Translate COP21

2045 outlook and implications for offshore wind in the North Seas

- Public report –

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Executive Summary

In December 2015, at the Paris Climate Change Conference (COP21), 195 countries adopted the first-ever universal, legally binding global climate agreement to put the world on track to avoid climate change by limiting global warming to well below 2°C, and with an aim to limit the increase to 1.5°C. Since decarbonization of the electricity generation is generally considered as one of the “easiest” of all actions required, this should be realized with the highest priority, requiring CO_2 neutrality as early as 2045. The aim of this analysis is to estimate the amount of offshore wind capacity that is needed in the North Seas by 2045 to meet the COP21 targets.

Based on a 50% reduction in total energy demand by 2045 (relative to 2010), full decarbonization of the electricity generation and a 45% electrification level, a 230 GW offshore wind capacity target for 2045 is estimated for the North Seas countries (FR, BE, NL, UK, IE, LU, DE, DK, SE and NO). 180 GW of the total will be deployed in the North Sea and another 50 GW in the "other seas" (Baltic, Irish and Atlantic).

While there is sufficient space to deploy the target offshore wind capacity in the North Seas, some countries have a surplus of resource, whereas others have deficit. To ensure effective use of the available resources, there is a need for an international spatial planning strategy that ensures cost efficient utilization of the resource, aligned with off- and onshore grid developments and with maximum benefit for the environment.

A higher share of variable sources requires increased flexibility options. A well-developed network is a crucial enabler for pooling these flexibility resources. A high level 2045 interconnectivity assessment - based on first order adequacy, regional correlations, and flexibility potential estimates - shows the need for 50-80 GW of interconnection capacity. This in turn requires the development of a methodology to value grid stability that incentivizes interconnector capacity to maintain operational security.

In 2045 only 25% of the total electricity generation capacity will be dispatchable (compared to 64% today) requiring a significant increase in flexibility options. Increased use of cost efficient flexibility options, such as demand response, small/large-scale storage, power-to-gas, etc., will become essential in the 2045 scenario in face of decreasing dispatchable generation capacity. A realistic and robust roadmap is needed for all potential flexibility options by 2045, including a trade-off of some flexibility options with interconnection levels.

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1 The COP21 agreement implies a radical change in the electricity generation mix for the North Seas countries

At the Paris Climate Change Conference (COP21) in December 2015, 195 countries adopted the first-ever universal, legally binding global climate deal. The agreement sets out a global action plan to put the world on track to avoid climate change by limiting global warming to well below 2°C, and with an aim to limit the increase to 1.5°C. This significantly reduces the enormous negative effects of climate change that would impact global society and environment if we continued business as usual. The EU formally ratified the Paris Agreement, enabling its entry into force on 4 November 2016.

With the political will and mandate to act, the major challenge that Europe now faces is how to implement this agreement. Since reducing CO_2 emissions from electricity generation is generally considered as one of the “easiest” of all actions required, it should be realized with the highest priority and it probably requires CO_2 neutrality of the electricity generation as early as 2045. Key will be the increased and efficient deployment of renewables, as well as a smart and robust roll-out of interconnection between countries and development of sufficient flexibility options.

The aim of this analysis is to estimate the amount of offshore wind capacity that is needed in the North Sea by 2045, to ensure a fully sustainable power supply of members of the North Seas Energy Cooperation (the Netherlands, Germany, Belgium, Denmark, United Kingdom, France, Norway, Sweden, Luxembourg and Ireland). In this analysis, the Channel is included as part of the North Sea, whereas the "North Seas" refer to all seas - North Sea, Irish Sea, Baltic Sea and Atlantic Ocean - that border the countries that have signed the political declaration on North Seas Energy Cooperation.

2 North Seas offshore wind is pivotal to realize a 100% decarbonization of the electricity supply

To accommodate the future power demand in a sustainable way, a substantial increase in the capacity of sustainable sources has to be realized, and offshore wind has the growth potential which is needed for that.

The deployment potential of most renewable energy sources onshore is limited by spatial constraints, be it due to available area or visual and noise impacts for example. The North Seas, however, provide an enormous area with an abundance of sustainable energy potential, with less restrictions than onshore. This makes offshore wind an important resource in the supply of our future energy demand.

In this chapter an estimate for the offshore wind capacity in 2045 which is required for the COP21 target is given. First the methodology is explained, after which the results are presented. Finally, a possible pathway towards 2045 is given.

2.1 Approach and methodology

To determine the required capacity of offshore wind, first the electricity demand in 2045 must be determined. The starting point is the total final energy demand of each country in 2010. This total final energy demand is estimated to be reduced by 50% by 2045[1]. It is expected that due to substantial electrification of energy use, 45% of total final energy demand is covered by electricity in 2045[1], compared to 21% in 2010[2]. This results in the amount of electricity which must be supplied by renewable sources in 2045.

The required capacity of the various renewable sources is modelled in such a way that each country fulfils its own electricity demand. This is done in order to calculate the contribution of each separate energy source per country. This does, however, not mean that interconnections between the countries are absent. Nor does it mean that the estimated offshore wind capacity must be realized within the national parts of the North Seas. These topics are addressed in section 4.

The maximum capacity of all renewable and nuclear sources, except offshore wind and solar PV, are calculated first, after which the remaining required capacity is distributed between offshore wind and solar PV. The installed capacities of hydro power, bio power and other renewables (e.g. tidal) are based on the maximum amount in available scenarios[3]. The installed capacity of onshore wind is based on the capacity in the Wind Europe high 2030 Scenario[4]. The estimate for 2045 is equal to this capacity estimate for 2030, because after 2030 only a marginal increase of onshore wind capacity is expected, as almost all suitable locations for onshore wind will be exploited by then. Considering the installed capacity of nuclear energy, all currently operational nuclear power stations are

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[1] Ecofys/WWF (2011) The Energy Report.

[2] IEA statistics (2014)

[3] Fraunhofer ISI (2011). Tangible ways towards climate protection in the European Union; PRIMES, 2016, EU Reference Scenario

[4] Wind Europe (2015). Wind energy scenarios for 2030

expected to be phased out in 2045. Only the capacity of nuclear power plants which are currently, or are expected soon to be, under construction is included.

The remaining electricity demand is divided over generation by offshore wind and solar PV by applying a distribution which differs by country. The distribution is based on the ratio between wind and solar in the PRIMES 2016 EU reference scenario[5].

To determine the amount of offshore wind to be installed in the North Seas, the calculated offshore capacity is divided between the North Sea and other seas (Irish, Baltic, Atlantic). The distribution between the North Sea and other seas is done separately for each country. To calculate the future distribution both the current distribution between North Sea and the other seas offshore installed capacity in each country is used, as well as expected future expansion, taking into account the depth of the sea and the location of load centers. Also, it is assumed that all offshore wind capacity of Luxembourg is located in the North Sea.

2.2 Results

This analysis shows that a total offshore wind capacity of 230 GW is required in the North Seas by 2045 to ensure a fully sustainable power supply for the surrounding countries in line with the Paris Agreement's objective. Of this total, 180 GW is to be installed in the North Sea itself, 50 GW in the other seas. Figure 1 shows the required capacity on the North Seas per country. Figure 2 shows the total required offshore capacity per country for the North Sea alone. Figure 3 and Figure 4 give the energy mix for the region and per country in 2045.

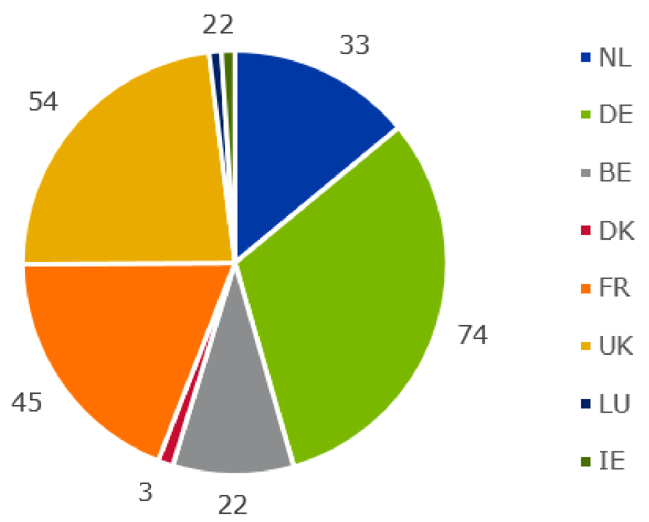

Figure 1: Estimated installed offshore wind capacity [GW] in the North Seas per country in 2045

[5] PRIMES, 2016, EU Reference Scenario

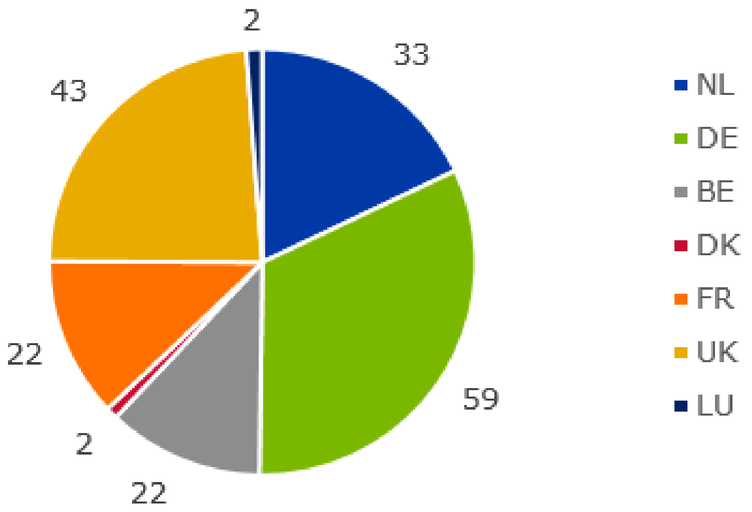

Figure 2: Estimated installed offshore wind capacity per country in the North Sea only, per country in 2045

The estimate of 230 GW is based on a possible scenario towards 2045. Clearly, different input parameters and assumptions would result in somewhat different results. For instance, a higher electrification ratio would immediately lead to a higher overall offshore wind target. In paragraph 2.3, a sensitivity analysis is performed on the main input parameters. The sensitivity analysis shows that the 230 GW estimate provides a solid indication of the order of magnitude of offshore wind power required by 2045.

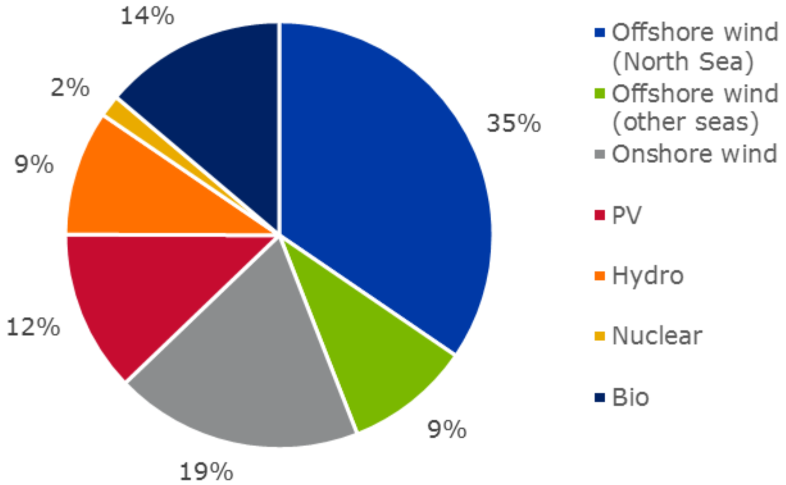

Figure 3: Energy mix per country in 2045

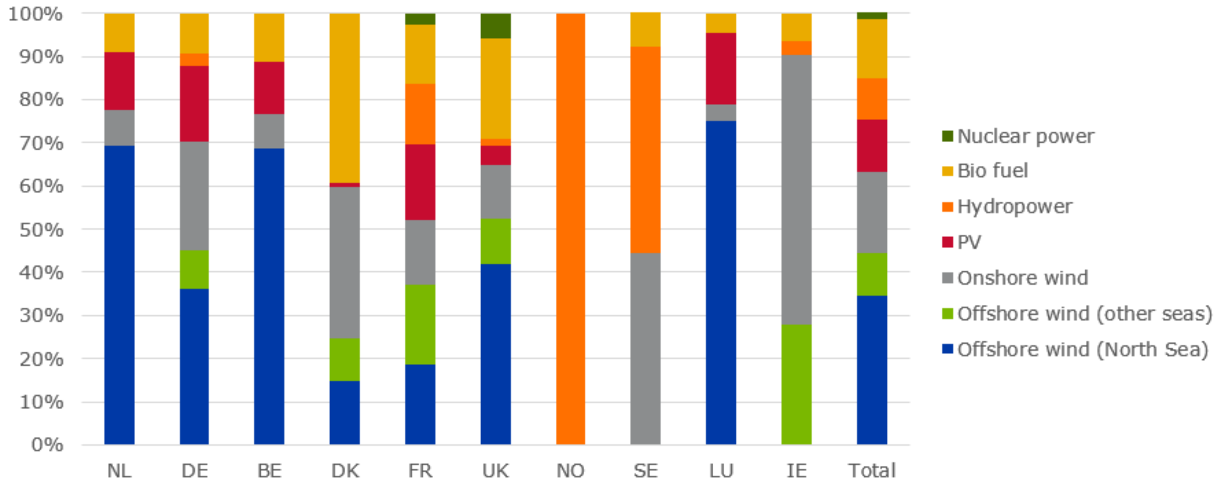

Figure 4: Total energy mix in 2045

2.3 Sensitivity analysis

A sensitivity analysis has been performed on some of the main parameters. In this analysis, the influence of the total energy demand reduction and electrification, as well as the number of full loads hours per year of onshore and offshore wind energy on the required offshore wind capacity is studied.

The resulting offshore wind capacities are given in Table 1. The total energy demand reduction is reduced from 50% to 45%, and the electrification is increased from 45% to 50% (reflecting a 10% change in each of these parameters). It can be seen that both result in a significantly higher offshore wind capacity.

The number of full loads hours for offshore wind has been increased from 4000 to 4500 hrs/year, and for onshore from 2500 to 3250 hrs/year, reflecting the projections in the Technology Data Catalogue for Energy plants[6]. Again, a significant change in capacity is shown, a reduction in this case. This change is relatively smaller compared to the other two sensitivity parameters.

[6] Danish Energy Agency (2016) Technology Data Catalogue for Energy Plants

Table 1: Sensitivity analysis on main input parameters

Parameter	Reference Value	Sensitivity value	Offshore wind capacity North Seas	North Sea wind capacity
Total energy demand reduction	50%	45%	270 GW	210 GW
Electrification	45 %	50%	280 GW	220 GW
Offshore wind full load hours	4000 hrs/year	4500 hrs/year	210 GW	160 GW
Onshore wind full load hours	2500 hrs/year	3250 hrs/year	210 GW	170 GW

2.4 Pathway towards 2045

To reach a capacity of 230 GW offshore wind in 2045, the offshore wind installation rate needs to increase considerably.

Figure 5 shows the currently planned additional capacity per year for Europe[7], as well as the projected capacity required to reach the 230 GW target. The planned capacity up to and including 2023 is considered certain, and won't be affected much by new policies and targets. New policies and market integration progress are required to ensure an increased roll-out after 2023 to enable reaching the 2045 target.

The average planned added capacity up to and including 2023 is approximately 3 GW/year. After 2023 a ramp-up of 1 GW/year per year is assumed until 2030. A higher ramp-up could be difficult to achieve due to the required expansion of industrial fabrication and installation capabilities. A lower ramp-up, on the other hand, would yield the 2045 target difficult to attain. The current approach results in a net installation rate of 10 GW/year from 2030 onwards, which is sufficient to reach the 230 GW in 2045.

[7] WindEurope (2017) North Seas declaration: Support Frameworks and Finance Presentation

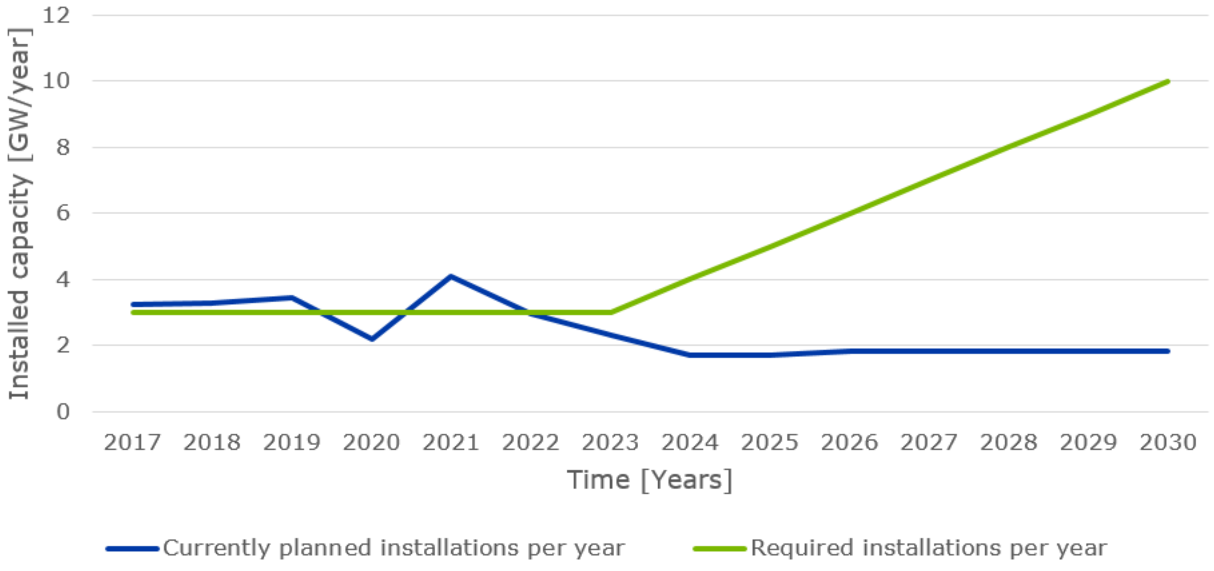

Figure 5: Currently planned and required installed capacity per year to reach 230 GW of installed offshore wind capacity in 2045

Figure 6 shows the projected pathway until 2045 for the North Seas area. This pathway would result in an installed capacity of 83 GW in 2030, an increase of 70 GW compared to 2016.

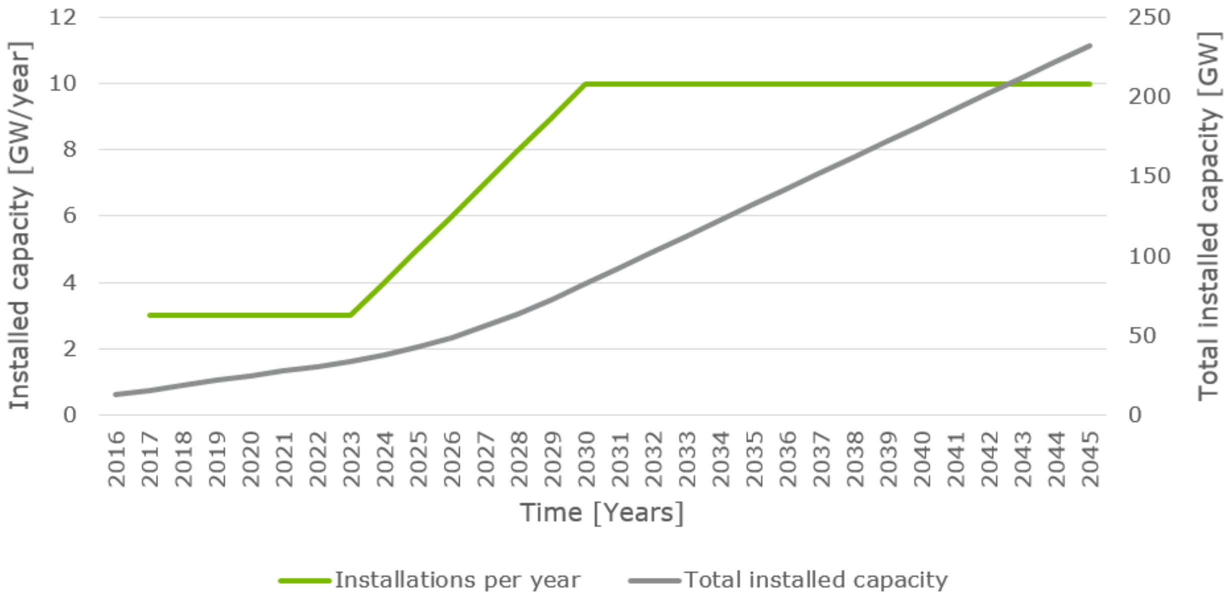

Figure 6: Project trajectory of installations and total capacity until 2045

A similar pathway for the capacity on the North Sea is shown in Figure 7 and Figure 8. The installed capacity per year until 2023 is estimated to be 70% of the total installed capacity, equal to the current share of offshore wind in the North Sea. From 2023 until 2030 an increase of 0.8 GW per year is estimated, 80% of the total increase per year, which is equal to the calculated future share of offshore wind in the North Sea. After 2030 a constant 8 GW of new installations per year is sufficient to reach 180 GW in 2045.

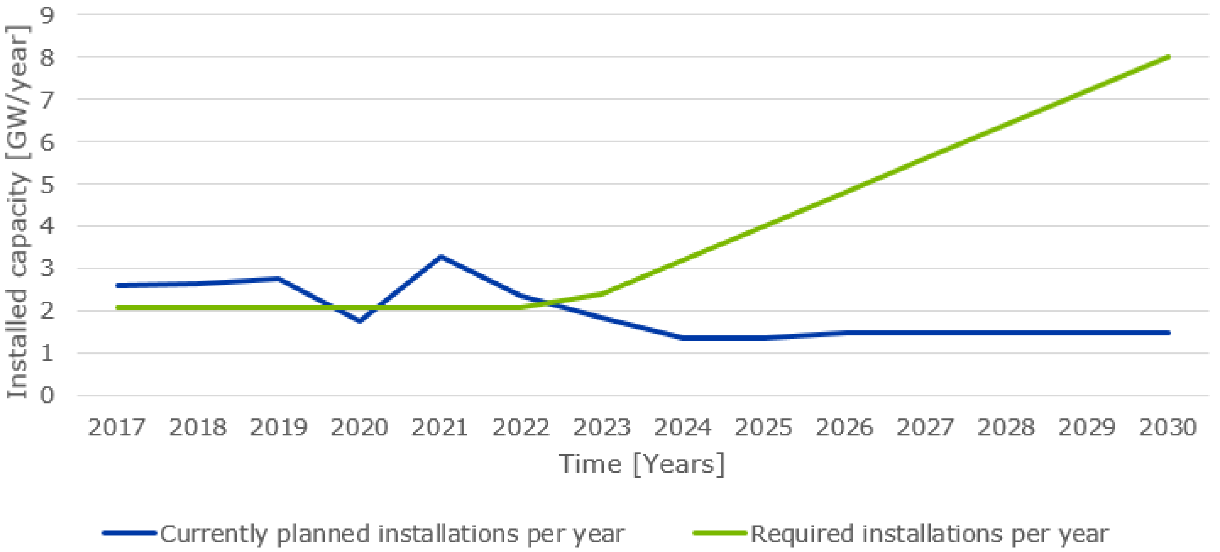

Figure 7: Currently planned and required installed capacity per year in the North Sea

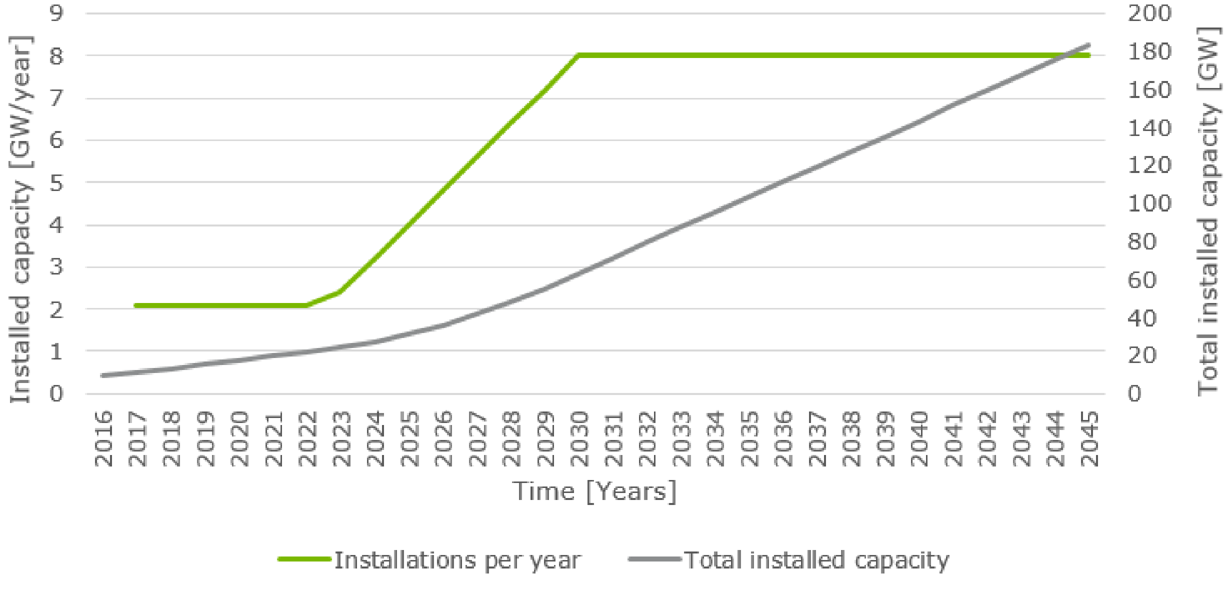

Figure 8: Project trajectory of installations and total capacity in the North Sea until 2045

3 Cost efficient realization of offshore wind capacity requires cross border cooperation and a strategic approach to overall spatial planning of offshore wind in the North Seas

The North Sea is intensively used by many stakeholders and is of vital importance to our ecosystem. A first high level analysis shows, that while there is sufficient space to develop the required offshore wind capacity, a careful balance needs to be maintained between ensuring maximum benefit to the environment on the one hand, and cost efficient development of both wind farms and associated infrastructure on the other hand.

This requires a long-term view and close collaboration between all North Seas countries, taking into account changes in use (e.g. decommissioning of oil & gas infrastructure), and an overall spatial planning strategy that ensures cost efficient utilization of the resource, aligned with off- and onshore grid development and with maximum benefit for the environment, recognizing all stakeholders' interests.

3.1 Approach and methodology

The below results with respect to North Sea spatial planning are derived from an analysis performed by Royal Haskoning DHV, based on their extensive knowledge of, and involvement in, spatial planning activities both for the offshore wind sector, as well as for other important North Sea stakeholders such as the oil & gas industry. The analysis focuses on the southern North Sea (France, Belgium, United Kingdom, Netherlands, Denmark), being the most intensively used area by a range of stakeholders, and thus relates approximately to the 180 GW combined offshore wind capacity target as estimated in the previous section. Norway is not included in this part of the analysis as it focuses on areas with water depths <40 m (which is currently perceived as economically viable to develop), of which Norway has negligible resources in the North Sea region. With the advancement of new technologies, such as floating turbines, this may change in the future and increase the total available space for wind deployment.

Starting point of the analysis is an overview of current use of the North Sea and its impact on offshore wind development potential (Figure 9).

For the development of offshore wind, an average density of 5 MW/km^2 is assumed. For reference, the total Borssele wind energy area of 1,400 MW - which has relatively many obstacles within the area - covers an area of 344 km^2 (4 MW/km^2), while the permitted area is 230 km^2 (6 MW/km^2).

When focusing on the North Sea only, the 2045 offshore wind target is estimated at 180 GW, requiring a deployment area of approximately 36,000 km^2. With a total surface area for the North Sea of approximately 750,000 km^2, offshore wind farms will cover approximately 5% of the total North Sea area in 2045.

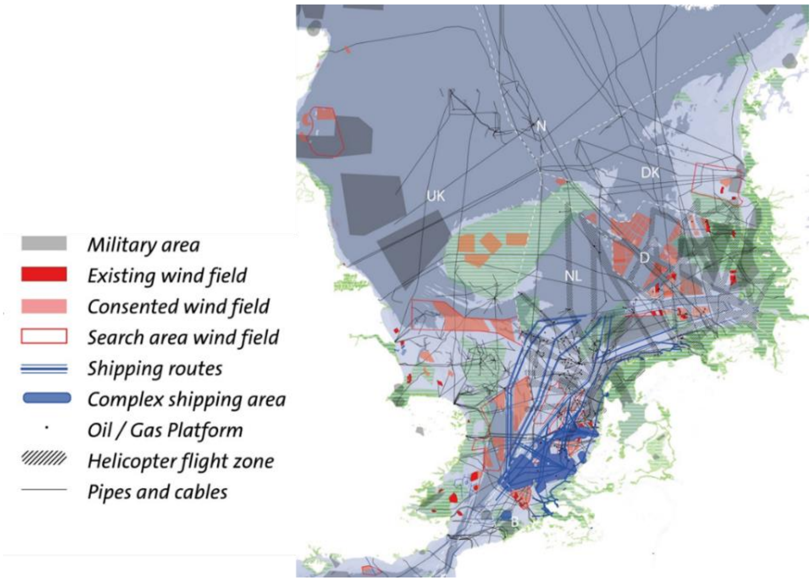

Figure 9: Combined current spatial constraints with respect to offshore wind deployment in the North Sea

3.2 Conclusion

From the above analysis, the following conclusions can be drawn. First, spatial planning for offshore wind towards 2045 is an **international** challenge. While some of the North Seas countries have overabundant space in their part of the North Seas to meet their national offshore wind capacity requirements (e.g. Denmark and the United Kingdom), other North Seas countries lack sufficient space within their own territorial waters for offshore wind deployment in line with the national projected capacity (e.g. Belgium and France).

Second, when viewed in the context of the complete North Sea, and the combined offshore wind target for this region, there is **sufficient space available**, with ultimately an offshore wind coverage of ~5% of the North Sea surface by offshore wind activities. This is especially true when also Natura 2000 are considered viable for wind energy deployment.

Third, within the context of a long term spatial planning strategy, the balance between creating maximum benefit for the environment[8,9,10,11], cost efficient deployment of offshore wind (by maximizing the use of shallow waters, high wind speeds, accessibility for operation and maintenance), efficient grid integration both with respect to onshore connection and North Sea interconnection (see also the section about interconnection below) and use by other stakeholders of North Sea (shipping, oil & gas, military, fishery, ...) should be carefully considered.

[8] BEAGINS project - http://www.beagins.eu/
[9] http://www.ecofys.com/files/files/ecofys-navigant-2017-the-north-sea-as-a-hub.-for-re-sust-econ-biodiv.pdf
[10] Leanwind (2014), "Logistic Efficiencies and Naval architecture for Wind Installations with Novel Developments," EU funded FP7 program
[11] International Union for Conservation of Nature, "Greening Blue Energy"

4 Higher levels of renewable energy sources require increased interconnectivity

The analysis provided in this chapter points at a minimum offshore interconnection level in 2045 in the range of 50 to 80 GW. It is based on a first order adequacy assessment in a triangle of three subsystems:

- Great Britain / Ireland
- Continental North-West Europe
- Nordics

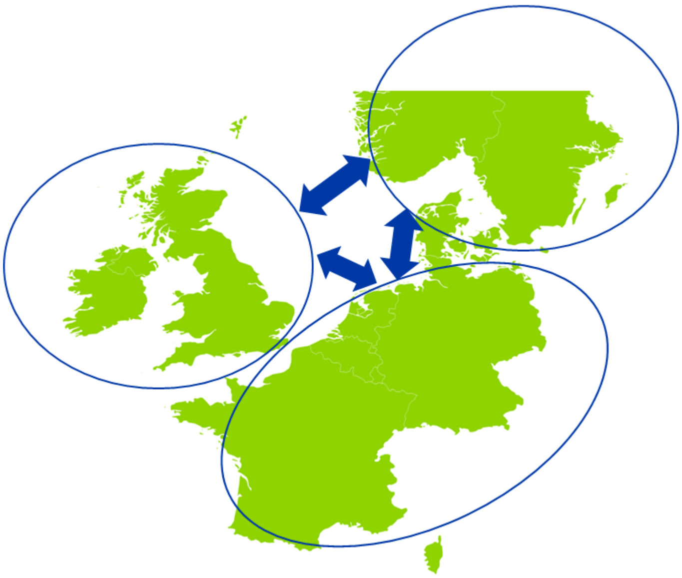

Figure 10: Three main subsystems of the North Sea region

Offshore interconnections between these subsystems gives an opportunity for pooling generation/flexibility resources from across regions to avoid loss-of-load under stressed power system conditions. The analysis is based on the scenario outlined in section 2, complemented with a reasonable development of various flexibility options, incl. storage and demand response at small- and large-scale levels.

In our 2045 scenario, offshore wind would become the dominant generation source for North Western Europe in the coming decades, while supplying levels of electricity consumption that are higher than today. A great amount of flexibility is needed in the power system to cope with higher shares of variable renewable generation and lower shares of dispatchable generation. Historically conventional generation was the greatest source of flexibility ('dispatchable generation') to ensure a constant instantaneous supply/demand balance. Today's installed generation covers 64% dispatchable generation[12]. A transition is already occurring now with other cost effective flexibility sources becoming available such as storage, demand response and ancillary services from renewables, while at the same time variable resources require higher levels of flexibility. In a 2045 scenario dominated by variable renewables, the use of these new flexibility sources will become essential.

A crucial enabler for such a flexible power system is a well-developed network, with interconnection levels much higher than today. In the case of the North Sea, where offshore wind will be dominant, this entails a system with high levels of interconnectivity. Nowadays the level of offshore interconnections is still relatively limited. Business cases for new projects are based on economic triggers of operational cost savings (quantifiable socio-economic welfare based on fuel and carbon cost savings in generation dispatch). Such positive and robust business cases allow for National Regulatory Authorities to let Transmission System Operators recover investment costs via tariffs and congestion rents, or for merchant investors to seek financing. The latest pan-European Ten Year Network Development Plan 2016 covers about 17GW of offshore interconnection across the North Sea by 2030, with even more interconnector projects being in an early study phase. Higher levels of interconnectivity give lower societal welfare gains per GW and are thus expected to guide investments to an optimal interconnectivity level based on cost/benefit rations. However, in systems with higher shares of RES, a Cost Benefit Analysis (CBA) methodology with benefits based on only fuel and carbon cost will also see benefit margins decreasing. Additional interconnections can only have equal or less operation cost savings per GW, while at the same time the whole system is seeing decreasing fuel and carbon costs. A monetized conventional societal welfare is still the main focus for investors, but may undervalue the need for additional interconnections. Project CBAs will have to valorize other aspects of an interconnection such as increased system security.

In a 2045 system, the main need from interconnection will come from allowing the system to pool together flexibility sources, and to ensure a regionally adequate system. It comes down to ensuring that essential / non-flexible demand can still be supplied. While the need for more interconnection can be clearly described, the incentives to enable these investments have to come from updated CBA methodologies and regulatory measures.

The need for interconnection of the three North Sea subsystems is analyzed via an adequacy assessment as depicted in Figure 11. Under system annual peak demand conditions, the following supply options are analyzed:

- The Reliable Available Capacity of renewable infeed:
  - PV is assumed at 0% as peak demand is assumed during evening hours
  - Wind is assumed at 15% of installed capacity based on geographical spread of wind, and similar assumptions taken in present ENTSO-E seasonal adequacy assessments
- The Reliable Available Capacity of dispatchable generation (bio-fuels and limited nuclear) is assumed at 80% of installed capacity, considering maintenance and overhauls. Together with the renewable capacity

[12] https://www.entsoe.eu/Documents/Publications/Statistics/Factsheet/entsoe_sfs2015_web.pdf

this considers a substantial part of the net generating capacity to be unavailable during system peak conditions[13].

- Storage (both small- and large-scale) are assumed to be 80% available during peak conditions
- Demand flexibility is in this case a very simple representation of 10 to 30% peak load reduction potential.

Taking the Reliable Available Capacity on the supply side, the storage resources and the demand flexibility, the subsystem either has a positive or negative margin. In case of a negative margin this implies another local flexibility solution is needed, or interconnection with another subsystem. As such, this margin is a measure for the minimum level of interconnection needed. More detailed methodologies exist, which are discussed in Section 6.

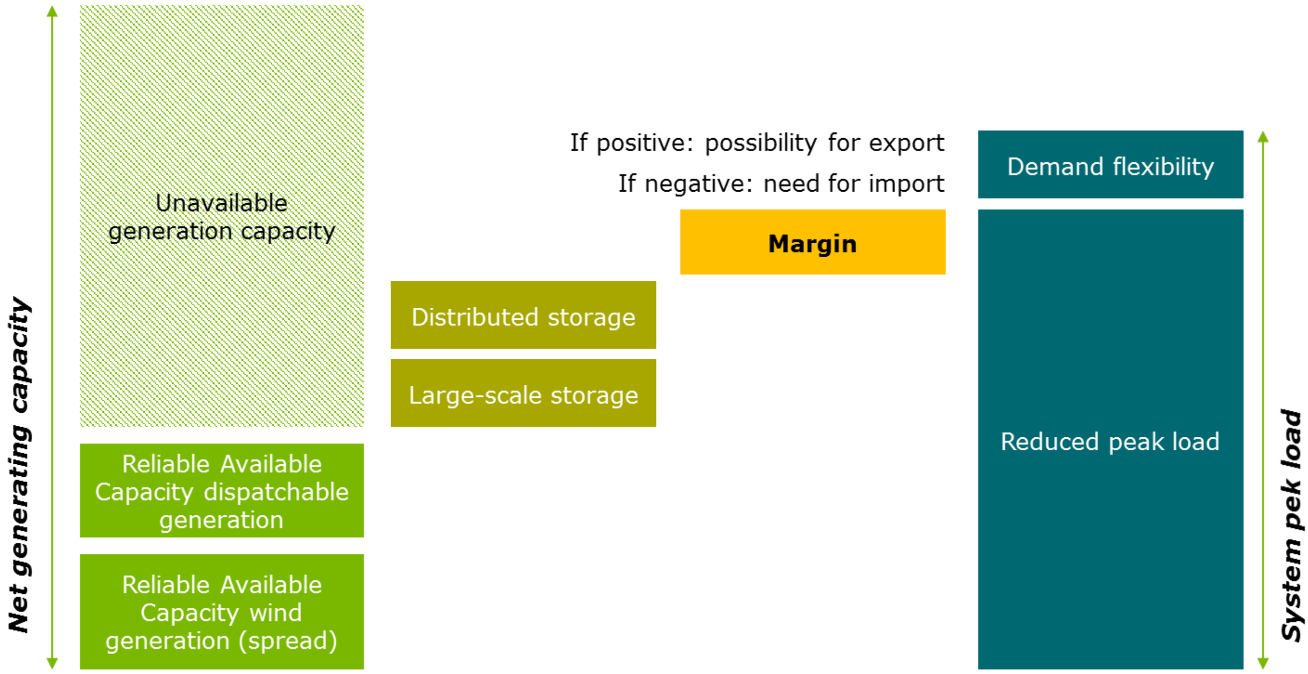

Figure 11: Simplified adequacy assessment applied for 2045 scenario to identify interconnection needs

[13] Non-usable capacity in this analysis reflects the same term (subject to assumptions) as applied by ENTSO-E: "Aggregated reduction of the net generating capacities due to various causes, including, but not limited to: temporary limitations due to constraints (e.g. power stations that are mothballed or in test operation, heat extraction for CHPs); limitations due to fuel constraints management; limitation reflecting the average availability of the primary energy source; power stations with output power limitation due to environmental and ambient constraints, etc."

5 Recommendations

This study has shown the levels of installed offshore wind capacity needed to reach the COP21 targets, and the related levels of offshore interconnection to ensure reliable operation of the system. The following recommendations are put forward to facilitate these implementations.

Offshore wind roll-out

Development of an internationally coordinated roll-out under a stable political framework that ensures appropriate market signals and facilitates offshore grid roll-out aligned to onshore grid integration.

Spatial planning

Development of a long term spatial planning strategy - including an internationally coordinated roll-out with maximum benefit to environment, optimal grid integration at lowest societal cost and recognizing all North Seas stakeholders.

Interconnectivity

Development of a methodology to value grid stability that incentivizes interconnector capacity to maintain operational security.

Flexibility

Develop a better understanding of market/operation issues resulting from an electricity generation mix with significantly reduced dispatchable capacity, including economic triggers and additional capacity reserves.

Development of a 2045 roadmap for flexibility options (storage, demand response, capacity reserves, and other energy sectors).

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