TYNDP 2024

Offshore Network Development Plans

European offshore network transmission infrastructure needs

Pan-European summary **January 2024**

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**

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Executive Summary

The European Union (EU) is fully committed to leading the global energy transition towards a decarbonised future and ensuring strategic autonomy for the European energy supply. These factors have become the main long-term drivers for EU energy policy and legislation.

The vast offshore renewable energy potential of Europe's sea-basins will play a crucial role in the future decarbonised energy system. They offer a clean, endogenous and efficient source of renewable energy. The sea basins will have to host the offshore network transmission infrastructure needed to further integrate the national energy systems. This Offshore Network Development Plan (ONDP) provides some high-level information related to this transmission infrastructure in the TEN-E offshore priority corridors, needed to connect the offshore renewable energy sources (RES) capacities foreseen by EU Member States and some neighbours.

This Pan-European Summary Report of the ONDP gives a high-level overview of the infrastructure needs[1], related components and their anticipated – although increasingly uncertain – costs. The plan is based on the European Member States' non-binding agreements on offshore goals from January 2023[2]. In line with the European Commission's Offshore RES Strategy[3] from 19 November 2020 and Regulation (EU) 2022/869, EU Member States agreed to increase their efforts to integrate up to 354 GW of offshore RES generation capacities by 2050[4] in European energy systems.

What is the Offshore Network Development Plan and for whom is it important

The ONDP translates the non-binding agreements delivered by EU Member States in January 2023 into offshore transmission equipment needs and related costs. The transmission equipment needs cover both radial links and offshore hybrid transmission infrastructure.

The information included in the ONDP is important for:

- The supply industry: They have to produce the equipment on time;
- The ones who have to pay: Further specifications on this topic are expected by June 2024, when the European Commission (EC) will deliver guidance on sea-basin cost–benefit cost sharing[5];
- The governments: They have to balance between marine environmental protection, biodiversity needs and the needs of further marine industrial users; and
- The offshore wind industry and developers: Without offshore and onshore infrastructure, their efforts would be in vain.

Thus, the ONDP helps to accelerate the implementation of the European offshore RES targets by providing the information necessary for multiple political and industrial discussions.

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[1] This is a task for ENTSO-E set out in EU 2022/869 Art. 14.2.

[2] Delivery of these joint-non binding agreements is a task for the Member states set out in EU 2022/869 Art. 14.1.

[3] See here

[4] See here

[5] This is a task for the European Commission as set out in EU 2022/869, Art. 15

Main findings of the ONDP study

Offshore RES[6] will become the third- important energy resource in the European power system, providing 18 % of the dispatched energy in 2040 and 2050[7], which is sufficient energy to supply up to 55 million households[8] in 2040 already, if everything runs according to the Member States' goals. The additional offshore RES capacity must not be solely connected to the onshore systems, but the energy must also be efficiently integrated into Europe's energy systems. Implications for the onshore system will be assessed as part of the TYNDP24 system needs study.

ENTSO-E's investigations consider both EU27 Member States' non-binding agreements, and the goals of adjacent countries, such as Norway and Great Britain, which also aim to deliver substantial offshore RES-development. This explains why the total sea basin capacities in Figure 1 exceed the EU27 Member States goals.

The size of the task and the speed required is huge. As of today, just a small fraction of the envisaged offshore RES capacities have been installed. Already, to reach the 2030 ambitions, annual installations of (153 GW/6 years) ~25.5 GW annually have to be installed in the entire area, with EU countries needing to deliver 15 GW annually (Norway plus Great Britain together 10.5 GW each year). According to Wind-Europe, the average annual installation rate during the last 10 years was 2.5 GW, which illustrates the huge challenge for the Wind Industry. Offshore RES expansion has to be 9 times as fast as it was during the last 10 years.

The same challenge as for the Wind Industry applies to Transmission System Operators (TSOs) and Third-Party Infrastructure project promoters having to connect offshore RES. These connections of the offshore RES cluster to the onshore systems need to be timely provided and need to match at least the same pace as foreseen for the new generation clusters. As both industries are supplied by the same original equipment manufacturers, a tight supply market is already seen e.g. by the IEA in a recent analysis[9].

The ONDP identified a route length in the range of 48,000–54,000 km for offshore infrastructure installations, i.e. spanning nearly 1.5 times around the equator. The satisfaction of these equipment needs will be a challenge for the supply chain.

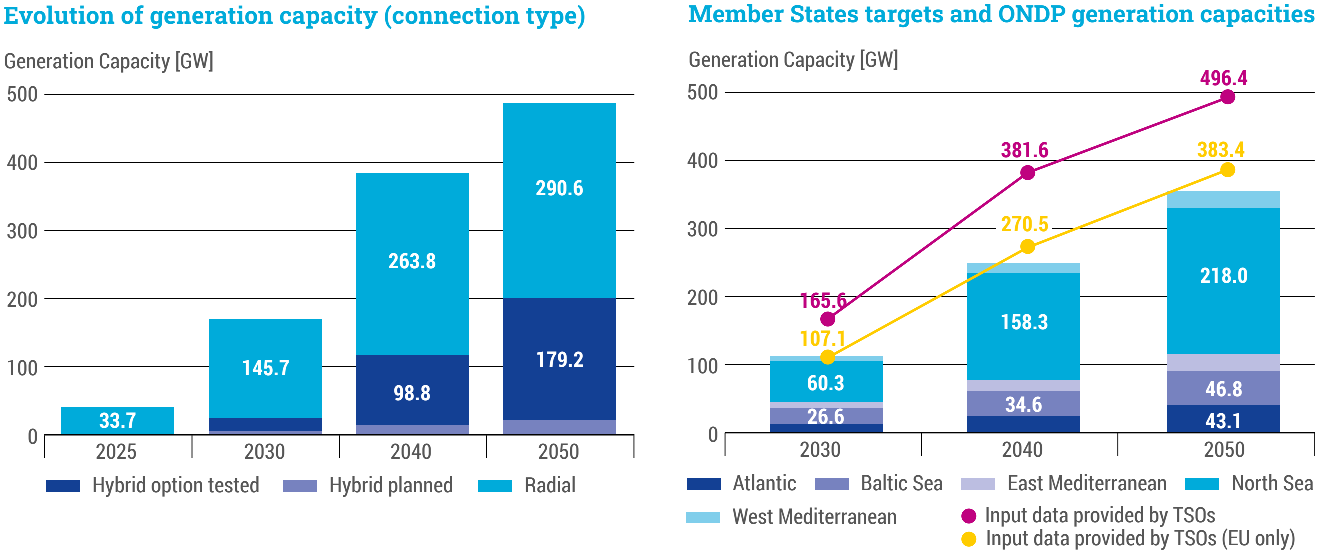

Figure 1 – European Member States' goals (bars, per sea basins), Input data (EU only) and input data including NO and GB.

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[6] In this first edition, ENTSO-E has considered only offshore wind generation capacities, in line with the information delivered by the Members States.

[7] These figures refer to the Distributed Energy scenario behind the TYNDP 2022, which has been the basis for the ONDP.

[8] See here

[9] See also recent IEA report (23 Oct 2023)

Massive capital expenditures for offshore transmission infrastructure are necessary. The ONDP finds that, to optimally integrate the offshore RES capacities of up to 383 GW in the EU27 plus 15 GW in Norway and 97 GW in Great Britain by 2050, around 400 bn € of investments are needed. Figure 2 summarises the ONDP results, highlighting the identified CAPEX to cover offshore infrastructure needs. The cost-needs assessed by ENTSO-E cover both the transmission infrastructure integrating the offshore RES capacities to the onshore systems and the additionally identified hybrid transmission corridors connecting some of the offshore RES clusters to different national systems.

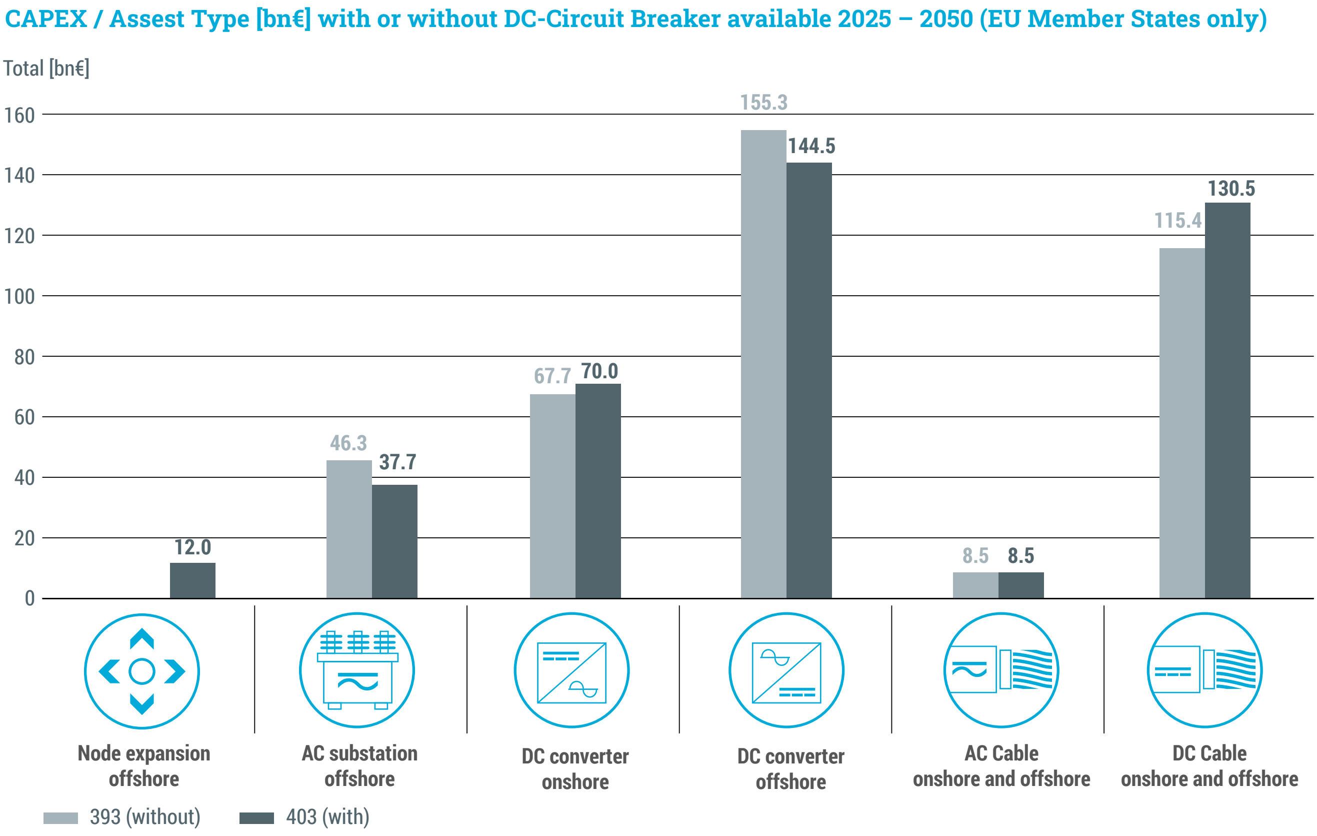

Figure 2 – Needed CAPEX for investments in offshore network infrastructure (2025–2050).

Most offshore RES is expected to be connected via radial connections. Up to 9 % of the 2050 offshore RES will be connected to more than one jurisdiction (7 % of EU Member States' offshore RES), beyond the already envisaged 26 GW by TSOs for 2050 (referring to the entire study area). **Adding both values gives a perspective of 14 % of offshore RES being connected via dual purpose hybrid infrastructure.** To identify the additional links, 380 expansion candidates were tested during the ONDP-exercise considering the entire study area. In general, between 13–34 candidates, (i.e. 4 % … 9 % of the 380 candidates) have been selected based on their economic efficiency.

	Additional interconnections [GW] related to the 2030 starting situation/total offshore RES capacity	
	a) With DC Circuit Breaker	b) Without DC Circuit Breaker
Within EU countries 2040 [GW]	13	2
Between EU countries + NO + GB 2040 [GW]	25	7.5
Within EU countries 2050 [GW]	27/383	5.4/383
Between EU countries + NO + GB 2050 [GW]	44.3/496	14/496

Table 1: Identified offshore capacities linking offshore nodes to another jurisdiction.

The future European offshore transmission system will not be fully "meshed" but will consist of a combination of radial offshore connections to offshore RES, classical point-to-point interconnections between countries, offshore hybrid projects combining both functions and even multi-purpose solutions integrating energy sectors by including e.g. hydrogen solutions.

The availability of commercially attractive DC-circuit breakers will make a difference. Related technology development and investment of additional 10 bn € will triple the interconnectivity of the entire study area by 2050 (see Figure 2 and Table 1). Already for the 2040 time-horizon, the overall European interconnectivity can increase by an additional 8–25 GW. This equals 9–29 % in addition to the new 88 GW net transfer capacities (NTC) increases identified in the TYNDP 2022 exercise for entire Europe, which formed the starting point of the ONDP analysis.

This shows that – compared to the entire necessary investments in offshore network infrastructure – relatively few offshore hybrid transmission corridors can bring potential benefits to the European system, such as the usual benefits of connecting markets:

- better use of offshore RES;
- better European energy security due to increased network redundancy;
- better usage of the maritime space;
- potential avoidance of CO_2-emissions of 5–8 mio t annually for the entire European (+NO+GB) energy systems– in addition to the potential CO2 savings of 31 mio t per year that had been identified in the TYNDP 2022 investigations, when increasing international connections by 88 GW across Europe; and
- price convergence between market areas.

Expansion results are based on economic benefits only.

Table 1 also confirms that by 2050, most of the offshore RES (86 %) is still expected to be radially connected; 14 % will be connected via offshore hybrid projects, either already planned or found by the ONDP exercise, referring to the entire study area.

Hydrogen can have a role in the integration of offshore RES. Especially in the Northern Seas, the integration of the electrical power system with hydrogen production potential has been identified as an option by some countries which already pursue this integration. For these countries, the ONDP includes for 2050 up to 34 GW already "known" power-to-H2 offshore units that transform an additional 171 TWh/year of offshore renewable energy into molecules, thereby contributing to covering the related national H_2-demand. However, this figure should be understood as a rough estimate as more thorough investigations on combined electricity-and-hydrogen will be executed in the fully integrated TYNDP 2026 process, when presumably also the information database on national plans and on asset-prices will have evolved.

The development of the offshore network infrastructure should happen in synergy with the protection of the maritime environments, achieving a sustainable energy system coexisting with biodiversity. Therefore, the ONDP can contribute to the coordination between offshore installations and other users of the maritime space such as environmental protection areas, fishery, shipping, military usage and sand extraction. ENTSO-E also intends with this first edition of the ONDP to break silos. Thereby, the further acceleration of RES-target-implementing shall be supported by the cooperation of concerned parties. The Renewables Grid Initiative (RGI)[10] describes in Chapter 4 of this report how environmental protection and offshore development can coexist

This first edition of the ONDP will help to create a long-term framework for offshore energy industry (promoters, manufacturers and developers). This plan will be updated every two years.

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[10] See here

1 The ONDP – a new TYNDP product

Offshore wind energy will represent a key contribution to reaching the objectives of the EU Green Deal. The magnitude of the transition will raise new challenges for the European electricity system. The scale of the increase in offshore RES power generation will affect the manner in which the electricity system is designed and operated.

To cope with these developments, ENTSO-E and TSOs are expanding their planning support tool – the Ten-Year Network Development Plan (TYNDP) – to integrate offshore and onshore developments, ensuring holistic planning across time, space and sectors (a one-system approach) to bring offshore renewable energy to end-users. Recent initiatives by the European Commission – the Wind Power Action Plan[11] from October and the EU Action Plan for Grids from November 2023[12] – specifies which actions the European Commission envisages to accelerate practical network expansion.

Among the many challenges raised by the exponential increase in offshore RES and transmission are the following: accomplishing the necessary connections and grid development at least cost while considering key constraints linked to spatial planning, environmental protection and public acceptance, and achieving an integrated perspective over time, space and sectors. The first edition of the ONDP is a first step towards tackling these challenges.

1.1 What to keep in mind when interpreting the results

ENTSO-E presents the first edition of the ONDP, produced in less than one year.

- This is ENTSO-E’s best possible assessment for this first edition, considering the legal deadline of 24 January 2024;
- Based on Member States’ non-binding offshore RES goals;
- A product of TSO cooperation, providing valuable local expertise;
- The cut-off date for Member State goals translation for the study in April 2023; national updates after that date are not considered in the study but mentioned in regional chapters or appendices of the sea-basin reports; and
- The ONDP focuses on the offshore infrastructure development; implications for the related onshore needs will be delivered as part of the TYNDP 2024 needs identification in summer 2024.

The ONDP completes the TYNDP by answering a different question than other components of the TYNDP package. By providing key information on offshore hybrid corridors, it will enable a first integrated onshore–offshore needs assessment in the TYNDP 2024 System Needs Study and will be part of a fully holistic assessment in future TYNDP editions.

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[11] See here

[12] See here

TYNDP Scenarios	TYNDP Offshore Network Development Plans	TYNDP System needs	TYNDP cost–benefit analysis of infrastructure projects
What would the European Energy System look like in the storylines "Distributed Energy" and Global Ambition in 2040/2050?	What does it take to integrate 360 GW to 496 GW of offshore RES in 2040 and 2050?	Where could the onshore and offshore power system be more economically efficient?	How does this project impact the pan-European energy system?
The investment model can invest in generation, infrastructure, DSR, flexibility measures etc. All-in-one optimisation, not including offshore hybrid.	The investment model is only allowed to invest in offshore infrastructure, starting from candidate links without a specified transmission capacity. All other parameters remain locked in this first edition. Implications on the onshore systems will be part of the TYNDP System needs study.	The optimiser can invest in transmission, storage, peaking capacity and offshore hybrid, based on a list of candidate projects having a fixed capacity value. The outcome will be a fully integrated onshore–offshore needs assessment.	We assess a series of indicators including RES integration, CO_2 and other emissions, electricity losses, security of electricity supply … with and without the project.

Concrete simplifications were applied in this first edition:

- **The ONDP study used the TYNDP 2022 "Distributed Energy" scenario and model** together with the January 2023 Member States' offshore RES targets. Latest minor translations from the Member States' targets to simulation input were made in March 2023. National updates after that date could not be considered in the study, but are mentioned in the Sea-basin reports, chapter 9 or the appendices. Usage of the TYNDP 2022 was decided as the delivery dates for the ONDP (24/01/2024) and other parts of TYNDP 2024 (summer 2024) differ.
- **The ONDP uses a slightly different methodology than the System Needs Study:** while the ONDP uses linear optimisation plus regional plausibility checks, the System Needs Study builds on mixed-integer simulation method. Further details are explained in the dedicated methodology report[13].
- **For the ONDP, the electricity demand in all countries had been linearly increased by an arbitrary 8 %** to better represent electrification and ensure model convergence[14].
- **CO_2 emissions have not been investigated intensively for each sea basin** in this edition as the implementation of Member States' Offshore RES goals for the EU does already implicitly conder the policy targets aiming to reduce emissions.
- **Cost assumptions are consistent to each other but have evolved since the study started.** The results provided in the ONDP reports are based on the most recent validated data available both in terms of system costs (e.g. fuel costs, CO_2 ETS prices, ...) and asset costs (e.g. HVDC converter, HVDC cables). This means data from TYNDP2022. However, to consider the significant assets cost increase observed these last months, sensitivities have been analysed in additon to the results provided in the ONDP reports. These sensitivities are available in the visualisation tool. In addition as these costs are mainly related to conceptual projects, a general uncertainty range of -20- + 100 % should be considered.

Further Remarks:

The starting grid (used as a fixed starting point for the optimisation) is developed in such a manner that the RES capacities, communicated by every Member State through the non-binding agreements, are all met. To fill the gap between the planned projects and these RES goals, conceptual radial connections to the respective countries have been added to the system.

The ONDP-study assumed essentially two technical setups and three cost sets, culminating in two main configurations. Results are communicated as a range[15]. The upper range shown in the reports refers to optimistic conditions with: lowest costs, offshore converter stations being already prepared to host potential DC-circuit-breakers and the early availability of commercially attractive DC circuit breakers – at least from 2040 onwards. The lower end of the ranges shown in the reports assumes the non-availability of DC-circuit breakers, but still lowest costs.

ENTSO-E anticipates that both the offshore RES development and the related infrastructure development will materialise somewhere between the ranges shown in the ONDP.

13, 14, 15 See here

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 EU Action Plan for Grids of November 2023[16].

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

1.2 Legal Background

On 3 June 2022, the revised TEN-E regulation (EU) 2022/869 entered into force, mandating ENTSO-E with the new task of developing an ONDP for each sea basin by 24 January 2024. Formally, the ONDPs are part of ENTSO-E's TYNDP. The offshore plans must build on the joint Member States' non-binding agreements on joint offshore RES goals for each sea basin. Member States had to and did deliver this information to the European Commission on 20 January 2023.

The ONDP delivers a high-level outlook on offshore generation capacities potential and resulting to the offshore network infrastructure needs for each sea basin, in line with the priority offshore grid corridors as defined 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; and
- Atlantic offshore grids (AOG), including the North Atlantic Ocean waters.

The sea basins and involved countries are defined in the regulation and shown in Figure 3.

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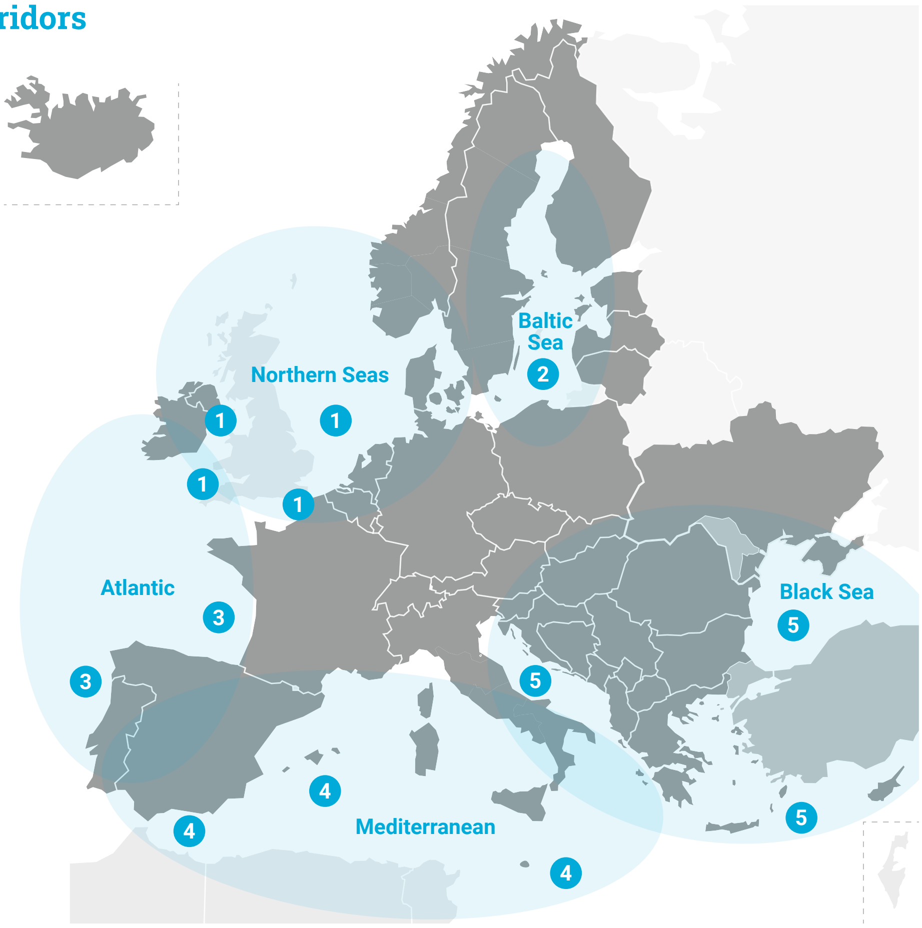
[16] See here

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)

▬ ENTSO-E Member
▬ ENTSO-E Observer Member



TEN-E Priority Offshore Grid Corridors	Countries involved
1. NSOG	BE, DK, FR, DE, IE, LU; NL, SE
2. BEMIP offshore	DK, EE, FI, DE, LT, LV, PL, SE
3. AOG	FR, IE, PT, ES
4. SW offshore	FR, GR, IT, MT, PT, ES
5. SE offshore	BG, CY, HR, GR, IT, RO, SI

Figure 3 – TEN-E Priority Offshore Grid Corridors as laid down in Regulation (EU) 2022/ 869.

Art. 14.2 of (EU) 2022/869, specifies what the high-level, strategic overview on offshore network infrastructure needs should include namely, potential needs for interconnectors, hybrid projects, radial connections, reinforcements and hydrogen infrastructures.

ENTSO-E translates this task into delivering the amount of transmission investments per category [km/number/€] needed to integrate the Member States' non-binding offshore RES goals into the energy system. The ONDP investigates the possible configurations to connect offshore RES clusters, considering the space available and relevant technological and cost assumptions[17].

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[17] The methodology and assumptions are available in the ONDP methodology report.

2 Offshore infrastructure evolves to integrate the goals set by EU Member States

The starting point for the ONDP expansion study is the outcome of the 2040 and 2050 horizon of the TYNDP 2022 Distributed Energy (DE) scenario, integrated with offshore RES capacities in line with Member States non-binding agreements delivered in January 2023, and for which the base demand considered in the 2022 scenarios has been increased by 8 %. The objective of the ONDP study is to assess the potential for development, from a mainly single purpose infrastructure to an increasingly "dual-" and "multi-purpose" one. The candidates assessed for further development in this study are hence planned in addition to the already identified projects and concepts.

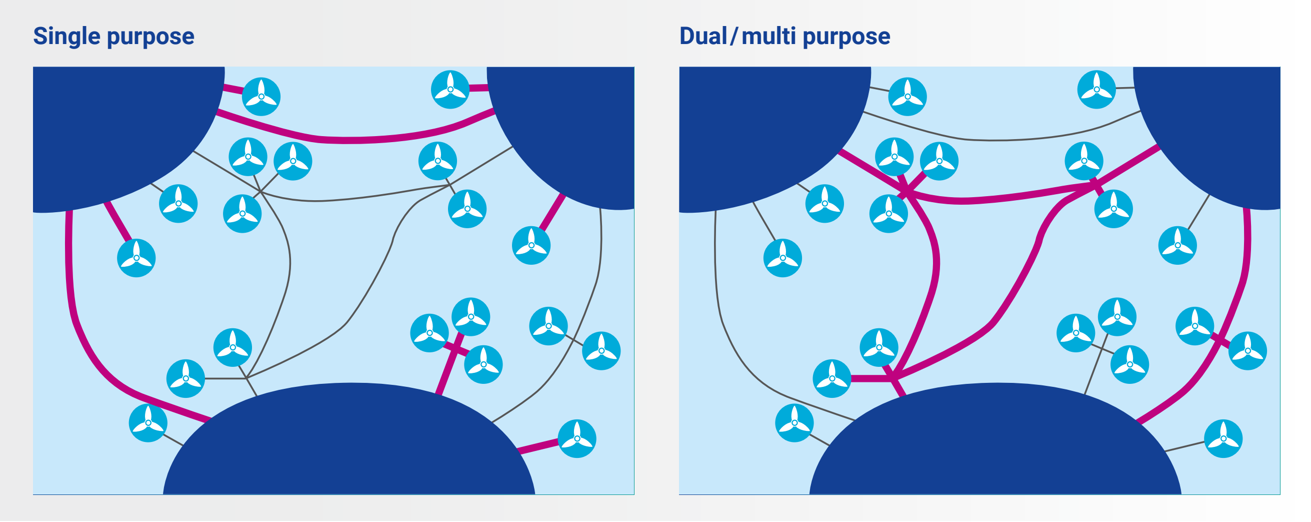

Figure 4 – Connection categories.

The first onshore electricity connections evolved from point-to-point connections to meshed networks; something similar is now happening in some offshore areas. A growing share of wind power connections will have additional functions, such as the connection of different countries or regions. An increasingly integrated and meshed offshore network infrastructure will allow the transmission infrastructure assets to be used more efficiently: either to bring offshore renewable generation to the shore or to trade electricity among adjacent countries and market zones. Hence, considering the ONDP for the TYNDP 2024 System Needs Study will ensure coordination between offshore and onshore needs.

Offshore wind energy has been applied since 1991, when the first offshore wind park of approximately 5 MW was installed in Danish waters. Since then, the installed capacity has ramped up to roughly 32 GW by mid-2023 in Europe, of which 14 GW are located in the UK waters. The capacity in European waters is expected to increase~6-fold to ~182 GW by 2030 (incl.3 GW in NO and 71 GW in GB).

Reaching today's 32 GW (28 GW connected to the electrical grid and 4 GW "standalone") required more than 30 years of development and innovations in addition to brave and sometimes expensive decisions by some companies. While the first offshore wind park was installed at a specific CAPEX of approx. 2 M€/MW, today's offshore RES installations have increased to 3.2 M€/MW[18] together with size, the largest being the 300-fold size plant[19]. Today's OWFs are built further off the coast and in deeper waters compared to the first small-sized parks. Furthermore, the CAPEX for infrastructure has seen price developments.

Until now, almost all offshore wind capacity has been radially connected, with the only exception being Krieger's Flak-Combined Grid Solution in the Baltic Sea[20]. However, more offshore hybrid projects are to come with the dual purpose of connecting the offshore generation to shore and linking two or more countries/market zones. The TYNDP 2022 included already six of these projects[21]. These are depicted in Figure 4.

The path from connecting the early 5 MW-offshore wind parks to shore to today's up to 1,500 MW plants has seen a variety of technologies being used. In the beginning, AC technology to connect near-shore parks was used, with voltages starting at 50 kV AC, passing the 150 kV, 220 kV and 380 kV to today's 525 kV DC connections, with voltage level increasing together with the park size. In the 2000s, a standardisation to 900 MW HVDC platforms took place e.g. in Germany due to the long distance passing the Wadden Sea. A modular method of DC-platform expansion was developed in Belgium in the 2010s.

Today's offshore wind turbines have, according to WindEurope[22], an average size of 12.2 MW. Considering that a park has 50–100 turbines in it, we can assume an average size of 900MW for an offshore plant. Furthermore, cable capacities connecting these have increased too, with ENTSO-E's expectation to increase to up to 2 GW in the near future. For the ONDP, a size of 2 GW has been assumed for the 2040- and 2050- time horizons, with a reference voltage level of 525kV (for the DC converters).

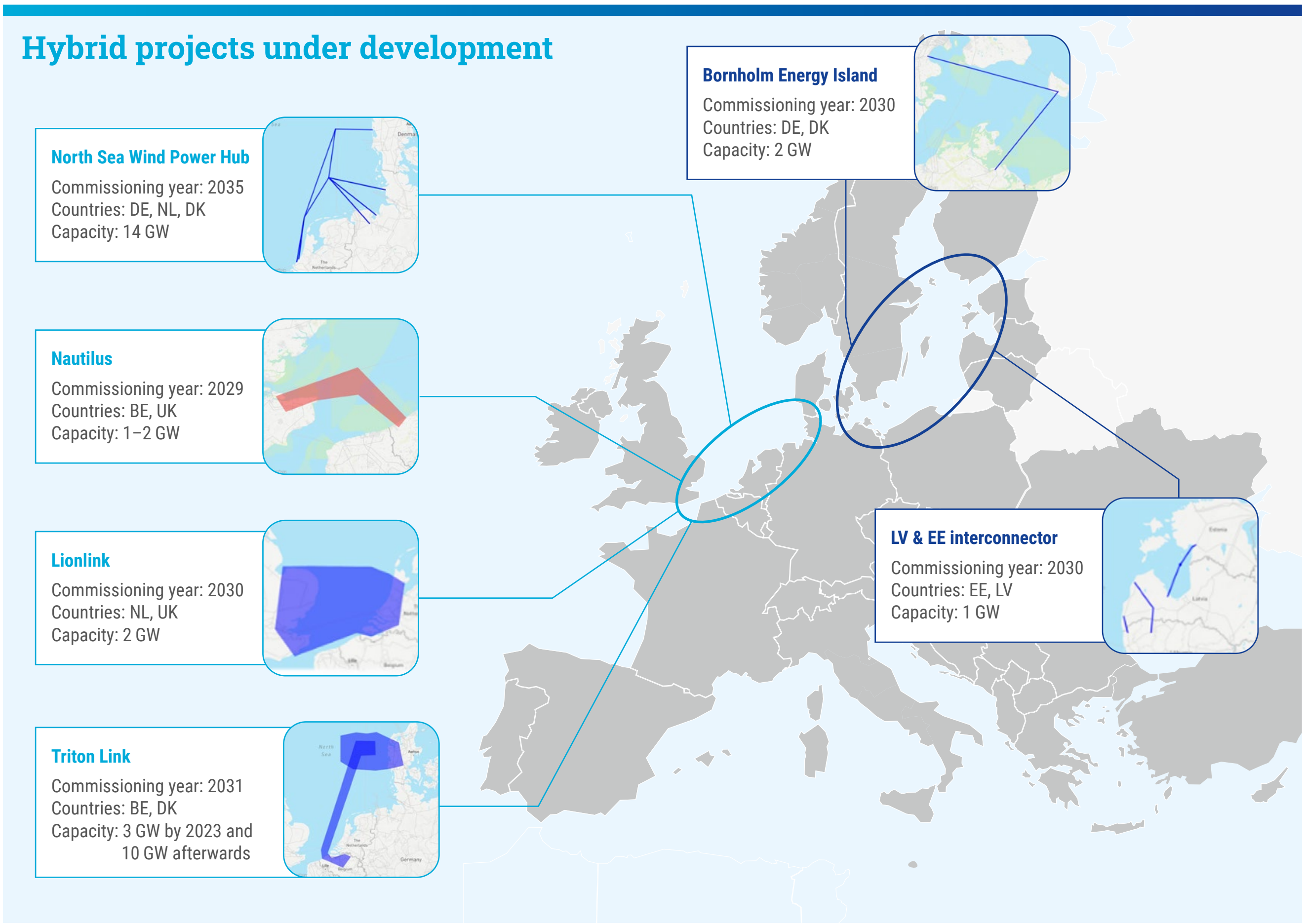

Figure 5 – TYNDP 2022 offshore hybrid projects (NOTE that the TYNDP 2024 will include additional offshore hybrid projects.).

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[18] Information provided by WindEurope

[19] A 1,500 MW OWF in the Netherlands (in operation since Sept 2023) is now the largest OWF; until recently, Hornsea 2 in Great Britain with 1,386 GW, in operation since August 2022 was the biggest OWF.

[20] Connected via the "Kriegers Flak Combined Grid Solution", in operation since October 2020

[21] See here

[22] See here

2.1 ENTSO-E's ONDP study

The complete overview on the modelling methodology applied in this ONDP is described in the ONDP methodology report, together with the set of assumptions considered and the candidates' selection.

For the ONDP study, a starting configuration of the offshore network infrastructure, where the capacities coming from the Member States' agreements are mostly connected radially to the onshore systems, is complemented by additional expansions of the offshore transmission infrastructure, finally linking offshore RES clusters of different national transmission systems with each other via so-called offshore hybrid interconnections.

To explore possible expansion-opportunities, candidates for offshore hybrid connections have been added in addition to the starting network configuration. The criteria to identify a so-called "candidate"-link are based on either the geographical proximity of the generation capacities or beyond that a direct TSO–TSO interest (meaning two TSOs having interest in exploring a connection between generation capacities included in their own respective areas). By running an expansion-model and simulating the investigated candidates in addition to the starting network configuration, opportunities for offshore hybrid interconnections are identified. These opportunities are output of the expansion run and thus form a sub-set of the candidates, which are input data.

A cost-effective number of offshore hybrid transmission corridors is identified, aiming to integrate the additional RES while simultaneously optimising the energy market integration while considering environmental impacts. The expanded system allows connections of the offshore generation to multiple demand centres with complementary profiles, allowing to integrate and make use of more offshore RES produced energy than in the reference case.

2.2 ENTSO-E's ONDP study results

Figure 6 includes the cost needs assessed by ENTSO-E for the transmission infrastructure integrating the capacities considered in the ONDP (UK radial capacities are not included in the equipment and costs assessment).

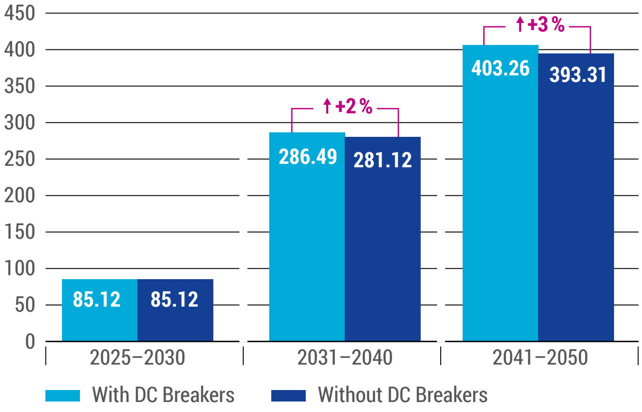

Figure 6 – Needed CAPEX [bn €] for investments in transmission network infrastructure (cumulative values) to connect the ENTSO-E countries' RES capacities considered in the ONDP. The costs do not include the radial capacities in UK.

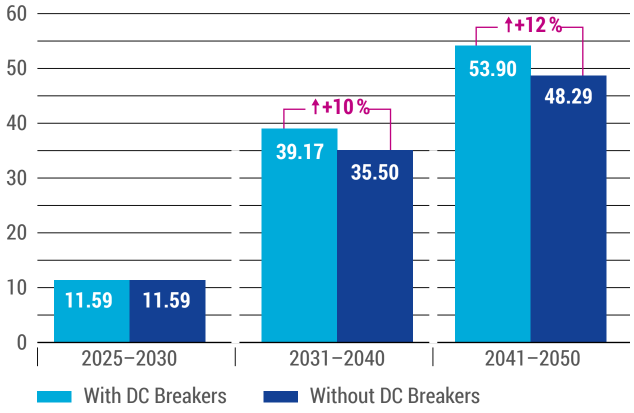

Figure 7 – Evolution of the route lengths [km] covered by transmission assets connecting ENTSO-E countries RES capacities (cumulative). The route lengths do not include UK radial capacities.

The two figures show the two cases defined by the use-or-not-use of DC circuit breakers to implement DC hubs in the realisation of multi terminal hybrid infrastructure. In addition, the costs are separated based on the type of infrastructure. The numbers are provided for two different configurations: a first configuration assuming the availability of DC circuit-breakers in the respective time horizons and thus facilitating the development of hybrid corridors ("With DC breakers") and a second configuration assuming the DC circuit-breakers will not be commercially attractive in due time, and thus all additional links will be regular point-to-point interconnection ("Without DC breakers").

- Radial: costs for transmission infrastructure connecting the radial capacities, not available for hybrid expansion in the ONDP expansion study (UK radials are not included);
- Expansion: costs for the transmission infrastructure to expand the assets, thus creating offshore hybrid solutions;
- Radial (considered in the expansion): costs for transmission infrastructure connecting the radial capacities, considered as available for hybrid expansion in the ONDP expansion study.

Table 2 summarises the results obtained through the expansion modelling runs.

		New links	Transmission Capacity [GW]	Route length [km]	Costs [bn€]
2040 expansion results only					
Candidate links for expansion		108	/	35,032	/
Corridors selected	With DC circuit breakers	18	25	5,900	23
	Without DC circuit breakers	6	7.5	2,300	12
2050 expansion results only					
Candidate links for expansion		266	/	70,200	/
Corridors selected	With DC circuit breakers	16	19	4,600	18
	Without DC circuit breakers	7	6.4	2,700	13

Table 2 – Results of the 2040 and 2050 hybrid expansion simulations.

The ONDP foresees – for the development of offshore connections in the northern European sea basins, the Northern Seas and the Baltic Sea in particular – developing from point-to-point connections towards a more integrated offshore and onshore network with an increasing share of offshore hybrid interconnections. Offshore infrastructure in the Atlantic, the Mediterranean and the Black Sea will instead be characterised by the radial connection of offshore RES and interconnectors.

The ONDP concludes that Europe will need an additional 54,000 km of offshore network transmission infrastructure routes (radial+hybrid) by 2050 compared to 2025 levels to optimally realise the Member States' goals. This translates into extra usage of around 50 TWh/year from 2040 to 2050, and additional 32 TWh from 2050 onwards, for a total of 82 TWh/year of additional RES energy integrated in the onshore system.

The additional transmission capacity in addition to the starting situation, connecting all offshores RES to the onshore systems forms the hybrid corridors. These require additional investments of 31 to 41 bn € by 2050 (in 2023 €), for both new connections to shore (22 bn €) and cross-border corridors (19 bn €) via offshore RES generators ("offshore hybrid projects"). These new cross-border investments would allow 50 TWh/year of additional RES integration from 2040 to 2050 and would contribute to a reduction of 5–8 mio t/yr of CO_2 emissions. This refers to the identified expansions of the offshore infrastructure.

For comparison:

The TYNDP 2022's **88 GW** cross-border capacity-increase between 2025 and 2040, helping to avoid **31 mio t/year**.

The ONDP's additional **up to 25.2 GW** cross-border capacity-increase between 2025 and 2040 via offshore hybrid projects, avoids an additional **5–8 mio t/year**[23], (w/o or with DC circuit breakers).

- **Offshore Hybrid projects:** In 2040 there will be approximately 6,000 km route length hosting offshore hybrid transmission corridors, while in 2050 route lengths of 4,600 km will be added in addition to the 2040 installations. This is additional offshore transmission infrastructure available for the dual purposes of RES integration (25 GW by 2040 and further 19.5 GW by 2050 respectively) and cross-border trade ("offshore hybrid transmission projects").
- **Radial connections and connections to shore:** in 2040: 261 GW of offshore RES generation will be radially connected, arriving at 292 GW in 2050. In addition, ONDP considered 48 GW in 2040 and 85 GW in 2050 of connections to shore, meaning transmission assets connecting generation capacities that have been considered in the expansion modelling.
- **Multi-purpose infrastructure:** In the North Sea Basin, national plans/Memoranda of Understandings (MoUs) currently estimate 34 GW of potential offshore electrolysis (e.g. in Dutch/Danish/Irish waters).

The further development of H2 infrastructure, in combination with storage and flexibility solutions can enable the additional annual integration of 628 TWh RES energy in the energy system, which, according to this first high-level study, would otherwise remain unused[24].

The first optimisation performed for the ONDP will be further consolidated in the System Needs Study of the TYNDP 2024, with an assessment of the impact of offshore developments on onshore networks.

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[23] It is important to mention that the demand level of both studies differ. To catch the trend of electrification, the overall demand has been increased in the ONDP by 8 % in the entire Europe.

[24] **Disclaimer** – It is important to note that for the purpose of this first edition of the ONDPs, the TYNDP22 DE scenario has been applied, attaching the Member States' offshore RES capacities to it. The study was not subject to a complete optimisation and builds on scenarios which do not represent latest developments, such as the development of demand, of electrification outlooks etc.

3 Sea Basin Highlights

3.1 Northern Seas Offshore Grid (NSOG)

- The Northern Seas sea-basin is expected to see the rapid expansion of offshore wind – 119 GW by 2030, around 332 GW by 2050. This is supported by the high political ambitions of the Esbjerg and Ostend-declaration – respectively 65 GW of offshore RES by 2030 and 150 GW of offshore RES by 2050, and 120 GW by 2030. The North Seas Energy Cooperation (NSEC) published an Action Agenda on 20 November to deliver on these ambitions[25].
- By 2040, the total offshore wind capacity is, according to the goals of the Northern Seas countries, expected to be about 274 (EU+NO+UK) GW. ENTSO-E's analyses show that a first step towards a more integrated offshore network infrastructure – hybrid interconnectors - in the Northern Seas would be economical beneficial.
- Towards 2050, the total offshore wind capacity will, according to the goals of the Northern Seas countries, be more than 332 GW. As this development is expected to be even farther from shore, an even more complex offshore grid is anticipated.
- Thus, the region sees an increase from 27 GW today to 333 GW in 2050. 333 GW translates into approximately more than 167 wind parks with approx. 22,000 wind turbines, assuming an average of 15 MW/turbine.
- This fundamental change of the power generation mix will lead to a more variable and less controllable system from the generation side. To increase the flexibility of the system, a variety of actions need to be taken, including tighter cooperation with other energy-sector, increased flexibility on the demand-side and strengthened interconnector capacity.
- Two main high-level corridor directions have been identified: a North–South corridor and an East–West corridor.

These corridors appeared already as of 2040. On the one hand, these corridors help countries with a RES-deficit to access the huge potential available in countries with excess- RES. On the other hand, these corridors exploit the decorrelation between the various RES in the EU.

- 15 % of offshore RES will be connected via offshore hybrid infrastructure; the rest will be radially connected.
- Configuration changes are possible and are robust in the event that technology advances and DC circuit breakers are commercially attractive.

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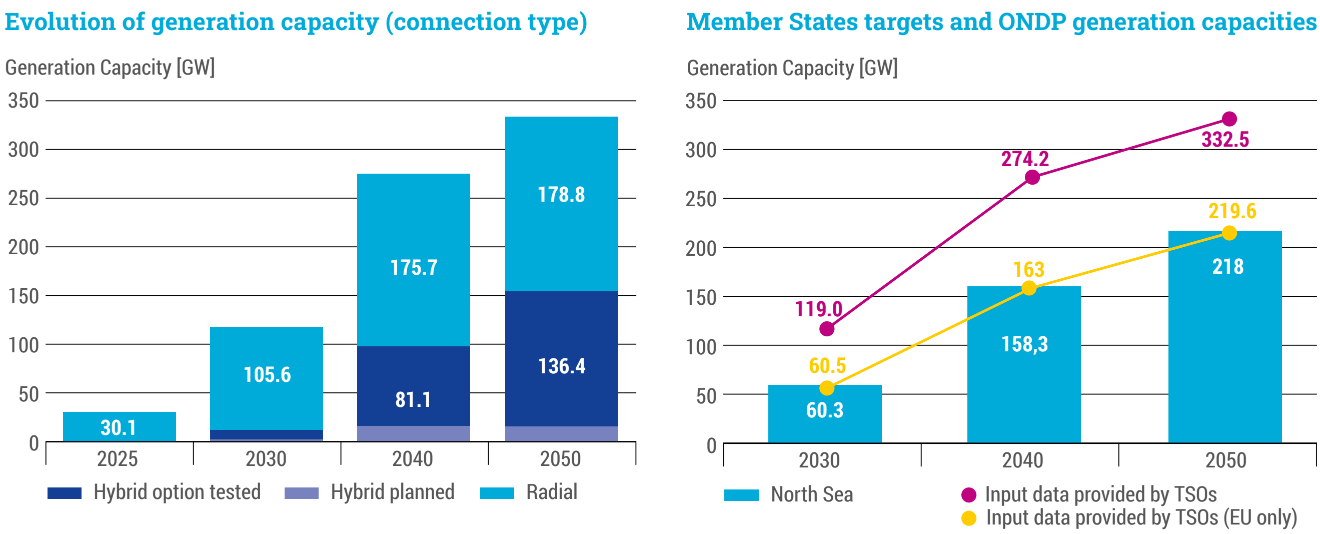
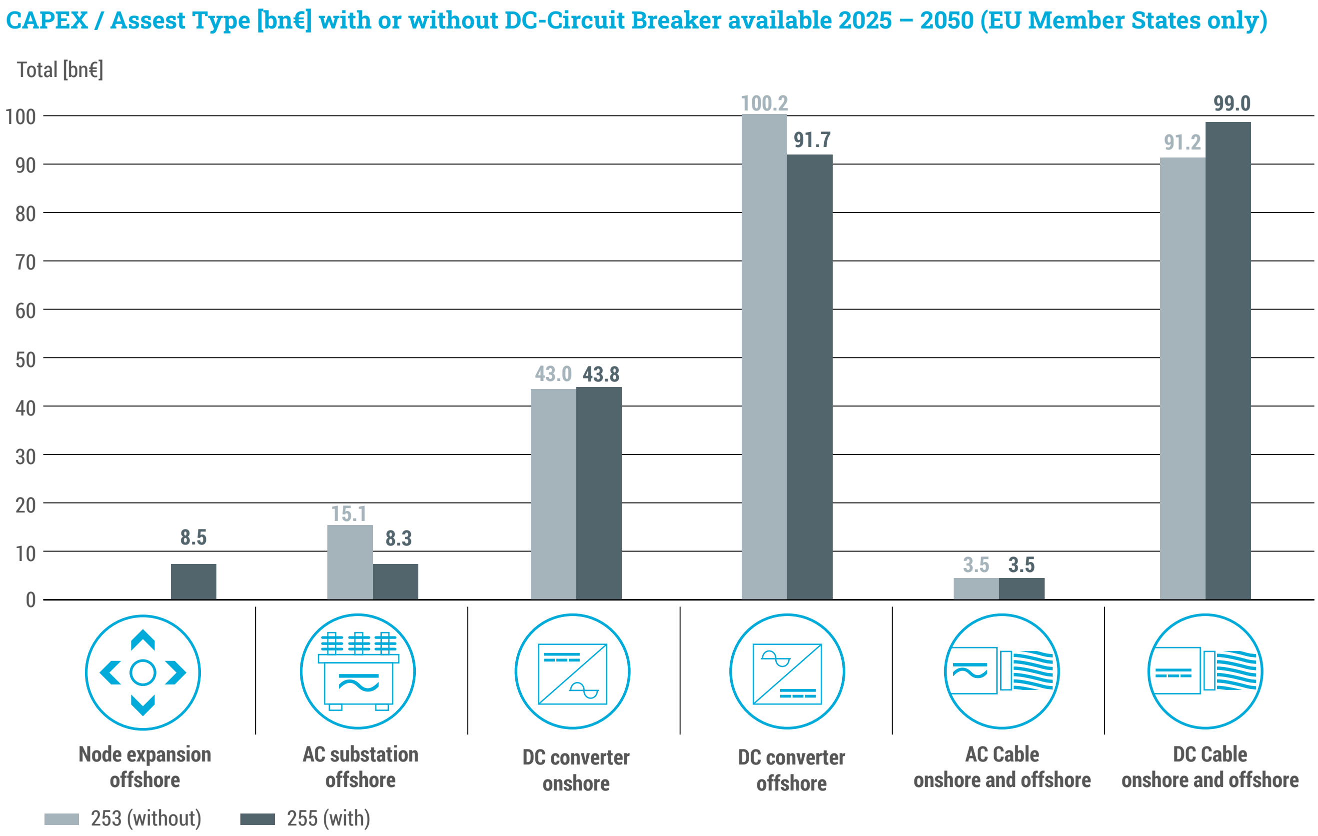
[25] See here



Evolution of generation capacity (connection type)

Member States targets and ONDP generation capacities

Figure 8 – NSOG Member States' goals (bars, per sea basins), Input data (EU only) and input data including NO and GB.



CAPEX / Assest Type [bn€] with or without DC-Circuit Breaker available 2025 – 2050 (EU Member States only)

Figure 9 – Needed CAPEX for investments in offshore network infrastructure (2025–2050).

3.2 BEMIP Offshore

- Baltic Sea basin offers 70 GW of offshore RES potential. Offshore transmission infrastructure can make it easier to incorporate offshore wind energy into the larger (onshore and offshore) electricity grid, improving its dependability and effectiveness.
- The total offshore wind capacity according to the goals of the Baltic Sea countries in 2030 is about 27 GW. Up to 2030, the majority of projects will be connected radially and a few hybrid projects are expected to be under development phase
- In 2040, most of the offshore RES will be connected radially, but new cross-border offshore hybrid projects will also be developed. Depending on the technology and configuration, up to two additional links have been identified, on top of the radial capacities connected, with a total capacity of 3 GW and a total route length of 875 km. According to the member states goals for 2040 it is expected that in the Baltic Sea region the installed capacity could reach 45 GW.
- In 2050 the grid is forming its shape and more hybrid connections between different countries will be established. Depending on the scenario, up to 3800 km of additional routes might be covered by transmission infrastructure may, for 10,6 GW of additional hybrid transmission capacity. Baltic Sea member state goals in 2050 is to have 46,8 GW of additional offshore wind capacity installed.

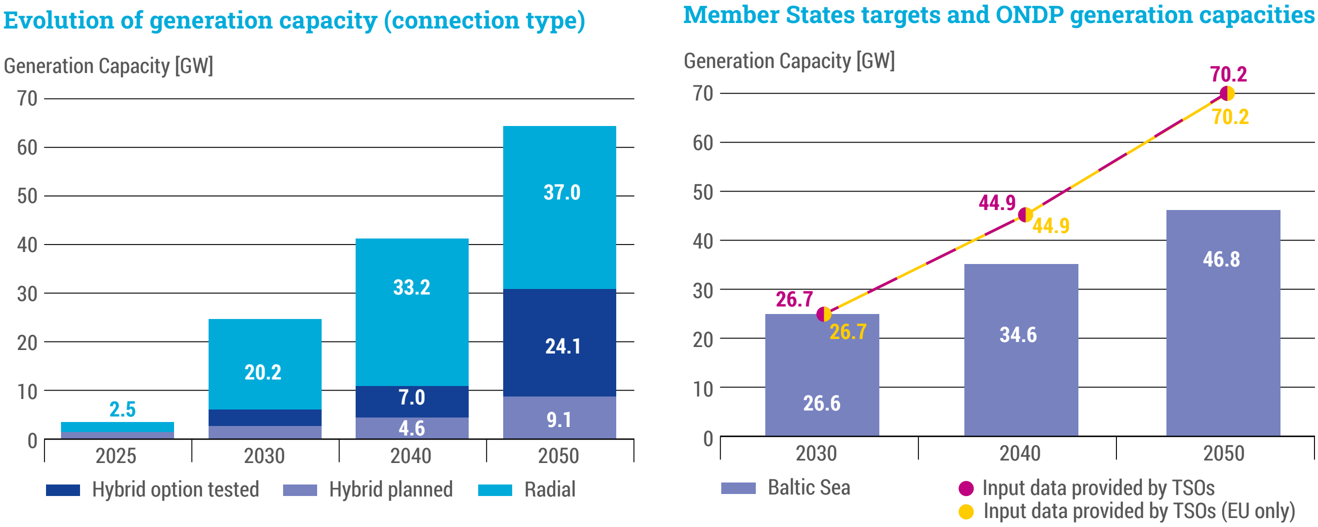


Figure 10 – BEMIP Member States' goals (bars, per sea basins), Input data (EU only) and input data including NO and GB.

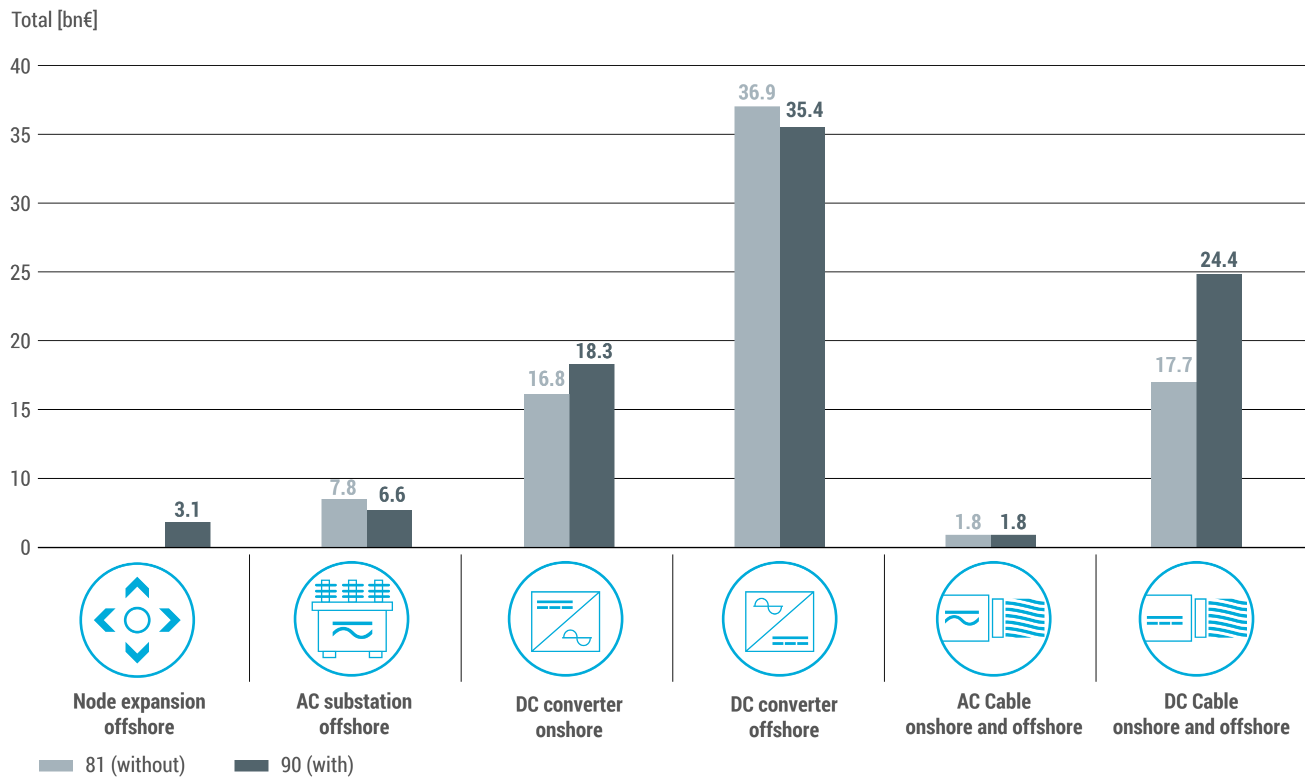
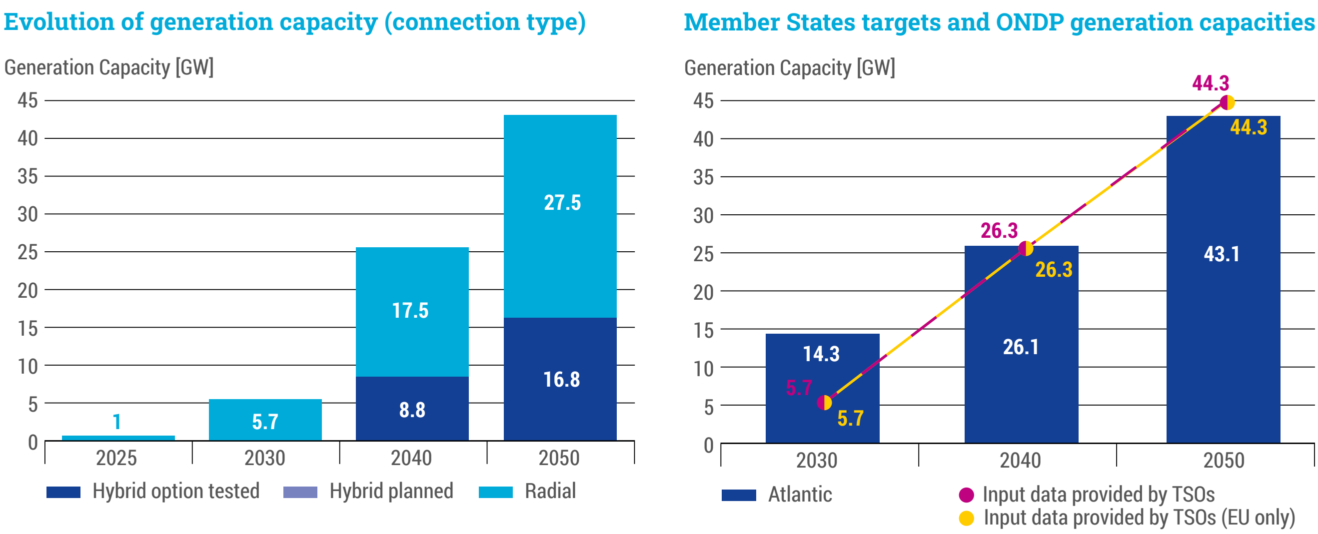

CAPEX / Assest Type [bn€] with or without DC-Circuit Breaker available 2025 – 2050 (EU Member States only)

Figure 11 – Needed CAPEX for investments in offshore network infrastructure (2025–2050).

3.3 Atlantic Offshore

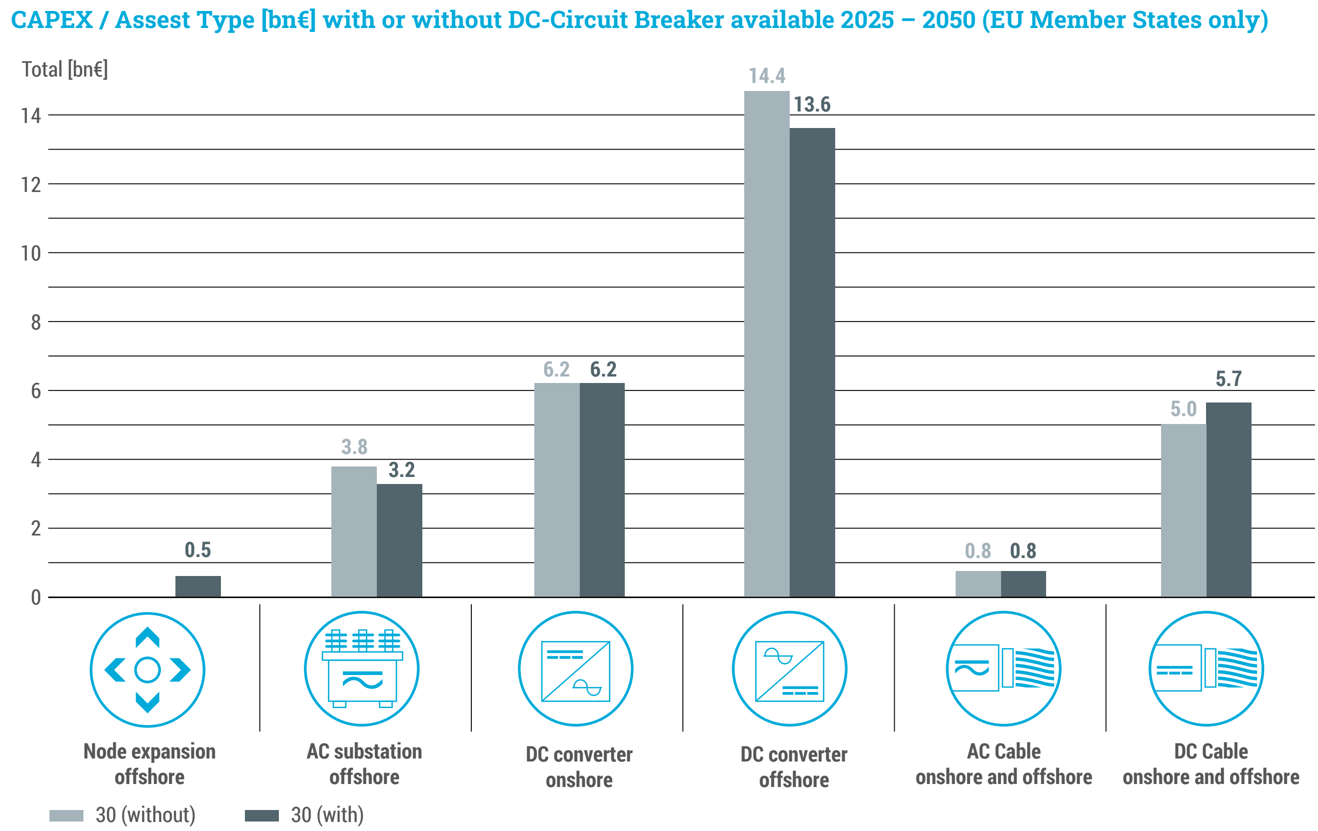
- Evolution of offshore wind capacity: from radial connections in 2030 to first hybrid projects by 2040 and 2050 in north Atlantic. 5.7 GW offshore wind capacity is currently expected to be radially connected in 2030. In the 2040- and 2050- time horizons, the offshore wind capacity will grow to values of 26.3 GW and 44.3 GW respectively;
- Changes in power flows generation patterns are expected, due to future offshore wind development in the 2030, 2040 and 2050 horizons; and
- Floating technology is the solution for the offshore development in the Atlantic Ocean Basin. The Atlantic Ocean Basin often features deep water sites, where fixed bottom foundations are impractical due to depth limitations. For offshore energy integration, additional flexibility solutions that enable adaptations to the variable nature of wind, balance the grid, and ensure stable and sustainable energy supply, need to be implemented. These include interconnectors, energy storage electrolysers, demand-response.



Evolution of generation capacity (connection type)

Member States targets and ONDP generation capacities

Figure 12 – Atlantic Member States' goals (bars, per sea basins), Input data (EU only) and input data including NO and GB.



CAPEX / Assest Type [bn€] with or without DC-Circuit Breaker available 2025 – 2050 (EU Member States only)

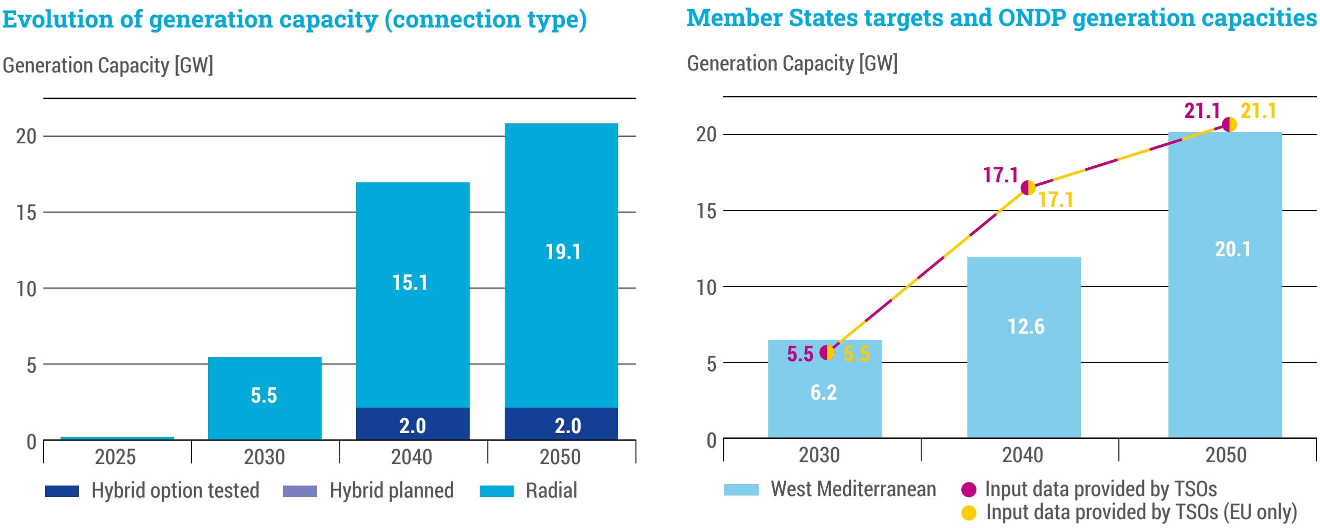
Figure 13 – Needed CAPEX for investments in offshore network infrastructure (2025–2050).

3.4 South & West Offshore (SW Offshore)

Total transmission infrastructure in 2030, 2040 and 2050:

- As of today, the offshore transmission infrastructure is mostly composed of pure transmission assets (cross-border interconnectors and internal reinforcements). The total amount of offshore RES connected to the continental systems totals 110 MW;
- In the coming decades, offshore transmission infrastructure will develop to support on and offshore RES integration, both with direct connections to the offshore generation units, offshore HVDC reinforcements strengthening the continental transmission systems and cross-border transmission infrastructure;
- The present assessment considers that the total amount of offshore generation is foreseen to be connected through radial configurations. Hybrid solutions might become interesting once offshore RES integration picks up speed and the regional framework for these kinds of solutions becomes clearer;
- To connect the offshore RES capacities to the mainland, a considerable amount of transmission assets will need to be laid down in the corridor's waters. **5.6, 17.1 and 21.1 GW of transmission assets will be needed in 2030, 2040 and 2050 respectively.** The overall investments up to 2050 could total **14.3 bn €**, just considering the transmission infrastructure connecting the units. The needed internal reinforcements ensuring the adequate dispatch of the energy produced are not considered in the estimated total investment;

- The deployment of offshore RES in the South and West Offshore Grids corridor strongly depends on the development of floating technologies and dynamic cables due to the important depths (beyond 100 m) reached by all national waters just a few nautical miles off the coasts; and
- The unique marine environment characterising South and West offshore grids corridor will require a particular effort in spatial planning to ensure the coexistence of the energy infrastructure, nature conservation and economic interests.


Evolution of generation capacity (connection type)

Member States targets and ONDP generation capacities

Figure 14 – SW Member States' goals (bars, per sea basins), Input data (EU only) and input data including NO and GB.

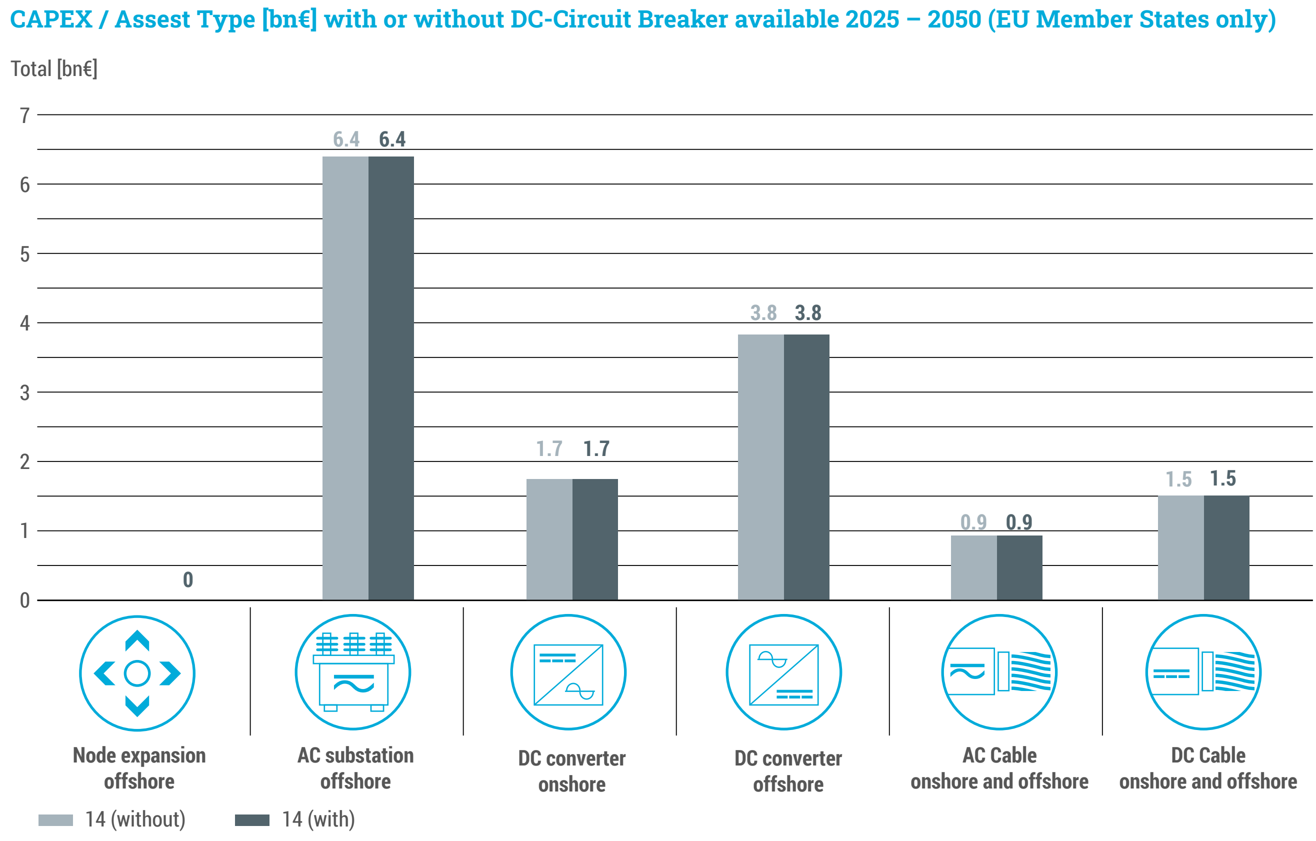

CAPEX / Assest Type [bn€] with or without DC-Circuit Breaker available 2025 – 2050 (EU Member States only)

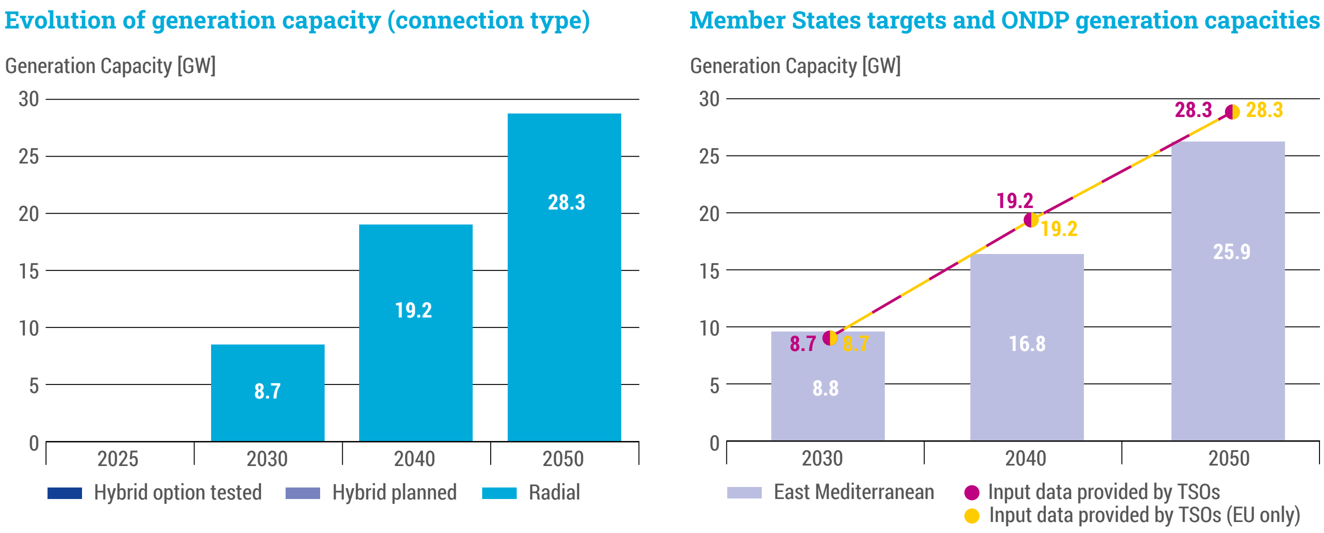
Figure 15 – Needed CAPEX for investments in offshore network infrastructure (2025–2050).

3.5 South & East Offshore (SE-Offshore)

Offshore energy sector has great potential in the Sea Basin and new offshore plants can help the electricity sector to achieve the goals for 2050- time horizon and to become a net zero emission sector in the region and in the whole EU.

- Today, only Italy has installed capacities in offshore wind, and the numbers are not significant regarding the total production for the Continental South-East region and Sea Basin. The plans for the 2040- and 2050- time horizons are highly ambitious compared to the current numbers. Some countries such as Italy and Greece will lead the region in achieving its targets;
- The offshore transmission infrastructure is the necessary asset to connect the RES capacities to the continental energy system. To connect the offshore RES capacities to the mainland, a considerable amount of transmission assets will need to be laid down in the SE offshore grids corridor's waters. **8.7, 19.2 and 28.3 GW of transmission assets will be needed in 2030, 2040 and 2050 respectively**, covering almost 1,600 km of routes. The overall investments up to 2050 could total **15 bn €**, just considering the transmission infrastructure connecting the units. The necessary internal reinforcements ensuring the adequate dispatch of the energy produced are not considered in the estimated total investment;

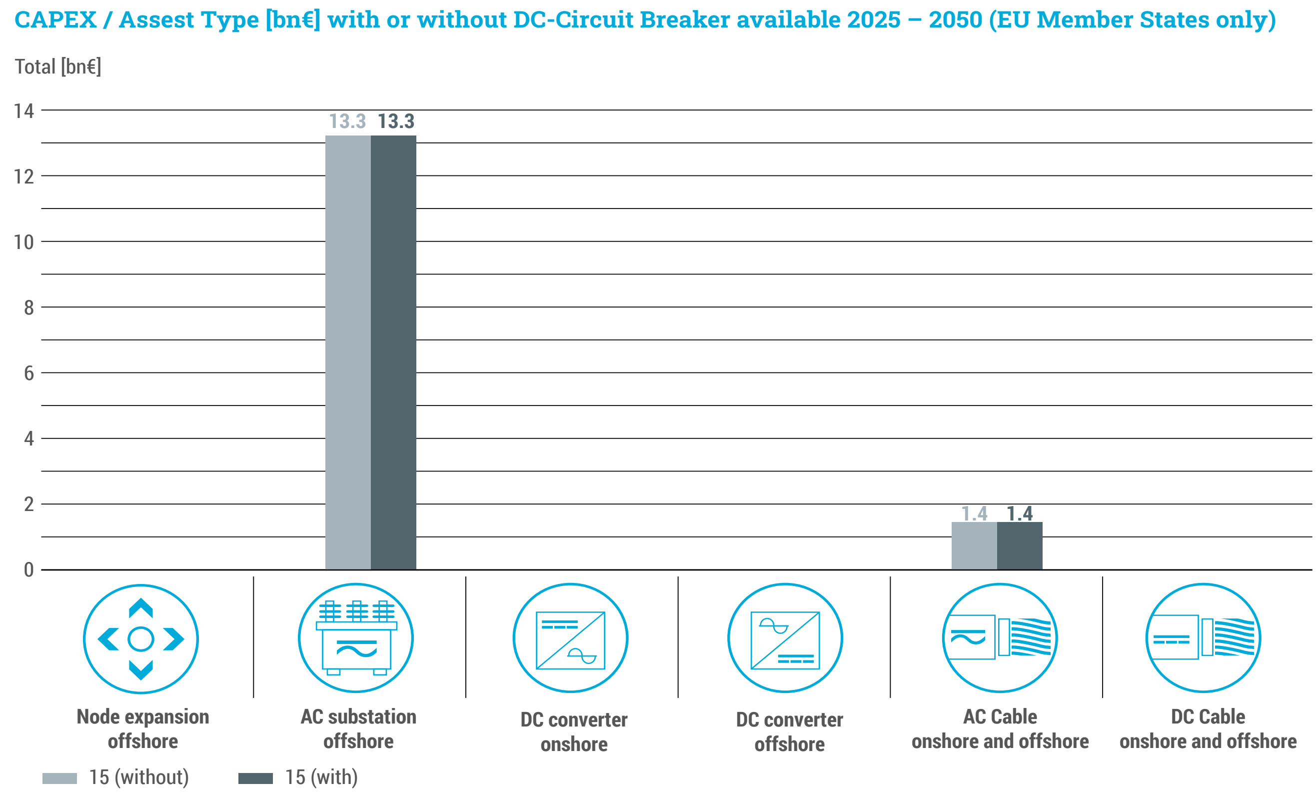
- Hybrid solutions might become interesting once offshore RES integration pick up speed and the regional framework for these kind of solutions become more clear;
- The main challenge for this Sea Basin is the establishment of maritime spatial plans (MSPs) in every country included. This is the first step, which must be followed in parallel with the implementation of Member States goals in national databases, development plans and goals defined in country energy strategies. In addition, it is important to further investigate in more detail the applicable technologies of offshore wind; and
- A key challenge to address is the lack of internal infrastructure for accepting higher amounts of energy produced from offshore wind power plants. This implies additional reinforcements and the establishment of strong (e.g. 400 kV) points in the network near the coast.



Evolution of generation capacity (connection type)

Member States targets and ONDP generation capacities

Figure 16 – SE Member States' goals (bars, per sea basins), Input data (EU only) and input data including NO and GB.



CAPEX / Assest Type [bn€] with or without DC-Circuit Breaker available 2025 – 2050 (EU Member States only)

Figure 17 – Needed CAPEX for investments in offshore network infrastructure (2025–2050).

4 Offshore infrastructure and environmental protection go hand in hand – Recommendations by the Renewables Grid Initiative

This entire chapter has kindly been provided by RGI.[26]

Balancing the rapid deployment of offshore grid infrastructure with the need to preserve and restore our marine environment is paramount. The health of our seas and the wellbeing of fragile marine ecosystems are vital for human life and economy. Therefore, while energy infrastructure development requires acceleration to meet the EU's climate goals, nature must be considered in the process.

The biodiversity and climate crises urgently need to be confronted in tandem to push forward offshore renewables and connect grids in a manner that (1) avoids or reduces ecological damage and/or (2) actually benefits nature. Maritime Spatial Planning, mitigation, and nature enhancement are all key aspects in this context and will be discussed as necessary positive measures on the next pages.

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[26] See "About RGI" box at the end of this chapter

4.1 Maritime Spatial Planning to speed up offshore infrastructure, reduce conflict and support nature

When building energy infrastructure at sea, the first challenge is to find suitable space that minimises conflicts with other human activities, from shipping corridors to fishing grounds and areas reserved for military use. In addition, European seas have been damaged by decades of industrial **human activities**, making it necessary to safeguard areas for nature to recover. This means that even if an area is suitable for energy infrastructure to be built, extra consideration must be given to environmental impacts – see more on this below. In this context, **nature** plays a special role and should not simply be considered as another sector utilising the ocean, but rather as a provider of ecosystem services which life on earth and all other sectors depend upon. This makes the overall wellbeing of nature a top priority.

Maritime Spatial Planning (MSP) was established as a tool to address these competing spatial claims. A key success factor for any agreement in this process is the meaningful involvement of stakeholders. If done well, and sufficiently integrated with energy planning, MSP is an effective tool to reduce administrative burdens and costs. In **the Netherlands**, for example, MSP cut costs in the offshore wind permitting process by two-thirds.

Simultaneous planning of both energy infrastructure areas and nature areas during the MSP process presents many advantages in terms of effective space allocation and reduced impacts. The alternative can lead to an increase in conflicts and delays, whereas implementing a true **ecosystem-based approach** to MSP ensures that these considerations are taken into account from the very beginning. This approach, to be employed by Member States in their MSP, can involve avoiding building infrastructure in sensitive areas or in migratory corridors, when possible, as well as ensuring connectivity between ecologically valuable sites. It can also consist of mapping an ecosystem's vulnerability to cumulative pressures and then positioning human activities in areas of lower sensitivity. The **European Commission's guidelines** are a valuable resource to better understand how to apply an ecosystem-based approach to MSP.

It is also important to consider the **cumulative effects** of offshore renewables and grids on ecosystems since these effects can extend beyond borders and add to the already existing impacts of human activities. For this reason, **a sea basin approach** is needed to assess the cumulative impacts of all activities. In that respect, the Baltic Sea can be seen as a success story with the **transboundary cooperation** between regional organisations HELCOM and OSPAR, which led to a joint MSP Working Group and the **first guidelines** on an ecosystem-based approach to MSP. The methodology of the cumulative impact assessment tool developed by Sweden, **Symphony**, was also applied by HELCOM in their **holistic assessment of the Baltic Sea**, an important tool that could be replicated in all sea basins.

The MSP process requires the collection of information and spatial data related to a variety of issues such as assessing the state of marine biodiversity, cumulative impacts or the suitable zoning of economic activities. The EC's recently published **MSP data framework** is of great support to facilitate the MSP data collection process and its management, as well as MSP monitoring and evaluation. As a rule, MSP data should be FAIR (Findable, Accessible, Interoperable, and Reusable) to minimise challenges related to data sharing, reuse and collaboration, and enable transboundary cooperation.

To go further, the **Offshore Coalition for Energy and Nature**, where TSOs, the wind industry and NGOs joined forces to find solutions for nature-friendly offshore wind and grid development, published a set of **recommendations to improve MSPs**, with inspiring examples from across Europe.

4.2 Reducing Environmental Impacts of Infrastructure and Enhancing Nature at Sea

The most prominent impacts grid infrastructure can have on the marine environment are habitat disturbances, production of underwater noise and vibration, collision of wildlife with construction and maintenance vessels, electromagnetic fields (EMF) and heat emissions. Fortunately, these impacts can be avoided or minimised by applying certain mitigation measures.

Habitat disturbance predominantly occurs during the project's construction phase and can affect benthic communities/ seafloor ecosystems, fish, marine mammals and seabirds. Therefore, a top priority during the planning phase is to carefully **select site locations**. This includes minimising the interference with **Marine Protected Areas** and other habitats which are valuable for vulnerable species, such as areas used for spawning, nursery, and feeding, or haul-out grounds (areas where seals temporarily leave the water to rest. Furthermore, careful micro-siting can also be applied by choosing routes for subsea cables that minimise the interference with dense aggregations of reef-building organisms, if any are present on the site. Based on the available baseline information on the distribution of sensitive species and habitats, exclusion zones for anchoring should also be defined during the planning phase. Habitat spoiling during construction can be significantly reduced by choosing the **right timing and cable laying techniques**. It is recommended to minimise the interference with sensitive spawning times for substrate spawning fish species and the seasonal migration of valuable fish species, details of which will be defined in consultation with relevant authorities and experts during the EIA process. The technique chosen for cable laying should also consider the type of seabed at the site and its accompanying ecosystems. The primary objective should be to use the technique that best minimises sediment release or re-suspension. Furthermore, the use of Horizontal Directional Drilling (HDD) to minimise the damage in intertidal and landfall areas with sensitive habitats is recommended. Such a technique is already being applied by TenneT in the Wadden Sea, a particularly valuable intertidal area.

Another potential environmental impact related to grid infrastructure is the production of **underwater noise and vibrations**, especially during the construction phase. One source of this impact may come from unexploded ordnances (UXO), which should ideally be identified during the planning phase through specialist geophysical surveys. Identified relevant sites should then be avoided. During construction, it is preferable to **schedule activities** at times when sites are not being used for spawning, breeding or as nurseries to avoid negative impacts on sensitive species defined during the EIA process. When piling during construction of offshore grid platforms, damping noise emissions by deploying technologies such as bubble curtains or cofferdams can help reduce negative impacts on animals. This choice should be based on the thresholds relevant for the species potentially under threat. If the site is being used by noise-sensitive species, it is recommended to use acoustic deterrence devices to displace them from the area of risk. Additionally, it is advisable to have a Marine Mammal Observer (MMO) on board the installation vessel to prevent any harm or disturbance to marine animals caused by noise or vibration.

During all life stages of grid infrastructure, vessels are used for different activities such as surveying, construction or maintenance. Since these vessels might encounter fish, sea mammals, turtles, and/or seabirds, there is a **risk of collision or disturbance**. To reduce the risk of fatal injury, the speed of the vessel can be adjusted to observe and react in time, and an MMO could be present on the vessel. Careful timing is important to avoid collisions: it is advisable to minimise interference between the construction phase and over-wintering periods or sensitive times for vulnerable seabird species, such as breeding periods. Lastly, to minimise the potential of contact between vessels and wildlife, it is advisable to reduce the **overall number of maintenance vessel trips**.

The research on the impact of **electromagnetic fields and heat emissions** produced by grid infrastructure on wildlife is still inconclusive, and more research to properly address the knowledge gap on electromagnetic fields is needed. Currently, burying cables is most recommended to address this potential impact and minimise it as much as possible. Cable burial is sometimes even mandatory, for example in the Netherlands where the Water Act prescribes burial 1m below the seabed to avoid the effect of EMF. Furthermore, results from research conducted on heat emissions entering the environment due to grid infrastructure were found to be negligible and are not usually considered a major threat to the environment.

"Fish hotels" on TenneT's offshore platform in Hollandse Kust Noord wind farm.

Besides applying mitigation measures to avoid or reduce negative impacts on the environment, grid operators should also take proactive steps that contribute to **nature enhancement** on- and off-site. As our seas are already in a degraded state, future offshore grid developments should demonstrate that simultaneously achieving climate goals, decarbonisation and biodiversity targets is in fact possible. One potential way to contribute to this goal is to utilise **nature-inclusive design (NID)**. Pilot projects developing and testing NID are already ongoing, but much more are needed. The collaboration between TenneT, Equans, Ecocean, and Smulders validated the positive benefits of NID. They developed the concept of "fish hotels" or "nursery habitats" for juvenile fish and installed them in the Hollandse Kust Noord platform. This concept will, in fact, become part of TenneT's technical standards. Furthermore, **offsite nature restoration projects** — such as Red Eléctrica's Posidonia oceanica seagrass meadow recovery in the Bay of Pollensa — play a vital role in compensating for environmental impacts. The goal of these projects, however, should be to work towards achieving the target of biodiversity net gain and not simply to fulfil the compensation requirement.

Lastly, to be able to evaluate the results of mitigation measures, NIDs, or restoration projects, long-term and **consistent data collection** is imperative. A good example here is the Belgian Offshore Wind Monitoring programme for offshore renewable projects, which has been running since 2005. This **centralised** model provides the necessary data to measure the combined impacts of all offshore renewable projects at the national level, allows open access to marine data and contributes to **data sharing** at the international level – another key aspect to better understanding the impacts at the sea basin level. Furthermore, The European Marine Observation and Data Network (EMODnet) is a valuable resource that provides a plethora of environmental data, maps and models. With consistent monitoring, efforts to avoid or reduce adverse environmental impacts can be assessed and adapted if necessary.

4.3 Recommendations

For offshore developments to succeed and for nature to thrive, the following actions are recommended with regard to the topics discussed above:

- To promote **transboundary cooperation**, Member States must ensure the accessibility of environmental and spatial data for all stakeholders and facilitate its sharing with regional organisations and neighbouring countries;
- Regional organisations should adjust existing methodologies to measure **cumulative impacts** in each sea basin and extend the ecosystem-based approach to Maritime Spatial Planning (MSP) at the regional level. This approach enhances **ecological connectivity** and minimises the adverse effects of site selection;
- Good practices in **stakeholder engagement** and consultation frameworks, such as those exemplified by Ireland, Estonia, and Latvia should be disseminated to countries less experienced with the MSP process;
- In addition to applying mitigation measures, grid developers are encouraged to develop, test, and implement Nature Inclusive Design **(NID) and offsite restoration projects**;
- Further research is needed to close the knowledge gap on the relationship between certain pressures caused by grid infrastructure and the surrounding environment, as in the case of Electromagnetic Fields **(EMF)**;
- Mitigation measures that should be applied during the **decommissioning** of grid infrastructure need to be researched further to avoid and/or minimise future negative environmental impacts;
- Consistent and continuous **environmental monitoring** should be applied in order to assess the results of mitigation measures, NIDs and restoration projects. Furthermore, this monitoring should be the basis of adaptive management;
- In addition, all relevant parties, including Member States, developers, and investors should strive to ensure that **local communities** benefit from the energy transition.

About RGI

RGI is a unique collaboration of NGOs and TSOs (Transmission System Operators) from across Europe engaging in an “energy transition ecosystem-of-actors”. We promote fair, transparent, sustainable grid development to enable the growth of renewables to achieve full decarbonisation in line with the Paris Agreement. RGI Members originate from a variety of European countries, consisting of TSOs from Belgium (Elia), Croatia (HOPS), France (RTE), Germany (50Hertz, Amprion, TenneT and TransnetBW), Ireland (EirGrid), Italy (Terna), the Netherlands (TenneT), Norway (Statnett), Portugal (REN), Spain (Red Eléctrica) and Switzerland (Swissgrid); and the NGOs Bellona Europa, BIOM, BirdLife Europe, Climate Action Network (CAN) Europe, Ember, France Nature Environnement (FNE), Friends of the Earth Ireland, Fundación Renovables, Germanwatch, Legambiente, NABU, Natuur&Milieu, the Royal Society for the Protection of Birds (RSPB), WWF International and ZERO. Europacable and IUCN are Supporting Members. In 2020, RGI established the Offshore Coalition for Energy and Nature (OCEaN), a collaboration between the wind industry, TSOs and NGOs to align offshore infrastructure with the preservation and restoration of marine ecosystems.

5 With the ONDP, TSOs contribute to a faster deployment of offshore systems

ENTSO-E and Transmission System Operators (TSOs) are accelerating the deployment of offshore energy in cooperation with Member States. Acceleration of the construction of the required infrastructure is impossible without a clear view of the targets and needs. The ONDP provide a consistent view of the non-binding goals per sea basin and identifies the infrastructure needs via a first optimisation of the potential for offshore transmission corridors and the potential for offshore RES integration via single-, dual- or multi-purpose[27] offshore infrastructure (see also illustration in chapter 2).

The ONDP for each European sea basin is a kick-start for the necessary energy network developments and a more coordinated and focused planning of offshore systems. The cumulative offshore RES capacities agreed by Member States add up to a maximum of 112 GW, 248 GW and 354 GW in 2030, 2040 and 2050, requiring a sufficient amount of transmission capacity connecting the generation to the onshore systems.

These offshore RES capacities are further complemented, by capacities provided through some Member States updated strategies and by non-EU countries (NO and GB) who contributed to the 2024 ONDP, providing data on an additional 58 GW, 110 GW and 112 GW by 2030, 2040 and 2050. These add to European Member States' 166 GW, 271 GW, and 383 GW in EU waters.

To connect the target generation to the energy system by 2030, more than 11 thousands km of cable routes will radially connect 87 GW in European Member States at an overall cost of approximately 85 bn € for transmission infrastructure assets.

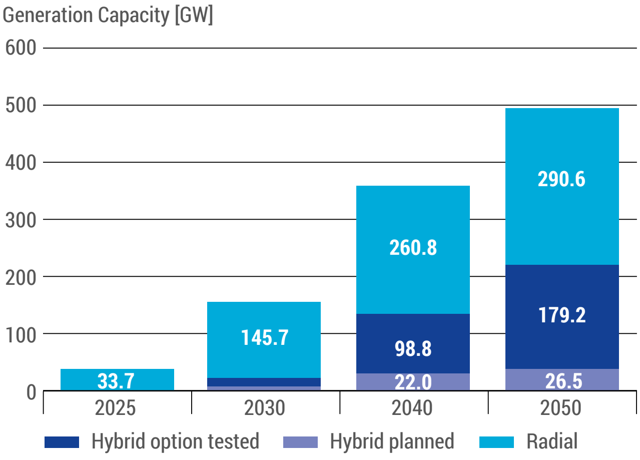
Evolution of generation cap. (connection type)

Figure 18 – Input data (EU+NO+GB): Generation capacity and their connection type.

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[27] The definition of single, dual and multi-purpose infrastructure can be found in ENTSO-E position paper on offshore development

	2025–2030		2031–2040		2041–2050		Total 2025–2050	
	w/o DC breakers	w. DC breakers	w/o DC breakers	w. DC breakers	w/o DC breakers	w. DC breakers	w/o DC breakers	w. DC breakers
Cable routes (both AC and DC)	11,600 km	11,600 km	24,000 km	27,600 km	12,800 km	14,700 km	48,292 km	53,904 km
Offshore DC converter stations	39	39	82	76	51	43	172	158
Offshore AC substations	67	67	47	41	23	15	137	123
Onshore DC converter stations	39	39	79	83	49	54	167	176
DC circuit breaker sets	0	0	0	18	0	16	0	34
Costs (depending on technology and configuration)	85 bn €	85 bn €	196 bn €	201 bn €	112 bn €	117 bn €	393 bn €	403 bn €
Cost range due to uncertainties	+30 % … +100 %		+30 % … +100 %		+30 % … +100 %		+30 % … +100 %	

Table 3 – Equipment and costs needs from 2025 to 2050.

Coordinated planning, the establishment of offshore hybrid projects and the joint operation of offshore network infrastructure will help to reduce the need for maritime space and the environmental impact, and provide visibility for industry by exploiting synergies.

5.1 Components of the offshore network infrastructure

When discussing offshore network infrastructure, ENTSO-E considers a variety of designs and technologies. The offshore network infrastructure will comprise radial connections and classic point-to-point interconnections in addition to the newer category "offshore hybrid projects", also called "hybrid interconnectors". Figure 7[28] below indicates which assets belong to this newer category. An easy-to-remember rule is that generation assets do not belong to this category.

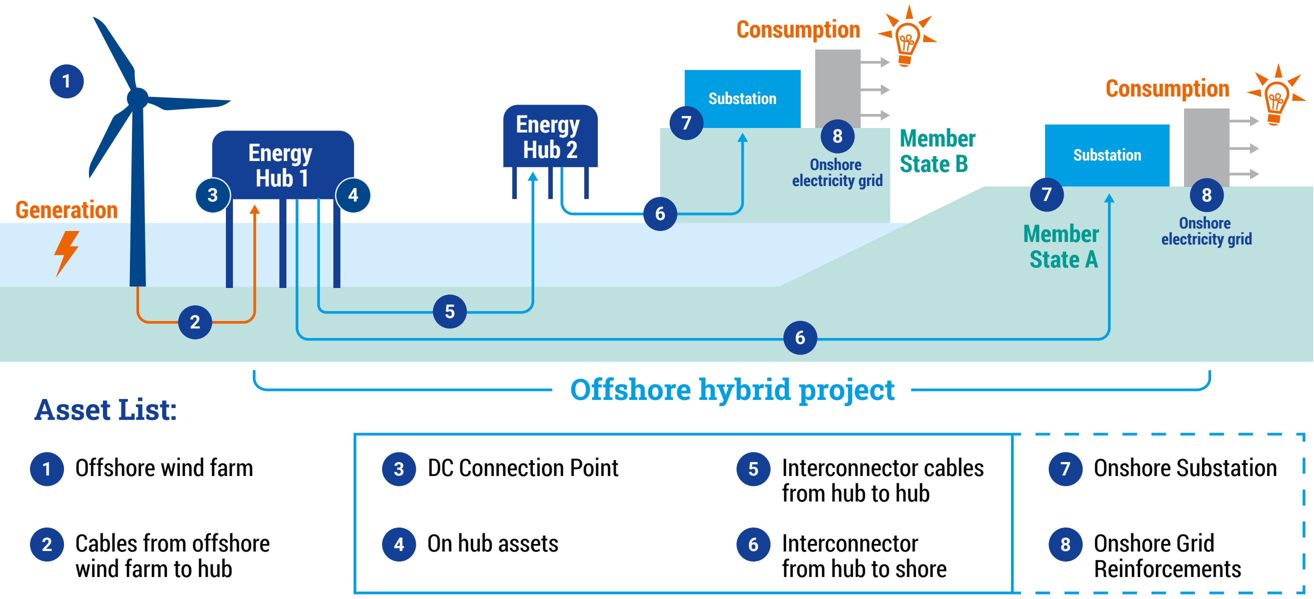

Figure 19 – Components of an offshore hybrid infrastructure.

The infrastructure can be of AC or DC technology, depending on the distance to shore. The standard transmission technology considered for the ONDP study is HVDC, with 525 kV VSC converter technology. 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. They depend on the availability of DC circuit breakers.

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[28] Source: see here

- One technical configuration assuming DC circuit breakers are commercially mature by 2040 and 2050 ("with DC breakers"). The offshore DC corridors are connected on the DC-side of a converter through DC hubs including DC-breakers; and

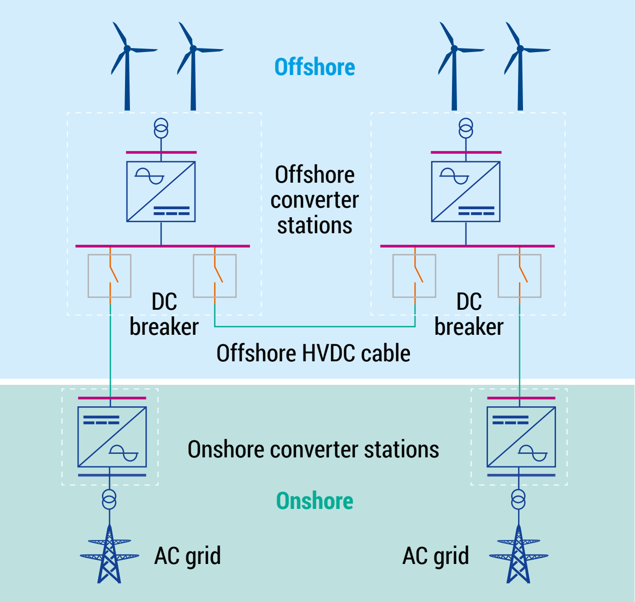

Figure 20 – Example of hybrid configuration using DC breakers, with only one converter per offshore substation.

- One technical configuration assuming DC circuit breakers are not commercially mature ("without DC breakers"). The offshore corridors are connected at the AC side through the use of AC hubs, each link including a dedicated AC/DC converter.

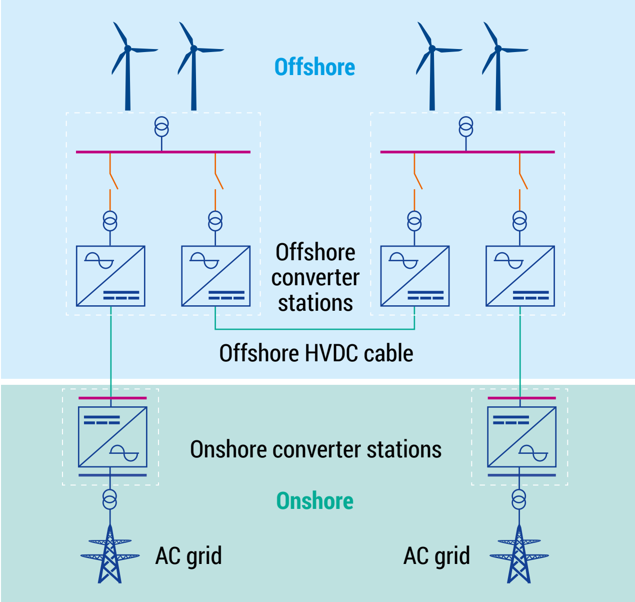

Figure 21 – Example of hybrid configuration without DC breakers, foreseeing a dedicated converter for each HVDC link.

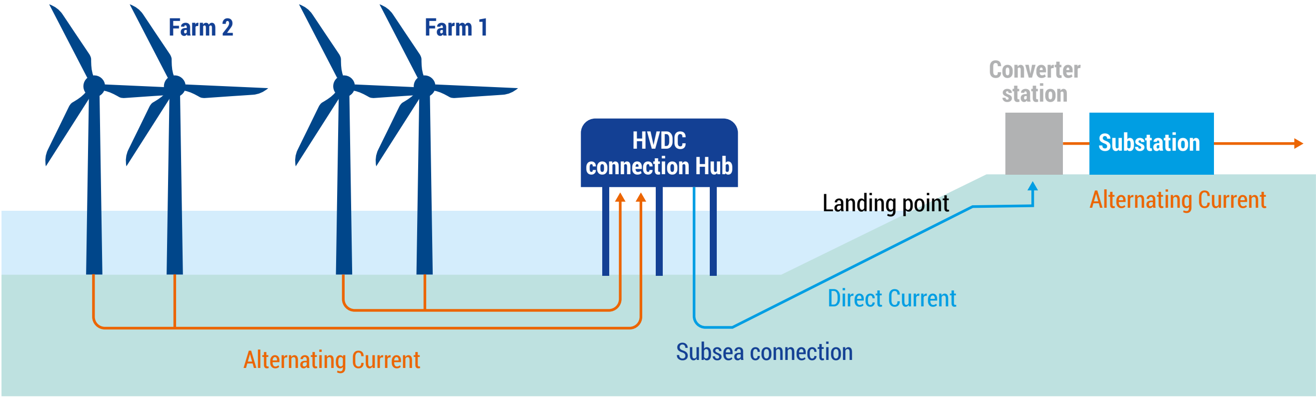

Figure 22 – A typical radial offshore connection scheme (continental "TSO-model").

The main components of the standard 525 kV HVDC electricity transmission infrastructure considered in the ONDP-expansion study are listed below. These are the elements used when testing if an additional link e. g. between two offshore nodes benefits the overall system, (see also [ONDP methodology report](), "step 2" of the process.

An expansion considers an **offshore platform** hosting an HVAC substation connecting the inter-array cables exporting electricity from the wind turbines, and a HVDC converter station:

- In the configuration with the DC circuit breaker, when the HVDC offshore substation is considered "expandable", it means that for the purpose of the study, additional space on the platform for a DC circuit breaker has been assumed. Thus, the platform is therefore assumed to be able to connect other projects on the DC side. The extra cost for the additional space on the platform is smaller compared to the installation of an entirely new platform for the DC breaker. This optimistic assumption has been selected to provide best conditions for offshore hybrid projects and thus get an indication of some possible high expansion margin.

Figure 23 – Works at the landing point, RTE, Saint Nazaire, France.

- In the “configuration without DC breakers”, this has not been foreseen, and an additional platform would be needed;

An expansion considers an **export cable** connecting the offshore platform with another offshore node, or a new landing pointor expanding the connection to the existing landing point;

- An **onshore junction box** linking the offshore and onshore cable systems, representing the physical landing point of the infrastructure;
- A **onshore cable** between the onshore junction box and the onshore converter station; and
- An **onshore converter station, and an onshore HVAC substation** connecting the HVDC system to the onshore transmission grid.

Floating offshore substations have not been considered in this first edition of the study given the uncertainty around the time horizon for the development of floating HVDC dynamic cables and substations.

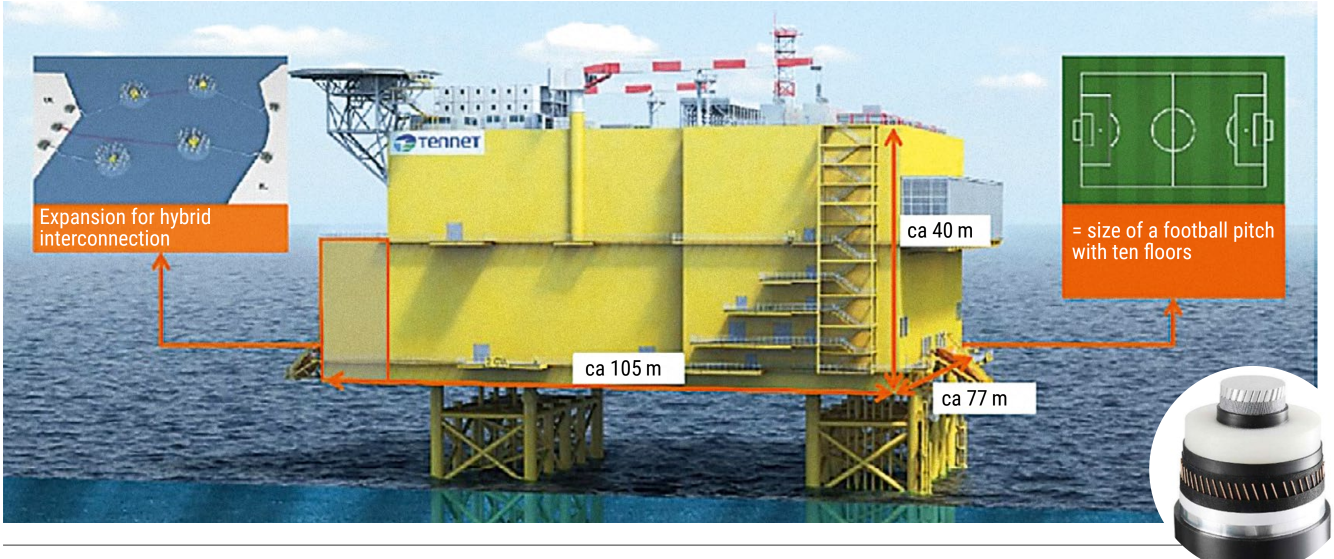

Figure 24 – Possible 525 kV HVDC offshore platform (Tennet) and 525 kV submarine cable (Prysmian).

Figure 25 – 525 kV onshore converter station (Statnett, Tonstad, Norway) and onshore 525 kV cable (NKT).

5.2 Industrial manufacturing and installation capacities

In the past, the HVDC offshore infrastructure market has been driven by large interconnector projects, decided on a case-by-case basis, and radial connections in a limited number of markets. This has not encouraged the investments necessary to scale up production facilities. Currently, the demand exceeds the capacity of the supply chain. As a result TSOs have noticed that the lead time for construction has almost doubled.

Among the network components, high voltage transformers, port and yard capacities able to build large DC topsides and subsea cable manufacturing capacities are the most critical ones.

In addition, a lack of specialised workforce working with offshore is another main limiting factor.

Considering the volume of investments needed and the timescale of building new manufacturing and installation facilities, ENTSO-E and TSOs consider the following factors to be crucial in order to stimulate investment in Europe and hence make the ONDP perspectives possible:

1. Provide a long-term perspective: authorities need to build on the ONDP and other European and National planning tools to approve and commit to integrated energy marine spatial planning, with a clear vision of wind farm areas, offshore grid corridors and target grid structures;
2. Standardisation and framework contracts by grid developers, materialising the development requested by authorities. Several TSOs with large portfolios have already scaled up their procurement strategies, providing enhanced visibility. This ensures replicability and facilitates the optimisation of industrial processes and hence speed; and
3. Appropriate tax reliefs and incentives to stimulate R&D, training and industrial investments should be enhanced and current European legislation or processes such as CBAM could be reviewed to facilitate European manufacturing (excluding cables) while ensuring a reasonable transition towards more sustainable technologies.

The investments needed are not limited to facilities for the construction and installation of offshore network infrastructure. A full overview of the value chain necessary for network expansion should be considered. Critical raw materials such as copper, intermediate products such as aluminium and steel, essential components such as IGBT and semi-conductors all constitute scarce resources with sovereignty risks for Europe.

6 Conclusions and next steps – towards future ONDPs

The first edition of the ONDPs shows that to integrate up to 384 GW of offshore wind in EU waters, (that become 496 GW with the capacities included in UK and Norway's waters), Europe will need substantial investments in offshore transmission infrastructure.

The total amount of CAPEX needed to connect the generation capacities to the entire investigated area including NO and GB[29] are currently estimated at 362 bn € from 2025 to 2050 (even though huge uncertainties are currently characterising the supply chain costs). This is complemented with investments of an additional 31–41 bn € expansions between different jurisdictions, thus creating offshore hybrid corridors. These total investments of 393–403 bn € will provide the European consumers with more than 1,600 TWh of clean energy every year, making offshore wind the third energy source in the European energy system.

The ONDP study also demonstrates that hybrid transmission projects can contribute to optimising the integration of offshore energy, contributing with up to 82 TWh/year of additional energy integrated, through an increase in the transmission capacity connecting the offshore generation hubs between each other.

The assessment shows the potential of the northern basins for the development of these solutions, with the North Sea hosting most of the expanded hybrid infrastructure (30 GW of corridors identified through modelling). However, hybrid transmission corridors have been found in other basins too, with the Baltic Sea showing potential for 13.6 GW of hybrid transmission.

In the western and southern basins (Atlantic, Mediterranean and Black Sea), the offshore energy infrastructure is still dawning but the interests of the Member States are growing and, given the adequate technological evolution of floating solutions, offshore RES can become an important component of the generation mix. A total of 94 GW of offshore RES by 2050 could be installed in these waters, delivering almost 230 TWh/year of energy, mostly through radial connections. It is important to underline that in most cases, particular attention will have to be given to spatial planning given the peculiar marine environment characterising some of these areas.

The achievement of Member States' goals concerning the installed RES generation capacities cannot happen at the cost of the marine environment. However, the impacts of the development of offshore energy infrastructure can be avoided or minimised by applying certain mitigation measures. For offshore developments to succeed and for nature to thrive, action can be taken from inter government cooperation on spatial planning to the application of Nature Inclusive Design during the realisation of single projects.

This first edition of the ONDP will allow, in the basins where the offshore sector is more developed, to accelerate the individuation of project candidates, while in the basins still at the beginning of offshore development it will enable the assessment of the needs to accelerate the deployment of offshore energy.

The ONDP has already proven be an important addition to the TYNDP, and its results will feed into the upcoming TYNDP 2024 System Needs study to be released in the summer of 2024. This will allow the individuation of the onshore reinforcements needed to optimise the future transmission system with a holistic onshore–offshore perspective.

The ONDP will be the basis for the Cost–Benefit Cost Sharing exercise that ENTSO-E is mandated to develop following Article 15 of EU Reg 2022/869 and the guidance that is set to be delivered by the European Commission in June 2024. The future ONDP-editions will be further developed to increasingly coordinate with the national spatial planning tools and offer an even more integrated perspective of the development of offshore energy systems.

ENTSO-E intends to evolve the ONDP already in the next edition, by further integrating the product with the other TYNDP processes. By applying an increased holistic approach to the investigation of opportunities for offshore RES integration, the ONDP (and the TYNDP in general) will gain an integrated modelling process, optimising on and offshore infrastructure simultaneously.

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[29] Cost of UK radials are not included.

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The ONDP Package was elaborated under the guidance of the **ONDP Central Group**, led by: **Antje Orths (Energinet)** and **Francesco Celozzi (ENTSO-E)**.

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