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How offshore wind will help Europe go carbon-neutral

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November 2019

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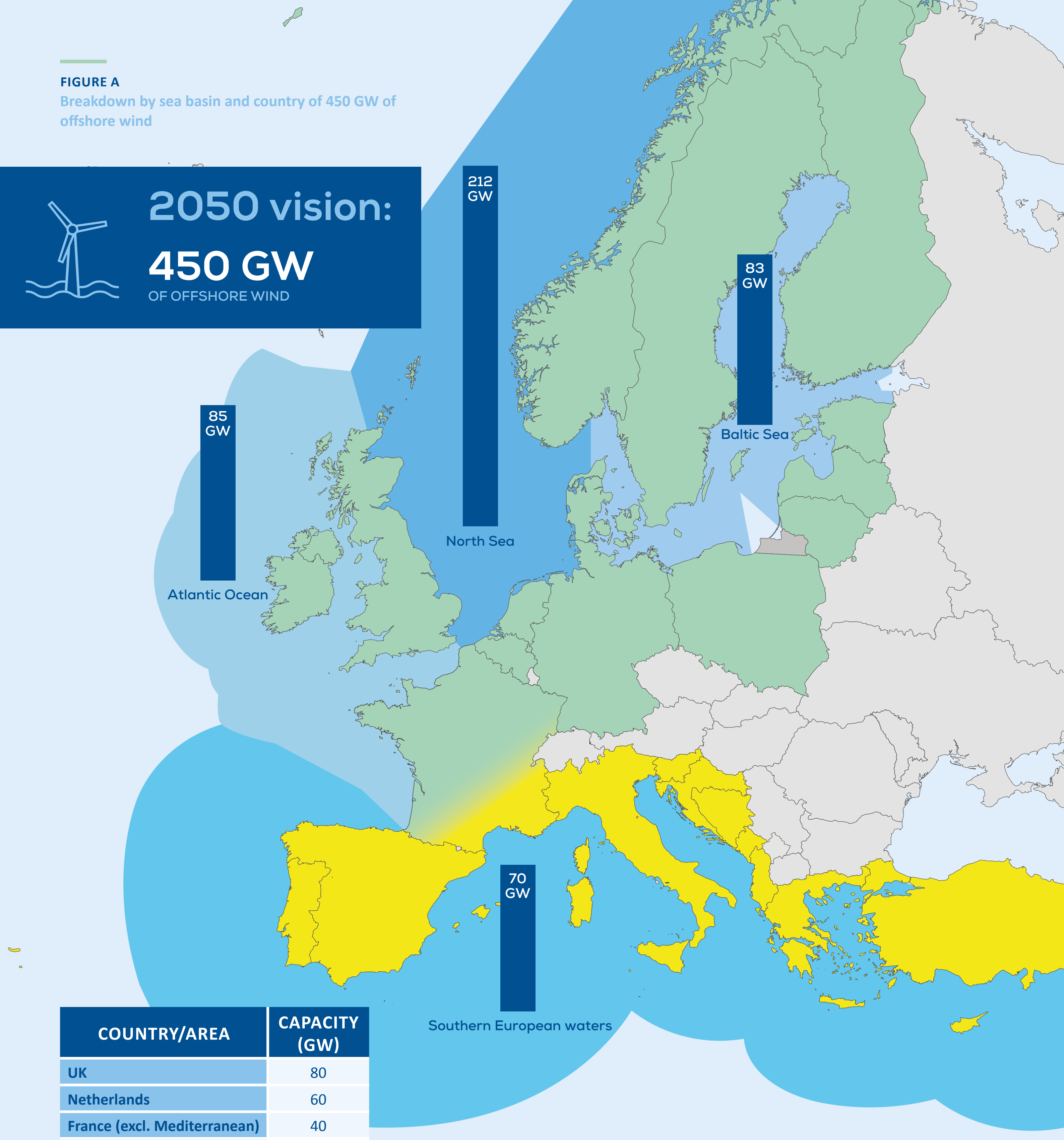
FIGURE A

Breakdown by sea basin and country of 450 GW of offshore wind



COUNTRY/AREA	CAPACITY (GW)
UK	80
Netherlands	60
France (excl. Mediterranean)	40
Germany	36
Denmark	35
Norway	30
Poland	28
Ireland	22
Sweden	20
Finland	15
Belgium	6
Lithuania	4
Latvia	3
Estonia	1
Total	380

COUNTRY/AREA	CAPACITY (GW)
Rest of Mediterranean	31
France (Mediterranean)	17
Spain	13
Portugal	9
Total	70

Northern Seas: 380 GW
Southern European waters: 70 GW
Rest of Europe

EXECUTIVE SUMMARY

Offshore wind energy is at the core of how Europe can go carbon-neutral. Europe sits on one of the world's best offshore wind resources. According to the International Energy Agency (IEA), it could become the number one source of power generation in Europe by 2042. The 20 GW currently installed cover on average 1.5% of Europe's annual electricity demand.

The European Commission says Europe needs between 230 and 450 GW of offshore wind by 2050[1], making it a crucial pillar in the energy mix together with onshore wind. **450 GW would meet 30% of Europe's electricity demand in 2050**, which would have grown 50% compared to 2015 due to electrification.

Europe needs a visionary approach to deploy such volumes and deliver on the commitments of the incoming EU Commission President to achieve carbon-neutrality by 2050.

This report addresses the mandate given by North Seas Energy Ministers at their High Level meeting in Esbjerg in June 2019 to examine the need for space, grids and supply chain development for offshore wind. It shows that it is feasible **to deploy 450 GW by 2050 and where this capacity could be located most effectively**. The report focuses mainly in the North Seas, where most of installations are expected to concentrate.

WHERE TO PUT OFFSHORE WIND

We expect **85% of capacity by 2050 to be developed in the North Seas** (the Atlantic off France, Ireland and the UK, the North Sea, Irish Sea and Baltic Sea) based on the good wind resources, proximity to demand and supply chain efficiencies. This is equivalent to around 380 GW out of the 450 GW. The remaining 70 GW **would be located in Southern European waters**.

The total area of the North Seas needed for 380 GW of offshore wind would be 76,000 km², an area just below the size of the island of Ireland. This is **2.8% of the total area of the North Seas**, without considering exclusion zones.

1. European Commission, 2018. A Clean Planet for All.

In at least 60% of the North Seas it is not possible to build offshore wind farms today. These "exclusion zones" exist either for environmental reasons or because space is set aside for fishing, shipping and military activity[2]. The future allocation of sites for offshore wind will depend crucially on what happens with these exclusions zones. This report considers two opposing scenarios: a hypothetical one in which there were no exclusion zones; and one in which the current exclusion zones remain as they are up until 2050.

In the hypothetical scenario in which there were **no excluded zones**, 380 GW of offshore wind could be built in the North Seas as follows:

- 248 GW at very low LCOE (below €50/MWh);
- 130 GW at low LCOE (between €50/MWh and €65/MWh);
- 2 GW at medium LCOE (between €65/MWh and €80/MWh); and
- No capacity needs to be built at high LCOE (above €80/MWh)[3].

However, **if current exclusions continue as they are to 2050**, the breakdown becomes:

- 112 GW at very low LCOE (below €50/MWh);
- 264 GW at low LCOE (between €50/MWh and €65/MWh); and
- 4 GW at medium LCOE (between €65/MWh and €80/MWh).

Challenging the status quo on spatial planning is essential to getting the most out of the steep cost reduction in offshore wind over the last 5 years. With the current exclusion zones, **almost three quarters of the future offshore wind power capacity cannot be built at a very low LCOE in the North Seas. Considering society's aspirations for a cost-effective energy transition, this should be a wake-up call for policymakers and sea space planners.**

The cheapest and most space-efficient way to build the 450 GW is through the **multiple-use of the same maritime space by different sectors**. Governments should explore the scope for shared use of space by offshore wind and e.g. fishing, shipping and military activity. They should review whether all the zones from which offshore wind is currently excluded should remain excluded- in order the maximise the amount of offshore wind they can deploy at very low LCOE.

HOW TO DEPLOY 450 GW

To build 450 GW of offshore wind by 2050, **annual installation rates need to increase substantially**. Today Europe installs around 3 GW per year. This will increase to 7 GW per year by the second half of the 2020s. **After 2030, this needs to rise to over 20 GW per year**.

The offshore wind industry is gearing up to meet this challenge. It will need to invest in the supply chain significantly and in ports and logistics. It will need to mobilise significant finance, both private and public, to support the development of the necessary infrastructure.

Offshore wind would require an additional 1,500km^2 per year at sea by the second half of the 2020s, and 4,500km^2 per year by the mid-2030s. Industry and planning authorities would need to scale up their activities by consenting and developing a significant pipeline of projects well in advance:

- **In the Atlantic Ocean (including the Irish Sea):** As of 2019, less than 1 GW per year is installed in this region. The annual rate of consenting through the 2030s needs to increase from just under 2 GW today to 3.9 GW. This means going from a yearly rate of 370 km^2 today to 770 km^2.
- **In the North Sea:** The annual rate of consenting in the late 2020s needs to increase from 5 GW to 8.8 GW. This means going from a yearly rate of 1,000 km^2 to 1,800 km^2. In the 2030s, this rate needs to grow even further: we need 9.8 GW (2,000 km^2) per year up to 2040.
- **In the Baltic Sea:** The annual rate of consenting needs to increase from 2.2 GW (430 km^2) to 3.4 GW (670 km^2) in the late 2020s. In the 2030s, this rate needs to grow even further: we need 3.6 GW (720 km^2) per year between 2030 and 2040.
- **In Southern European waters**: Between now and 2027, the rate would need to rise from almost 0 to over 4 GW per year or 840 km^2 per year.

To deliver the 450 GW it is essential to plan for the grid infrastructure early enough. It can take up to 10

2. The exclusions include environmentally protected sites: Natura2000 full exclusion zones (zone types A and C), protected sites, Natura2000 partial exclusions (zone type B) excluded at 50%; pipelines and the like: vessel density (greater than 10 hours per month), waste disposal dumped munitions, cables with 1nm buffer, natural gas pipelines with 1nm buffer, other pipelines with 1nm buffer; and areas to avoid that are specific to offshore wind: distance to shore less than 12nm, water depth greater than 1000m.
3. All these costs are based on LCOE in the year 2030.

years to plan and coordinate the onshore and offshore developments to transmit electricity from generation to the end-user.

We estimate that investments in offshore grids would need to ramp up significantly: from less than €2bn in 2020 to up €8bn per year by 2030. This is less than the €100bn over the decade that the European Commission and ENTSO-E have estimated in the past. After 2030, grid investments for offshore hybrids and offshore meshed grids would need to amount an average of €15bn per year until 2050.

In addition onshore grid investments need to step up significantly. Europe would need between €10 bn to €50 bn per year, depending on the transmission technologies used. This investment will benefit end-users so that they receive electricity not only from offshore wind but also from other renewables.

CHALLENGES

There are several challenges to realising the 450 GW vision:

- **Increasing the rate of site allocation and development**: It typically takes about eleven years to get from the start of wind farm development to the completion of installation and start of electricity generation. Annual installation rates need to increase from 7 GW in the late 2020s to over 20 GW in the late 2030s. We need a significant increase in site allocation development and consenting from 2020.

- **Environmental impacts**: We need to know that building 450 GW of offshore wind is the right decision for the environment. We need comprehensive data about offshore species, habitats, and the cumulative environmental impact of offshore wind. We will need to include the many positive environmental impacts too. Offshore wind can improve the marine environment by supporting the growth of new artificial reefs and by protecting sea life with no-fishing areas.

- **Ensuring multiple use**: More activities in Europe's seas will lead to increased spatial demands and growing competition between sea users. Authorities can allow different activities to take place within and around offshore wind farms in order to increase the functionality of the sea. Having the ability to easily share the sea with other users is central to having cost-effective offshore wind. Multi-use of space will be increasingly necessary.

- **Building the grid offshore and onshore**: The electricity grid infrastructure in Europe should anticipate major growth in both offshore and onshore wind energy. It requires the expansion of offshore grids and the reinforcements of onshore grids. Governments should promote hybrid offshore wind projects with connections to more than one country: in order to pool assets and optimise space. They should support the development of meshed offshore grids. This will require enhanced cooperation between countries.

- **Developing hybrids and the legal framework**: Hybrid offshore wind farms with connections to more than one country raise a number of legal issues to which there is currently no clear answer. An EU regulatory framework for offshore hybrids would help clarify the risks, costs and benefits of investing in hybrid assets and create a mechanism for countries to collaborate in the development of such projects.

- **Facilitating system integration**: By 2050 the electricity grid will be a converter-based system, with little physical inertia in the system. This could lead to grid stability and balancing challenges. Many existing solutions can overcome these. Industry and transmission system operators would need to cooperate and coordinate on the implementation of such solutions.

- **Developing storage and power-to-x**: Not all the electricity generates by offshore wind will be consumed directly off the grid. It is likely that at least 5% and possibly up to 25% of the electricity will go into power-to-x, mainly as power to hydrogen or other gases.

- **Expanding the supply chain**: The offshore wind supply chain requires the prospect of stable rates of installation for at least 10 years to make Final Investment Decisions in new manufacturing plant. This enables the supply chains for components, vessels, ports services and Operation and Maintenance Services (OMS) to amortise investment over a reasonable period.

- **Mobilising investments**: We estimate that a more than threefold increase in CAPEX is needed for offshore wind farms and transmission grids, from around €6bn per year in 2020 to more than €21bn per year in 2025. And by the 2030s the investment needs will be around €45bn yearly. Additionally, onshore grid reinforcement could amount between €10-€50 bn per year. In total, investments will be over 10% of current annual infrastructure spending across Europe.

POLICY RECOMMENDATIONS

To overcome the aforementioned challenges and to reach 450 GW of offshore wind by 2050, WindEurope makes the following calls on policymakers:

1. Governments should set ambitious maritime spatial planning policies to deliver 450 GW by 2050.

2. Governments should ensure that permitting and other relevant authorities have the necessary expertise and resources to consent enough sites.

3. Governments should accelerate the expansion of the necessary on- and offshore grid infrastructure.

4. The EU should elaborate a regulatory framework for offshore hybrid projects.

5. Governments should accelerate the electrification of transport, heating and industrial processes.

6. Governments should ensure visibility and confidence in volumes and revenue schemes.

1. INTRODUCTION

Europe is exploring how to become carbon-neutral by 2050. This would contribute to limiting global warming to less than 1.5°C by the end of the century in line with the Paris Climate Agreement. To achieve this, Europe will have to transform its energy system by replacing fossil fuels with renewable electricity across the economy.

Offshore wind energy is at the core of how Europe can go carbon-neutral. **The European Commission estimates that an installed capacity of between 230 and 450 GW could be needed by 2050**[4], making it a crucial pillar in the energy mix together with onshore wind.

Recent offshore wind projects are cheaper than new nuclear power capacity and gas-fired power plants. Offshore wind has lower variability and high capacity factors, which according to the IEA range between 40% to 50% for new projects.

Today there is only 20 GW of offshore wind operating in Europe. But over the last ten years it has attracted average annual investments of €9.4bn, fuelling the development of a thriving sector. This has created jobs and worldwide exports in equipment, skills and services.

Scaling up from 20 GW today to 450 GW by 2050 will require a visionary approach. The current 2030 policy framework can deliver 89 GW by 2030. Governments must start setting the course for enabling higher levels of deployment. And they need to do it now. Countries with offshore wind resources have a geographical responsibility to lead Europe in this.

The North Seas Energy Forum, under the political declaration signed between between ten countries around the North Seas, should continue to be the platform for governments to coordinate and collaborate to make this vision a reality. Other initiatives such as the Baltic Energy Market Integration Plan (BEMIP) should step up their work on offshore wind and use the lessons learned from the North Seas.

4. European Commission, 2018. A Clean Planet for All.

Delivering such volumes is feasible and the industry can meet this challenge. It calls all policymakers to work anticipate all challenge and work together in delivering this vision.

This report, prepared by BVG Associates (BVGA) for WindEurope, shows that it is feasible to deploy 450 GW offshore wind by 2050. It identifies the challenges involved and recommends how policymakers can help tackle them. Specifically, the report:

- presents a feasible deployment scenario to achieve 450 GW;
- establishes the areas where the 450 GW of European offshore wind could be located;
- describes a vision of the technology of offshore wind in 2050 and the electrical grid, interconnectors, storage and other technologies that could enable such a large volume of offshore wind to be successfully exploited;
- presents the main challenges and solutions to achieving this vision; and
- recommends actions based on this analysis.

The report has 6 main chapters. After this Introduction Chapter 2 describes the optimum location of 450 GW of offshore wind in 2050. Chapter 3 shows pathways to this vision for each sea basin in Europe. Chapter 4 discusses the challenges in achieving this vision, both across Europe and by country. Chapter 5 outlines policy recommendations. And Chapter 6 details all the underlying assumptions about e.g. technology and grid development.

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METHODOLOGY

This study focuses on the North Seas. We have applied a less detailed approach to offshore wind potential in southern Europe. Further detailed work on these sea basins could be the basis of a separate study in the future.

First, we established a realistic basis for the location of 450 GW of offshore wind across the North Seas and southern Europe. We expect that 380 GW of the 450 GW of offshore wind (85% of the expected capacity by 2050) will be developed in the North Seas (the Atlantic off France, Ireland and the UK, the North Sea, Irish Sea and Baltic Sea). This is based on the good wind resources, proximity to demand and supply chain efficiencies. We expect that large demand centres continue to be located around these North Seas because the wind resources and site conditions are good, and because there is less potential for economic solar electricity generation than in the southern parts of Europe.

Second, we established a vision for offshore wind and associated infrastructure in 2050, covering four areas:

- The wider energy system;
- Offshore wind technology;
- Offshore grids; and
- Spatial planning and site allocation.

Third, we discussed and validated:

- The locations for offshore wind and the 2050 vision;
- The key challenges in achieving the vision of 450 GW by 2050; and
- The national and international actions needed to address these challenges.

Finally, we captured in a high-level summary the critical actions per country and recommended a policy roadmap for governments and the EU institutions.

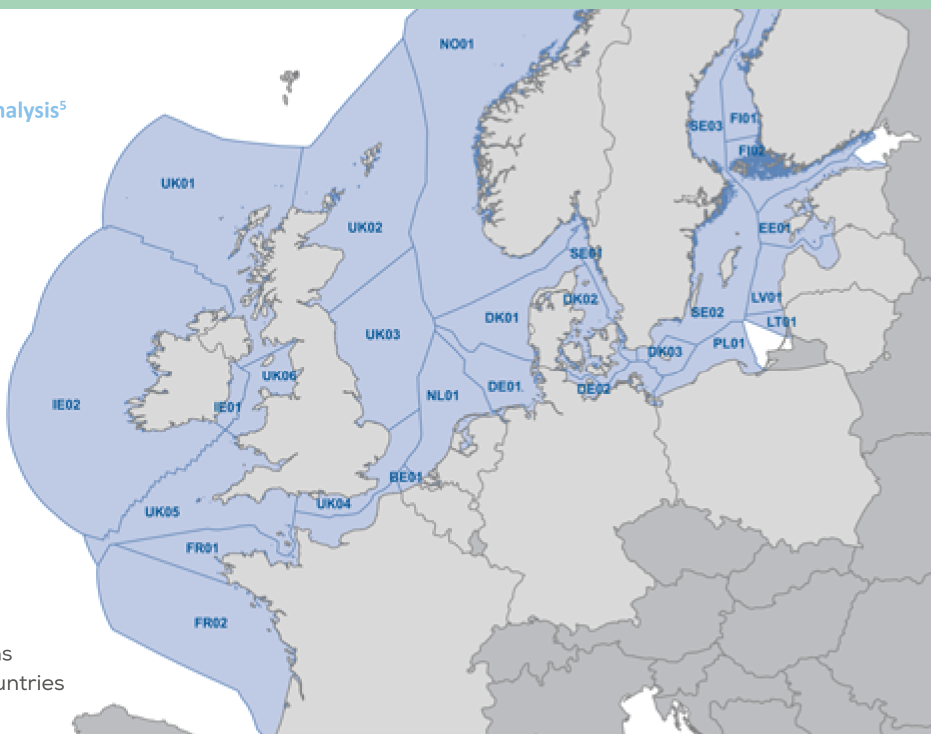
We divided European waters into two regions:

- North Seas; and
- Southern European Waters.

NORTH SEAS

We divided the North Seas into sub-regions based on Exclusive Economic Zones (EEZs) (see Figure 1). We subdivided the EEZs of Ireland, France, the UK, Denmark, Germany, Sweden and Finland because of the complexities associated with the use of these areas. We did not subdivide the EEZs of Belgium, the Netherlands, Norway, Estonia, Latvia, Lithuania and Poland.

FIGURE 1
Sub-regions used in the analysis[5]



North Seas sub-regions
North Seas coastal countries

5. Sub-regions are labelled in the form ""LLNN" where LL is the two-letter country code and NN is the two-number label for each sub-region according to figure 1.

To allocate 380 GW of offshore wind, first, we calculated the capacity needed to meet 30% of each country's power demand in 2050. This is in line with the European Commission's decarbonisation strategy[6]. The current population density was used to define the location of this future demand as shown in Figure 2[7]. We did not consider spatial restrictions at this point.

For countries with multiple sub-regions in their EEZs, we apportioned capacity based on the population onshore from each sub-region. This brings us to 240 GW.

We apportioned the remaining 140 GW (and, where necessary, re-apportioned capacity between sub-regions) by considering:

- The benefits of wide geographical distribution to reduce the variability of energy output due to weather patterns;
- The relative cost of energy from offshore wind that could be located in each sub-region[8] (considering environmental and other constraints); and
- Political ambitions in specific countries.

For each country, we calculated the offshore wind capacity needed to meet the electricity demand located 100km from the coast and for the rest of the country. Where more capacity is available than the total demand in a country, this is used for exports.

SOUTHERN EUROPEAN WATERS

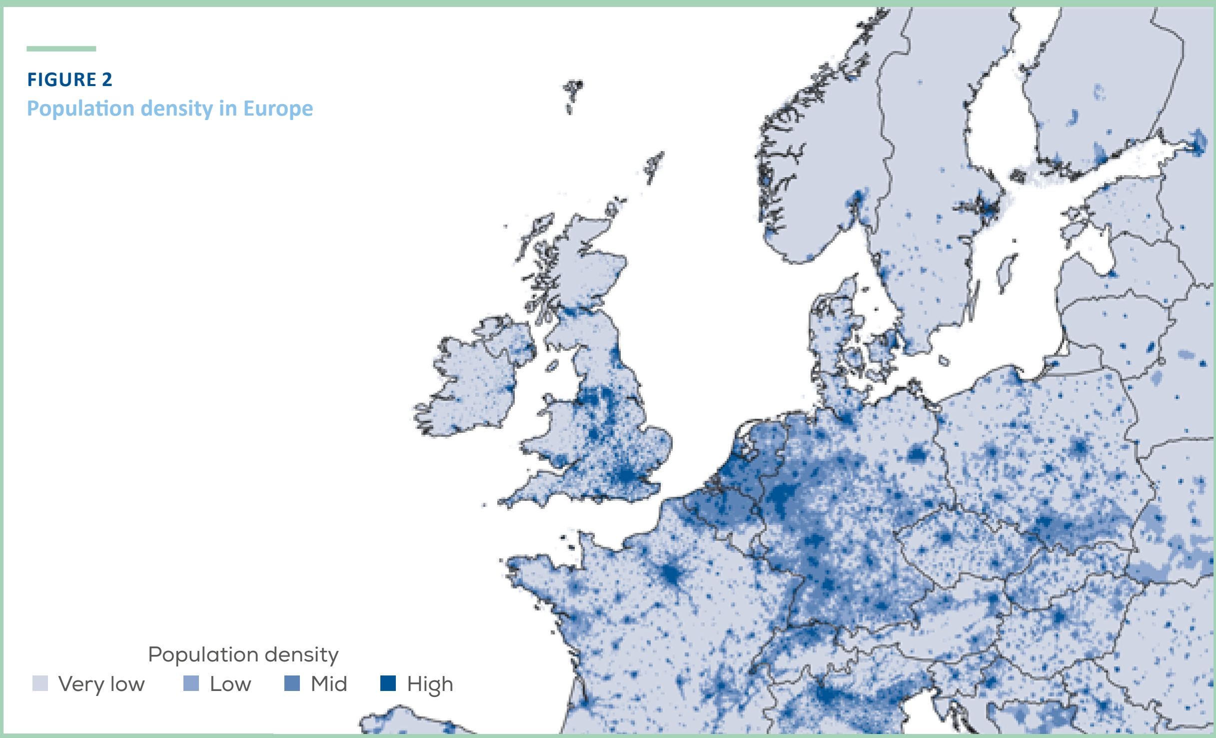
We allocated the 70 GW of offshore wind as follows:

- France (Mediterranean): 17.4 GW corresponding to 30% of the total capacity of France, based on the ratio of populations of its sub-regions;
- Portugal: 9 GW based on anticipated potential;
- Spain: 13 GW based on anticipated potential; and
- Rest of Mediterranean: 30.6 GW

The resulting capacity allocations provide a vision of the future. For any country, ambitions may change, and practical challenges may impact the ability to deliver the volumes allocated.

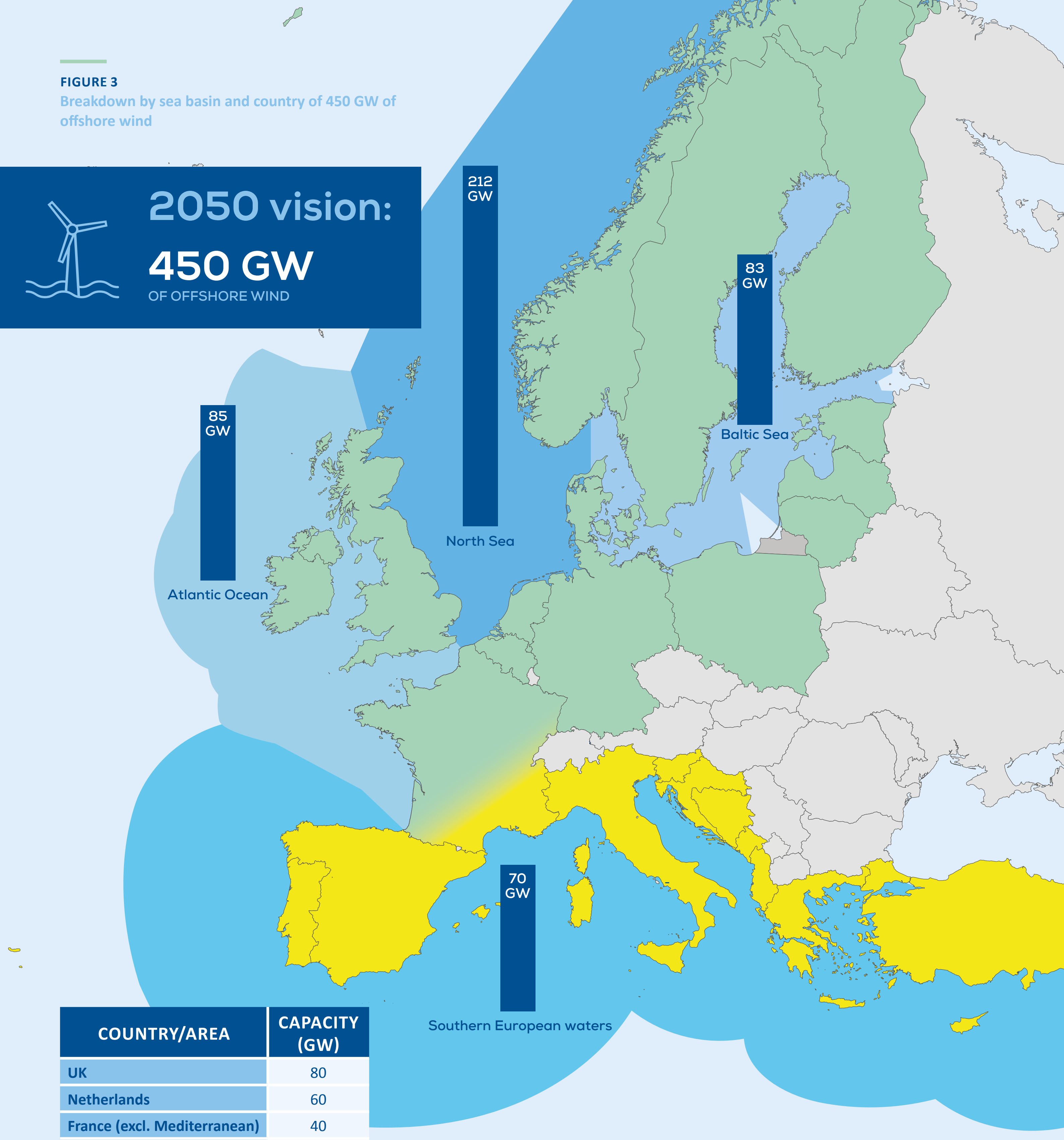
Our objective is to test the feasibility of accommodating up to 450 GW of capacity in the North Seas. As such the allocation of capacity per country is illustrative, as the deployment of this level of capacity requires international cooperation. Our analysis allocates a certain amount of offshore wind to per country. But this does not mean that any country should limit itself to "only" that capacity.

FIGURE 2
Population density in Europe



6. Following the 1.5 TECH scenario.
7. From Gridded Population of the World, Version 4 (GPWv4) Revision 11, NASA Socioeconomic Data and Applications Center's (SEDAC).
8. We used cost assessments consistent with the upside scenario in *Unleashing offshore wind*, authored by BVG Associates for Wind-Europe in 2017.

FIGURE 3
Breakdown by sea basin and country of 450 GW of offshore wind



COUNTRY/AREA	CAPACITY (GW)
UK	80
Netherlands	60
France (excl. Mediterranean)	40
Germany	36
Denmark	35
Norway	30
Poland	28
Ireland	22
Sweden	20
Finland	15
Belgium	6
Lithuania	4
Latvia	3
Estonia	1
Total	380

COUNTRY/AREA	CAPACITY (GW)
Rest of Mediterranean	31
France (Mediterranean)	17
Spain	13
Portugal	9
Total	70

Northern Seas: 380 GW
Southern European waters: 70 GW
Rest of Europe

2. WHERE TO PUT OFFSHORE WIND IN THE NORTH SEAS

2.1. BREAKDOWN BY SEA BASIN, COUNTRY AND SUB-REGION

The total area of the North Seas needed for 380 GW of offshore wind is 76,000km^2, an area approximately the size of the island of Ireland. This is 2.8% of the total area of the North Seas, based on an average density of offshore wind of 5 MW/km^2.

Using the methodology outlined on page 14, we allocated the 380 GW of offshore wind to the sub-regions of the North Seas, as shown in Figure 4. In Table 1, the sub-regions are shown by country from west to east. We show a detailed analysis per country in Chapter 4.6.

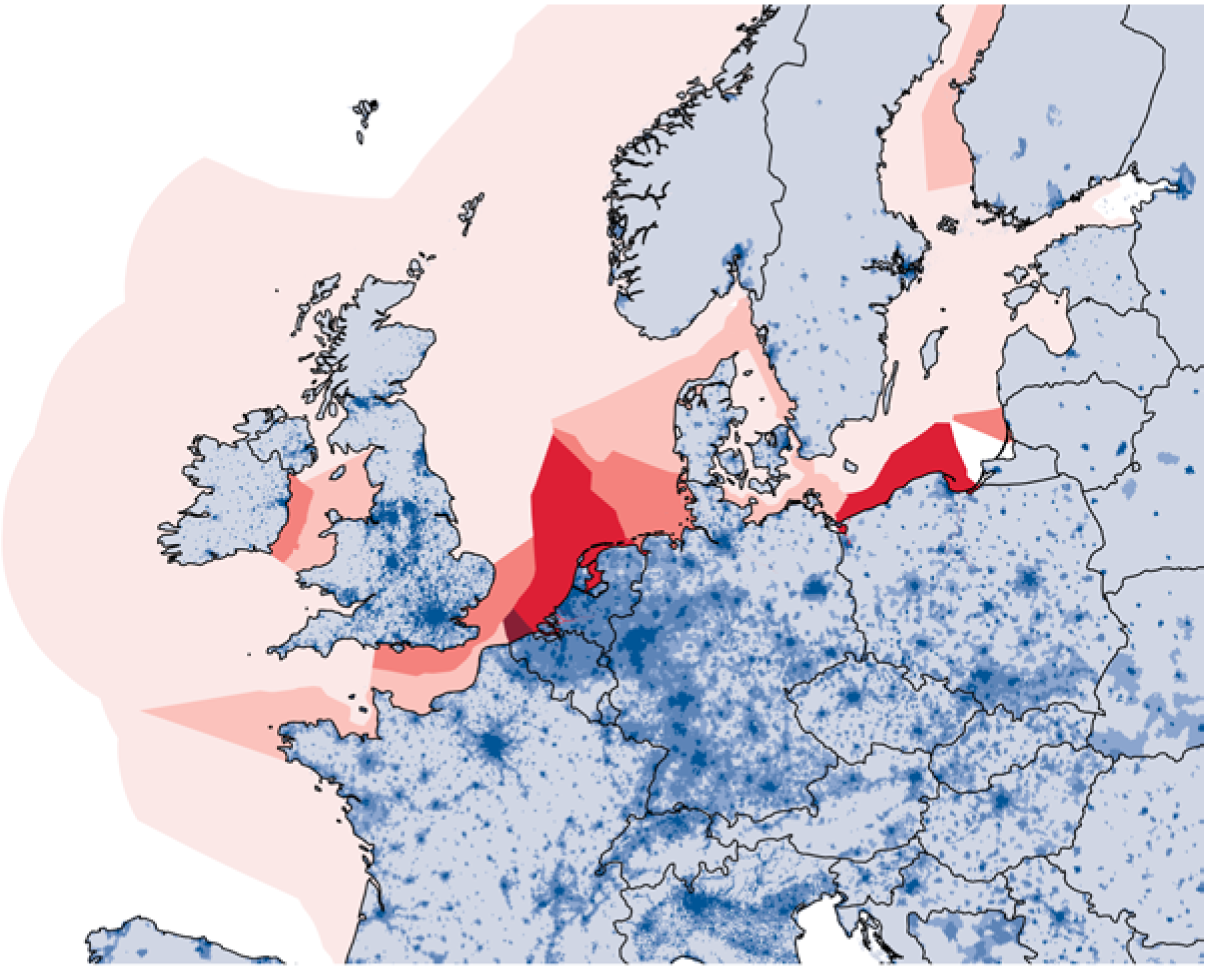
For some countries, like the Netherlands and Denmark, the capacity allocated was higher than might be expected from the population and energy distribution elements. This is because these countries have relatively lower power domestic demand compared to their space and available offshore wind resource. This opens the possibility to significant electricity exports and the conversion of offshore wind electricity into hydrogen[9].

There are 13 sub-regions (of 27) where the area needed is greater than 5% of the total, and 7 sub-regions where the area needed is greater than 10%.

9. *Infrastructure Outlook 2050.* A joint study by Gasuine and TenneT on integrated energy infrastructure in the Netherlands and Germany, 2019 and Energinet.DK press releases

FIGURE 4

Location of 380 GW of offshore wind in 2050 by percentage of total sea area (without spatial exclusions), by sub-region



Area taken up by offshore wind in 2050

<5% 5-10% 10-15% 15-20% 20-35%

Population density

Low Mid High

TABLE 1
Location of offshore wind in North Seas, by sub-region

SUB-REGION[10]	CAPACITY ALLOCATED (GW)	OFFSHORE WIND AREA (km^2)	TOTAL SUB-REGION AREA (km^2)	OFFSHORE WIND AREA AS FRACTION OF TOTAL AREA IN SUB-REGION
IE01	6.7	1,340	10,567	12.7%
IE02	15.5	3,100	416,505	0.7%
FR01	20.9	4,180	70,056	6%
FR02	19.6	3,920	187,515	2.1%
UK01	2.6	520	238,475	0.2%
UK02	7.2	1,440	209,542	0.7%
UK03	27.2	5,440	117,352	4.6%
UK04	22.9	4,580	34,585	13.2%
UK05	8.5	1,700	111,447	1.5%
UK06	11.6	2,320	30,084	7.7%
BE01	6	1,200	3,494	34.3%
NL01	60	12,000	64,322	18.7%
DE01	31	6,200	41,334	15%
DE02	4.5	900	14,998	6%
DK01	27.7	5,540	60,076	9.2%
DK02	5.2	1,040	33,443	3.1%
DK03	2.1	420	11,520	3.6%
NO01	29.6	5,920	768,979	0.8%
SE01	7.6	1,520	16,206	9.4%
SE02	9.4	1,880	86,381	2.2%
SE03	2.8	560	52,794	1.1%
FI01	11.3	2,260	42,983	5.3%
FI02	4.2	840	38,493	2.2%
EE01	1.5	300	36,438	0.8%
LV01	2.9	580	28,360	2%
LT01	3.6	720	6,839	10.5%
PL01	27.9	5,580	29,984	18.6%
TOTAL	**380**	**76,000**	**2,762,772**	**2.8%**

10. Refer to page 14 for nomenclature.

2.2. COSTS WITHOUT SPATIAL EXCLUSIONS

Figure 5 shows the LCOE ranges for the North Seas including the grid connection cost. It is based on the wind speed, distance to shore and water depth of each 5x5km coordinates in the map. It assumes 15 MW turbines and connection to the nearest onshore point[11]. More information about our assumptions is included in chapter 6.

We grouped the values into the following LCOE bands:

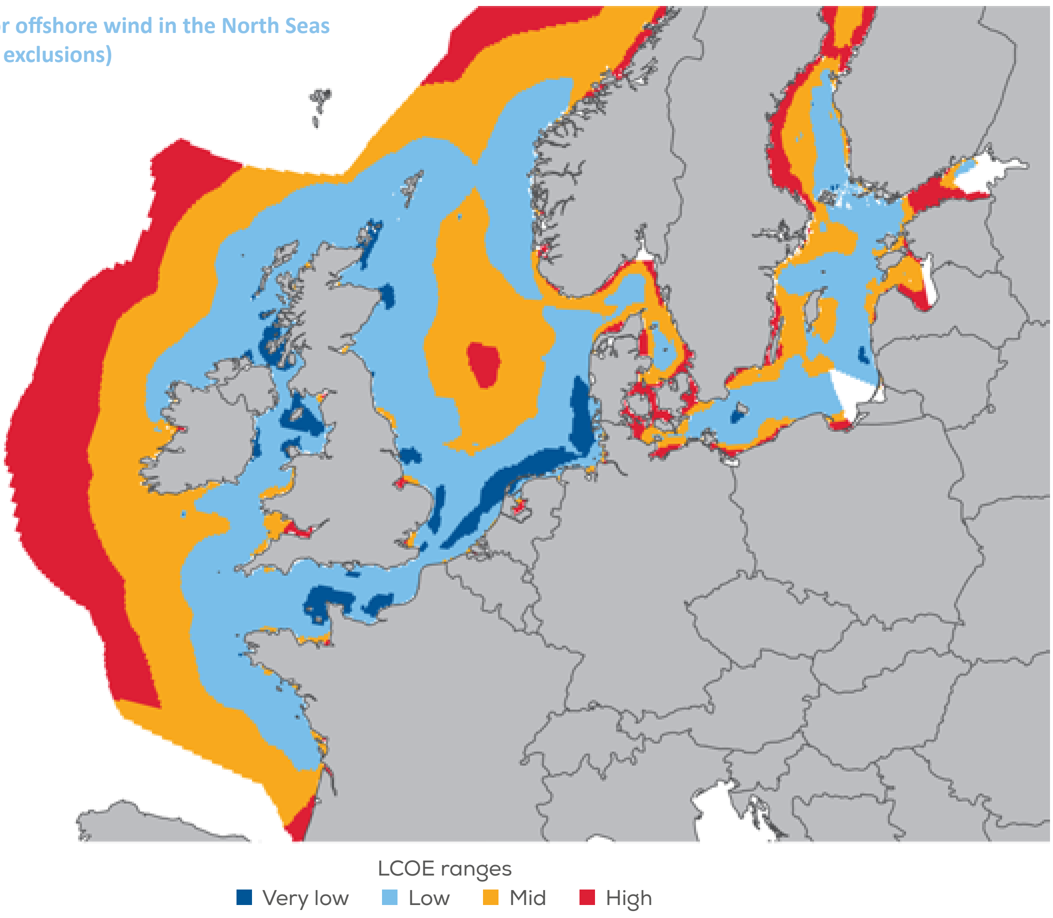
- Very low LCOE is below €50/MWh in 2030;
- Low LCOE is between €50/MWh and €65/MWh in 2030;
- Medium LCOE is between €65/MWh and €80/MWh in 2030; and
- High LCOE is above €80/MWh in 2030.

We consider the first two LCOE bands economically attractive today. But in reality these estimations are conservative for future projects. Recent auctions had prices of approximately €53/MWh[12] including the grid connection for projects expected to be operational by 2025.

Table 2 shows the amount of sea area in each sub-region in different LCOE bands overall, and the amount that would require floating technology. For example, in Norway a lot of the low LCOE areas will need to use floating technologies, while in Belgium there are no sites that would require floating.

Without considering spatial exclusions, 248 GW of the 380 GW of offshore wind in the North Seas could be built at very low LCOE, 130 GW at low LCOE, and only 2 GW at medium LCOE. No capacity needs to be built at high LCOE.

FIGURE 5
Relative LCOE for offshore wind in the North Seas (without spatial exclusions)



11. This is based on the upside LCOE scenario in the report *Unleashing offshore wind, BVGA for WindEurope.* In the 2017 report, specific transmission hubs were used. Here, we do not use these and the LCOE is shown for generic radial transmission. This is because the 2017 report considers a 2030 analysis with appropriate specific hubs, whereas here we consider a 2050 scenario in which meshed grids are typical.
12. The lowest price at the last UK auction (Sep, 2019) was £39.5/MWh (2012 indexed). This is equivalent to €53/MWh with an inflation index of 1.186 (UK RPI) and an exchange rate of 1.12 €/GBP.

TABLE 2

Percentage of area in the North Seas, split according to LCOE range (without spatial exclusions) and water depth (<50m, >50m)

SUB-REGION	Very low LCOE		Low LCOE		Mid LCOE		High LCOE		Points not analysed[13]
	<50m	>50m	<50m	>50m	<50m	>50m	<50m	>50m	
IE01	13%	0%	19%	60%	0%	0%	0%	0%	8%
IE02	0%	0%	1%	11%	1%	37%	0%	48%	2%
FR01	8%	4%	24%	45%	2%	14%	0%	0%	4%
FR02	0%	0%	6%	23%	2%	52%	1%	15%	2%
UK01	2%	2%	6%	49%	3%	21%	1%	4%	12%
UK02	21%	5%	31%	33%	7%	2%	0%	0%	2%
UK03	2%	2%	3%	37%	0%	32%	0%	22%	1%
UK04	1%	2%	3%	59%	0%	27%	0%	2%	6%
UK05	2%	0%	25%	35%	7%	25%	1%	2%	3%
UK06	12%	0%	67%	9%	2%	0%	0%	0%	9%
BE01	28%	0%	66%	0%	3%	0%	0%	0%	3%
NL01	25%	0%	39%	0%	28%	0%	2%	0%	5%
DE01	27%	0%	51%	0%	16%	0%	1%	1%	4%
DE02	0%	0%	48%	0%	20%	0%	18%	0%	14%
DK01	7%	0%	42%	8%	21%	15%	2%	3%	3%
DK02	0%	0%	21%	0%	31%	1%	30%	0%	16%
DK03	9%	0%	20%	70%	0%	0%	0%	0%	2%
NO01	0%	1%	0%	13%	1%	17%	1%	64%	3%
SE01	0%	0%	4%	9%	28%	24%	20%	4%	11%
SE02	0%	0%	15%	28%	18%	29%	4%	0%	6%
SE03	0%	0%	0%	0%	7%	34%	25%	23%	11%
FI01	0%	0%	12%	28%	12%	19%	23%	1%	6%
FI02	0%	0%	42%	18%	7%	11%	7%	3%	12%
EE01	0%	0%	14%	26%	22%	6%	9%	9%	14%
LV01	2%	0%	16%	41%	13%	3%	12%	0%	12%
LT01	5%	0%	37%	46%	1%	1%	0%	0%	9%
PL01	0%	0%	27%	38%	13%	7%	7%	2%	6%

0% - 14% | 15% - 39% | 40% - 100%

13. A fraction of each domain (EEZ) was not analysed because the resolution of the environmental datasets does not allow for detail around coastlines and islands.

2.3. COSTS WITH SPATIAL EXCLUSIONS

In at least 60% of the North Seas it is currently not possible to build offshore wind farms today. This amounts to 1,700,000 km^2. These exclusion zones account both for other uses and for a range of environmental protection measures[14].

While most of these exclusion zones could remain as they are to 2050, a different approach to allocate sites for offshore wind is needed. 380 GW of offshore wind in the North Seas, including repowering of sites, would only need 2.8% of the total sea area. The minimum overlap between offshore wind and other activities should be addressed through collaboration between all sea users.

Protecting biodiversity will continue to be paramount for the wind industry. The same goes for economic development at sea and national security. Fishing, shipping lanes, sand extraction, telecoms, pipelines and other activities can coexist happily with offshore wind in a carbon-neutral Europe.

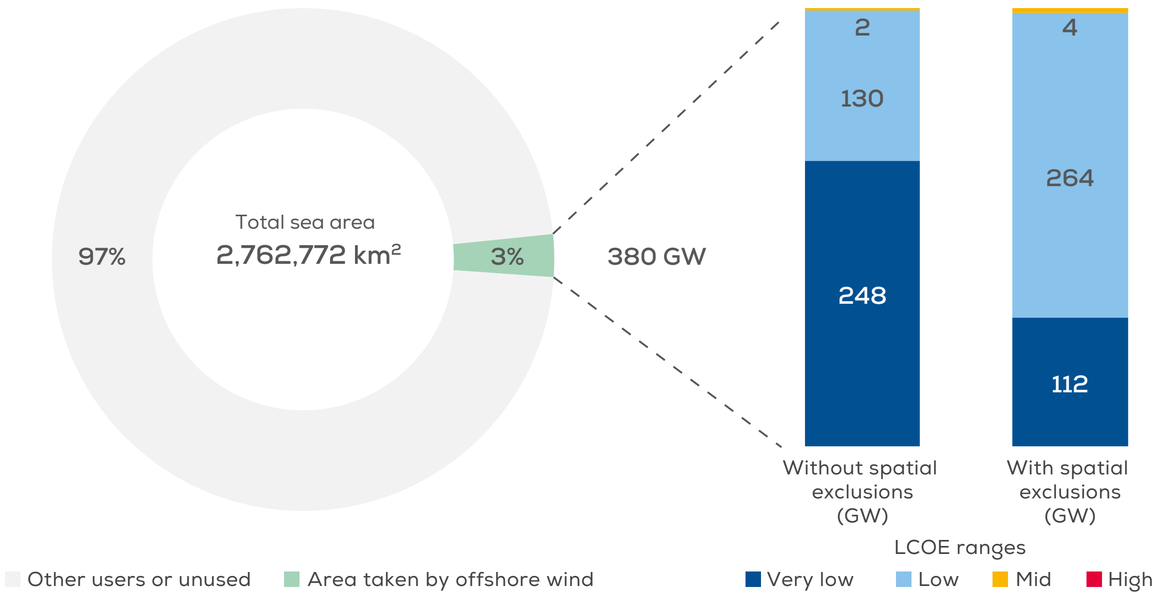
For the purposes of this analysis, we have assumed that current exclusions continue as they are until 2050. In reality, over time some new areas may be made available for offshore wind use (if other uses are stopped or multi-use cases are developed), while other areas may be lost. Offshore wind farms that are already installed are considered as exclusions, as these form part of the 380 GW cumulative capacity.

Table 3 and Figure 7 show the extent of these exclusions. There are 11 sub-regions where offshore wind would need more than 20% of the available area outside the exclusion zones. These are shaded in Table 3.

Moreover there are three additional sub-regions where offshore wind would need more than 50% of the area outside the exclusion zones. These are the west of Sweden, the German Baltic and Belgium. For the Swedish and German areas, the main reason for the exclusions is the proximity to shore of large areas of the sub-regions. These are excluded as there is typically a preference to avoid near-shore areas which are visible from the coast. For the west of Sweden and the German Baltic to deliver their share, social acceptance of viewing offshore wind from the shore would need to be explored. In Belgium, the government has already sought to address the challenge of limited sea area by requiring that offshore wind shares the sea with other uses (see page 27).

FIGURE 6

Distribution of area per sea per LCOE to allocate offshore wind in a scenario without and with spatial exclusions



Source: BVG Associates for WindEurope

14. The exclusions include environmentally protected sites: Natura2000 full exclusion zones (zone types A and C), Protected sites, Natura2000 partial exclusions (zone type B) excluded at 50%; pipelines and the like: vessel density (greater than 10 hours per month), waste disposal dumped munitions, cables with 1nm buffer, natural gas pipelines with 1nm buffer, other pipelines with 1nm buffer; and areas to avoid that are specific to offshore wind: distance to shore less than 12nm, water depth greater than 1000m.

When the exclusions are considered in the analysis, of the 380 GW of offshore wind in the North Seas, only 112 GW can be built at very low LCOE, 264 GW can be built at low LCOE and 4 GW at medium LCOE[15].

With the current exclusion zones, almost three quarters of the future offshore wind power capacity (268 GW) cannot be built at a very low LCOE in the North Seas (Figure 6). Considering society's aspirations for a cost-effective energy transition, this should be a wake-up call for policymakers and sea planners.

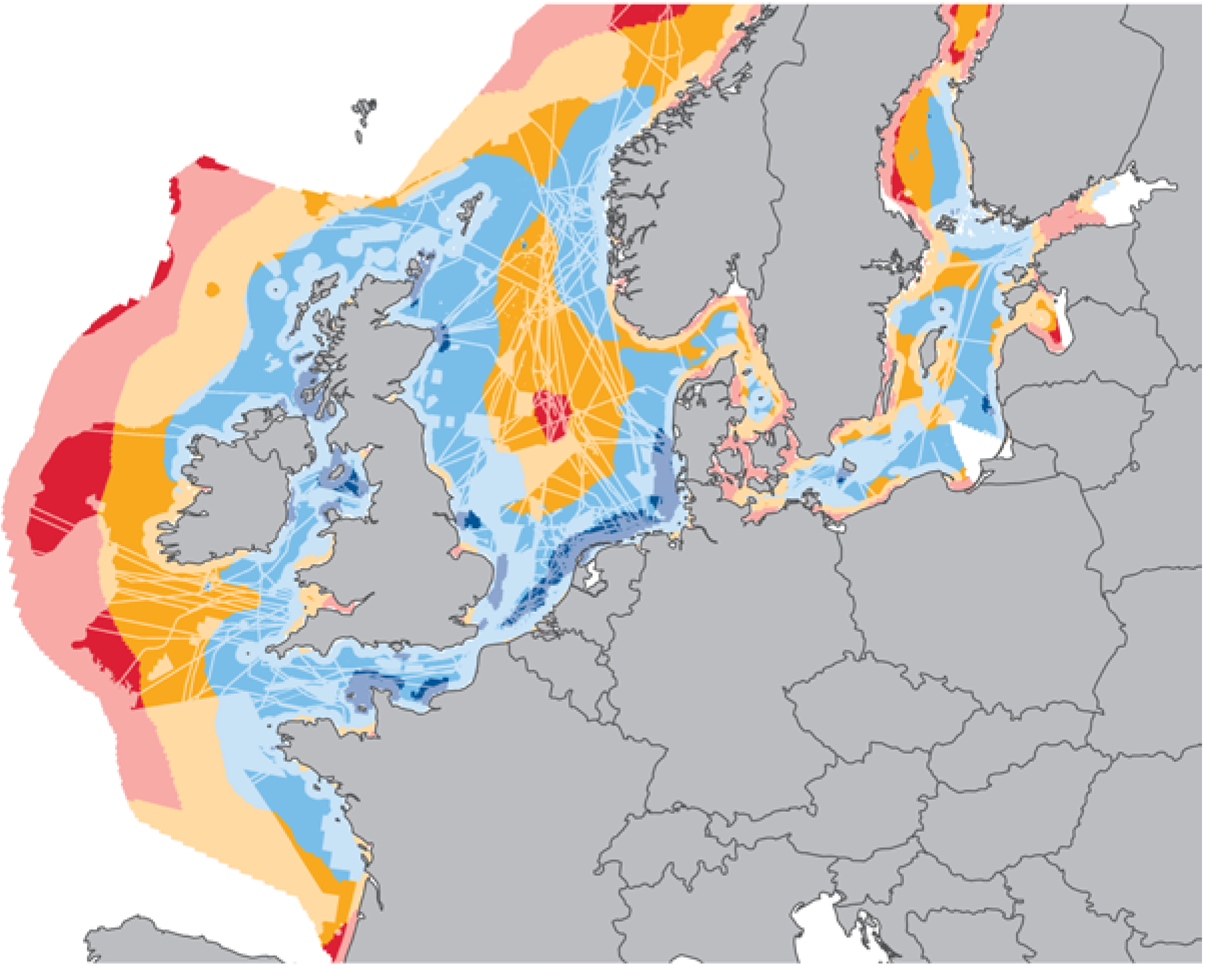
TABLE 3
Offshore wind use and exclusions in the North Seas by sub-region[16]

SUB-REGION	Percentage of total sea area available for offshore wind	Percentage of total sea area excluded for offshore wind	Offshore wind as a percentage of total sea area	Offshore wind as a percentage of total non-excluded sea area
IE01	40%	60%	13%	31%
IE02	42%	58%	0.7%	2%
FR01	23%	77%	6.0%	26%
FR02	19%	81%	2.1%	11%
UK01	21%	79%	0.2%	1%
UK02	55%	45%	0.7%	1%
UK03	62%	38%	4.6%	7%
UK04	29%	71%	13%	45%
UK05	52%	48%	1.5%	3%
UK06	28%	72%	7.7%	27%
BE01	24%	76%	34%	142%
NL01	48%	52%	19%	39%
DE01	47%	53%	15.0%	32%
DE02	7%	93%	6%	88%
DK01	64%	36%	9.2%	15%
DK02	8%	92%	3.1%	41%
DK03	19%	81%	3.6%	19%
NO01	65%	35%	0.8%	1%
SE01	16%	84%	9.4%	58%
SE02	36%	64%	2.2%	6%
SE03	46%	54%	1.1%	2%
FI01	50%	50%	5.3%	11%
FI02	22%	78%	2.2%	10%
EE01	27%	73%	0.8%	3%
LV01	55%	45%	2.0%	4%
LT01	54%	46%	11%	20%
PL01	52%	48%	19%	36%

15. 2 GW of the offshore wind in BE01 does not fit in the sub-region using these exclusion assumptions. We have added this capacity to the low LCOE group as this is the band in the nearest neighbouring waters but continued to shore Belgium's full allocation of 6 GW in table 4.
16. Shaded rows are sub-regions where offshore wind shows more than 20% of the total non-excluded sea area (fourth column).

FIGURE 7

Relative LCOE for offshore wind in the North Seas (with spatial exclusions)



LCOE ranges in

Areas available	Very low	Low	Mid	High
Areas excluded	Very low	Low	Mid	High

TABLE 4

Percentage of area in the North Seas, split per LCOE range (with spatial exclusions)

SUB-REGION	Very low LCOE		Low LCOE		Mid LCOE		High LCOE		Points not analysed[17]
	non-excluded	excluded	non-excluded	excluded	non-excluded	excluded	non-excluded	excluded	
IE01	0%	13%	40%	39%	0%	0%	0%	0%	8%
IE02	0%	0%	7%	5%	21%	17%	14%	34%	2%
FR01	4%	7%	20%	49%	0%	16%	0%	0%	4%
FR02	0%	0%	12%	17%	6%	47%	1%	15%	2%
UK01	0%	3%	16%	20%	3%	26%	3%	17%	12%
UK02	1%	2%	42%	22%	12%	16%	0%	2%	2%
UK03	1%	1%	38%	23%	22%	12%	2%	1%	1%
UK04	2%	10%	27%	52%	0%	2%	0%	0%	6%
UK05	0%	4%	35%	26%	16%	10%	0%	6%	3%
UK06	6%	19%	22%	36%	0%	8%	0%	0%	9%
BE01	15%	13%	9%	56%	0%	3%	0%	0%	3%
NL01	10%	15%	21%	19%	16%	12%	0%	0%	5%
DE01	6%	21%	29%	22%	10%	6%	1%	1%	4%
DE02	0%	0%	7%	42%	0%	20%	0%	18%	14%
DK01	2%	5%	35%	15%	25%	10%	2%	2%	3%
DK02	0%	0%	5%	16%	3%	29%	0%	30%	16%
DK03	2%	7%	17%	72%	0%	0%	0%	0%	2%
NO01	0%	1%	9%	4%	12%	6%	43%	22%	3%
SE01	0%	0%	7%	6%	9%	43%	0%	23%	11%
SE02	0%	0%	19%	24%	17%	30%	0%	4%	6%
SE03	0%	0%	0%	0%	37%	6%	9%	37%	11%
FI01	0%	0%	27%	13%	19%	11%	3%	21%	6%
FI02	0%	0%	15%	46%	7%	11%	0%	9%	12%
EE01	0%	0%	22%	20%	5%	24%	0%	15%	14%
LV01	2%	0%	45%	13%	5%	11%	3%	9%	12%
LT01	1%	3%	53%	30%	0%	3%	0%	0%	9%
PL01	0%	0%	44%	21%	7%	13%	0%	9%	6%
North Sea	0%	2%	15%	17%	12%	23%	6%	20%	5%
Atlantic	1%	3%	20%	12%	13%	8%	26%	13%	3%
Baltic	0%	0%	19%	21%	13%	19%	2%	16%	10%

0% - 14% | 15% - 39% | 40% - 100%

17. A fraction of each domain was not analysed because the resolution of the environmental datasets does not allow for detail around coastlines and islands.

2.4. REDUCING THE IMPACT OF EXCLUSIONS

For 450 GW to be developed with the most efficient use of space and at the lowest cost, multi-use of space and international collaboration will be needed.

Figure 6 shows a difference of 136 GW between the capacities that could be built in both scenarios at a very low LCOE. This means that continuing assigning sea areas for offshore wind as usual will result in a higher cost. Authorities should explore opportunities to address exclusions which would substantially benefit the development of very low cost offshore wind, and the reasons for current and future exclusions.

Having the ability to easily share the sea area with other users is central to having cost-effective offshore wind. Offshore wind can happily coexist with other activities such as aquaculture, some fishing techniques, energy generation and storage. Crucially, offshore wind can also contribute to seabed restoration and the protection of marine biodiversity. To enable this, multiple-use options should be clearly defined in each country's maritime spatial planning (MSP) and they also need to be backed up by a clear regulatory framework to ensure that all different activities take place safely and efficiently.

For sub-regions where offshore wind will take up more than 10% of the sea area, the neighbouring sub-regions could have an increased amount. For example, the amount of offshore wind in Poland could be shared with areas to its north, like Denmark and Sweden. In the Netherlands and the German North Sea, the amount of offshore wind could be shared with Denmark. Some of the capacity in the English Channel could be shared with the east of England near the coast of Norfolk, the south west of England or neighbouring locations in France by the Channel Islands. Collaboration between countries will clearly be needed to maximise these opportunities.

Such sharing could further reduce overall average LCOE. For example, in Baltic Denmark, there are low LCOE areas that could be of use in powering western Sweden. In Bornholm, there are low LCOE areas that could be of use in powering Poland.

Therefore countries should explore how to do joint projects where exclusion zones in one country increases the cost of offshore wind. Today there are no examples of projects developed jointly under this approach. Countries could also execute offshore hybrid projects, which combine an interconnector with offshore wind farms connected to it. This would reduce the overall space needed for both offshore generation and transmission. Offshore hybrids are also attractive because they would increase the interconnectivity across countries, allowing the electricity to flow where needed, making offshore wind the new baseload generation.

The 2016 Noth Seas Energy Cooperation's political declaration[18] is exploring how an enhanced collaboration between project developers with nearby wind farm plans could lead to synergies in space planning and grid development. The central idea is to build one or more wind farms jointly with the grid connections between two or more countries. This clustering and hybridisation approach could open areas for developing offshore wind energy (e.g. beyond each country's EEZ) and for cross-border projects (inside a country's EEZ but exporting to other countries).

The European Commission has found in preliminary assessments that hybrid offshore wind projects would generate environmental and planning benefits as well as potential costs savings (see page 44).

18. European Commission (2016). https://europa.eu/rapid/press-release_IP-16-2029_en.htm

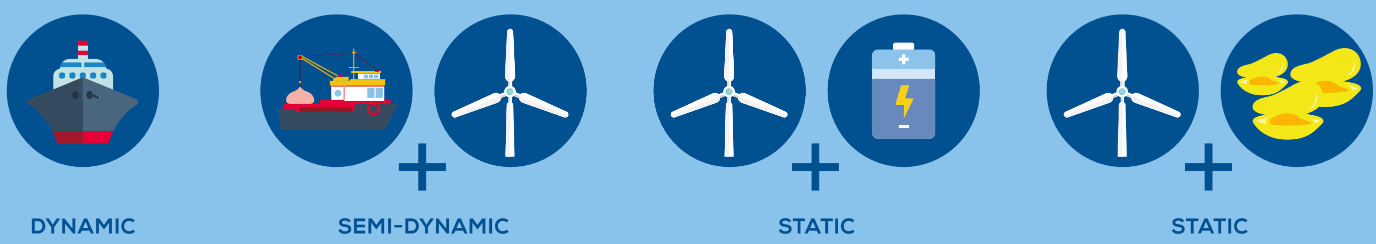
Maritime spatial planning and multiple uses of offshore wind farms

More activities in Europe's seas has led to increased spatial demands and growing competition between sea users. Maritime spatial planning (MSP) is a tool that Governments can use to organise and optimise their sea space. With MSP authorities can allow different activities to take place within and around offshore wind farms in order to increase the functionality of the sea.

First, governments must define specific environmental, economic and societal objectives so that maritime spatial planning (MSP) achieves broad consensus on priority actions. Choices need to be backed up by a clear regulatory framework that ensures that the co-location of the different activities will take place safely and efficiently. Governments should also coordinate their MSP regulations regionally in order to harmonise as much as possible the criteria used for allocating sites for offshore wind.

The Belgian Maritime Spatial Plan for the period 2020-2026 will add approximately 285 km² as extra zones for wind farm developments, 35 km from the coast. Belgium included the multiple uses of offshore wind farms to ensure high efficiency of its limited sea, to boost ecosystem services, as well as to solve potential spatial conflicts. Multiple-use activities included are: research activities, commercial aquaculture, combination of renewable energy sources and/or storage, nature protection, restoration and passive fishing. Any seabed disturbing activity will be banned from the moment that offshore wind farms are fully operational.

The Belgian Maritime Spatial Plan distinguishes between three forms of use of space



3.

HOW TO DEPLOY 450 GW

Today Europe installs around 3 GW of offshore wind per year. To become carbon-neutral it will need to significantly accelerate the installation rate over a sustained period.

The first half of the 2020s has a well-stablished pipeline of projects which is set to increase the installation rate to 7 GW per year by the second half of the decade.

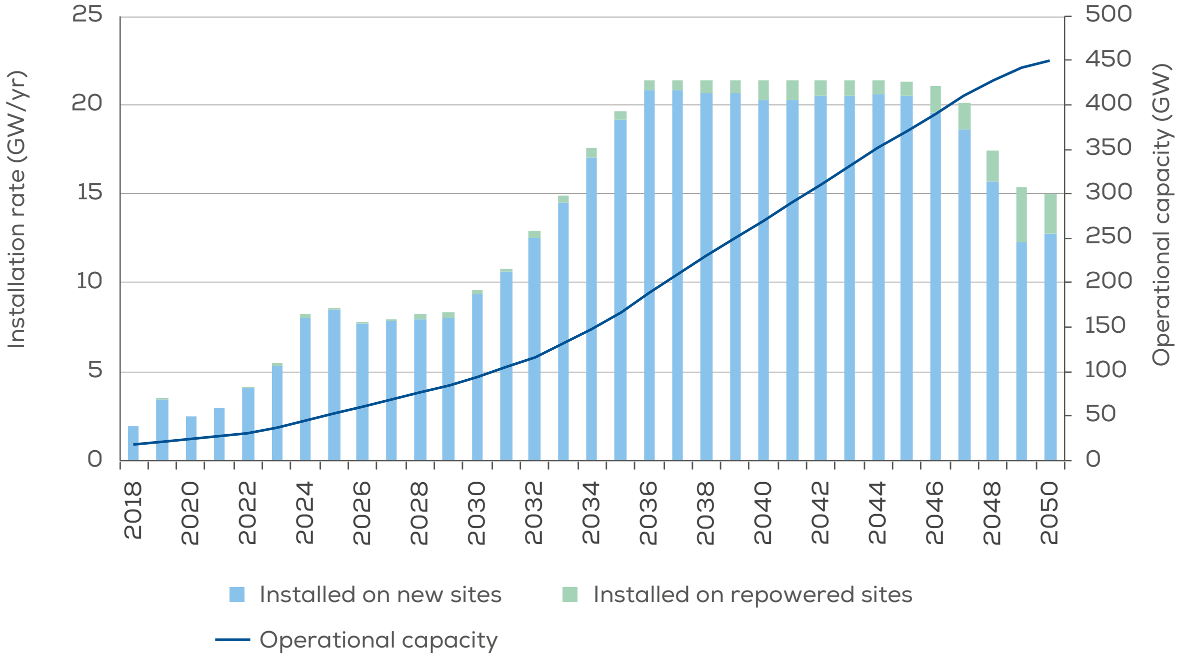
This rate needs to increase considerably – to over 20 GW per year – by the mid-2030s. This is equivalent to ensuring enough sites at an annual rate of 1,500km^2 in the second half of the 2020s and 4,500km^2 in the 2030s.

The industry is gearing up for this challenge, but the supply chain requires stable rates of manufacturing and installation for a minimum of 10 years in order to make Final Investment Decisions. In this way suppliers of components, vessels, ports services and Operation and Maintenance Services (OMS) can amortise investment over a reasonable period of time.

From 2050 onwards, the installation rate for offshore wind assets should settle at about 15 GW per year. This will come from the repowering of projects, assuming a 30-year lifetime.

These three stages drive the rates depicted in Figure 8. Table 5 shows the average annual rates for each period of time to reach the 2050 vision.

FIGURE 8
Installation rate required to achieve 450 GW by 2050



Source: BVG Associates for WindEurope

TABLE 5
Installation rates required to achieve 450 GW by 2050

	AVERAGE RATE					
	2019 to 2025	2026 to 2030	2031 to 2035	2036 to 2040	2041 to 2045	2046 to 2050
Installed on new sites (GW/year)	5.0	8.2	14.8	20.7	20.5	15.8
Installed on repowered sites (GW/year)	0.08	0.20	0.39	0.72	0.88	2.03

OFFSHORE WIND FARM DEVELOPMENT STAGES

To better understand the impact on planning from the steep increase of installations in Figure 8, we describe in this section the different phases and timing for the development of an offshore wind farm.

The timing shown in figure 9 is indicative. There can be a large variation per project and activities can be carried out in a different order across countries.

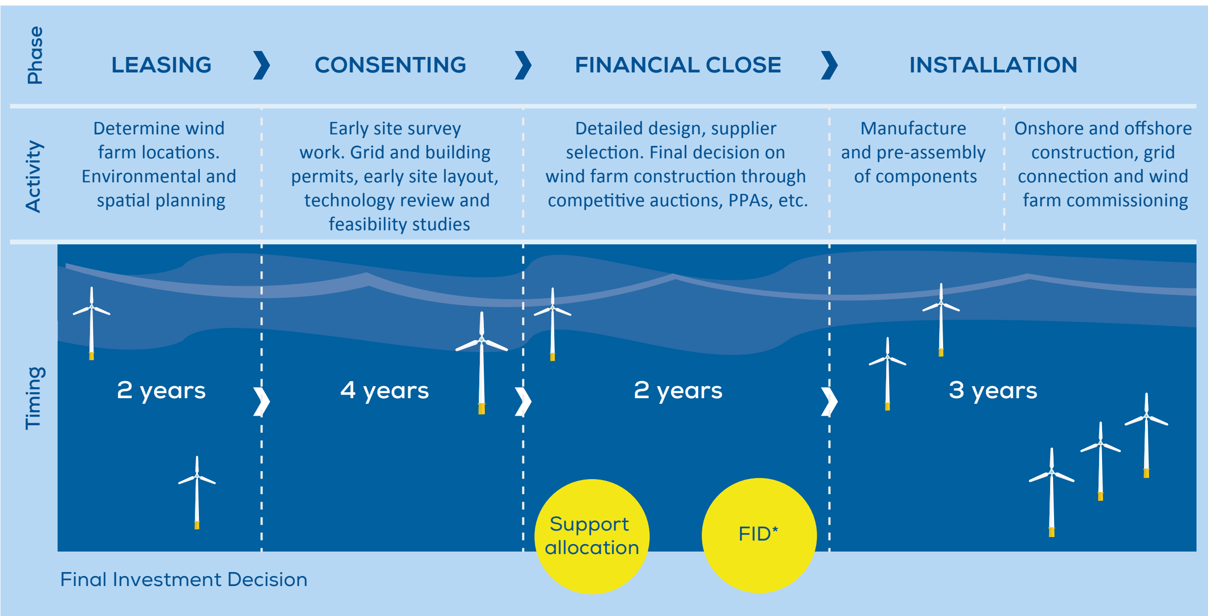
- **Leasing.** This comprises the process of selecting wind farm locations, taking into account environmental, maritime spatial planning (MSP) and other user considerations. Typically it takes 2 years. Leasing is complete when a developer has secured the exclusive right to develop a wind farm in a given location, normally as part of a competitive process.

- **Consenting.** This comprises securing the relevant permits to construct and operate the project including transmission assets. The front-end engineering design and the early site surveys run in parallel to the permitting process. Typically it takes 4 years; 2 years to gather data and 2 years to gain consent. In some cases, projects can take significantly longer. Some projects may fail for economic or environmental reasons during this stage. Consenting is complete when a developer has obtained consent to install and operate the project.

- **Financial close.** This phase includes a detailed design, procurement and positive financial investment decision to construct the wind farm. Often this stage also includes securing a power purchase contract for the electricity that will be produced. This may be as part of a competitive process. Typically, this process takes 2 years from consent, depending on the timing of any competitive auctions. Some projects may fail to proceed beyond this stage, but the impact of this on necessary development rates is not modelled.

- **Installation.** This phase includes onshore and offshore construction and grid connection. It also comprises the manufacture and pre-assembly of components prior to installation. It takes about 3 years from the point of financial close to completion. The wind farm is commissioned once it starts generating and transmitting power back to shore.

FIGURE 9
Offshore wind farm development stages



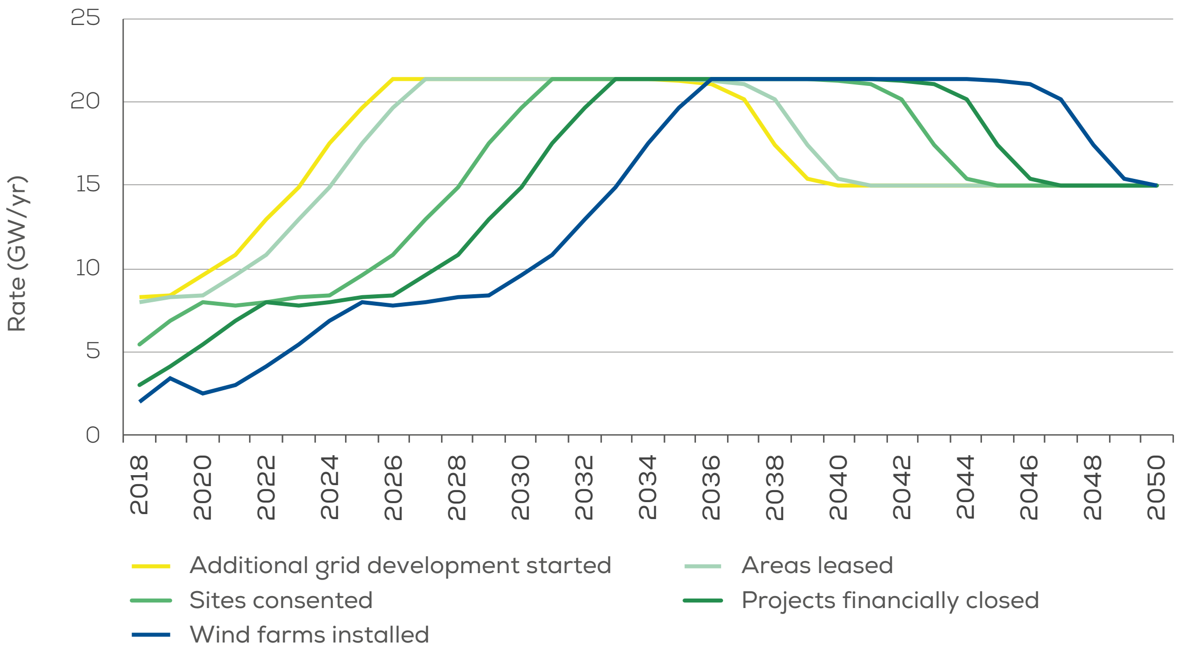
In parallel with the development of the site, the onshore grid needs to be ready to receive the power. This may only require a new connection to the wind farm, but may also require reinforcements to the grid. It could experience long delays given the multiple stakeholders along the cabling route. Therefore, early planning is essential to deliver projects on time. Onshore grid development can take up to 10 years to plan and coordinate with the offshore grid.

Figure 10 shows all the stages for developing offshore wind projects together with the timing when grid development needs to start. It is evident that to reach the maximum rate of deployment of 20 GW per year by the 2030s, all the development activities need to ramp-up sharply during the next decade.

In figure 10, the legend 'additional grid development started' refers to the additional offshore wind capacity that will need to be connected, but shifted back 10 years in time to reflect when planning should start. It does not indicate the new grid capacity needed (i.e. it may require less than a one-to-one ratio). To estimate this, it is necessary to model the onshore grid, the future electricity generation and the demand locations.

In the following sections we analyse the consenting rates per sea basin. This should allow sea planners and authorities to focus their efforts at regional level to allocate enough sites for offshore wind, notably the North Seas Energy Cooperation (NSE) and the Baltic Market Interconnection Plan (BEMIP) groups.

FIGURE 10
Grid development, leasing, consenting, financial closure and installation rates required to achieve 450 GW by 2050



Source: BVG Associates for WindEurope

ATLANTIC OCEAN

Figure 11 shows the installation required in the Atlantic Ocean (including the Irish Sea) to achieve the 85 GW needed to meet the 450 GW overall in 2050. Table 6 shows the consenting rates required to achieve this. In the early phase, just under 2 GW (or is 370km²) per year is required. This rises to 3.9 GW (or 770km²) per year across the Atlantic region through the 2030s. As of 2019, less than 1 GW per annum (pa) is installed in this region, so the increase required is a doubling of consenting rate by 2025 and a fourfold increase to achieve the rate required in the 2030s.

FIGURE 11

Consenting and installation rates required to achieve 85 GW by 2050 for the Atlantic Ocean

Source: BVG Associates for WindEurope

TABLE 6

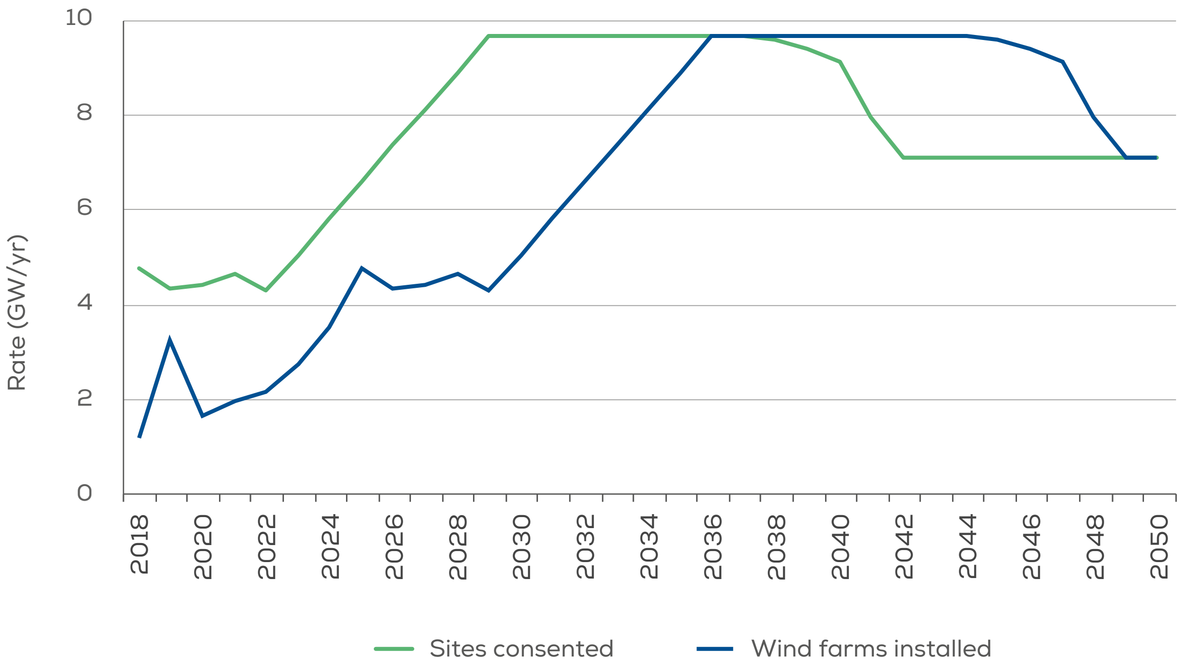
Consenting and installation rates required to achieve 85 GW by 2050 for the Atlantic Ocean

	AVERAGE RATE						TOTAL CAPACITY BY 2050
	2019 to 2025	2026 to 2030	2031 to 2035	2036 to 2040	2041 to 2045	2046 to 2050	
Installed (GW pa)	1.1	1.8	2.7	3.9	3.9	3.4	85
Consented (GW pa)	1.9	3.4	3.9	3.8	3.2	3.1	
Consented (km² pa)	370	680	770	750	630	620	

NORTH SEA

Figure 12 shows the consenting and installation rates required in the North Sea to achieve the 212 GW needed to meet the 450 GW in 2050. Table 7 shows the consenting rates required to achieve this. The highest consenting rate is 9.8 GW pa or 2,000km² pa across the North Sea. As in the Atlantic, the required consenting rate in the early 2020s is approximately half that required at the maximum. By the late 2020s, however, the required consenting rate need to rise to 8.8 GW pa or 1,800km² pa.

FIGURE 12
Consenting and installation rates required to achieve 212 GW by 2050 for the North Sea



Source: BVG Associates for WindEurope

TABLE 7
Consenting and installation rates required to achieve 212 GW by 2050 for the North Sea

	AVERAGE RATE						TOTAL CAPACITY BY 2050
	2019 to 2025	2026 to 2030	2031 to 2035	2036 to 2040	2041 to 2045	2046 to 2050	
Installed (GW pa)	2.8	4.5	7.4	9.8	9.8	7.6	212
Consented (GW pa)	5.0	8.8	9.8	9.3	6.6	6.1	
Consented (km² pa)	1,000	1,800	2,000	1,900	1,300	1,200	

BALTIC SEA

Figure 13 shows the consenting and installation rates required in the Baltic Sea to achieve the 83 GW needed to meet the 450 GW overall in 2050. Table 8 shows the consenting rates required to achieve this. The highest consenting rate is 3.6 GW pa or 720km^2 pa across the Baltic Sea. This is over 50% more than the rate required up to 2025.

FIGURE 13
Consenting and installation rates required to achieve 83 GW by 2050 for the Baltic Sea

Source: BVG Associates for WindEurope

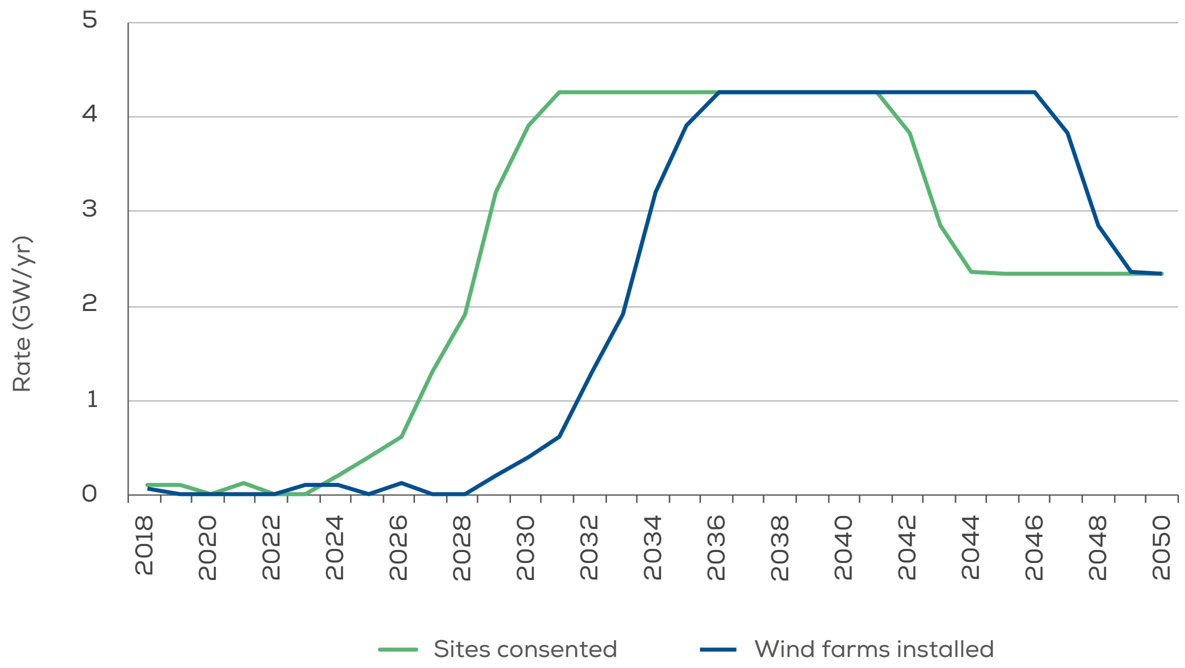
TABLE 8
Consenting and installation rates required to achieve 83 GW by 2050 for the Baltic Sea

	AVERAGE RATE						TOTAL CAPACITY BY 2050
	2019 to 2025	2026 to 2030	2031 to 2035	2036 to 2040	2041 to 2045	2046 to 2050	
Installed (GW pa)	0.8	2.0	3.0	3.6	3.6	3.4	83
Consented (GW pa)	2.2	3.4	3.6	3.6	3.2	3.2	
Consented (km^2 pa)	430	670	720	720	640	630	

SOUTHERN EUROPEAN WATERS

Figure 14 shows the consenting and installation rates required in the Southern European Waters to achieve the 70 GW needed to meet the 450 GW overall in 2050. Table 9 shows the consenting rates required to achieve this. Between now and 2031, the rate rises from almost 0 to over 4 GW pa or 840km² pa across the region. This is a major increase but is necessary because little capacity is likely to be installed through the 2020s.

FIGURE 14
Consenting and installation rates required to achieve 70 GW by 2050 for Southern European waters



Source: BVG Associates for WindEurope

TABLE 9
Consenting and installation rates required to achieve 70 GW by 2050 for Southern European waters

	AVERAGE RATE						TOTAL CAPACITY BY 2050
	2019 to 2025	2026 to 2030	2031 to 2035	2036 to 2040	2041 to 2045	2046 to 2050	
Installed (GW pa)	0.0	0.1	2.0	4.2	4.2	3.4	70
Consented (GW pa)	0.3	3.4	4.2	4.1	2.9	2.7	
Consented (km² pa)	70	670	840	820	580	530	

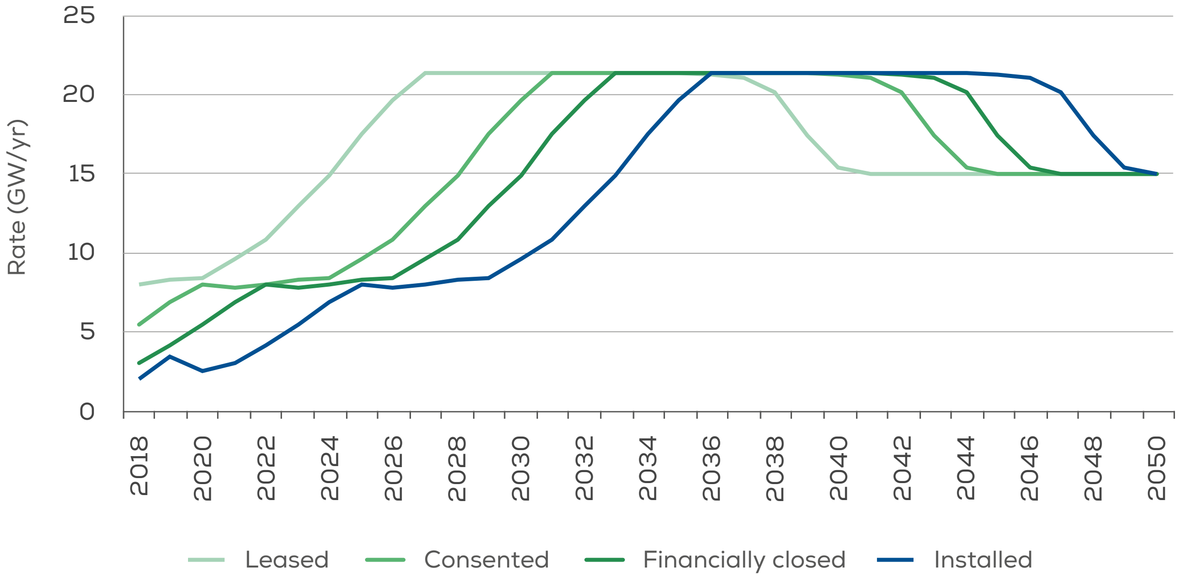
4.
CHALLENGES

There are many challenges to realising the 450 GW vision. In this chapter we analyse some of them in depth to provide actions and recommendations to policymakers and the industry. The main challenges are: ensuring enough sites, environmental impacts, getting supply to the demand; enabling timely investment, and expanding the supply chain. We present country-specific recommendations in the last section to realise this vision.

4.1. ENSURING ENOUGH SITES

The point at which the developer (or in some cases, government) starts its activities for a site will typically begin approximately nine years before the farm is installed, as shown in Figure 15. This period will vary between jurisdictions. This shows that we need a significant ramp-up in the rate of site development from 2020.

FIGURE 15
Leasing, consenting, financial closure and installation rates required to achieve 450 GW by 2050



Source: BVG Associates for WindEurope

Site development also requires that maritime spatial planning (MSP) has secured broad agreement that the site is to be used for offshore wind and that the site will have a grid connection to enable the transmission of power to users, so early progress in these areas is especially important.

In the rest of this section, we explore the challenges that need to be overcome to achieve the necessary rate of starting new project development.

MARITIME SPATIAL PLANNING (MSP) AND MULTIPLE-USE

In 2050, offshore wind will take up a much larger share of sea area than now: increasing from half the area of Luxembourg to the area of Ireland. This change makes offshore wind a major consideration in maritime spatial planning.

Offshore wind can share the sea with other activities, such as aquaculture and some fishing techniques. It can share space with natural protected areas too. Conversely, offshore wind may be excluded from areas for sand and gravel dredging, major shipping lanes, cable and pipeline routes, and military uses. However, investment in infrastructure to deploy current radar and other mitigation technology and further advances in technology with time will help minimise the impact of offshore wind in this regard.

REGIONAL COOPERATION

In Governments will need to coordinate with one another on maritime spatial planning. They will also need to provide signals to industry that they understand the rate of development required and that this will be supported. Such signals are particularly powerful if provided at a pan-European level. They help support a stable market in which successful development leads to further certainty and stability.

National governments will need to facilitate national and local consenting bodies and statutory consultees with the resources to assess enough sites to achieve the necessary rate of offshore wind development. This is especially important in terms of maritime spatial planning which is most beneficial if it informs site decisions before leasing commences.

To ensure that jurisdictions meet the required rate of development, it may be necessary for governments to become more involved in facilitating early site identification and timely consenting processes. As an industry we cannot afford to expend resources developing many projects that do not get built.

Finally, governments can support the offshore wind industry by reinforcing the message that the use of the seas for offshore wind will help us to achieve our climate goals. They must work to maximise shared use, so that offshore and coastal stakeholders are as supportive as possible about offshore wind at this scale.

4.2. ENVIRONMENTAL IMPACTS

As a society and as an industry, we need to know that building this level of offshore wind is the right decision for the environment. To know this, we need comprehensive data about the offshore environment: both about species and habitats, and about the cumulative environmental impact of offshore wind. This includes the shoreline and onshore impacts of export cabling.

Gathering and analysing this environmental information can take many years. Figure 15 shows that the required upswing in development rate begins in 2020. This task is pressing. National and international bodies will need to work together and take a strategic approach to the assessment of future offshore wind impacts, both at a project level and also with regard to underpinning research and survey work.

The environmental impacts of offshore wind can be positive. Offshore wind can improve the marine environment by supporting new growth on the artificial reefs created by cabling and turbine foundations, and by protecting sea life in non-fishing areas.

The environmental and social acceptance of development of more farms is vital for the energy transition. The offshore wind industry will therefore need to continue to work closely with governments and non-governmental organisations (NGOs) to achieve this.

ROADMAP

ACTIONS	TODAY	2020-2021	2022-2025	2026-2028	2028-2030	POST-2030
1. Governments should set ambitious maritime spatial planning policies to deliver 450 GW by 2050.						
• Set ambitious targets for renewables in the National Energy and Climate Plans (NECPs) to 2030 and beyond						
• Specify detailed policies to achieve such targets, starting immediately in 2020, including tender schedule and support mechanisms applicable						
• Coordinate to ensure that aggregated national targets are robust enough to pave the way for 450 GW by 2050						
• Coordinate National Energy and Climate Plans (NECPs) with the European Commission in regard to timely availability of sites using each country's Maritime Spatial Plan (MSP)						
• National maritime spatial plans should align, in the short term, with targets in NCEPs and must be published before March 2021 in accordance with the maritime spatial planning (MSP) directive						
• Coordinate internationally, share national plans and coordinate decisions at basin-level to optimise the use of sea space						
• Establish regional fora for maritime spatial planning discussions with society						
• Design a regulatory framework to allow co-use of wind farm areas with other sea users, including aquaculture, fisheries, other energy sources and defence activities						
• Explore and promote the co-existence of wind farms and natural protected areas, exploiting the potential of wind energy to serve restoration and conservation goals						
• Increase the leasing area for offshore wind energy from 2025 onwards in order to realise the 2050 vision						
• Accelerate the implementation of strategic environmental assessments (SEA)						
• Consider up to 450 GW of offshore wind in international strategic environmental assessments						
• Harmonise methodologies for carrying out environmental impact assessments						
• Create an open-source repository for environmental impact assessment data and information						
2. Governments should ensure that permitting and other relevant authorities have the necessary expertise and resources to consent enough sites.						
• Prepare for an increase in workload from 2022, which means they will need to develop resource and skills plans by the end of 2020 and begin recruitment and training by the end of 2021						
• Reapply best practices from other markets and share information across authorities						
• Establish one-stop shops for consenting projects and work towards the simplification of permitting procedures in line with the recast Renewable Energy Directive						
• Explore open-door consenting procedures where industry can take on part of the initial development work as from 2025						

4.3. GETTING SUPPLY TO THE DEMAND

The development of offshore wind needs the right electricity infrastructure. It needs to anticipate the growth of offshore (and onshore) wind energy so that there is a strong system to get the power produced to the demand locations.

Across Europe transmission system operators (TSOs) will need to accommodate more offshore wind on the grid. Figure 16 shows the ramp-up needed.

Planning for enough grid infrastructure is crucial to ensure that current and future projects will not be jeopardised by delays or high costs of deployment and significant curtailment rates.

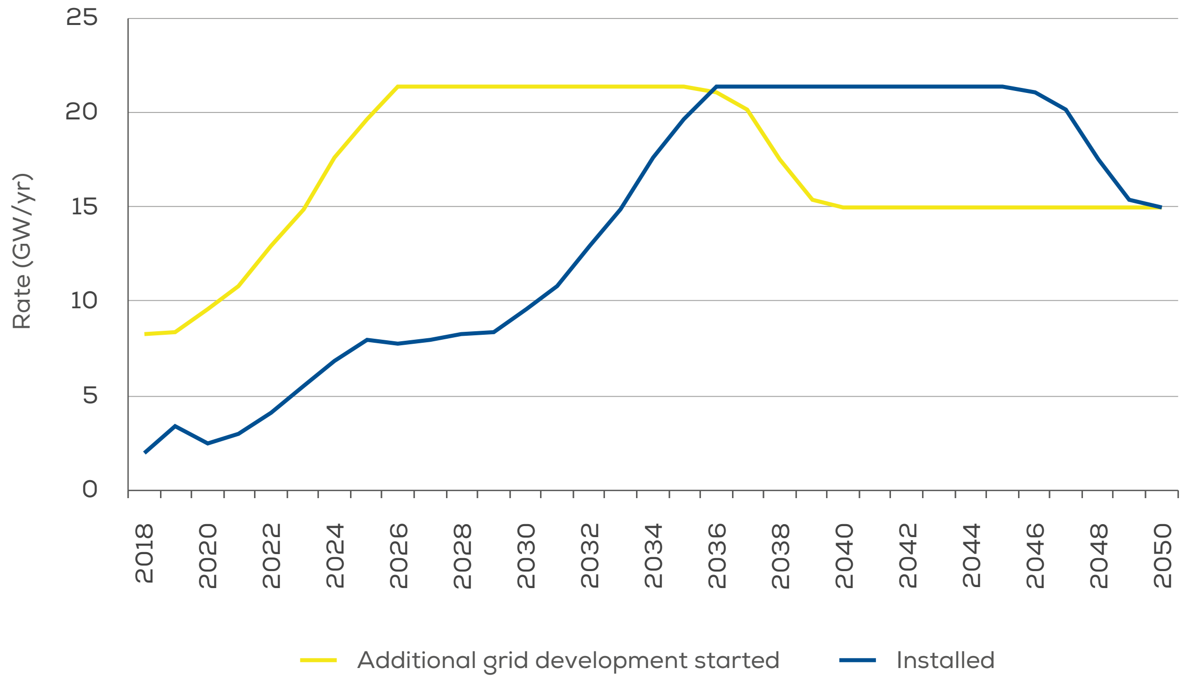
Overall, a good electricity grid will support household and industrial consumers across Europe, providing affordable renewable electricity. The direct use of electricity is the most efficient method of electricity deployment. Therefore, the major part of the electricity infrastructure will be the electricity grid. Complementing this, power-to-x should be for decarbonising industry or transport, where direct electricity use is less efficient or is not possible.

BUILDING THE GRID

Offshore point-to-point connections

In most markets, offshore wind farms are connected back to dedicated points on the onshore grid. In locations at the edge of the grid, for example in the west of Ireland or the north of Norway, this is the best way to extend the grid to connect offshore wind. In other locations, some offshore wind farms can be connected straight back to shore. But 450 GW of offshore wind cannot be connected in this way: there are simply not enough places to land the cables.

FIGURE 16
Additional grid development and installation rates required to achieve 450 GW by 2050



Source: BVG Associates for WindEurope

Hybrid offshore projects

A hybrid offshore wind project is one where an offshore wind project connects into an offshore electricity interconnector (see page 44). Hybrid offshore wind projects allow offshore wind power to be used by more than one country. The links between countries mean that power can be used where it is needed by being traded between the countries. This makes the energy system better able to match supply with demand.

Building a transmission connection to the offshore interconnector (rather than to the shore) reduces shoreline connections, along with the environmental impact on the shoreline. Generally, the length of the transmission link for the offshore wind farm will also be shorter, reducing cost.

It makes sense to jointly develop offshore wind farms and their grids. However, cross-border hybrid projects are currently not straightforward. The only such example of such a project – Kriegers Flak – has been in the making for 10 years. After overcoming multiple challenges the project is going ahead connecting Germany and Denmark, a downsizing of its original plan (which had included Sweden).

Planning for the right hybrid projects could pave the way towards more coordinated offshore wind development in Europe, and ultimately deliver the significant volume of projects and grids on time at an affordable price for society.

Developing an offshore meshed grid

Offshore wind farms can connect to offshore infrastructure that is purpose-built for them (modular grid), as well as to dual-purpose offshore interconnectors (offshore hubs). In Germany and Belgium, there are already shared offshore connection points where multiple farms connect offshore and use the same link back to shore. Any shared connections including combined grid solutions and the interconnector tie-ins can be called "meshed" grids. Meshed grid connections can be primarily interconnectors (electrical connections between countries) or primarily offshore wind links. Once wind farms are connected in this way, they form part of a single and resilient grid system, combined with the onshore grid.

A meshed grid imposes a lower environmental burden on the coastline than multiple single connections. It also uses the infrastructure in a more efficient way, which helps reduce cost and increase social acceptance. In the long-run, it could increase the overall security of supply in Europe. In particular, it could enable the dispatch of wind power generated from one country to another during periods of low demand.

The technical and regulatory requirements for an international meshed grid are more demanding than for the dedicated wind farm grid connections. To ensure that the investments can be made in parts of a meshed grid system in time to meet the 450 GW ambition, we need to start developing the regulatory framework now[19].

The ENTSO-E Ten Year Development Plan (TYNDP) foresees to 2030 €27bn (out of €114bn) for 21 individual projects that would develop into a "Northern Seas Grid Infrastructure"[20]. This is a step in the right direction. But the ENTSO-E modelling is based on 40-59 GW offshore wind by 2030 and a maximum of 127 GW by 2040. Government ambitions in the draft National Energy and Climate Plans (NECPs) submitted to the European Commission by Member States have indicated 78 GW of offshore wind by 2030. This is likely to increase to 89 GW in the final documents. ENTSO-E therefore has to include these developments in its planning and revise investment upwards.

Offshore gas legislation ensures that pipeline priority is given to gas supplied from the home country over gas using the pipeline as an interconnector. If offshore wind can use the same approach to ensure that moving power from the offshore asset gets priority over trading power between countries, then this is likely to smooth the regulatory process.

Onshore grid connections

To accommodate more offshore wind on the onshore grid, TSOs need to coordinate with governments to have 10-year plus visions for development. Such visions are likely to need input from developers, governments and other stakeholders. Different models could work in different countries, but there must be collaboration between jurisdictions.

19. PROMOTioN WP7 is already looking into a financial and legal regulatory framework for developing a meshed HVDC offshore grid.
20. TYNDP (October, 2018). Regional Insight Report: Northern Seas Offshore Grid (NSOG).

COORDINATION BETWEEN COUNTRIES

To plan the grid, long-term thinking is vital if we are to make the best use of the existing onshore grid and make sufficient, timely progress. This requires planning at a national level and international co-ordination to facilitate cross-border energy flows, using both offshore and onshore interconnectors. The countries surrounding the North Sea are already doing this to some extent. Progress in being made by the Baltic Sea countries. Central European countries may have grid interconnect constraints to overcome before they can utilise offshore wind generation.

ENTSO-E, ACER and the European Commission coordinate the Ten Year Network Development Plans. To get 450 GW of supply to the demand by 2050, they will need to take a longer-term view and collaborate at a deeper level.

With consistent governmental backing, the regulation and financing required for this grid expansion should not cause issues. At the moment, different jurisdictions have different grid requirements and different rules about gaining access to the grid. These differences will need to be smaller in future to enable efficient markets. Tariffs and other price support mechanisms will also need to have smaller differences if projects located in different jurisdictions supply the same consumers. This can only be done by inter-governmental co-operation.

One challenge may come from persuading some stakeholders that international interests should be put before national ones. Governmental co-ordination on regulation and pricing will be needed so that some countries aim to be carbon-negative rather than only carbon-neutral. This coordination will need to involve many of the northern countries exporting the equivalent output of multiple-GW of offshore wind capacity, as shown on page 16. The challenges of exporting from Ireland, the UK and Scandinavia are most critical.

SYSTEM INTEGRATION

Storage and power-to-x

The expansion of offshore wind from 20 GW today to up to 450 GW by 2050 as envisaged by the EU Commission presupposes the wider decarbonisation of the energy. The latter in turn requires a significant increase in the share of electricity in the energy: from its current level of 24% to over 50%. It's very important therefore that the expansion of offshore wind is accompanied by ambitious action on the electrification of heating, transport and industrial processes.

Offshore wind can play an important role in supporting the electrification of these sectors, not least because of its relatively high capacity factors, as noted in the IEA's Offshore Wind report for the World Energy Outlook 2019.

It can also play a role in supporting the indirect electrification through renewable hydrogen of those parts of the energy system, especially in heavy industry, which it is difficult to electrify directly.

Indeed, the electricity generated by 450 GW may not all be used directly but at least 5% and possibly up to 25% could go into power-to-x, mainly as power to hydrogen or other gases. Significant amounts of direct and indirect electrification mean increased opportunities for demand-side management.

Demand management can shift the use of electricity away from peak times, enabling the use of renewable energy at times when it is generated. Power-to-x and electrical storage will enable additional flexibility from short-term storage (up to 12 hours) to seasonal storage. However, the extent of use of power-to-x in 2050 is uncertain given the current technology costs and process efficiency. Large demonstration projects to achieve economies of scale are urgently needed.

The combination and optimisation of all these different technologies will be crucial for allowing the system to become fully renewable in 2050.

System stability

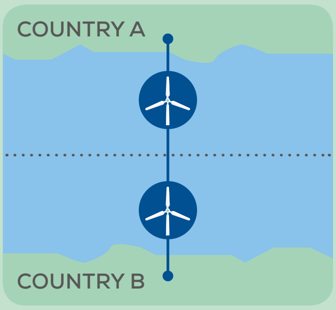
By 2050 the electricity grid will be a converter-based system, with little physical inertia in the system. This could lead to grid stability and balancing challenges. Many existing solutions can overcome these. Industry and TSOs would need to cooperate and coordinate on the implementation of such solutions.

OFFSHORE HYBRID PROJECTS: THE BEGINNING OF AN OFFSHORE MESHED GRID

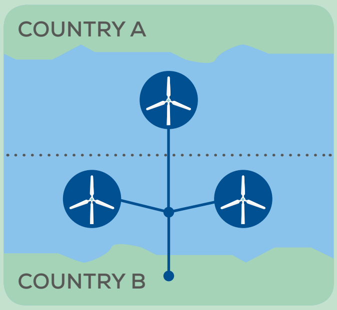
A hybrid offshore project is one where an offshore wind project connects into an offshore electricity interconnector. Hybrid offshore wind projects therefore allow the offshore wind power to be used by more than one country and allow for more efficient use of space in the sea. They could potentially enable the integration of innovative technologies like power-to-x.

Hybrid projects are classified as follows:

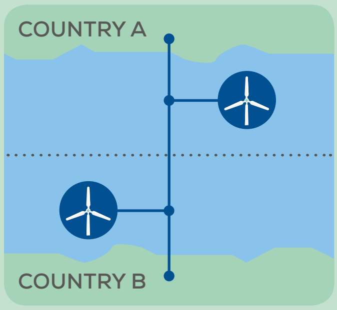
Combined grid solution



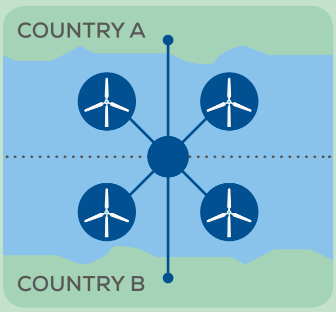
Modular grid



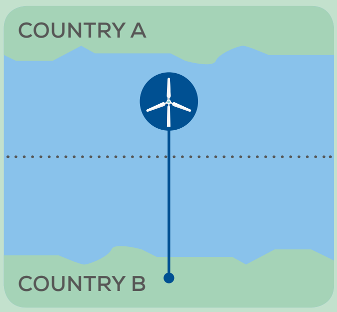
Interconnector tie-in



Offshore hub



Neighbour OWF



Hybrid projects should be always evaluated on a case-by-case basis. They will not always be advantageous over a regular wind farm to the different conditions and technical design. However, the most advantageous hybrid projects studied so far can realise savings of €300m-€2500m over the project lifetime, saving 5-10% of the total project cost[21].

Given these potential benefits, Members States should act decisively in removing the barriers for offshore hybrids. Key actions include starting the regional cooperation between countries in an early stage, and together with the European Commission, enhancing the allocation of different funds to de-risk the projects. Hybrid projects could improve the efficient use of space in the North Sea, ensuring meeting both the offshore wind volumes and interconnection targets on time.

21. U. Weichenhain, S. Elsen, T. Zorn and S. Kern, "Hybrid projects: How to reduce costs and space of offshore developments. North Seas Offshore Energy Cluster study," Roland Berger BmbH, Brussels, Belgium, 2019.

AN EU REGULATORY FRAMEWORK FOR OFFSHORE HYBRIDS

Today there are no operating offshore hybrid projects in Europe, and there is no regulatory regime with an explicit framework for the development of such projects. Member States have worked for over ten years to overcome regulatory barriers, but their efforts aim at facilitating coordination and cooperation on a voluntarily basis.

The North Seas Countries Grid Initiative (NSCOGI) and the following North Seas Energy Cooperation political declaration have made important progresses in the understanding of how to operate offshore hybrids assets in an integrated European market of electricity.

Hybrid offshore wind farms with connections to more than one country raise a number of legal issues to which there is currently no clear answer. An EU regulatory framework for offshore hybrids would help clarify the risks, costs and benefits of investing in hybrid assets and create a mechanism for countries to collaborate in the development of such projects.

Such regulation should comprise:

1. **Compatibility with the EU Electricity Regulation,** clarifying how offshore hybrid assets should comply with the minimum available capacity for cross-zonal trade of 70%

2. **Compliance with capacity allocation and congestion management rules,** ensuring that offshore hybrid projects are last curtailed in the case of interconnector congestion and the definition of bidding zones for the operating asset

3. **The revenue stabilisation mechanisms applicable to offshore hybrid assets,** establishing the mechanisms applicable for renewable cross-border projects that could apply, for example for funding or risk mitigation

4. **Consistency with the Third Energy Package,** regarding ownership rules applicable for offshore hybrid assets

ROADMAP

ACTIONS	TODAY	2020-2021	2022-2025	2026-2028	2028-2030	POST-2030
1. Governments should accelerate the expansion of the necessary on and offshore grid infrastructure.						
• Offer developers the option to build their own grid connections to shore for offshore wind projects in order to continue cost reductions						
• Coordinate tender schedules between countries with TSOs' regional development plans to allow the connection of wind farms to interconnectors on time						
• Coordinate a long-term vision with clear milestones for an integrated grid in the North Seas based on radial, hybrid, meshed connections, storage and power-to-x						
• Accelerate the permitting and building of projects of common interest						
• Coordinate and share best practices for grid optimisation and system operation with large amounts of renewable energy and electrification of most energy uses						
• Increase the funds for developing and reinforcing electricity infrastructure at national level						
• Increase interconnectivity between countries to 15% by 2030						
• Update grid modelling results for TYNDP-2018 with 2030 volumes to identify grid onshore reinforcements and implement in grid national plans						
2. The EU should elaborate a clear regulatory framework for offshore hybrid projects, which comprises.						
• The compatibility of offshore hybrid assets with article 16 from the EU electricity regulation that establishes 70% of available transmission capacity in all interconnectors for trading purposes						
• Compliance with capacity allocation and congestion management rules						
• Revenue stabilisation mechanisms applicable to offshore hybrids including the value of flexibility technologies like storage and power-to-x						
• Consistency with unbundling rules in the Third Energy Package with regard to ownership, construction and operation of offshore hybrid assets						
3. Governments should accelerate the electrification of transport, heating and industrial processes.						
• This process must be aligned with National Energy and Climate Plans (NECPs) considering offshore wind and other generation and grid technologies						
• Set clear electrification targets in National Energy and Climate Plans (NECPs)						

4.4. ENABLING TIMELY INVESTMENT

GENERATION AND TRANSMISSION

The wind farm and offshore transmission CAPEX required are shown in Figure 17. The most significant increase will come in the decade after 2030, when investments should reach around €45bn per year. This is less than half of what ENTSO-E and the European Commission have estimated in the past when current cost reductions are projected to the future[22].

Note that Figure 17 shows transmission CAPEX for an all-radial connection approach and a meshed and hybrid grid approach. The latter requires earlier investment but is more cost-effective overall. The final CAPEX is likely to be a blend of the two approaches.

Additionally, we anticipate the need for onshore grid enhancement investments, peaking in the range €10bn to €50bn per year. The range here is wide because of uncertainty about the location of these investments, the cost of future transmission technologies, and the nature of the ground to be crossed. This investment will also benefit onshore wind, solar, other renewables and demand management, and thus should not be counted solely against offshore wind.

Delivering such large investments will require the mobilisation of funds from governments and the private sector. Therefore, it will be crucial to enable more players and additional sources of finance to develop, build and operate such infrastructure.

REVENUE STABILISATION

Investors do not need the same lead-time to make their investments as key suppliers and project developers. Investors (and especially debt providers) need visibility on the revenue stream that will be generated by projects in which they have invested.

The current merchant electricity markets will not provide the certainty that investors need to provide the required volume of funding at affordable rates. Although LCOE for offshore wind will be close to the wholesale market electricity price from 2025, the average price received for that electricity will not necessarily be the same as the average market electricity price (because of demand-matching). To enable the volume of investment required from financial investors, electricity markets will need to evolve to enable investors to have confidence in a more stable price for electricity, even if at no more than average electricity prices. This could be provided by a combination of:

- Contracts for difference;
- Corporate renewable PPAs; and
- High and stable carbon prices.

Other developments such as demand management, electrification of transport and heating and power-to-x are likely to play a part in stabilising prices, as will corporate PPAs. But together these will not be enough to provide the revenue confidence needed for the volume of investment required.

Mechanisms will also need to be agreed on a Europe-wide basis for the transmission and trading of offshore wind energy, including energy generated in one country's EEZ, transmitted across another and supplied to a third. This is especially important for countries around the Baltic Sea, which will need substantial investment in ports and in onshore transmissions. The scale of this means that some countries will need significant inward investment.

If some price stabilisation is used to give financial investors' confidence in their returns, it is likely that at least some of the sources of capital that currently feed into other energy projects will transition into investment in offshore wind. Mobilising the volumes of investment shown in Figure 17 is therefore likely.

In summary, the challenges of delivering annual rates of 20 GW pa after 2030 are daunting. But if policies are ambitious enough in the next decade and regulation is stable, the European industry will have amassed unparalleled experience over more than two decades of offshore wind development, which will mean these challenges can be met.

22. ENTSO-E and the EC estimates are €100 and €150bn in offshore grids to support 100 GW of offshore wind by 2030. See WindEurope position paper on offshore grids, p.17

4.5 EXPANDING THE SUPPLY CHAIN

The key suppliers on the critical path for investment to achieve competitively priced offshore wind capacity are: wind turbine suppliers, installation contractors, vessel suppliers and construction ports. They invest in the development of next generation products, manufacturing capacity and skills training. The investment from key suppliers is needed to increase installation rates and to keep reducing the cost of energy through new generations of technology, especially larger wind turbines.

The challenge in getting timely investment from key suppliers is that they need confidence in the market for a duration that will give a return on their investment. This duration could be around 10 years for preparation and amortising of major investments in a market where margins are kept low by competitive auctions.

It is likely that in time, there will be increased supply from outside Europe, but as the global market for offshore wind grows, there will also be many more opportunities for the European supply chain to export, balancing this effect.

WIND TURBINE MANUFACTURERS

For turbine supply, around 1,000 units per year will be needed (assuming 20-25 MW turbines considering the assumptions in chapter 6), which could be produced by four or five main turbine manufacturers in up to ten main facilities located at key ports across Europe (or beyond).

OFFSHORE INSTALLATION SUPPLIERS

There will need to be investment in new vessels capable of installing the expected future large turbines and their foundations. We anticipate that at least ten new primary vessels will be required, each capable of annually installing up to 100 turbines or their foundations. This may include some new heavy-lift floating vessels for deep water sites. However, innovations in installation approaches and the use of floating wind turbines (built near-shore or in harbours and towed to site using cheaper vessels) may reduce the investment required.

In addition to investment by the current key suppliers, those transitioning from the oil and gas supply chain also have the potential to bring investment to the offshore wind supply chain.

PORTS

Construction port investment will be needed in all sea basins. We envisage in the North Sea (up to 10 GW pa) that there will be three or four ports that invest in being capable of building out 2 GW to 4 GW pa, with a number of other ports capable of building 1 GW pa. The smaller volumes in the other sea basins (around 4 GW pa) will drive investment into a small number of ports in each basin, each capable of supporting 1-2 GW pa.

With floating wind installations being significant, at least one port in each sea basin will either be capable of (or fully dedicated to) the build-out of floating wind projects. For more detail on the scale of early-stage investment required see the study performed for WindEurope's offshore wind ports platform[23].

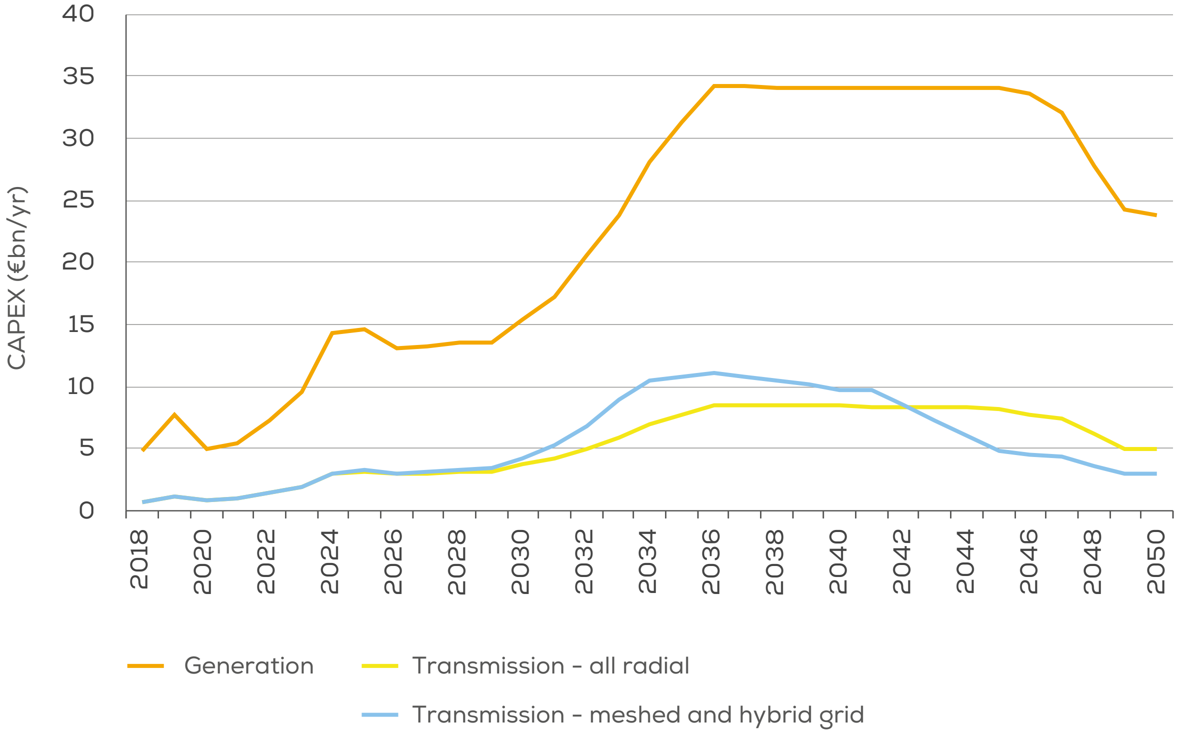
In certain jurisdictions, governments could support port infrastructure, directly helping to grow construction port volume capability.

PROJECT DEVELOPERS

To enable timely investments, project developers need to know that key suppliers are investing for the expected volumes. The project developers need to have the confidence to invest in expanding their project development teams. The timeframe needed by project developers is a little shorter: five to seven years ahead of installation. Project developers also need to have confidence that grid connections will be in place to supply their power to customers, or that they will be compensated if these connections are not ready. Lastly, project developers also need to know that project revenues will provide returns at low enough risk to enable progress, often with significant debt funding.

23. OWPP infographic, BVG Associates for WindEurope offshore wind ports platform, 2018

FIGURE 17
CAPEX rates required to achieve 450 GW by 2050



Source: BVG Associates for WindEurope

ROADMAP

ACTIONS	TODAY	2020-2021	2022-2025	2026-2028	2028-2030	POST-2030
1. Governments should ensure visibility and confidence in volumes and revenue schemes.						
• Design revenue stabilisation models and auction mechanisms at optimal costs for treasuries						
• Update mechanisms for selling energy and other grid services nationally to provide stable revenues						
• Update mechanisms for cross-border selling of power and services needed from 2025						
• Technical standards must be harmonised to help minimise repeat work without stifling innovation. The implementation of those standards must be coordinated across Europe						

4.6. COUNTRY-SPECIFIC CHALLENGES

In this section we look at each of the challenges by country.

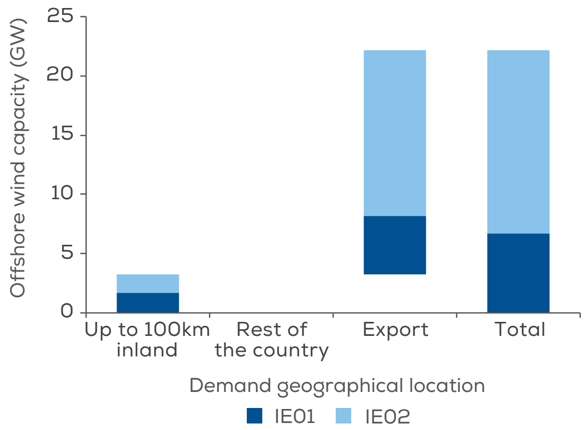
IRELAND

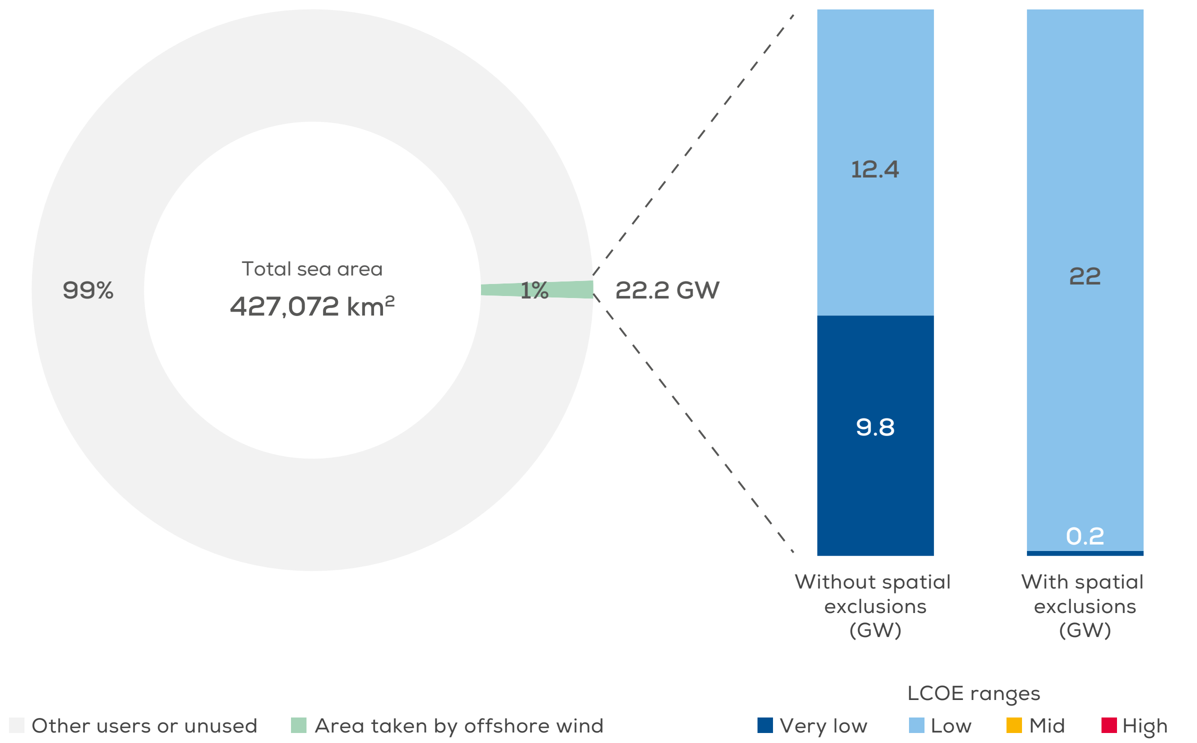
Ireland needs to significantly increase its leasing and consenting rate from 2021. It has enough space for the allocated capacity of 22.2 GW. Currently it has ambitions for at least 3.5 GW by 2030. Exclusions shift a significant part of capacity out of very low and into low LCOE. Ireland urgently needs to increase its interconnection with continental Europe. This is its biggest challenge. 19 GW could be used for trade purposes by 2050. Investments in generation, supply chain for components, infrastructure and transmission should start to be mobilised from 2025.

FIGURE 18

a) Distribution per country sub-region to allocate offshore wind up to 100km, >100km and for export

b) Distribution of area per sea per LCOE to allocate offshore wind in a scenario without and with spatial exclusions





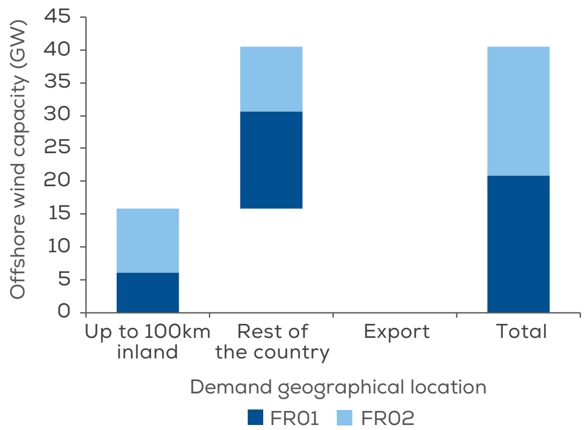
Source: BVG Associates for WindEurope

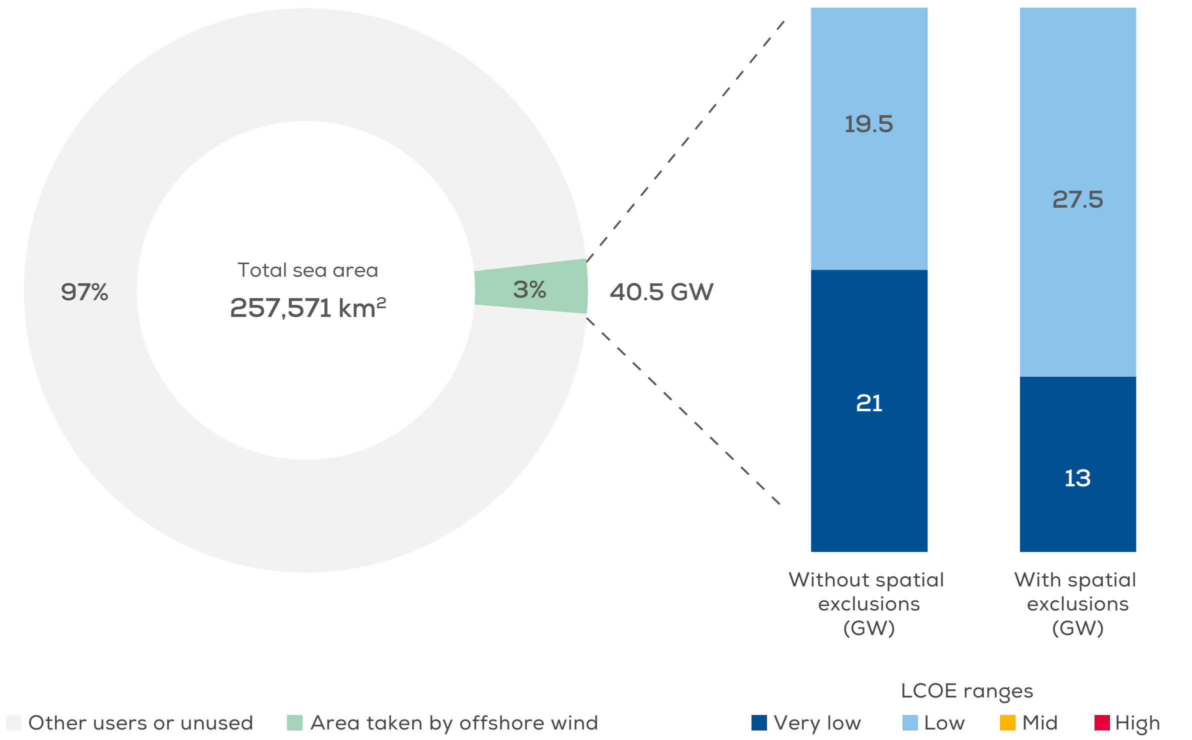
FRANCE

France needs to rapidly increase site leasing and consenting. The Atlantic Ocean could host up to 40.5 GW by 2050 in our analysis. And the Mediterranean basin could have an additional 17.4 GW. But the current exclusions shift a significant part of capacity out of very low and into low LCOE. Today France has ambitions for between 4.7 and 5.2 GW in operation by 2028, and would need to speed up grid reinforcement from 2025. This, and further investments, should be possible if there is clarity on France's post-2030 offshore wind ambitions by 2025. Figure 19 shows only the analysis only for the Atlantic Ocean.

FIGURE 19

a) Distribution per country sub-region to allocate offshore wind up to 100km, >100km and for export
b) Distribution of area per sea per LCOE to allocate offshore wind in a scenario without and with spatial exclusions





Source: BVG Associates for WindEurope

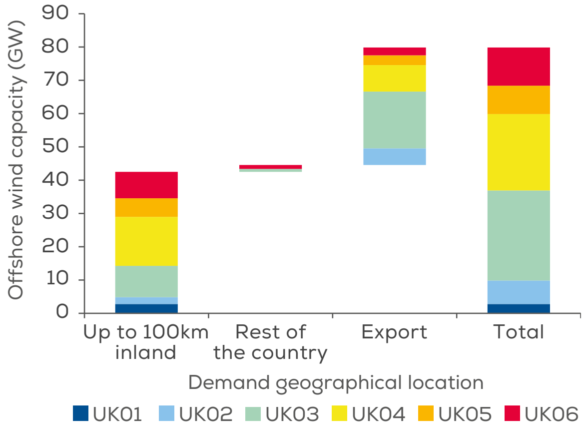
THE UNITED KINGDOM

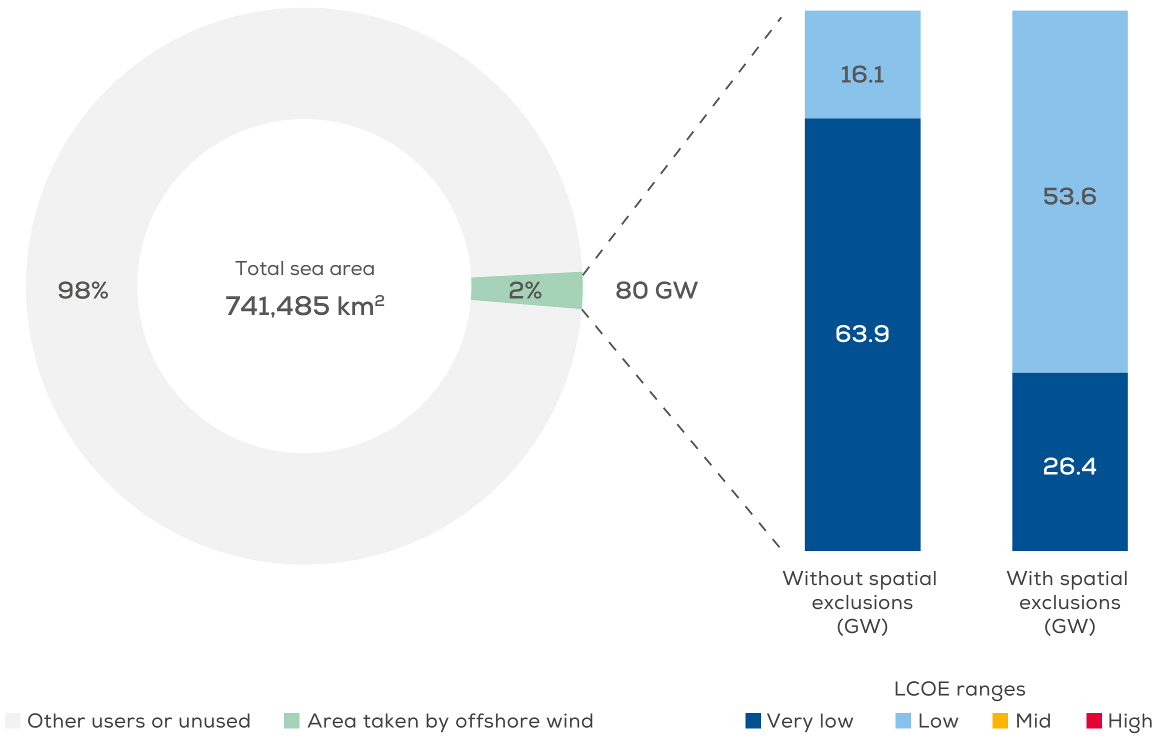
The UK has to increase the leasing of sites and consenting in the North Sea from 2025, and in the Atlantic from 2027 onwards. Crucially grid enhancement has to start rapidly for onshore and interconnection capacity from both the west and east coasts. Also in the southern part of North Sea, it is urgent to address the environmental impacts of large-scale offshore wind deployment. The cumulative environmental impacts are already decisive for project consenting. Current exclusions shift a significant part of capacity out of very low and into low LCOE. We do not foresee significant challenges in mobilising investments. The UK government has been the first advanced economy to pledge net-zero emissions by 2050, which would entail up to 75 GW of offshore wind. Our analysis has found potential for an additional 5 GW, totalling 80 GW by 2050.

FIGURE 20

a) Distribution per country sub-region to allocate offshore wind up to 100km, >100km and for export.

b) Distribution of area per sea per LCOE to allocate offshore wind in a scenario without and with spatial exclusions.





Source: BVG Associates for WindEurope

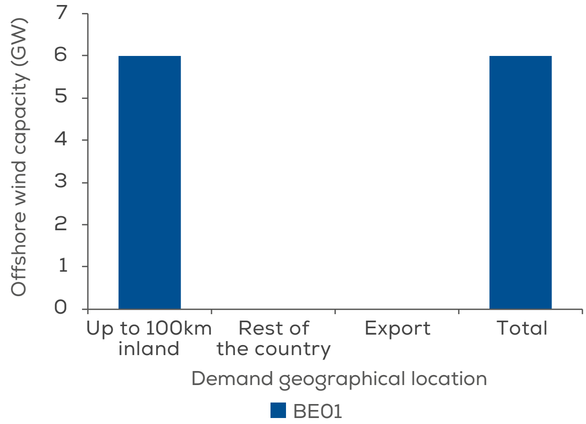
BELGIUM

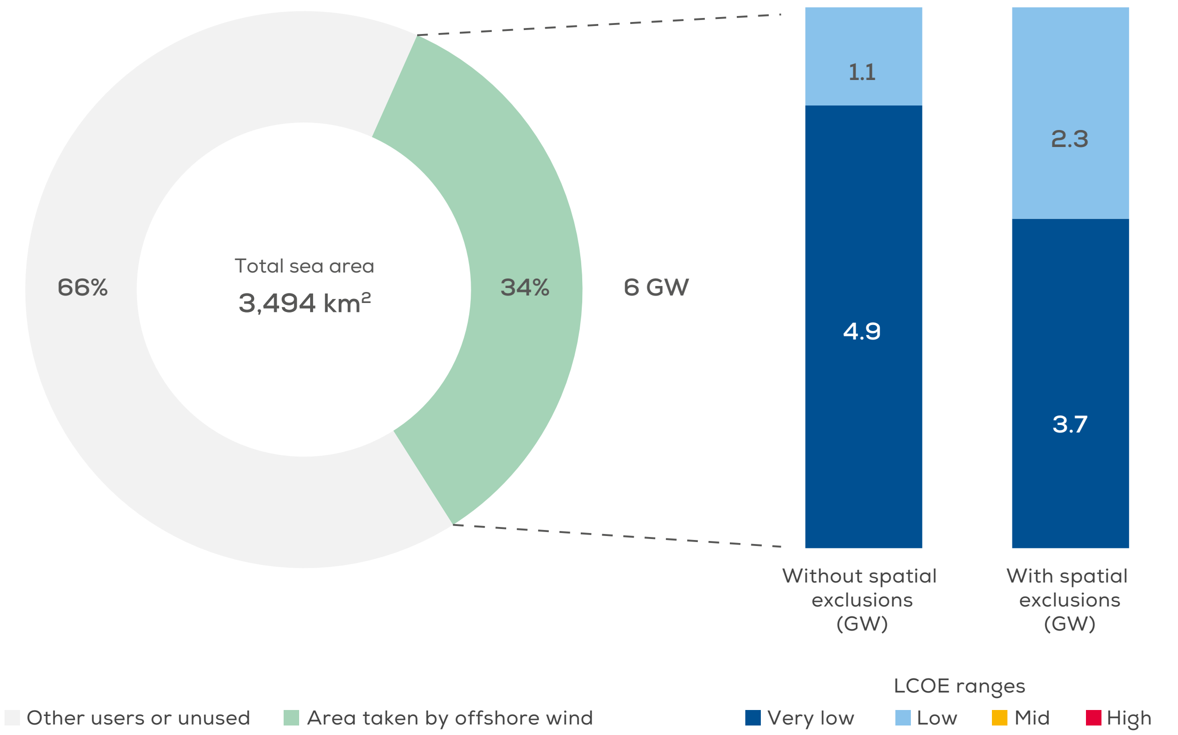
Belgium's single biggest challenge is its limited available sea area. Nevertheless, it has high offshore wind ambitions and this makes it a frontrunner in the optimisation of sea space. In our analysis, it has 6 GW of offshore wind by 2050 (assuming an average higher energy density compared to other countries of 7 MW/km^2), 2 GW up from 4 GW by 2030. For this to happen, onshore grid reinforcement and offshore wind farm clustering for the new zones has to start rapidly. And if it is to increase its installed capacity beyond 6 GW, the execution of offshore hybrid projects will be essential. Importantly it has to work with its neighbouring countries to address the cumulative environmental impacts of offshore development in southern areas of the North Sea.

FIGURE 21

a) Distribution per country sub-region to allocate offshore wind up to 100km, >100km and for export

b) Distribution of area per sea per LCOE to allocate offshore wind in a scenario without and with spatial exclusions





Source: BVG Associates for WindEurope

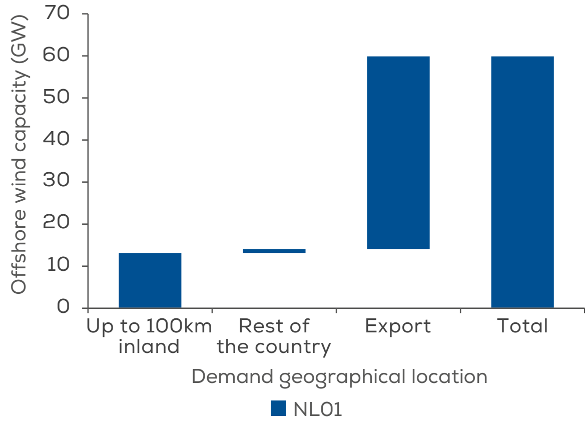
THE NETHERLANDS

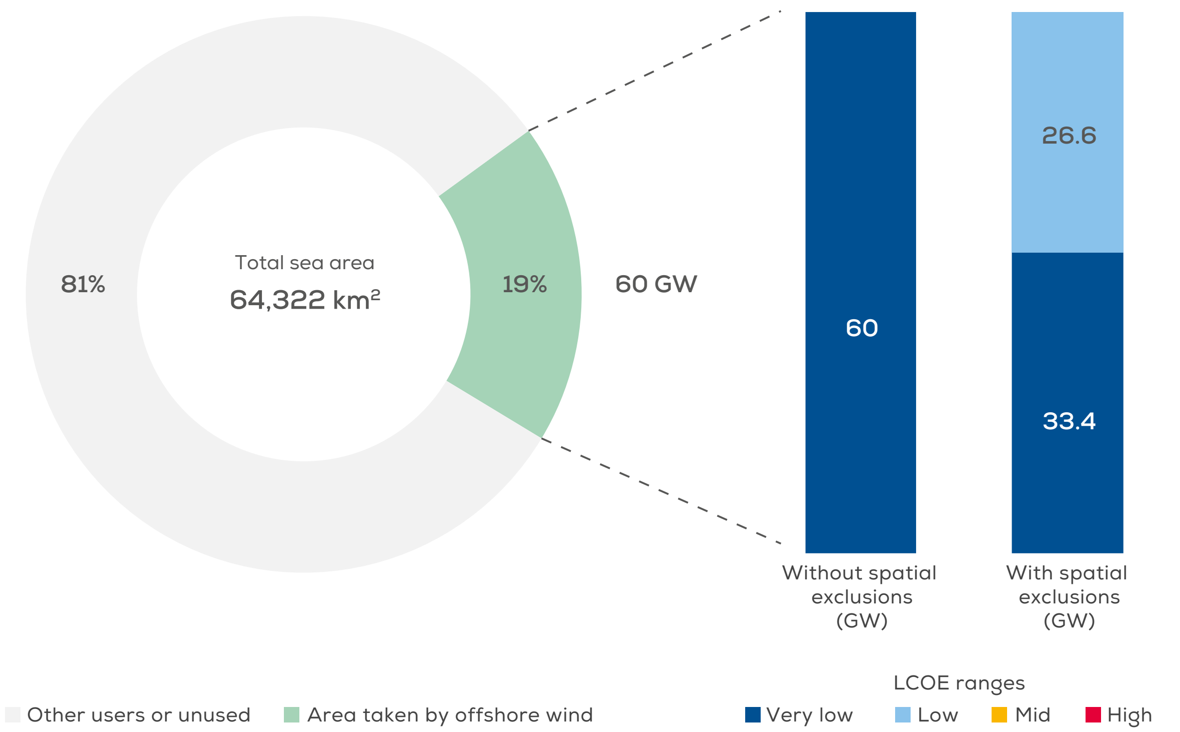
The Netherlands faces significant issues in enabling new sites for its immense offshore wind potential. The Netherlands could have 60 GW by 2050, almost 5 times the 11.5 GW it should have by 2030. But current exclusions shift a significant part of capacity out of very low and into low LCOE. A steep rate of site leasing and consenting should start from 2025 and continue well into the end of the 2030s. Allowing projects in natural protected areas is already an issue. The country will have to work intensively nationally and internationally to address concerns of local and cumulative environmental impacts. These would need to be balanced against climate change effects, like the rise of sea levels and temperature increases. Happy coexistence with important economic maritime sectors would be key too. Grid enhancement onshore and offshore will have to start from 2025, together with strategic planning for storage and power-to-x projects.

FIGURE 22

a) Distribution per country sub-region to allocate offshore wind up to 100km, >100km and for export

b) Distribution of area per sea per LCOE to allocate offshore wind in a scenario without and with spatial exclusions





Source: BVG Associates for WindEurope

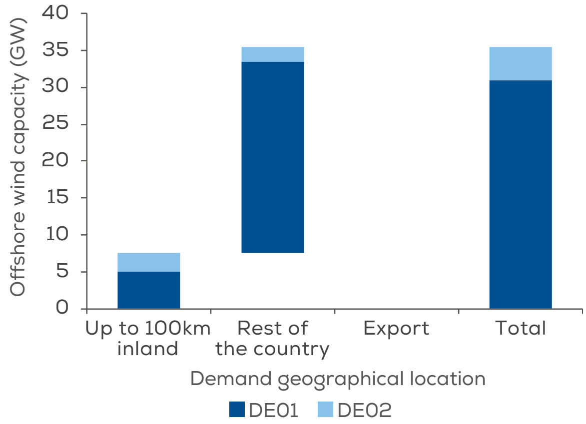
GERMANY

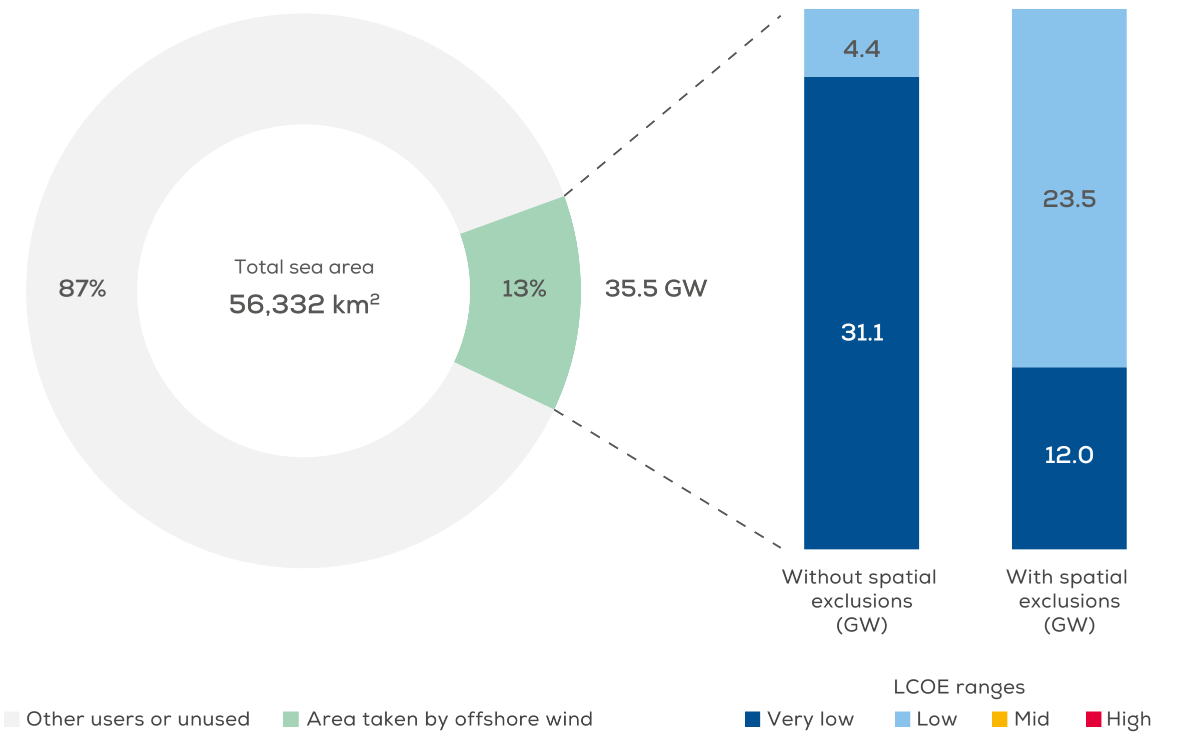
Germany will face significant issues in enabling new sites, particularly in its Baltic sea. Almost three-quarters of this region is within 22km of the coast, and offshore wind projects currently cannot be built there. If this exclusion continues, ensuring enough sites will be difficult in this region. In addition, Germany should review the current exclusion of offshore wind projects in natural protected areas. All these exclusions shift a significant part of capacity out of very low and into low LCOE.

Crucially Germany has to rapidly start its grid enhancement, particularly the onshore grid from north to south. It will have to cooperate with its neighbours for interconnection expansion, and to build offshore hybrid projects. Mobilising investments should not be a problem if the country tackles its grid bottlenecks and its post-2030 ambition on offshore wind.

FIGURE 23

a) Distribution per country sub-region to allocate offshore wind up to 100km, >100km and for export
b) Distribution of area per sea per LCOE to allocate offshore wind in a scenario without and with spatial exclusions





Source: BVG Associates for WindEurope

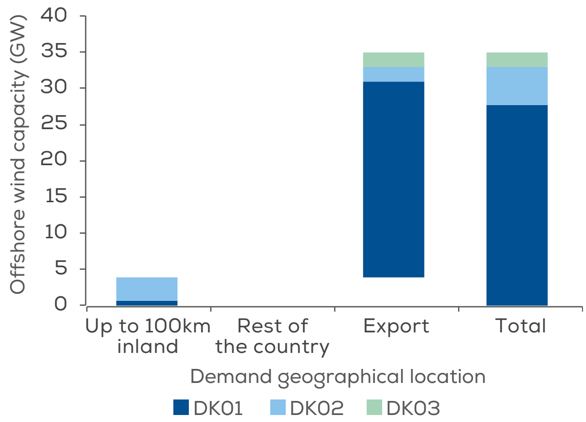
DENMARK

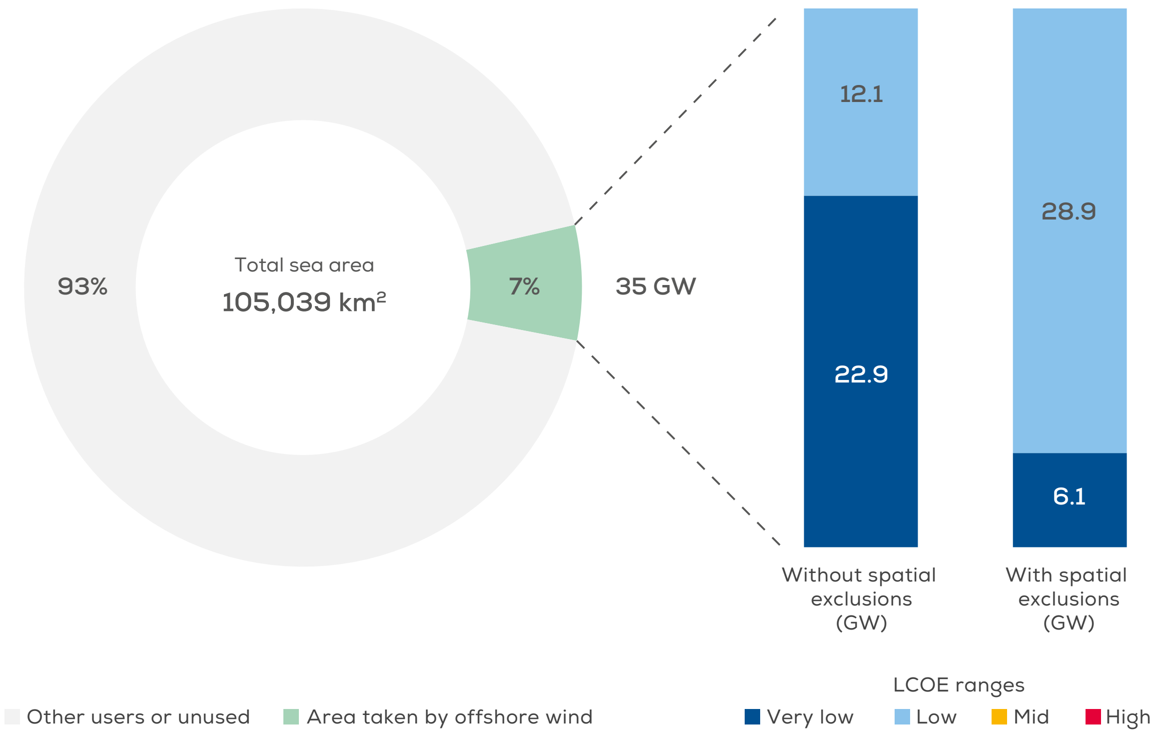
Denmark has to step up its grid enhancement if it is to realise the 35 GW by 2050. Out of this capacity, 25 GW would be for trade so interconnection to other countries will be key. It would need to accelerate its international cooperation in order to develop offshore hybrid projects and to address the cumulative environmental impacts of large-scale offshore wind in the North Sea.

Exclusions shift a significant part of capacity out of very low and into low LCOE.

FIGURE 24

a) Distribution per country sub-region to allocate offshore wind up to 100km, >100km and for export
b) Distribution of area per sea per LCOE to allocate offshore wind in a scenario without and with spatial exclusions





Source: BVG Associates for WindEurope

NORWAY

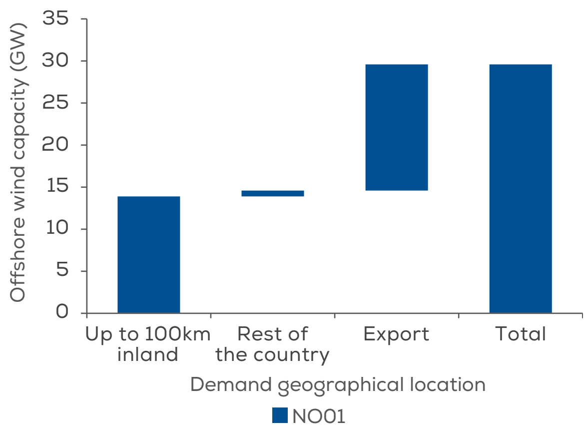
Norway's main challenge to achieve up to 30 GW of offshore wind by 2050 is to increase its interconnection capacity with Europe. Half of this potential capacity would be for export electricity to other countries. It should also enable more sites in its southern waters. The current planned sites in the north of the country are too far from the demand centres, and would require expensive grid investments. Mobilising investment should not be an issue, but targeted support for developing a supply chain for floating offshore wind would need to start by 2025.

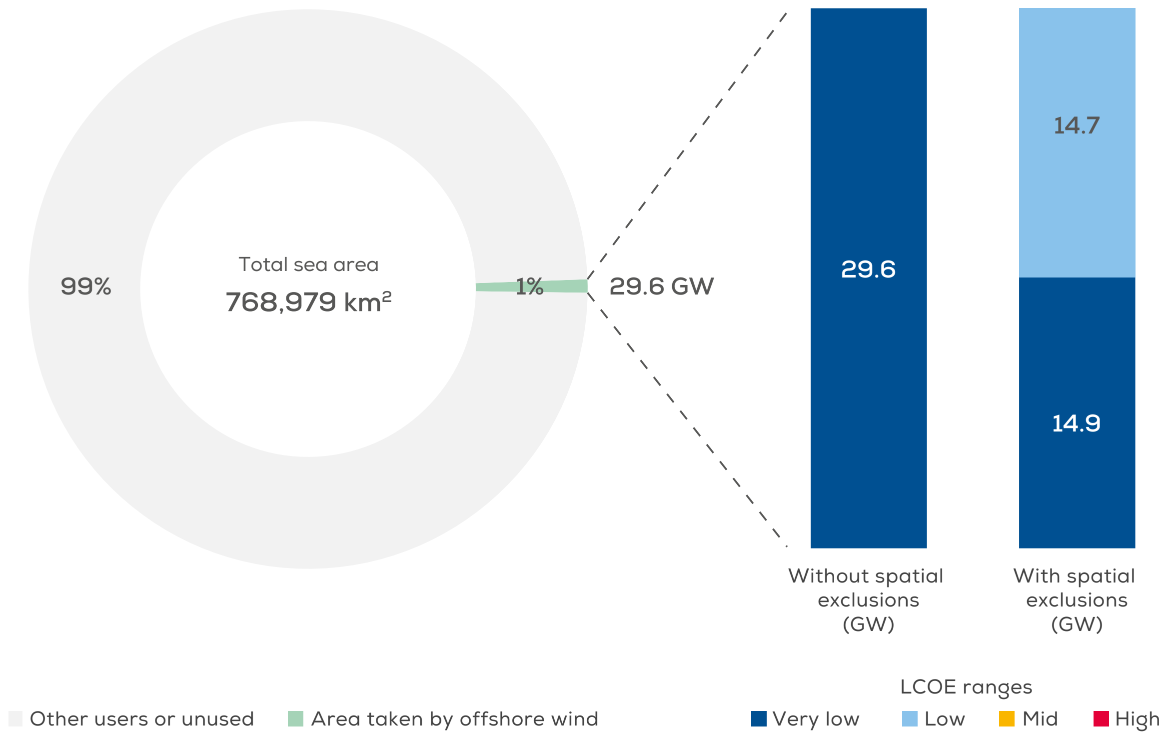
Exclusions shift a significant part of capacity out of very low and into low LCOE.

FIGURE 25

a) Distribution per country sub-region to allocate offshore wind up to 100km, >100km and for export

b) Distribution of area per sea per LCOE to allocate offshore wind in a scenario without and with spatial exclusions





Source: BVG Associates for WindEurope

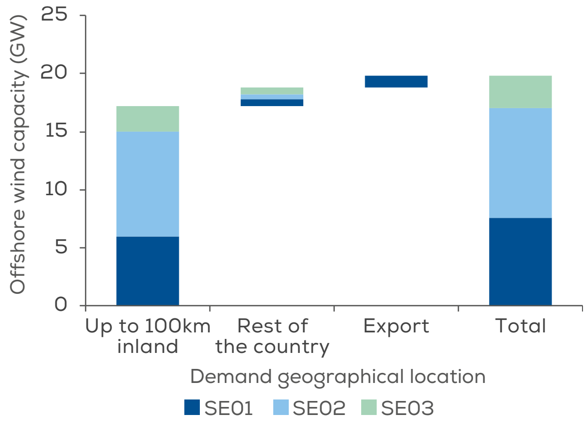
SWEDEN

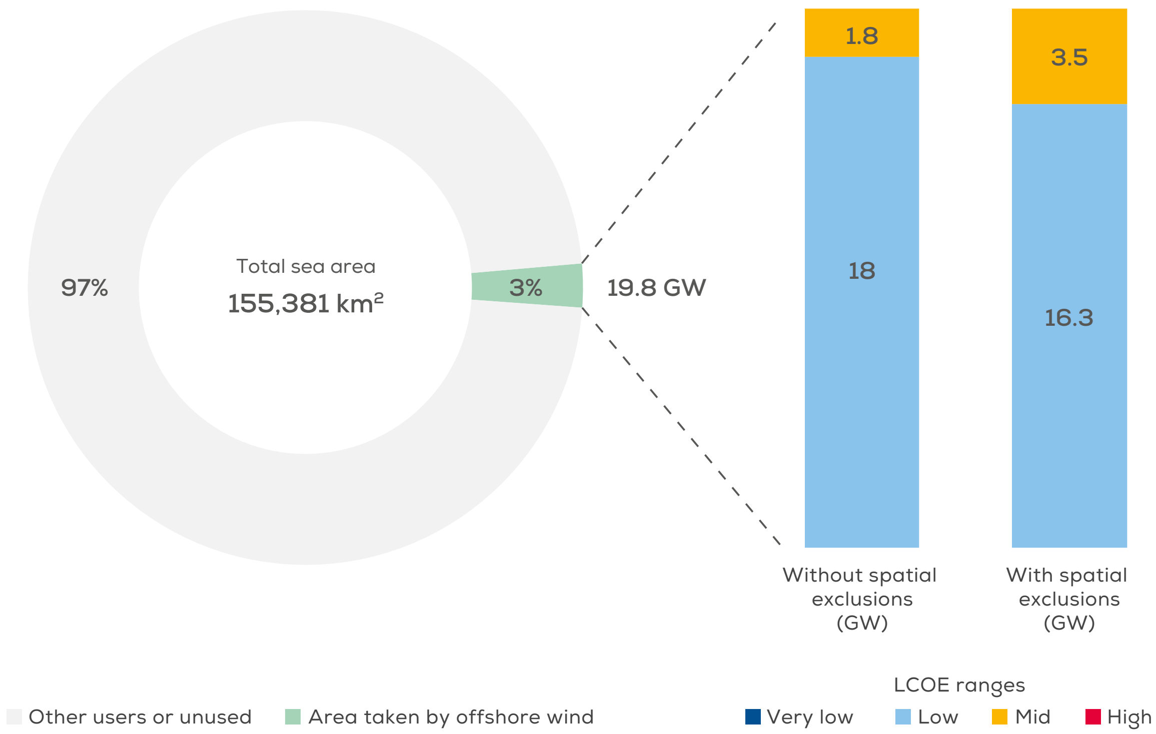
Sweden's main challenge is to enable sites for offshore wind by solving the current exclusions due to military radar issues. Crucially, it will have to step up its grid build-out to inland enhancement, as more than 17 GW out of the 20 GW it could have by 2050 would be to serve demand up to 100km from the coast. It would also need to cooperate internationally to address possible environmental impacts of large-scale offshore wind deployment in the Baltic Sea.

FIGURE 26

a) Distribution per country sub-region to allocate offshore wind up to 100km, >100km and for export

b) Distribution of area per sea per LCOE to allocate offshore wind in a scenario without and with spatial exclusions





Source: BVG Associates for WindEurope

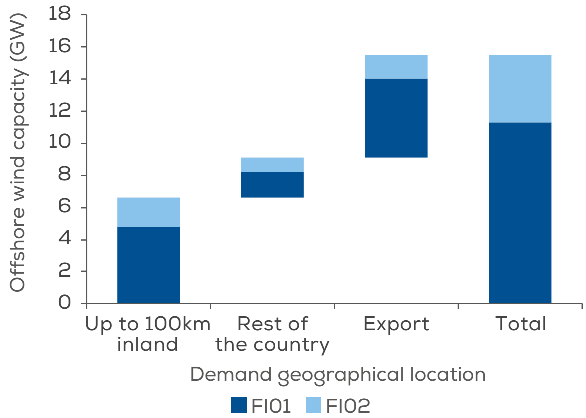
FINLAND

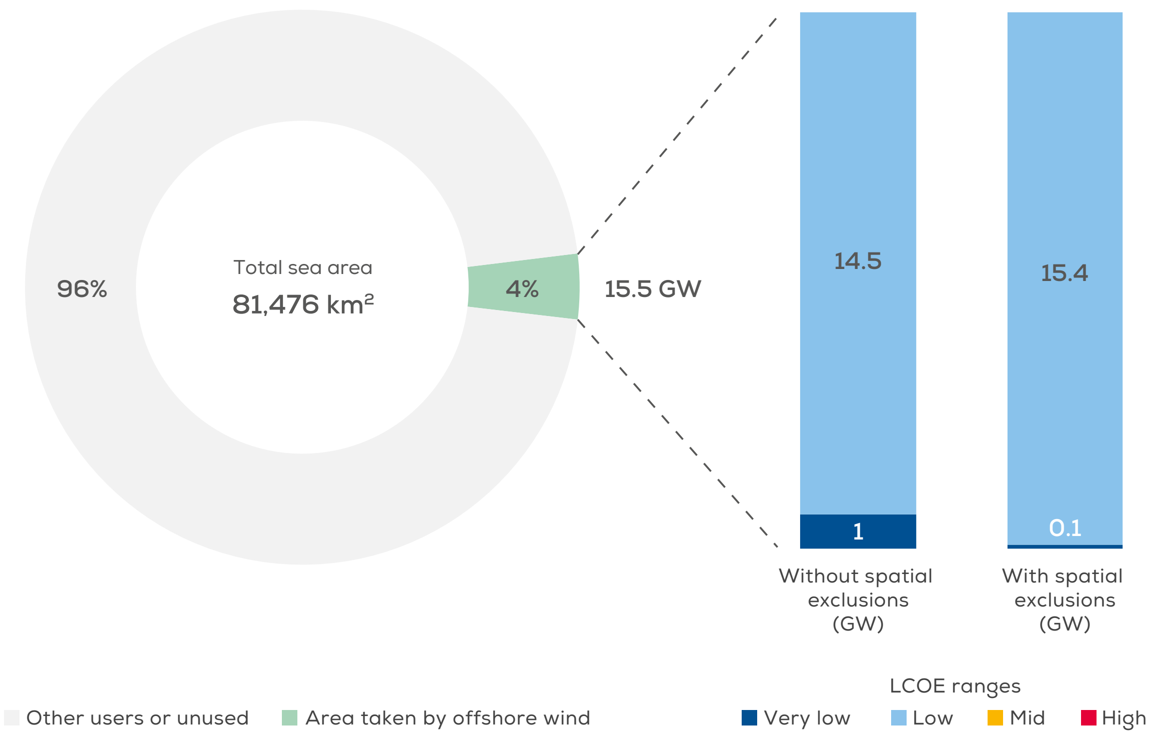
Finland's main challenge is to enable sites for offshore wind by solving the military radar issues leading to current exclusion zones. Particularly in the southern Baltic Sea. Another challenge is to enable revenue stabilisation mechanisms for projects and the lack of a regulatory framework for grid connection.

FIGURE 27

a) Distribution per country sub-region to allocate offshore wind up to 100km, >100km and for export

b) Distribution of area per sea per LCOE to allocate offshore wind in a scenario without and with spatial exclusions





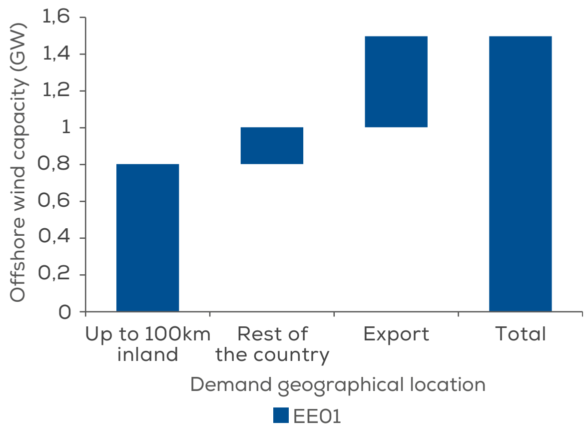
Source: BVG Associates for WindEurope

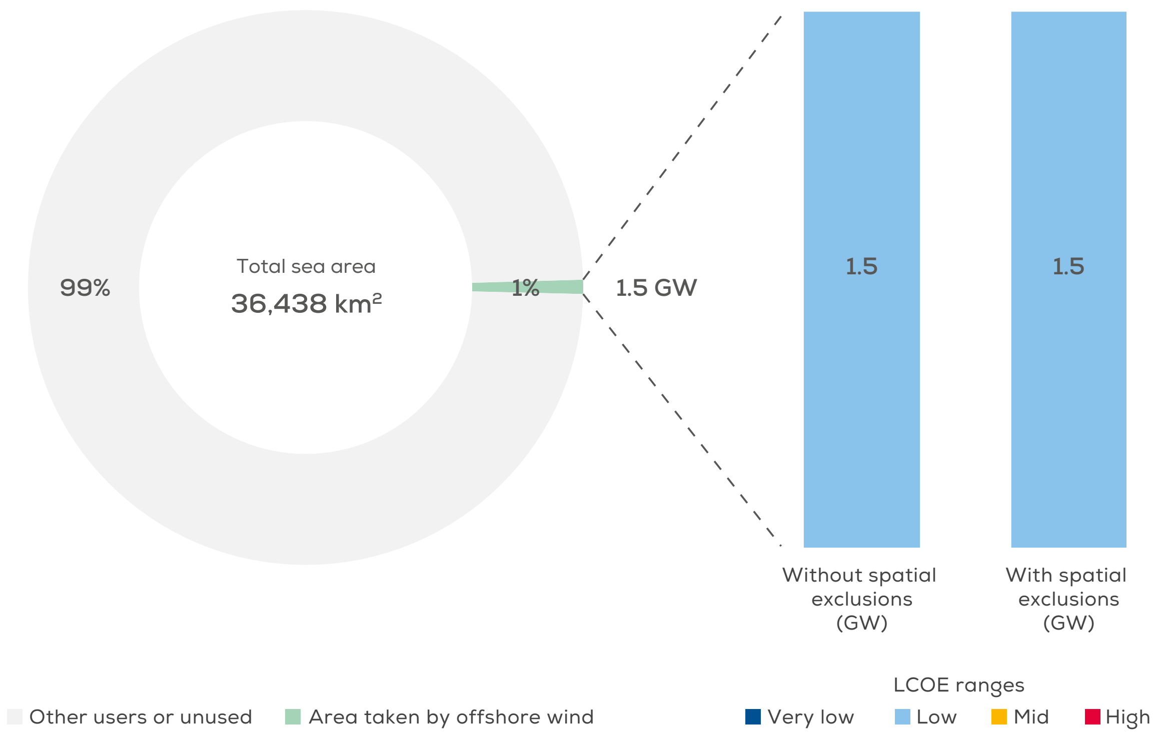
ESTONIA LATVIA AND LITHUANIA

The three Baltic States' main challenge is to address their interconnection and system synchronisation with central Europe. Internal grid enhancement would be key for Estonia, which could use more than half of its 1.5 GW of offshore wind in 2050 to serve its local demand. Lithuania and Latvia could have more than half of their offshore wind for trade electricity to other countries, so interconnection would be essential. In the three countries, timely investment in port infrastructure is a major challenge and should be addressed as early as 2025.

FIGURE 28a - ESTONIA

a) Distribution per country sub-region to allocate offshore wind up to 100km, >100km and for export
b) Distribution of area per sea per LCOE to allocate offshore wind in a scenario without and with spatial exclusions

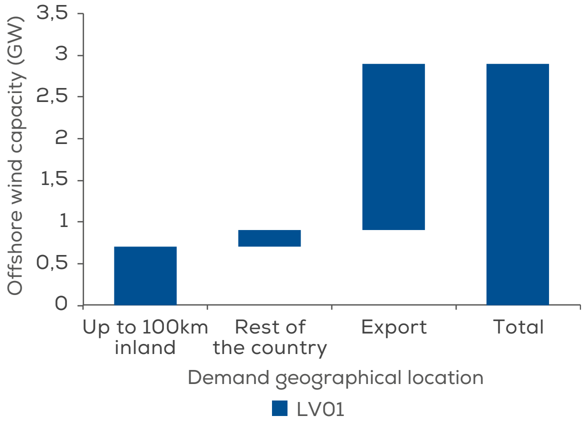


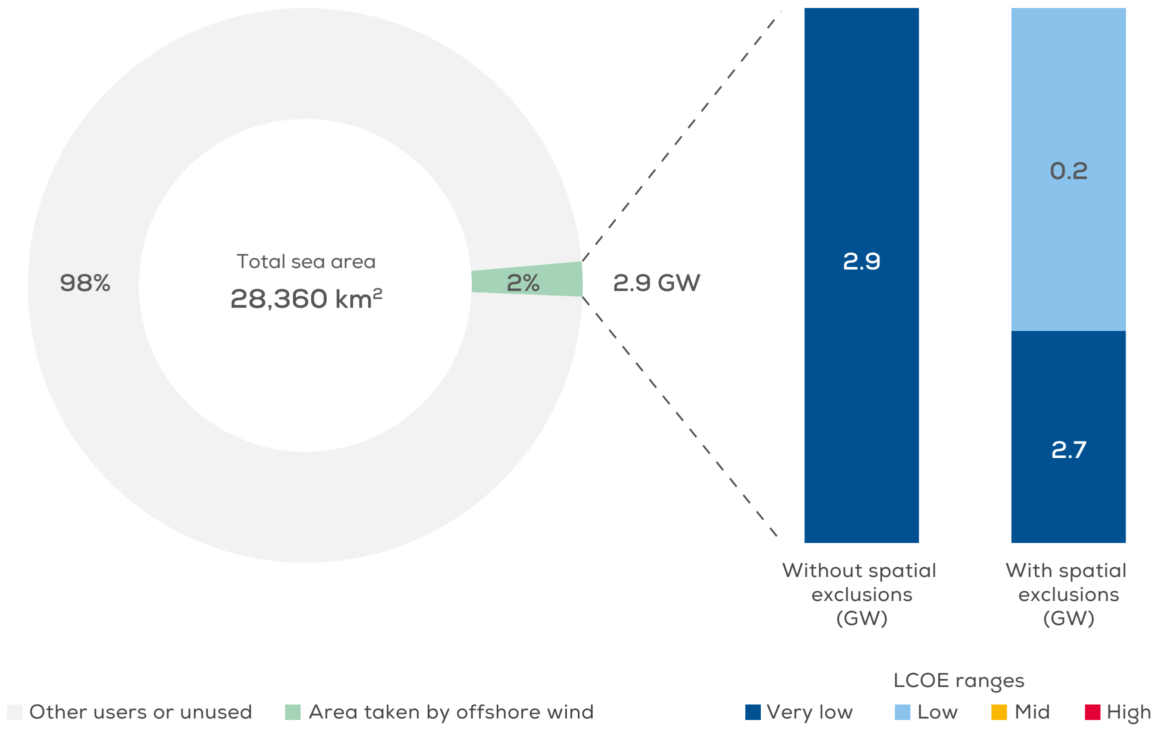


Source: BVG Associates for WindEurope

FIGURE 28b - LATVIA

a) Distribution per country sub-region to allocate offshore wind up to 100km, >100km and for export
b) Distribution of area per sea per LCOE to allocate offshore wind in a scenario without and with spatial exclusions



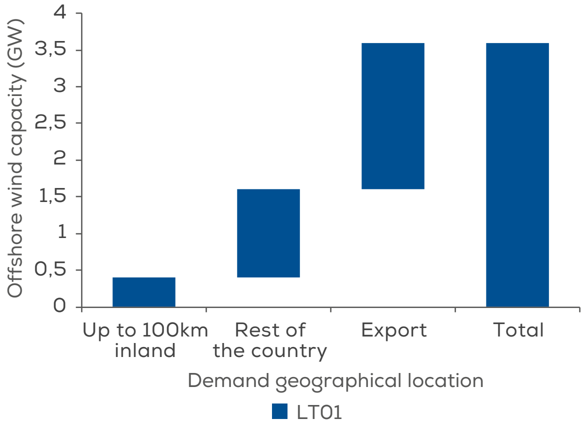


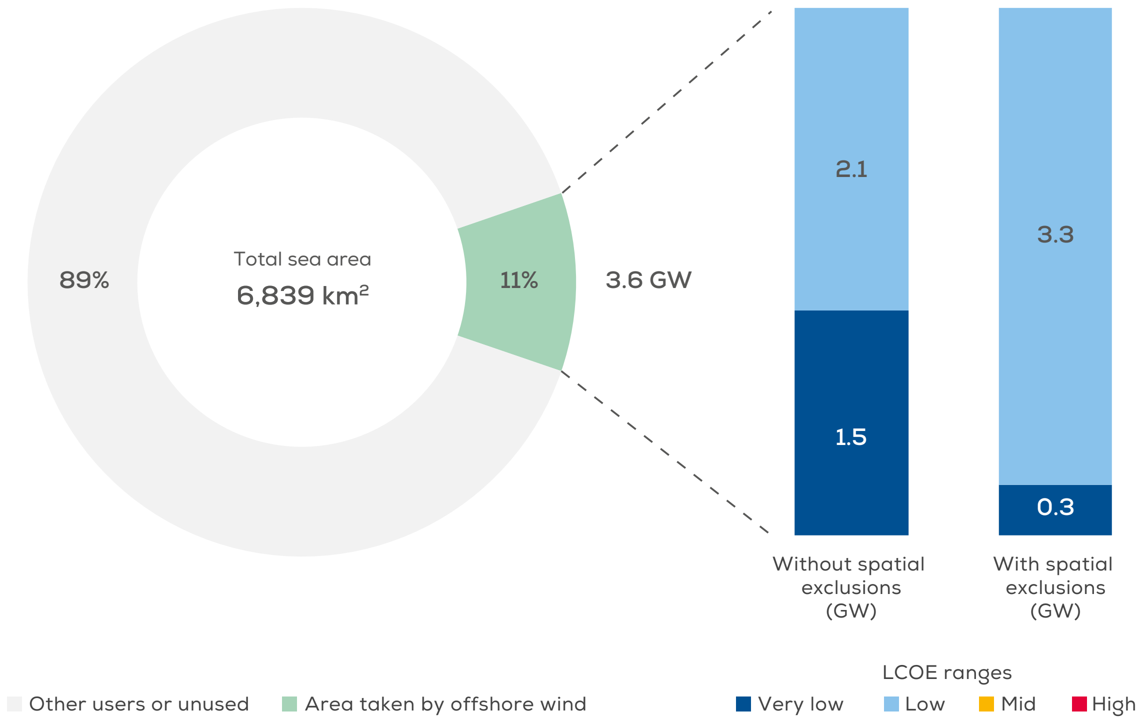
Source: BVG Associates for WindEurope

FIGURE 28c - LITHUANIA

a) Distribution per country sub-region to allocate offshore wind up to 100km, >100km and for export

b) Distribution of area per sea per LCOE to allocate offshore wind in a scenario without and with spatial exclusions





Source: BVG Associates for WindEurope

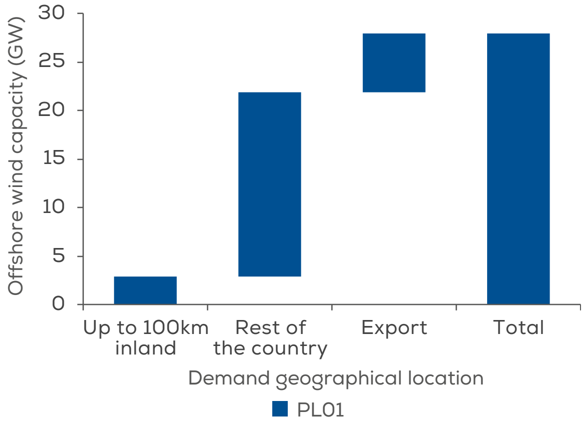
POLAND

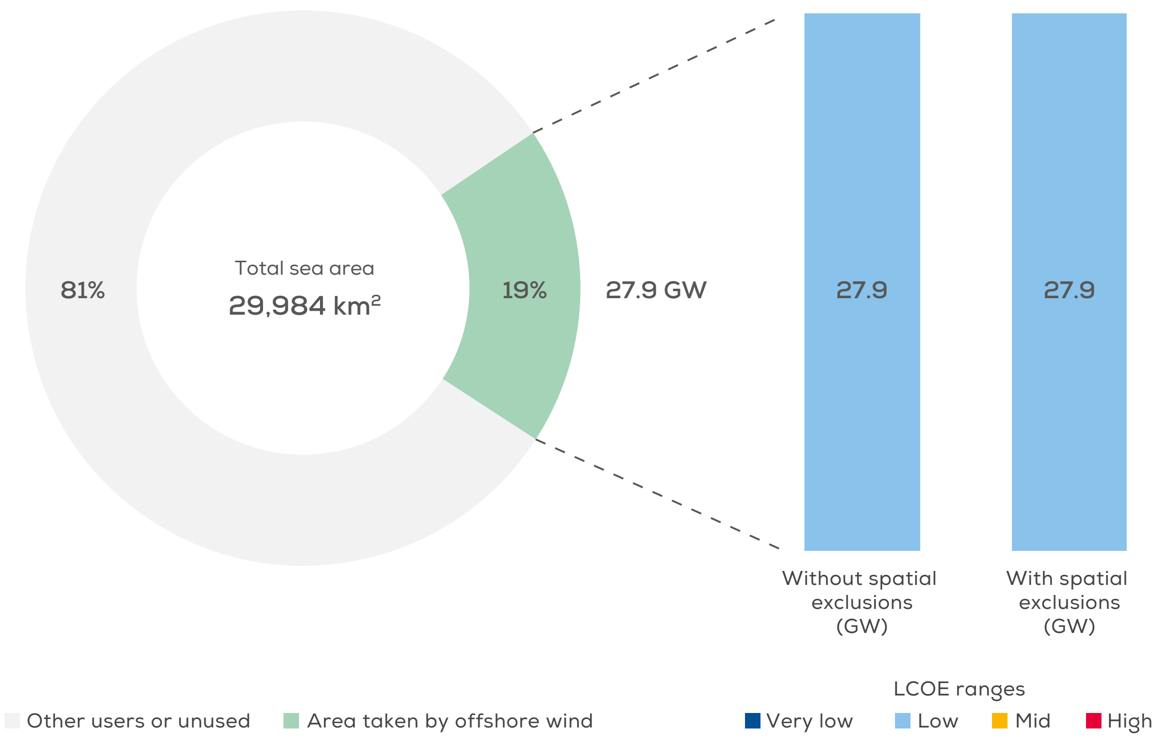
Poland's main challenge is to accelerate the enhancement of its national grid. Poland could host up to 28 GW by 2050, 22 GW of which would be to serve its national demand. Poland's interconnection capacity must also improve if it is to trade electricity with other Central and Eastern Europe countries. Work on grid enhancement should start as early as 2025.

FIGURE 29

a) Distribution per country sub-region to allocate offshore wind up to 100km, >100km and for export

b) Distribution of area per sea per LCOE to allocate offshore wind in a scenario without and with spatial exclusions





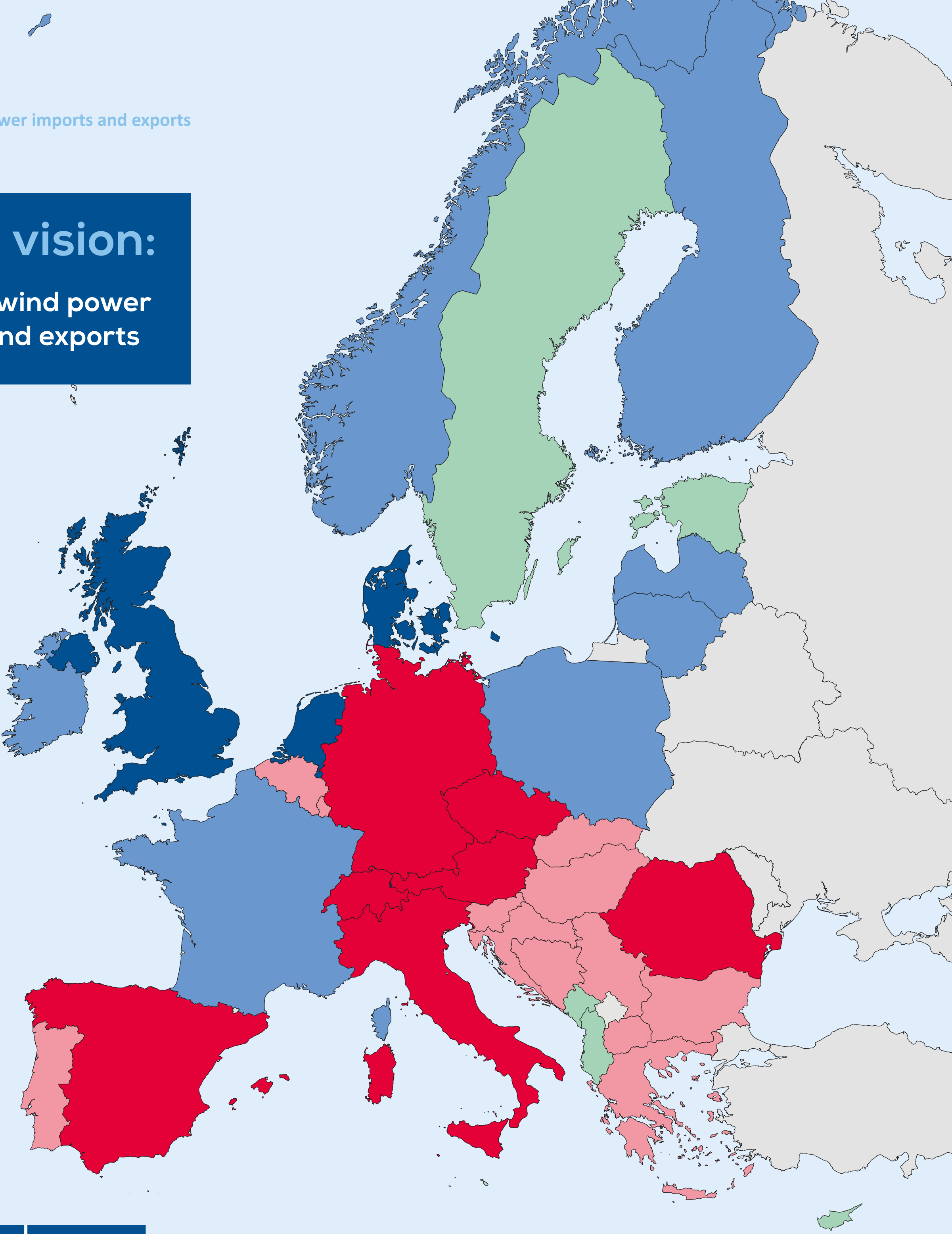
Source: BVG Associates for WindEurope

FIGURE 30

2050 vision: offshore wind power imports and exports

2050 vision:

Offshore wind power imports and exports



COUNTRY/AREA[24]	CAPACITY (GW)
Netherlands	46
United Kingdom	35
Denmark	31
Ireland	19
France	17
Norway	15
Finland	7
Poland	6
Latvia	2
Lithuania	2
Sweden	1
Estonia	1
Belgium	-3
Germany	-22

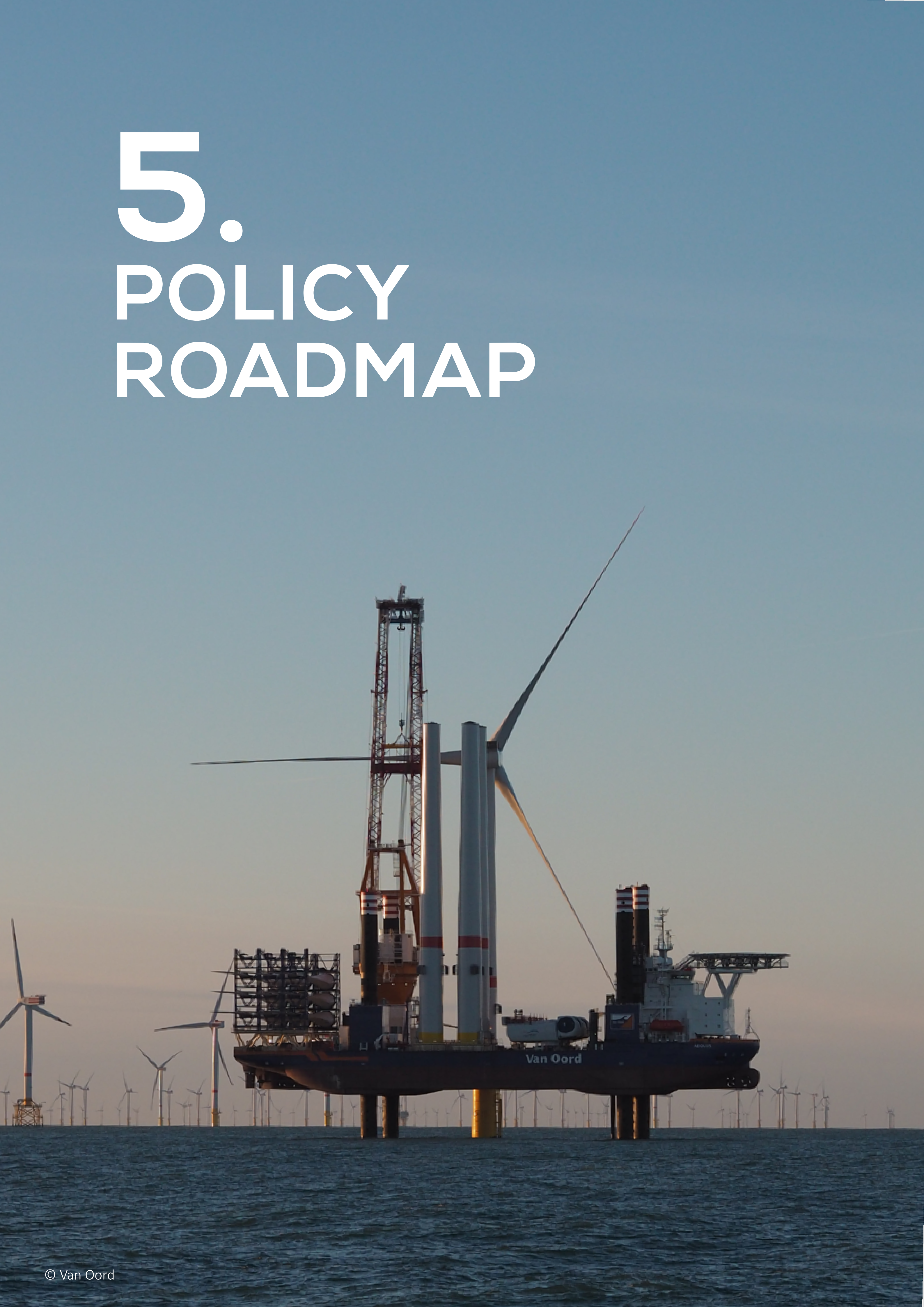
This map shows the offshore wind capacity available for electricity trading in 2050. It assumes that all countries in Europe supply 30% of their electricity demand with offshore wind. Countries with available capacity after meeting this share of demand are net exporters. The table shows the net capacity available for trading. A positive value denotes export, while a negative value represents import.

High export · Export · Neutral · Import · High import

24. For the countries outside the scope we assumed the same electricity demand as the North Seas countries.

5.

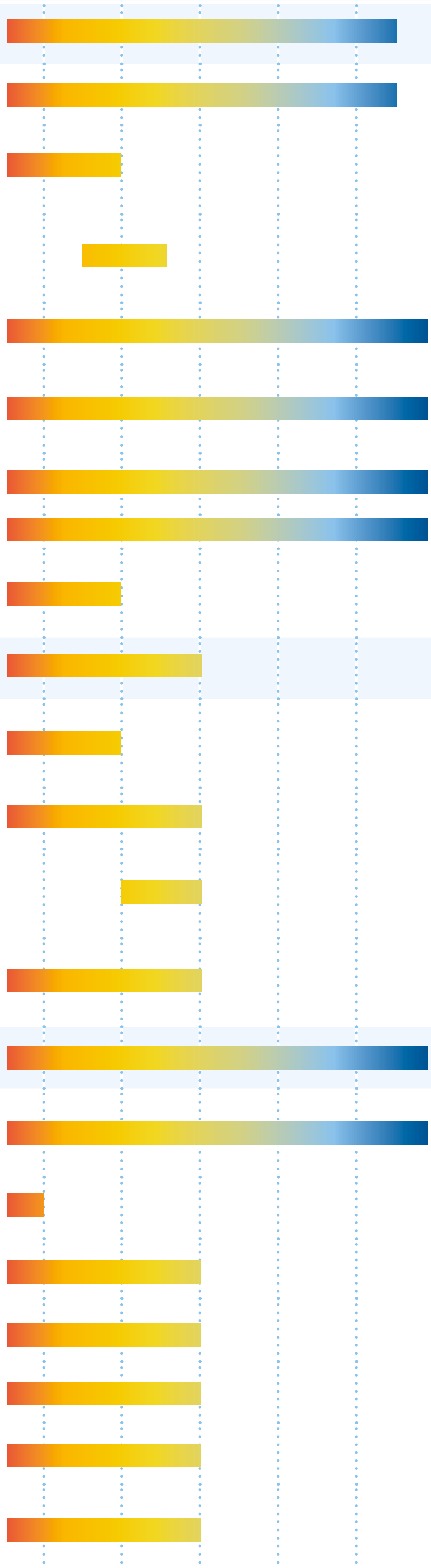
POLICY ROADMAP



In this chapter we list in one place all the policy recommendations that we have identified elsewhere in the report, along with a suggested timeline for action in order to realise the 450 GW vision by 2050.

ACTIONS	TODAY	2020-2021	2022-2025	2026-2028	2028-2030	POST-2030
1. Governments should set ambitious maritime spatial planning policies to deliver 450 GW by 2050.						
• Set ambitious targets for renewables in the National Energy and Climate Plans (NECPs) to 2030 and beyond						
• Specify detailed policies to achieve such targets, starting immediately in 2020, including tender schedule and support mechanisms applicable						
• Coordinate to ensure that aggregated national targets are robust enough to pave the way for 450 GW by 2050						
• Coordinate National Energy and Climate Plans (NECPs) with the European Commission in regard to timely availability of sites using each country's Maritime Spatial Plan (MSP)						
• National maritime spatial plans should align, in the short term, with targets in NCEPs and must be published before March 2021 in accordance with the maritime spatial planning (MSP) Directive						
• Coordinate internationally, share national plans and coordinate decisions at basin-level to optimise the use of sea space						
• Establish regional fora for maritime spatial planning discussions with society						
• Design a regulatory framework to allow co-use of wind farm areas with other sea users, including aquaculture, fisheries, other energy sources and defence activities						
• Explore and promote the co-existence of wind farms and natural protected areas, exploiting the potential of wind energy to serve restoration and conservation goals						
• Increase the leasing area for offshore wind energy from 2025 onwards in order to realise the 2050 vision						
• Accelerate the implementation of Strategic Environmental Assessments (SEA)						
• Consider up to 450 GW of offshore wind in international strategic environmental assessments						
• Harmonise methodologies for carrying out environmental impact assessments						
• Create an open-source repository for environmental impact assessment data and information						
2. Governments should ensure that permitting and other relevant authorities have the necessary expertise and resources to consent enough sites.						
• Prepare for an increase in workload from 2022, which means they will need to develop resource and skills plans by the end of 2020 and begin recruitment and training by the end of 2021						
• Reapply best practices from other markets and share information across authorities						
• Establish one-stop shops for consenting projects and work towards the simplification of permitting procedures in line with the recast Renewable Energy Directive						
• Explore open-door consenting procedures where industry can take on part of the initial development work as from 2025						

ACTIONS	TODAY	2020-2021	2022-2025	2026-2028	2028-2030	POST-2030
3. Governments should accelerate the expansion of the necessary on and offshore grid infrastructure.						
• Offer developers the option to build their own grid connections to shore for offshore wind projects in order to continue cost reductions						
• Coordinate tender schedules between countries with TSOs' regional development plans to allow the connection of wind farms to interconnectors on time						
• Coordinate a long-term vision with clear milestones for an integrated grid in the North Seas based on radial, hybrid, meshed connections, storage and power-to-x						
• Accelerate the permitting and building of projects of common interest						
• Coordinate and share best practices for grid optimisation and system operation with large amounts of renewable energy and electrification of most energy uses						
• Increase the funds for developing and reinforcing electricity infrastructure at national level						
• Increase interconnectivity between countries to 15% by 2030						
• Update grid modelling results for TYNDP-2018 with 2030 volumes to identify grid onshore reinforcements and implement in grid national plans						
4. The EU should elaborate a clear regulatory framework for offshore hybrid projects, which comprises.						
• The compatibility of offshore hybrid assets with article 16 from the EU electricity regulation that establishes 70% of available transmission capacity in all interconnectors for trading purposes						
• Compliance with capacity allocation and congestion management rules						
• Revenue stabilisation mechanisms applicable to offshore hybrids including the value of flexibility technologies like storage and power-to-x						
• Consistency with unbundling rules in the Third Energy Package with regard to ownership, construction and operation of offshore hybrid assets						
5. Governments should accelerate the electrification of transport, heating and industrial processes.						
• This process must be aligned with National Energy and Climate Plans (NECPs) considering offshore wind and other generation and grid technologies						
• Set clear electrification targets in National Energy and Climate Plans (NECPs)						
6. Governments should ensure visibility and confidence in volumes and revenue schemes.						
• Design revenue stabilisation models and auction mechanisms at optimal costs for treasuries						
• Update mechanisms for selling energy and other grid services nationally to provide stable revenues						
• Update mechanisms for cross-border selling of power and services needed from 2025						
• Technical standards must be harmonised to help minimise repeat work without stifling innovation. The implementation of those standards must be coordinated across Europe.						



6. ASSUMPTIONS UNDERPINNING OUR VISION

6.1. TECHNOLOGY

Here, we describe the typical technology operating in 2050. This is based on average 2040 installations rather than state of the art in 2050.

Turbines

The offshore wind turbines at a typical site in 2050 will have rated capacities of 20-25 MW. Radical developments such as airborne wind could be available but are not assumed to be a major part of the energy mix.

Reuse or recycling solutions at net-zero cost will be available for most wind farm components being decommissioned, including blades.

Offshore wind farms

Turbines will be in farms of 1 GW to 5 GW. Installation methods will be similar to current practices, but with larger installation vessels available.

Operations, maintenance and service (OMS) will mainly involve service operation vessels (SOVs) and will also make extensive use of technologies to reduce human effort and exposure to risk.

There will be reduced reliance on human effort through the use of automated systems, drones, sensors and actuators. Wind farms will last at least 30 years before a site is repowered or decommissioned, with offshore substations and export cables being designed such that they can be maintained and re-used for at least one further project.

Floating offshore wind

Floating offshore wind will be considered as simply another choice of foundation solution available for deployment on a site-specific basis, rather than as a separate offshore wind sector. Floating foundation solutions for areas with sea ice will be available. Between 100 and 150 GW of the 450 GW are anticipated to be floating.

6.2. SUPPLY CHAIN

The supply chain will have reached a capacity and installation rate of over 20 GW pa to get to 450 GW by 2050, but will have ramped down (or diversified to other markets) over a reasonable period to the required replacement rate by 2050.

The supply chains for turbines, foundations, cables, vessels and ports services will have the capacity to produce and install between 12 GW and 15 GW of offshore wind pa. This is the average replacement rate required to repower older wind farms and maintain offshore wind capacity at 450 GW from 2050 onwards.

6.3. OFFSHORE WIND MARKET DYNAMICS

Between five and ten project developers will be active in the market, ensuring competition for new projects.

There will be at least three turbine suppliers and a competitive supply chain for fixed and floating foundations, cables and substations, installation vessels and Operation and Maintenance Services activities.

Multiple ports will support each of the Atlantic, North Sea, Baltic Sea and Mediterranean basins. Some will provide capability to support installation and Operation and Maintenance Services, while some will focus on one or the other, depending on location and regional demand.

6.4. GENERAL ASSUMPTIONS ABOUT THE ENERGY SYSTEM

The vision of 450 GW of offshore wind capacity is predicated on the assumption that, by 2050, Europe has transitioned to an energy system that is founded on renewable sources of energy, with electrification and integration across all energy consumption sectors.

This analysis assumes that:

- Europe will have 650-700 GW of onshore wind capacity in addition to the 450 GW of offshore wind capacity;
- All European countries will develop and implement national renewable energy action plans that consider the EU's long-term greenhouse gas emissions reduction objective;
- National permitting procedures are streamlined to allow for the cost-effective deployment of offshore wind energy;
- A reformed EU Emissions Trading System provides for a high and stable carbon price, disincentivising investments in carbon-intensive and inefficient power plants;
- There will be ongoing contributions to the development of the energy system from electrification, hydrogen, power-to-x, energy efficiency and pursuit of a low waste circular economy; and
- There will be more bio-energy with carbon capture and storage (BECCS) and carbon capture and storage (CCS) than the COMBO scenario of the EC's A Clean Planet for All.

6.5. OFFSHORE GRID

In 2050 there will be a mix of grid ownership models.

Grid technology

In 2050, the electricity grid will be a converter-based system, with little physical (spinning) inertia in the system. The grid will transmit power from many geographically dispersed generators, rather than from a few large generators. To facilitate this change, we assume that Europe will have overcome the technical challenges of transient stability.

Generation, transmission, distribution, and customer systems will be a long way towards a single, dynamic and holistic system. Distributed systems, micro-grids and customer assets (such as batteries) will be an integral part of the system.

The physical grid will be optimised to meet demands, mainly via upgrades of dynamic line and transformer ratings, but also with much new-build. Transmission lines will be reused when thermal assets are retired. Additionally, new technologies for AC and DC transmission and modular power flow control will be needed. We have assumed that by 2050 there will be cost-competitive long-distance underground transmission.

Grid locations

According to our estimates, six offshore wind connection hubs will be built over the next three decades: four in the North Sea and two in the Baltic. All of these will connect to different jurisdictions, adding strength and flexibility to the network.

The longer links and large farm sizes mean that high voltage direct current (HVDC) grid infrastructure will play an increasingly important role. By 2050, we have assumed that HVDC links will make up a large proportion of the grid, both offshore and in onshore interconnection.

6.6. MARITIME SPATIAL PLANNING AND MULTI-USE

Sea use

We estimate that:

- Shipping corridors will be adapted to new transport needs, available technology, hydrographic conditions and port facilities, taking environmentally sensitive areas and key permanent structures into consideration.
- Visual impact from offshore wind farms will remain modest, with no wind farms developed close to shore or important tourism areas.
- Through improvements in technology, Europe will have overcome deployment constraints imposed by interference with military aviation, civilian aviation and aviation and weather radars. The resolution of spatial conflicts with the military will have unlocked other areas.
- Multi-use of the space occupied by offshore wind farms will be common, for example with aquaculture, passive fishing, the combination of energy sources, and/or environmental restoration.

We have assumed a reduction in the currently excluded areas. However, new constraints will likely emerge, so the overall excluded area is likely to remain the same.

Environmental impact

We have assumed that all EU Member States will prioritise reaching and maintaining the EU's Marine Strategy Framework Directive's Good Environmental Status.

Environmental impacts of offshore wind farms will decrease through new foundation and installation technology, use of low-emission vessels during the operational phase and through new environmental monitoring (real-time monitoring of bird migration, for example).

New technologies may allow biodiversity restoration or creation measures, which will increase the social acceptance for wind farms in protected areas.

Maritime spatial planning

We estimate that areas for different uses will be assigned using maritime spatial planning (MSP), maintaining an adaptive management approach and allowing change based on emerging conditions (demographic, economic or climate change), technologies and new forms of multiple uses.

We estimate that, in addition to National Plans, there will be coordinated maritime spatial plans at the level of each sea basin, agreed between jurisdictions as a "shared vision" by 2025 and "legally binding" before 2035. This will require major cross-border cooperation and planning. And it will enable leasing and project development to progress for much of the 450 GW with confidence in the ability to consent and deliver projects.

Maritime spatial planning at sea-basin level will improve the definition and planning of connectivity corridors (shipping, electricity, pipelines and environmental). Maritime spatial planning at sea-basin level will also regulate cross-border projects, particularly related to energy and environment and the balancing of their costs, impacts and benefits.

We anticipate that national maritime spatial plans will be developed by the end of 2021 (as required by the European maritime spatial planning Directive) before being used as input at sea basin level. For this reason, it is important that in time, single country maritime spatial plans are developed based on commonly agreed environmental, economic and social objectives and targets developed for the whole basin.

APPENDIX

APPENDIX A: OFFSHORE WIND VISION FOR 2050

TABLE 10
Location of 380 GW of offshore wind in 2050 vision, North Seas, by country

COUNTRY/AREA	CAPACITY (GW)
Ireland	22.2
France (excl. Mediterranean)	40.5
UK	80.0
Belgium	6.0
Netherlands	60.0
Germany	35.5
Denmark	35.0
Norway	29.6
Sweden	19.8
Finland	15.5
Estonia	1.5
Latvia	2.9
Lithuania	3.6
Poland	27.9
Total	380

TABLE 11
Location of 70 GW of offshore wind in 2050 vision, Southern European Waters, by country

COUNTRY/AREA	CAPACITY (GW)
Portugal	9.0
Spain	13.0
France (Mediterranean)	17.4
Rest of Mediterranean	30.6
Total	70

TABLE 12
Location of 380 GW of offshore wind in 2050 vision, North Seas, by country

COUNTRY/AREA	CAPACITY (GW)
Atlantic (including Irish Sea)	85.4
North Sea	211.6
Baltic	83.0
Mediterranean	70.0
Total	450

APPENDIX B: ABOUT THE AUTHORS

BVG Associates provides strategy consulting in renewable energy. We help our clients to do new things, think in new ways and solve tough problems. Our practical thinking integrates the business, economics and technology of renewable energy generation systems. We combine deep wind industry knowledge with skills gained in the world of business consulting. Our purpose is to help our clients succeed in a sustainable global electricity generation mix founded on renewables.

- BVG Associates was formed in 2006 at the start of the offshore wind industry.
- We have a global client base, including customers of all sizes in Europe, North America, South America, Asia and Australia.
- Our highly experienced team has an average of over 10 years' experience in renewable energy.
- Most of our work is advising private clients investing in manufacturing, technology and renewable energy projects.
- We've also published many landmark reports on the future of the industry, cost of energy and supply chain.

For more information, visit www.bvgassociates.com or email info@bvgassociates.com

WindEurope is the voice of the wind industry, actively promoting wind power in Europe and worldwide. It has over 400 members with headquarters in more than 35 countries, including the leading wind turbine manufacturers, component suppliers, research institutes, national wind energy associations, developers, contractors, electricity providers, financial institutions, insurance companies and consultants. This combined strength makes WindEurope Europe's largest and most powerful wind energy network.

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