have the scope of investigating the cross-border transmission needs in the European system. To do so, a certain amount of candidate projects is considered and then included in the optimisation algorithm. The transmission corridors identified in the expansion loop of the ONDP are used as a basis to define the conceptual project candidates linking the offshore nodes of the IoSN model through hybrid infrastructure.

By TYNDP 2026, the on-and offshore planning will pursue a fully holistic approach, being integrated in a single planning process in line with actions Nr. 2 of the EC's Grid Infrastructure Action Plan from November 2023:

- follow ENTSO-E's holistic approach (across time, space and sectors. crossing lands and seas) and
- The ONDP and TYNDP processes are the same, thus, data collection
- fully be integrated into the Scenario building/TYNDP process.
  - the sector integration aspect especially will gain from this integration as scenarios are always elaborated together with ENTSOG.

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