BEYOND HIGH WINDS: HARD TRUTHS ABOUT 'MADE IN THE EU' OFFSHORE WIND IN LOWER WIND REGIONS

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CEPS IN-DEPTH ANALYSIS

July, 2025-10

SUMMARY

Improving the currently limited prospects for offshore wind in Europe's lower wind speed regions, such as the Black Sea and Eastern Mediterranean, involves addressing several challenges. Chief among them are the noticeable lack of developer interest and an overall weak business case.

This report examines how lower wind speeds impact annual energy production and, in turn, worsen project economics, making these regions less attractive compared with high-wind areas. While certain technological adaptations can optimise energy capture, inherently weaker winds reduce the overall appeal for developers. This factor should be considered in any policy for offshore wind deployments in lower-wind regions.

Today, the global offshore wind market is dominated by commercially deployed bottom-fixed technologies. In this segment, China is leading installations in lower-wind areas, while Europe is largely absent. Yet, Europe still retains a competitive edge in floating wind technologies, with several small-scale farms recently going online in high-wind regions.

A forward-looking strategy is needed to drive EU innovation in floating offshore wind for lower-wind regions – capitalising on a window of opportunity that remains open. While China is likely to catch up regardless, there is still a chance for Europe to carve out its own space in this emerging segment, rather than relying exclusively on Chinese technology and supply chains in the future.

This will not be easy. Market demand for offshore wind in Europe's lower-wind regions remains limited, compounded by uninspiring project economics in these areas. That stifles both the development and deployment of floating wind concepts – and vice versa. Supply chain congestion and elevated costs in the wind industry, combined with an overall unfavourable macroeconomic context in recent years, have further constrained financing for prototypes in regions with lower wind speeds.

Without immediate action, the EU risks losing its technological edge in floating technologies for lower wind speed areas, further undermining decarbonisation efforts in southern Europe.

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The authors thank Robert Praas and Francisco Rios from the Data Science Team at CEPS for their help with the data set and data visualisation. The research project was supported by a dedicated team whose contributions were invaluable at every stage, from project management to editing (with particular thanks going to our dedicated editor, Kathleen King).

The authors also thank Mareike Leimeister, Research Associate at the Fraunhofer-Institut für Windenergiesysteme (Fraunhofer IWES), and Jose Rapha, Project Engineer, Power Systems at the Institut de Recerca en Energia de Catalunya (IREC), for providing feedback and comments on earlier drafts. Ad hoc discussions with BLOW partners have helped further refine the ideas. Any errors or omissions in the report remain the sole responsibility of the authors, and any views expressed are solely those of the authors.

This paper was prepared in the context of the BLOW project, which has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No. *101084323*.

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1. INTRODUCTION

For decades, southern Europe has remained a *terra incognita* for offshore wind. This is in stark contrast to northern parts of Europe, where offshore wind technologies have been actively pursued since the early 1990s.

Recently, however, the Mediterranean and Black Seas have been placed in the spotlight for offshore wind opportunities. This increased interest is highlighted by their inclusion in the EU Offshore Renewable Energy Strategy of 2020. Furthermore, non-binding offshore wind targets were established for these sea basins in 2023 (updated in 2024), following revision of the TEN-E Regulation in May 2022[1]. For the South and East offshore grids[2], these targets are set to reach up to 4.41 GW by 2030 and 25.1 GW by 2050[3] (European Commission, 2024).

This growing interest in offshore wind in southern Europe[4] has not come out of the blue. Offshore wind energy has emerged as a cornerstone of the energy transition, owing to its several inherent advantages. Among these benefits are reduced turbulence and enhanced wind speeds, which contribute to higher capacity factors compared with onshore wind or some other renewable energy sources (Desalegn et al., 2023). These benefits make offshore wind an effective solution for decarbonising energy systems and a strong contender for substituting shares of power generation traditionally filled by fossil fuels.

Given its stable and substantial output, offshore wind energy represents not only a reliable source of low-carbon electricity but also a critical enabler for broader energy system integration. Offshore wind holds potential for integration with power-to-X technologies, which allow for the conversion of (surplus) renewable electricity into hydrogen or synthetic gases. This provides a further promising pathway for decarbonising

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[1] The goal is at least 60 GW of offshore wind in the EU by 2030 and 300 GW by 2050, as outlined in the Offshore Renewable Energy Strategy (European Commission, 2020). This target was increased to approximately 111 GW (range of 109-111 GW) by 2030, based on the non-binding targets agreed in 2023, and downgraded to approximately 88 GW (range of 86-89 GW) in 2024 (European Commission 2023 and 2024). The expectation is to move beyond national approaches and towards regional, basin-focused cooperation.

[2] That is, in Bulgaria, Romania, Croatia, Slovenia, Italy, Greece, and Cyprus.

[3] These targets were downgraded compared with the one set in January 2023, with revised figures of 8.81 GW and 25.9 GW by 2030 and 2050, respectively (European Commission, 2023).

Although these targets are more modest compared with the commitments for the Northern Seas offshore grids (56.6 GW and 215.9-218.9 GW by 2030 and 2050, respectively), the current 2030 target for Southern and Eastern offshore grids is equivalent to 21 % of the EU’s offshore wind installed capacity by 2024.

[4] For the purpose of this study, southern Europe includes the maritime countries of the South and East offshore grids as defined by the European Commission (see footnote 2). It is interchangeably referred to as the Black Sea and the Eastern Mediterranean.

sectors beyond power generation, including transport, industry, and heating (Singlitico et al., 2021).

Much of the discussion around offshore wind development in southern Europe has focused on the need to establish robust regulatory frameworks, coherent support schemes, and finalise maritime spatial delimitation (Bălan et al., 2020 and 2023; Constantin et al., 2024; CSD, 2022 and 2024; Trifonova and Vladimirov, 2021). The technical and economic specificities of offshore wind, closely tied to the wind conditions of these regions, have received far less attention. Yet, these factors could ultimately serve as a tiebreaker in the success or failure of offshore wind deployment in southern Europe.

The lower average wind speeds in southern Europe, compared with regions like northern Europe where offshore wind projects have thrived, have significant implications for project economics, as they result in lower energy output per se. Making offshore wind projects economically viable – also by ensuring their sufficient energy production – in these lower-wind regions requires specialised technological adaptations to optimise energy extraction. This adds to the bill. In times of economic strain and inflationary pressures, with rising costs for materials and project development, all these factors can become decisive for project developers and deter them from lower-wind areas when selecting project locations.

Innovative solutions, particularly in floating offshore wind technologies for lower-wind areas, may help facilitate access to more stable winds further offshore. Even so, there is still a long way to go to advance prototype testing to a technology readiness level (TRL) of at least TRL 7[5].

This report provides an overview of the state of offshore wind technologies in lower-wind regions. It examines the key factors influencing offshore wind power output, as well as the market conditions and economics of these technologies.

The analysis is based on an in-house portfolio assessment of global and European offshore wind energy and research conducted as part of the Horizon Europe BLOW project. It included stakeholder interviews and discussions with actors involved in the offshore wind sector in these regions. Building on this analysis, the report discusses the policy implications of the current state of affairs for offshore wind in the lower-wind regions of southern Europe.

[5] In the context of EU research and innovation, TRL is the scale used to assess how ready a technology is for deployment and commercial application. TRL varies in scale from 1 to 9, where TRL 9 is the highest level (product on the market).

Section 2 begins by looking at the primary factor affecting wind power output – wind speed – and its impact on project economics. Section 3 provides a brief overview of current offshore wind technologies suited to various wind speeds, seabed conditions, and water depths across high- and lower-wind areas. Section 4 provides a snapshot of the global offshore wind market. It utilises an in-house model that matches wind speeds with current, planned, and announced wind projects worldwide to offer a broad perspective on the global distribution of offshore wind farms across different wind speed classes.

The report concludes by suggesting strategies the EU could adopt to advance offshore wind in lower-wind areas. Without targeted investment and policy support, floating wind technologies may fail to reach technological maturity and risk being outpaced by China's rapid advancements. This would have a negative impact on southern Europe and would require a reassessment of the role of offshore wind in the region's future energy system.

2. THE IMPACT OF WIND CLASS ON OFFSHORE WIND TECHNOLOGY, COSTS AND PROJECT ECONOMICS

Variations in wind speed across geographical areas have significant implications for offshore wind technology and its associated costs. These differences are rooted in the physics of wind energy, where even minor reductions in wind speed can substantially impact wind power generation. In lower-wind regions, specialised technological adaptations to wind turbines are critical for optimising wind power extraction. They come with added costs though. When these are combined with the inherently lower energy potential of these regions, they make offshore wind projects less economically attractive compared with high-wind areas. Therefore, these factors should be carefully considered in policy design for offshore wind deployment in lower-wind regions.

2.1 WIND CLASSES

Geographical regions vary in terms of wind conditions and speed and are thus categorised into different wind classes. These wind classes are defined within a standardised framework designed to assess the wind resources across different areas based on a range of factors, including mean annual wind speed, turbulence, and extreme gusts (IEC, 2019).

The International Electrotechnical Commission (IEC) offers a globally recognised classification for wind regions, which is determined by the annual average wind speed at hub height and turbulence parameters. This classification, outlined in the IEC 61400-1 set of design requirements, serves as the foundation for wind energy assessment and establishes universally-acknowledged standards for the design of wind turbines and generators, tailored to diverse wind conditions (IEC, 2019). Although various other factors are considered in the classification, annual mean wind speed serves as the determining variable for offshore wind classes. This is even more relevant at heights of at least 100 m above the sea surface[6], which typically tend to exceed those above land and exhibit less turbulence and greater consistency (Desalegn et al., 2023).

Conventionally, based on this classification, it is common to relate average wind speeds directly to wind classes. Wind areas are grouped into three main classes (Table 1): Class III, with annual mean wind speeds under 7.5 m/s; Class II, ranging between 7.5 and 8.5 m/s; and Class I, exceeding 8.5 m/s. These classes are generally (though with some degree of simplification) referred to as ‘low wind’, ‘medium wind’, and ‘high wind’, respectively.

[6] Currently, that is a typical hub height level. While some offshore turbine hub heights have reached 150 m (e.g. GE Vernova’s GE Halide-X 14 MW), these are still rare. Most large, commercially available offshore wind turbines are currently around 100 m.

Table 1. IEC wind class categorisation based on annual mean wind speeds (m/s)

IEC class	Common nomenclature	Annual mean wind speed range (m/s)
I	High wind	10-8.5
II	Medium wind	8.5-7.5
III	Low wind	7.5-6.0
IV*	Very low wind	<6.0

Source: Adapted from Onea and Rusu (2022).

Note: *IEC Class IV winds are not typically considered suitable for utility-scale wind farms (see Langer et al. (2022).

The classification of offshore winds reveals their heterogeneity across different geographic areas. In North America, the US and Canada have extensive swathes of Class I regions. In South America, a significant portion of the Brazilian coastline is Class II/III, while Chile and Argentina have almost exclusively Class I winds with some areas reaching average speeds of over 14 m/s.

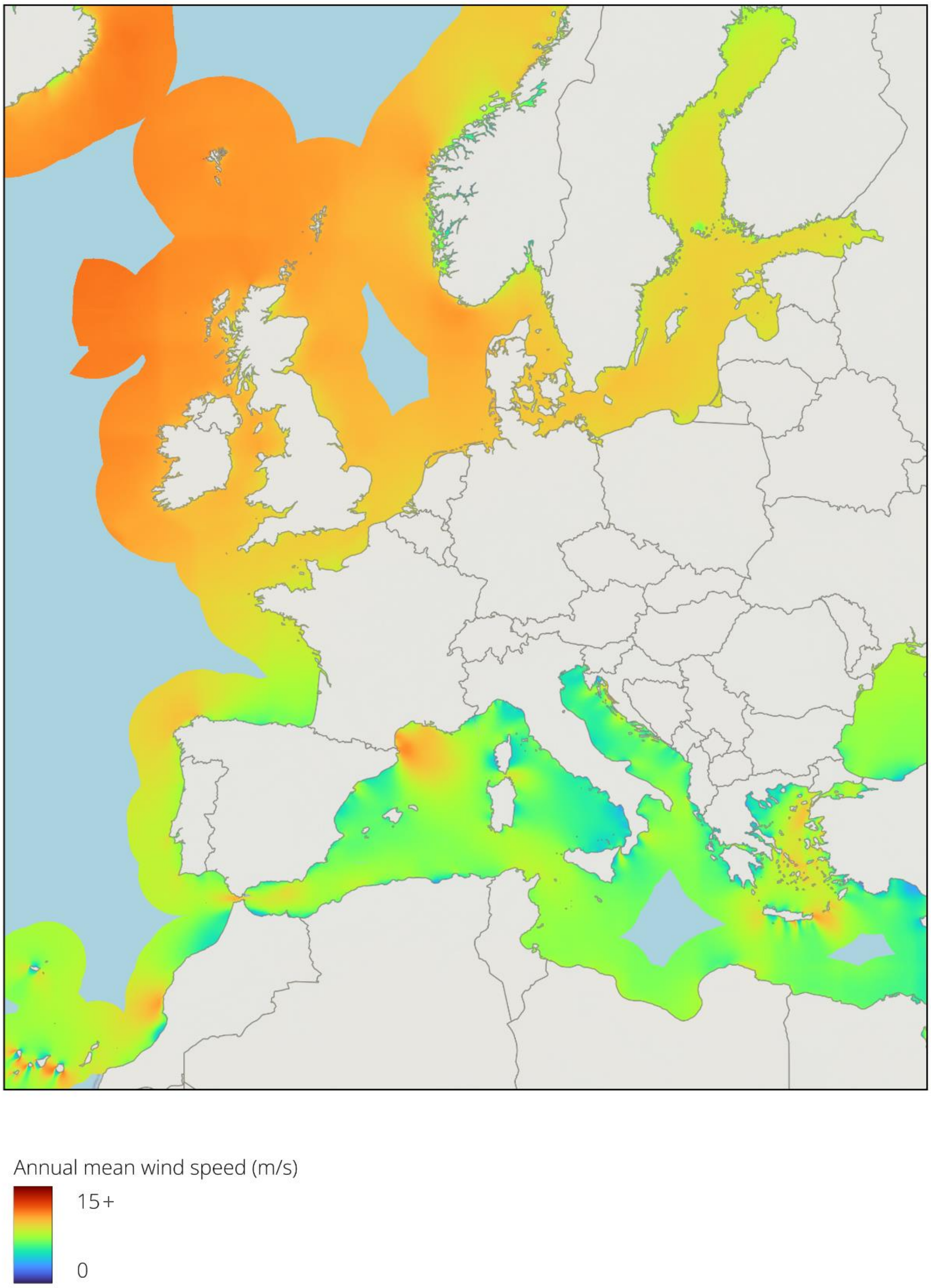
In Asia, the northern areas of China's coastline, as well as South Korea, Vietnam and India, are predominantly rated as Class II/III areas. Most countries in Southeastern Asia, including Indonesia, Malaysia and Myanmar, primarily fall under Class III, with wind speeds rarely surpassing 6 m/s.

In Africa, stretches of the West African coastline, such as from Guinea to Angola, are overwhelmingly Class III, while the southern coast provides Namibia and South Africa with Class I winds. The southern coast of Australia enjoys high wind speeds, while the northern parts fall into Class II/III categories.

Within Europe (Figure 1), areas in the north, Baltic, and Irish Seas, as well as those along the Atlantic coast, showcase extensive regions with annual mean wind speeds surpassing 10 m/s. The Exclusive Economic Zones of Belgium, Denmark, France, Ireland, the Netherlands, Norway, and the UK, as well as Poland and the Baltic States, mostly fall within Class I. These offshore areas, characterised by high-intensity winds, offer abundant opportunities for harnessing substantial wind energy resources.

However, other maritime areas in Europe experience weaker offshore winds. The coastal states of the Black and Mediterranean Seas, such as Bulgaria, Romania, Croatia, Greece, and Italy, have limited (if any) offshore areas attaining Class I wind conditions (except for some localised pockets of high wind speeds). The majority of their wind resources are deemed Class II and Class III, with annual mean wind speeds ranging from 6 to 8.5 m/s.

Figure 1. Europe's offshore wind resource – annual mean wind speeds (m/s) at 100 m above sea-level



Source: authors' compilation from Global Wind Atlas (2025)[7].

[7] For satellite-derived measurements of offshore wind speeds at specific heights, see the Global Wind Atlas.

2.2 HOW WIND CLASSES DETERMINE THE POWER OF WIND AND TECHNICAL OFFSHORE WIND POTENTIAL

Wind classes are crucial in determining power outputs and, consequently, the technical potential for wind energy in a specific area. Due to the fundamental physics of wind energy, even a slight decrease in the average wind speed can result in a marked reduction in the potential power extraction. As a result, offshore wind farms located in higher wind speed regions capture more energy from stronger and more consistent winds – maximising energy yields from current wind turbine technologies and accessing higher power densities[8]. In contrast, regions with lower wind speeds face major challenges in achieving similar energy outputs and require technological adaptations and innovations to optimise wind power extraction (Nizamani et al., 2024).

The power output a wind turbine can extract from the wind is directly proportional to its swept area and the cube of the wind speed – governed by the *cubic power law*:

$$P = \frac{1}{2}\rho v^3 A C_P \tag{1}$$

where P is the power output (W), ρ is the air density (kg/m^3), v is the wind speed (m/s), A is the wind turbine's swept area (m^2), and C_p is the power coefficient[9].

This law underscores the immense influence of wind speed on power generation. A slight increase in wind yields will significantly increase the electricity produced. For example, doubling the wind speed raises the available power eightfold. This means that *nearly three times* as much electricity can be generated from the *same* turbine placed in a site receiving 10 m/s wind speeds against an alternative site receiving 7 m/s wind speeds. Consider the difference between placing the same turbine in the high-wind Golfe du Lion in southern France (approximately 10.5 m/s) versus a few hundred kilometres away off the eastern coast of Sardegna (around 6.5 m/s). The turbine in the French waters could produce more than four times as much electricity as the same turbine in the Italian waters. Hence, nothing is more influential on the end power extraction as siting a turbine in an area with a greater wind resource.

In addition to the constraints imposed by the cubic power law, wind turbine designers must also factor in Betz's Law. Accordingly, the maximum power that can be extracted from wind is 59.3 % of the incoming energy in the wind. The capacity factor of a turbine specifies the actual energy conversion relative to the theoretically maximum possible output of energy based on the turbine's nominal power. Presently, the theoretical

[8] Power density is the power available per unit area, expressed in W/m^2. Power densities are greater at offshore locations with high wind speeds (Desalegn et al., 2023).

[9] Power coefficient is the ratio of power produced to the maximum available power (Douak et al., 2018).

maximum for commercial turbines may be estimated as around 50 %, which – considering the Betz limit – translates into only about 30 % of the total wind's incoming kinetic energy. In practice, the total energy conversion can be as low as below 15 %.

Although in Class II/III areas there is substantial technical potential over large areas, they cannot overcome the inherent problem: physical energy potential is a priori lower in Class II/III winds than in Class I, meaning that less energy can be extracted. For countries with only low- and medium-speed winds, this presents potentially show-stopping challenges.

The combination of a good wind resource and suitable technological adaptations can maximise energy outputs. Thus far, deploying wind turbines that are typically optimised for Class I winds in Class II/III conditions often results in lower performance, resulting in lower capacity factors. The physical shortcomings require technological adjustments to optimise power output.

2.3 TECHNOLOGICAL SOLUTIONS FOR CLASS II/III AND THEIR COST IMPLICATIONS

As explained in the previous section, the characteristics of wind require technological adjustments to optimise energy output. Appropriate technological adaptations for turbines in lower wind speed areas can enhance the capacity factors of Class II/III wind turbines – bringing them closer to those in Class I areas – and optimise their performance despite the lower resource.

A range of design modifications can be employed to enhance the suitability of offshore wind turbines for the conditions of Class II/III, ultimately elevating their annual energy production (AEP). As discussed in Section 2.2, the extractable power from a wind turbine is directly proportional to the turbine's swept area (A) and to the cube of the wind speed (v). Therefore, one of the key technological solutions revolves around enlarging the rotor's diameter by extending the turbine blades. Doubling their length results in a potential fourfold increase in wind power extraction. Increasing blade length overcomes the wind speed limitation: it exposes the turbine to a greater extractable wind resource without a set ceiling, unlike, for example, increasing the capacity factor of a turbine by improving blade design and minimising energy losses.

Recently, the market has witnessed a notable drive towards ever-larger turbines. Yet this drive for a rapid growth in size and capacity is due to the economies of scale and an effort to catch more from Class I winds, rather than an attempt to increase the capacity factor of Class II/III turbines. This trend, though, raises concerns about the need for standardisation and the limits of *gigantomania*.

However, the pursuit of longer blade length entails additional complications. As larger rotors need higher hubs, they require the utilisation of advanced strengthening techniques to safeguard against blade breakage, not to mention more steel and other materials. This elevates development and production costs.

In addition, with the pioneering efforts of key manufacturers, such as Vestas and Goldwind, pushing blade lengths beyond 100 m[10], construction and shipping costs for blades exceeding 90 m are destined to rise. Moreover, in contrast with onshore wind turbines, the transportation of offshore wind blades via road infrastructure becomes unfeasible with current logistical capabilities. For longer blades, this also adds to dependence on (and the costs of) installation vessels and their availability in the market. As a result, blades of this magnitude might necessitate on-site construction or modular assembly at the port, demanding new port infrastructure with the consequent increase of costs.

Adjustments for lower wind conditions typically include reducing the rating of wind turbines (i.e. their maximum power output), which typically results in larger rotors relative to the size of their generators. This enables them to capture more wind in lower wind conditions and offer enhanced electricity production in regions characterised by lower wind speeds, effectively shifting a project's power curve to accommodate these conditions (Aegir et al., 2021). This adjustment may require a greater number of turbines to achieve the same total capacity. Meanwhile, more turbines may imply rising expenditures.

Beyond enlarging the rotor's physical dimensions to increase the potential for capturing wind energy, several strategies can enhance a turbine's capacity factor, converting more of the wind's energy into usable power (Table 2):

- **Lighter and less stiff blades.** Using lighter and less rigid blades facilitates the start-up of the turbine's rotation under low wind, lowering the cut-in speed[11]. This also reduces the use of materials. In the less severe conditions of Class II/III, blades and other components do not need to be as strong as they do in the extreme conditions of Class I.

- **Direct-drive generators.** These generators omit gearboxes, thus boosting efficiency at lower wind speeds while eliminating the often-costly need for gearbox repairs. Although heavier than conventional gearbox systems and

[10] In 2023, a Goldwind turbine with a 252 m rotor diameter (GWH252-16 MW) was deployed at the Three Gorges Offshore Wind Farm in China. Vestas has developed a 15 MW, 236 m diameter offshore wind turbine (V236-15.0 MW).

[11] Cut-in speed is the minimum wind speed necessary for the turbine to start rotating, and thus generate power. Cut-in wind speeds for conventional wind turbines are typically in the range of 3-4 m/s. Turbines designed for lower wind speeds may be as low as 2.5 m/s, as in the MySE3.2-145 design (Asif Hanif et al., 2022).

associated with higher initial costs, they are commercially available. As for which generator is ideal for low-speed conditions, there is still heavy debate. Some argue that direct-drive systems will be less costly to maintain, yet others assert that geared generators are cheaper in the long term. Regardless of the type of generator, it must be rated for the high torque, low rotational speed resulting from this wind profile while also meeting grid input demands.

- Individual pitch control. Employing active pitch regulation allows the blades to rotate along their individual axes according to the incoming wind angle to capture more energy. This technology is also commercially available and not overly costly.
- Innovations in mooring systems for floating solutions. Mooring systems, comprising the physical tethers and connections between floating platforms and the seafloor, offer avenues for capturing additional wind. For floating offshore wind farms, recent technologies like single-point mooring systems enable wind turbines to align directly with the wind's direction, which potentially may increase capacity. This mooring system may trim maintenance costs due to its passive features, though its drawback is that it does not allow for wake steering[12], preventing the downstream turbines from accessing greater wind resources.

While the majority of the discussed technological solutions enhance the performance of Class II/III turbines, a fundamental caveat remains: these improvements simultaneously elevate the capacity of Class I turbines and thus further stimulate the development of the latter. Larger rotors will increase power production by similar factors regardless of the location of the turbine. However, it is worth noting that larger rotors proportionally benefit more areas with low wind, as Class I turbines already have a good capacity factor, and a larger rotor may not be worth it. Pitch regulation and generator improvements improve efficiency anywhere, and single-point mooring anchoring systems can work for floating offshore wind farms wherever the turbine is. Consequently, most of these adjustments render offshore turbines even more competitive when placed in Class I regions, in comparison with their deployment in Class II/III areas.

A vexing yet entirely logical question arises: why not first put these larger, more expensive and advanced turbines, adjusted for lower-speed wind conditions, in high wind areas, where their advantages for power extraction would be even more pronounced? The next section discusses the economic implications for Class II/III offshore wind projects.

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[12] Wake steering is a control strategy adopted by wind farms in which upstream turbines are intentionally misaligned from the incoming wind to avoid the 'wake effect' in downstream turbines. The wake effect is a phenomenon in which the wind resource increasingly degrades downwind, resulting in lower-speed and higher-turbulence winds available for the successive downwind turbines – after passing through previous upwind turbines (NREL, 2021; González-Longatt et al., 2012).

Table 2. Technological options for increasing power production of Class II/III offshore wind turbines – technology readiness level

Technological option	Relative cost	Improvement/increase in power generation	Status of development
Increase blade diameter	High	Significant	TRL 8-9 Significant efforts are needed to develop and improve manufacturing and transportation
Increase hub height	High; necessary with increasing blade size	Depends on wind profile	TRL 8-9 Significant efforts are needed to develop and improve manufacturing and transportation
Single-point mooring system for rotation into wind	Comparable to other mooring systems	Moderate, if compared with a yaw system, does not allow for wake steering	TRL 7 Various designs being tested in demonstration projects
Individual pitch control	Medium	Moderate	TRL 9 Offered on multiple major models
Constant pitch chosen based on lower wind speed	Low/None	Low	TRL 9 Turbines are calibrated to select the optimal pitch based on the wind environment
Direct-drive generator with permanent magnet generators	High; potential saving on operations and maintenance	Moderate	TRL 9 Commercially available, but the market has not agreed on cost/benefit

Source: authors' compilation.

2.4 HOW WIND CLASS AFFECTS THE ECONOMICS OF OFFSHORE WIND PROJECTS

Conventionally, the cost-effectiveness of energy sources is evaluated by the levelised cost of electricity (LCOE). This metric calculates the cost of producing a unit of electric energy by dividing the total lifetime cost of the electricity generation project by the total lifetime energy production:

$$LCOE = \frac{TAC}{E_{tot}} \qquad (2)$$

where *LCOE* is expressed in (EUR/MWh), *TAC* is the total annualised costs (EUR), and E_{tot} is the total energy output (MWh) (Upadhyay and Sharma, 2014).

LCOE accounts for the project's capital expenditure (CAPEX), operational expenditure (OPEX) and decommissioning expenditure (DECEX), as well as the weighted average cost of capital (WACC) over the project's lifetime. It enables comparison of different energy generation technologies on a consistent basis, despite differences in costs, returns, or lifespans.

Compared with onshore wind, the cost structure of offshore wind projects is more complex and expensive. Although CAPEX remains the predominant component of the cost structure (as is the case for many other renewable energy technologies), OPEX becomes increasingly significant for offshore wind projects, particularly for floating systems (Oladokun and Asemota, 2015). The proportion of maintenance and operational costs is elevated due to the inherent difficulty of accessing offshore wind platforms for regular or emergency maintenance, repairs, or major component replacements (Tumse et al., 2024; Satymov et al., 2025).

That notwithstanding, the weighted average LCOE for bottom-fixed offshore wind has shown a steady decrease over time – a 68 % reduction over 2010-2023 (IRENA, 2023; IRENA, 2024a; NREL, 2024). As always, however, the devil is in the detail. While LCOE analysis for a single wind turbine can be conducted with relatively low uncertainty (given site-specific parameters and a CAPEX-dominated cost structure), the situation becomes more complex when scaling up to an entire wind farm or comparing different sites. The uncertainty can increase substantially due to various factors, with cost differences potentially varying by up to 25 % depending on site-specific conditions, such as export cable length or wave and seabed characteristics (Offshore Wind Cost Reduction Task Force, 2012). This persisting uncertainty in determining absolute LCOE values has been acknowledged with a shift in focus towards reporting *differences in LCOE* between projects and technologies rather than precise absolute values for project cost (EPRI, 2020).

In floating offshore wind, the limited number of operational, full-scale farms renders generalisations of LCOE even more uncertain, although some estimates can be made (IREC, n.d.). Regardless of the analytical variations, it is widely accepted that the LCOEs for floating projects are higher than those of bottom-fixed projects, though the magnitude of difference between them varies depending on the study (DNV, 2023; Llorente et al., 2024; WindEurope, 2020). Still, expectations of a cost decline beyond 2030 may be plausible as floating projects advance through development, reach commercialisation, and achieve economies of scale[13]. The pace and trajectory of that cost decline nevertheless remain subject to considerable uncertainty.

Another dilemma in assessing the LCOE for offshore wind is that most general LCOE analyses assume site conditions with Class I winds, typically above 9 m/s at 100 m hub height. Calculating LCOE for sites with such average wind speeds provides investors with assurance that operational wind farms will deliver consistent and high levels of renewable energy, and that the LCOE for offshore wind is steadily decreasing. Yet, lower wind speed regions will likely experience higher LCOEs than reported owing to their lower actual power generation (compared with the power projections made under high wind speed assumptions). Since LCOE is heavily influenced by AEP, projects in lower wind speed areas need to spread their costs over fewer generated MW-hours, raising the cost per unit of energy. Consequently, the LCOEs for offshore wind projects in lower wind speed areas frequently have difficulty in achieving economic viability and competitiveness *when compared with Class I projects.*

The comparative economic disadvantages of Class II/III offshore wind projects can be mitigated – but only to a certain extent – through several options to optimise energy production. First, appropriately tailoring technologies to specific wind characteristics can improve AEP (as discussed in Section 2.3), although some of these modifications come with increased costs. Second, deploying turbines further offshore, where wind patterns tend to be more stable and consistent, can lead to more consistent AEP. As economies of scale drive component costs down, floating offshore technology may achieve a lower LCOE. All the same, the current immediate goal for floating wind technology for Class II/III areas is to progress from the current TRL 5 to at least TRL 7 by 2030 (European Commission, n.d.), a challenging leap given the substantial financial and technological barriers discussed in Section 3.

Given the uncertainties outlined above, it is unsurprising that wind developers generally exhibit reluctance towards lower AEP areas when more lucrative opportunities are readily available elsewhere in Europe. From a (European) project developer's perspective, the preferred sites for offshore wind projects have consistently been, and are likely to remain, higher wind speed areas, particularly the North Sea.

Consequently, the European offshore wind market has mainly expanded in regions with high wind speed resources, with limited focus on projects in lower wind speed areas. Similar to the onshore wind market, it is anticipated that as high wind speed sites become scarcer across Europe, interest may eventually shift to lower AEP areas. In this case,

[13] DNV (2024) projects a cost premium of 28 USD/MWh for floating offshore wind over bottom-fixed offshore wind by 2050.

however, developers might also direct their attention towards higher wind speed areas beyond Europe. Given the current pressures on the offshore wind industry in Europe, the availability of more favourable wind conditions elsewhere could further deter investment in less economically attractive Class II/III areas within Europe.

At the same time, it is worth noting that countries with Class II/III wind resources are not necessarily in direct competition with those boasting Class I wind conditions. Rather, their primary goal is to make offshore wind projects economically viable and competitive with domestic energy sources.

Price risks deriving from the present setup of the EU electricity market can also significantly amplify uncertainties for developers across all wind classes. Price stabilisation mechanisms, such as (two-way) contracts for difference (originally introduced in the UK) have recently been incorporated into the EU's electricity market design with arguably high hopes for providing much-needed price certainty for developers.

But recent auctions in Class I areas have seen insufficient bidder participation when strike prices have been set below anticipated costs and revenue forecasts (S&P Global, 2024). In Class II/III regions, characterised by weaker resource potential, these price risks may be even more pronounced and sensitive: the less favourable wind conditions in these areas, resulting in lower AEP and thus higher LCOE, raise the financial risks for developers.

Floating offshore wind is even more sensitive to price risks – the risks are even greater for projects in lower wind areas. For these projects, to succeed, high technology risks should not be compounded by price uncertainty: the lack of price stability has played a major role in deterring investors. Price stabilisation mechanisms are essential, especially in the context of lower AEP, to make these projects bankable.

An offtake agreement is thus highly desirable. Floating offshore wind projects in lower wind areas can present stronger business cases when directly linked to large consumers. One of the most promising opportunities remains attaching floating demonstration projects to supply offshore oil and gas platforms. In these cases, export cables – which may be prohibitively expensive due to the current macroeconomic environment and thus difficult to recuperate financially – can be avoided altogether.

It is important to keep in mind these limitations to make Class II/III projects attractive to developers.

3. OFFSHORE WIND SYSTEMS – BOTTOM-FIXED AND FLOATING – ACROSS WIND CLASSES

Within the offshore wind sector, two distinct types of support structures have gained prominence – bottom-fixed and floating systems. The choice between these systems largely depends on the geographical conditions of the project development site but may also entail a more general trade-off: bottom-fixed systems are typically installed closer to the shore, where installation is easier, but these locations may encounter *comparatively* less consistent wind speeds. By contrast, floating systems, while more technically complex and therefore potentially costlier, can be deployed further offshore where wind speeds are typically more consistent (WindEurope, 2017 and 2018).

Offshore wind development began with bottom-fixed structures in shallow waters with high wind resources, enabling their rapid commercialisation. Since then, bottom-fixed technologies have been adapted for lower-wind regions, with Chinese manufacturers at the forefront of these efforts. If projects in lower wind speed areas in Europe are to advance, there is a need to reflect upon their feasibility in the domestic European market.

For deeper waters and/or steep coastal profiles, floating wind turbines have improved in recent years. However, similar to bottom-fixed turbines, this development has primarily focused on high wind speed areas where more favourable conditions provide an optimal environment for validating these technologies. There is a potential window of opportunity for European technology providers to leverage their expertise in high wind floating solutions to advance these technologies towards operational prototypes in Class II/III areas.

Still, this nascent industry faces a ‘chicken and egg’ dilemma: low demand slows technological progress, while limited advancements hinder market growth, creating a bottleneck for further development in lower-wind areas. Additionally, the inherently higher costs associated with floating technology, as discussed in Section 2, present another sizeable barrier. Although European developers currently lead in floating wind technologies, this window of opportunity may soon close as Chinese technology rapidly moves forward in the field.

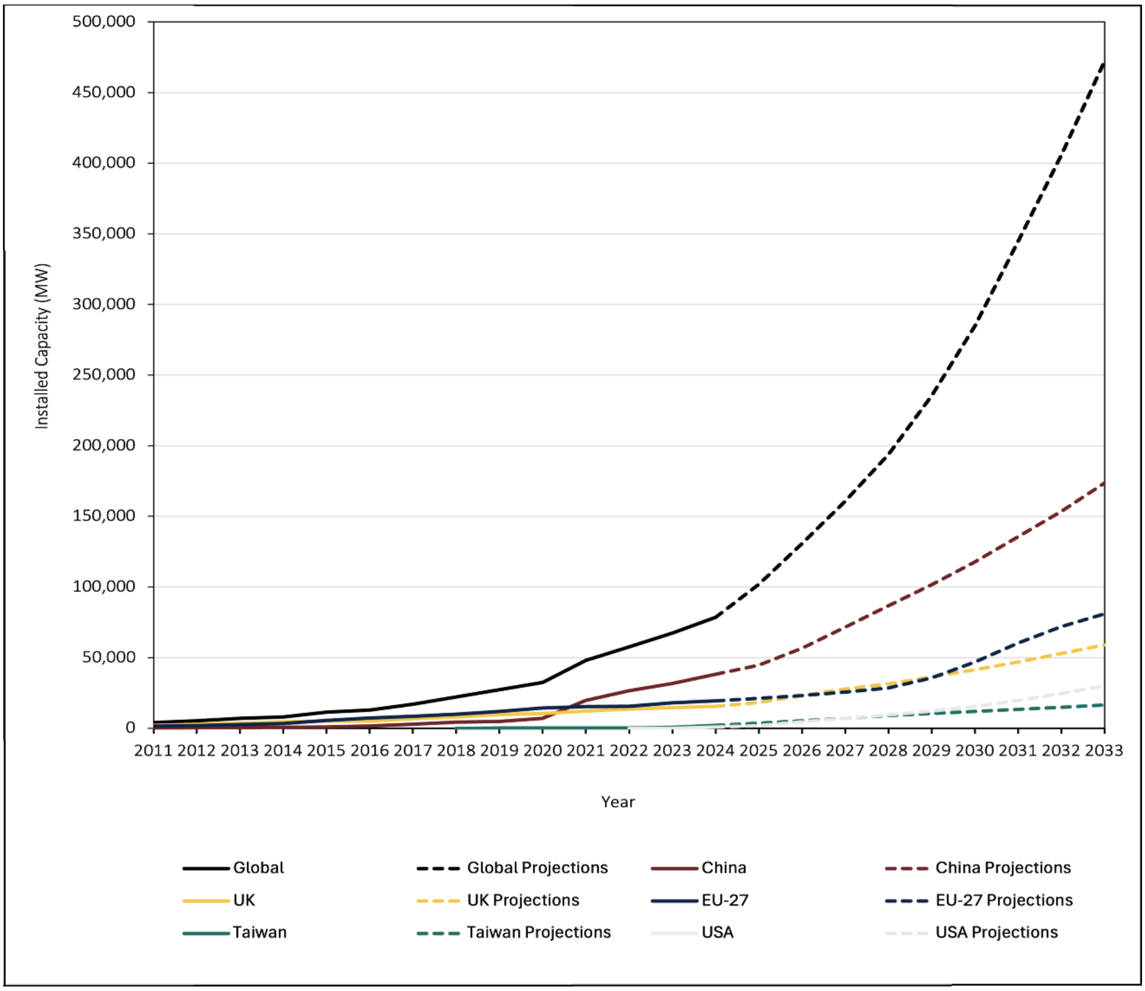
3.1 BOTTOM-FIXED OFFSHORE WIND SYSTEMS

Bottom-fixed systems involve turbine support structures founded in the seabed, making them suitable for shallower sea depths[14], and so are typically located closer to the shore. They have reached full maturity, boasting a cumulative nominal capacity of over 83.2 GW

[14] At the current stage of offshore wind technology development, bottom-fixed foundations are limited to water depths below 60 m (Wang et al., 2025).

worldwide and hundreds of fully operational commercial-scale farms (Figure 2) (GWEC, 2025). The first offshore wind farm, Vindeby, with 11 turbines and a capacity of only about 5 MW, was installed in Denmark in 1991 – an equivalent of today's demonstration units (Feng and Shen, 2017). In just three decades, wind farm capacities have dramatically expanded. Hornsea 2, which is located off the coast of north-east England and came into full operation in 2022, has an installed capacity of 1.3 GW. The Hornsea 3 expansion (completion expected by 2027) will host an additional 2.9 GW.

Figure 2. Installed capacity of offshore wind energy (MW) – global and leading markets (deployed capacities to 2024 and capacity projections to 2033)

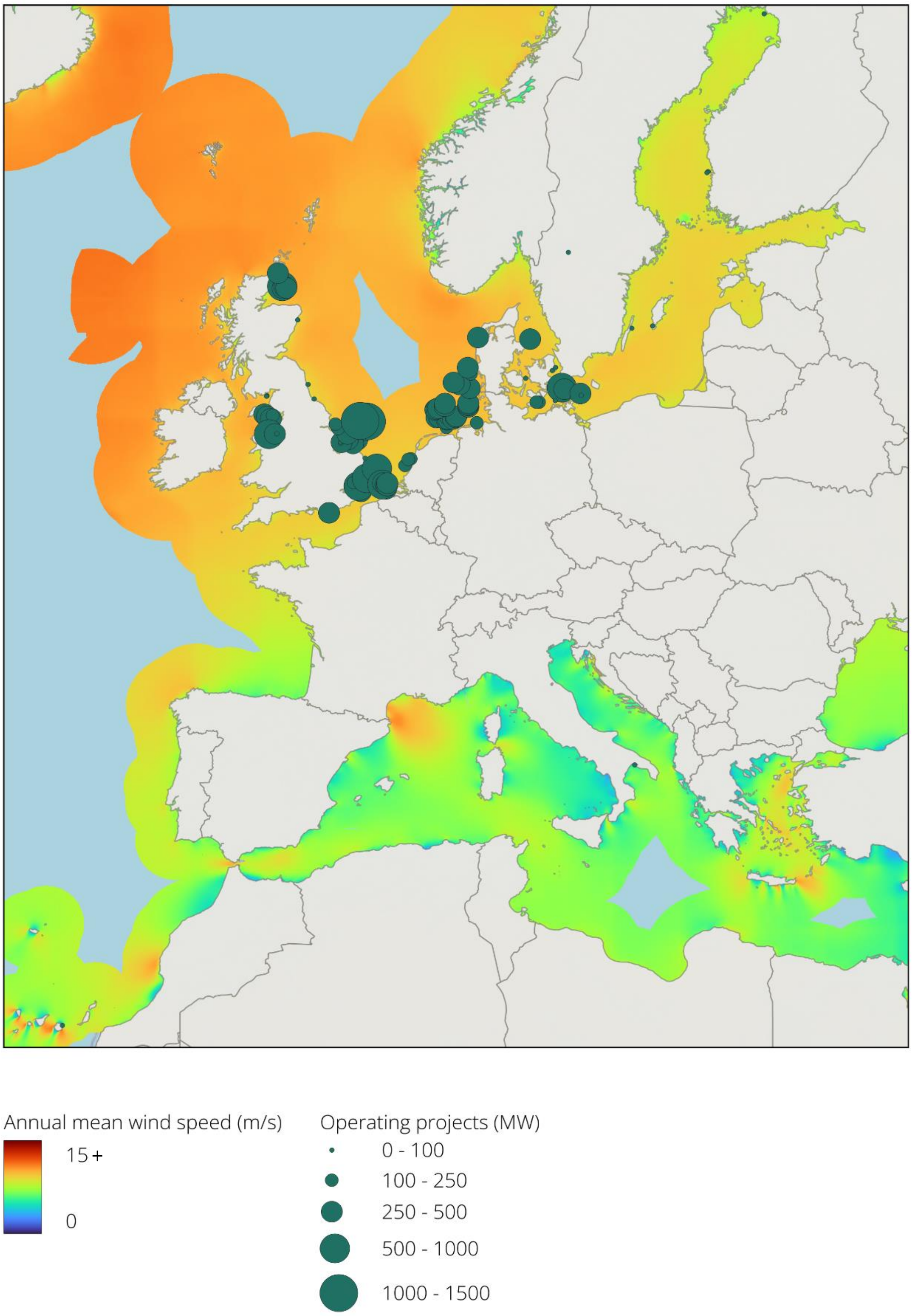


Source: authors' elaboration; data from GWEC (2011-2017, 2020-2024) and WFO (2020-2025).

Note: The data combines both bottom-fixed and floating offshore wind capacities.

Today's utility-scale, bottom-fixed offshore wind farms in Europe are principally clustered around the North, Irish, and Baltic seas, with some small-scale installations scattered elsewhere (Figure 3).

Figure 3. Location and capacity of operating bottom-fixed offshore wind farms in Europe



Source: authors' elaboration; data obtained from 4C Offshore (2025), EMODnet (n.d.) and Global Energy Monitor (2025).

While bottom-fixed systems may yield relatively less wind energy due to the weaker winds in proximity to the shore, they are presently more cost-effective than their floating counterparts. The rapid and continuous growth of the bottom-fixed market owes much of its success to the transfer of existing technology, scientific knowledge, and infrastructure from the offshore oil industry (Schneider and Senders, 2010). The installation process into the seafloor has benefited from a wealth of seafloor soil analyses, advanced methods of hydraulic impact piling, and the availability of installation vessels inherited from the oil and gas industry. Furthermore, lessons from the history of offshore energy systems have equipped wind turbine manufacturers with valuable insights into preventing premature degradation of sensitive electronics and turbine surfaces in the harsh marine saline environment.

Bottom-fixed turbines have demonstrated both technological and economic viability, encountering relatively few technological drawbacks. Their deployment has steadily expanded, and growth has mainly been constrained by non-technical factors such as lengthy permitting processes, challenges with grid connection, and competition with other marine activities and energy sources (WindEurope, 2020). European manufacturers like Vestas and Siemens Gamesa tend to focus on Class I wind regions, although some of their solutions are already adaptable to Class II/III conditions.

Meanwhile, Chinese manufacturers, including Goldwind, Envision, Mingyang and others, have been actively developing and deploying bottom-fixed turbines specifically designed for Class II/III wind conditions, showcasing their adaptability to these less favourable wind regions (Millard et al., 2024).

Ongoing technological developments in bottom-fixed offshore wind are still chiefly concerned with improving profit margins by reducing the LCOE (Section 2.4). This has been achieved by increasing the AEP through the deployment of larger turbines with larger rotor sizes and enhanced blade designs, including the widespread adoption of pitch regulation across all wind classes. Turbine manufacturers are now pushing nominal capacities well beyond 15 MW, with some designs inching towards the 20 MW threshold in the years to come. For instance, turbines like Mingyang's MySE 16 MW and 22 MW respectively feature a rotor diameter of over 240 m and 300 m.

These technological advancements, initially aimed at Class I regions, have had a trickledown effect, making some bottom-fixed turbines viable for use in Class II/III regions. In part, this is due to the availability of at-scale, operational facilities that can efficiently harness wind energy even in areas with more moderate wind resources. This transformation is particularly evident in the Chinese markets, where extensive projects in Class II/III regions have been completed, are under development, or have been announced, as discussed further in Section 4.

Looking forward, the next significant advancements in bottom-fixed technology are expected to focus on reducing OPEX costs. This will involve improving the reliability of critical components such as gearboxes and generators, thereby minimising maintenance needs and downtime expenses.

3.2 FLOATING OFFSHORE WIND SYSTEMS

Floating systems envisage mounting wind turbines on floating platforms that are anchored to the seabed using mooring systems. This design enables deployment further offshore, where turbines can capture more consistent wind speeds (WindEurope, 2017). This allows them to access higher capacity factors, quantified at an average of 50-53 % for floating systems (Heidari, 2017; Bjerkster and Agnotes, 2013), compared with <40 % experienced in UK bottom-fixed wind farms (Aldersey-Williams et al., 2020).

Consequently, floating systems are particularly valuable in deep-water areas where bottom-fixed turbines are not feasible. Floating systems can be moored at depths of up to 1 000 meters (Devoy McAuliffe et al., 2024). In addition to their suitability for deep-water sites, floating systems offer significant potential in Class II/III regions, where wind resources closer to the shore may be moderate or insufficient for economically-viable power production (using conventional bottom-fixed turbines). By positioning turbines further from the shore, floating systems can access more consistent and reliable winds, enhancing energy capture. This maximises the use of available wind resources, making floating systems a crucial technology for the future of offshore wind energy in lower wind regions.

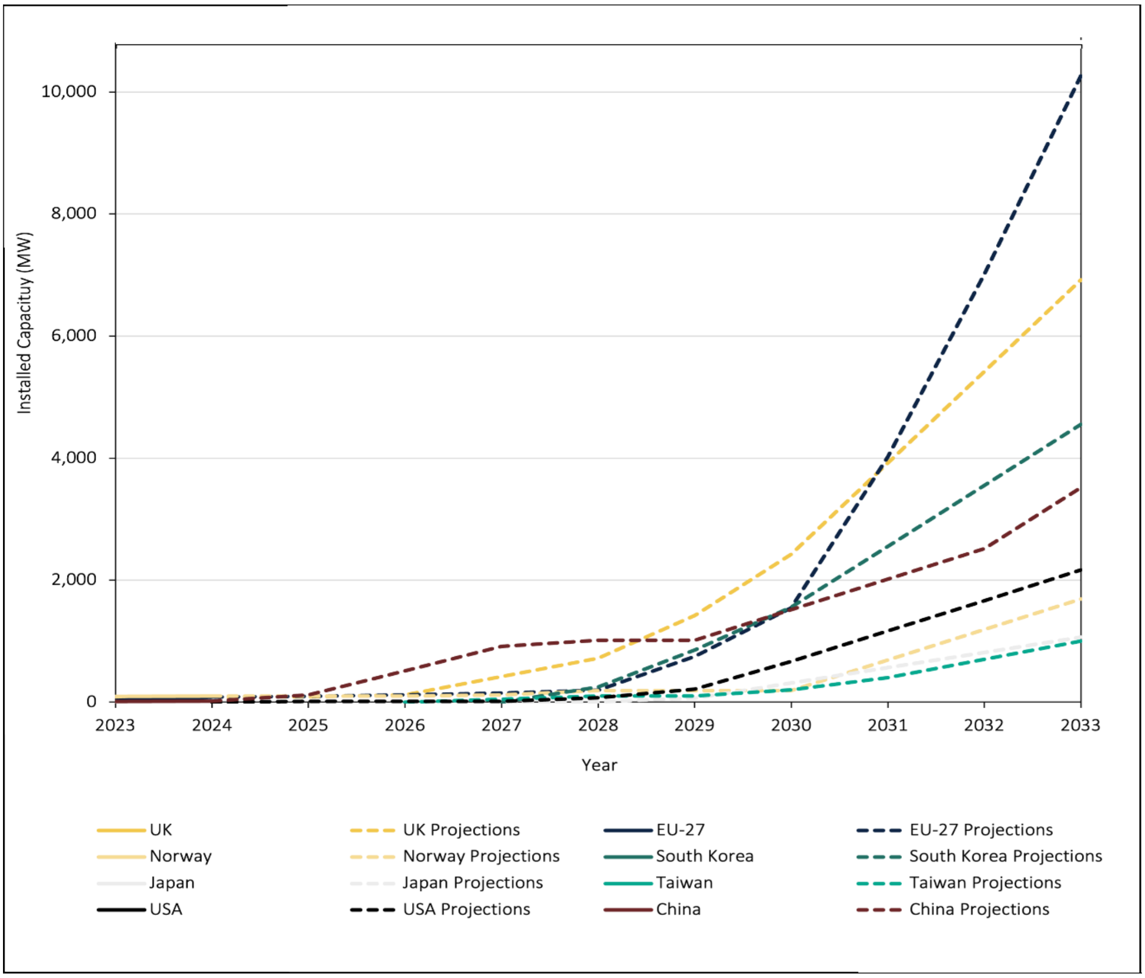
At the moment, floating offshore wind systems lag behind bottom-fixed systems in terms of TRL and commercial maturity. The development and deployment of floating systems are primarily hindered by the higher construction, operation, and maintenance costs associated with installing turbines further offshore. These systems require complex mooring and anchoring solutions, more robust structures to withstand harsher maritime conditions, and specialised vessels for installation and maintenance, all of which contribute to increased costs (Satymov et al., 2025).

By contrast, bottom-fixed systems have benefitted from decades of technological advancement and operational experience, making them a more established and reliable choice. These systems have lower upfront and operational costs due to simpler installation processes in shallow waters, already standardised components, and well-established supply chains. Additionally, the lower perceived risks associated with bottom-fixed technologies make them more attractive to investors, who likely prioritise projects with predictable returns and minimal technical uncertainties.

As a result of ongoing development, floating offshore wind technologies have advanced to the demonstration stage, with several small operational wind farms established in Class I regions, typically achieving TRL 7-8. These technologies are currently in the process of scaling up from initial demonstrator projects and small operating farms to larger, more commercially-viable wind farms.

Several examples highlight the progress made in floating offshore wind – reaching a global installed capacity of 270 MW as of 2023 (IRENA, 2024b). Figure 4 displays projections for future capacities.

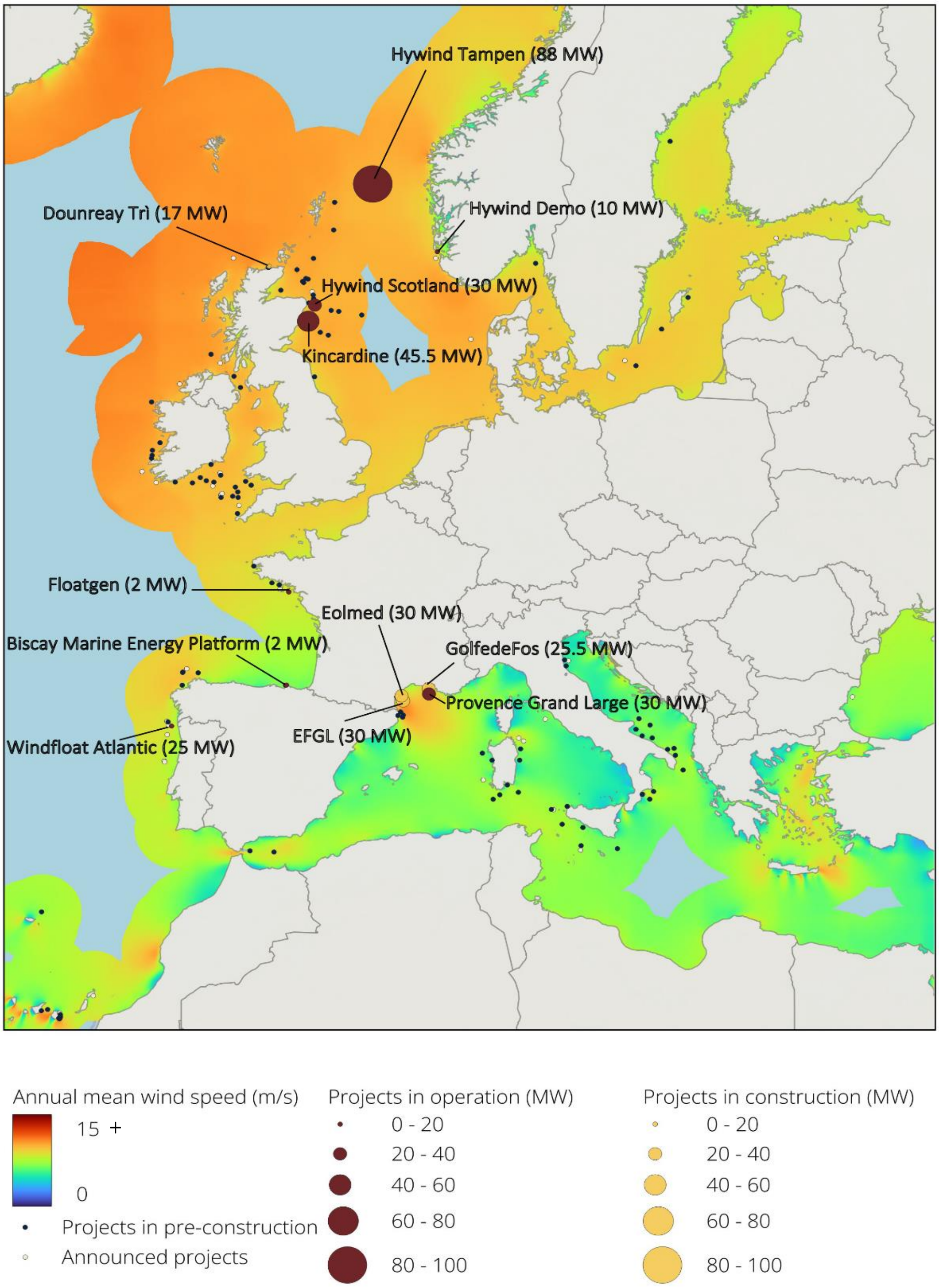
Figure 4. Installed capacity of floating offshore systems in leading markets (deployed capacities to 2024 and projections to 2033)



Source: authors' elaboration; data from GWEC (2024-2025).

In Europe, which remains at the forefront in the floating offshore wind sector, the majority of projects have been deployed mostly in Class I areas (i.e. the North Sea), although projects are increasingly considered in lower wind speed regions, e.g. the Mediterranean and Black Seas (Figure 5).

Figure 5. Location and capacities of floating offshore wind farms in operation and construction stages



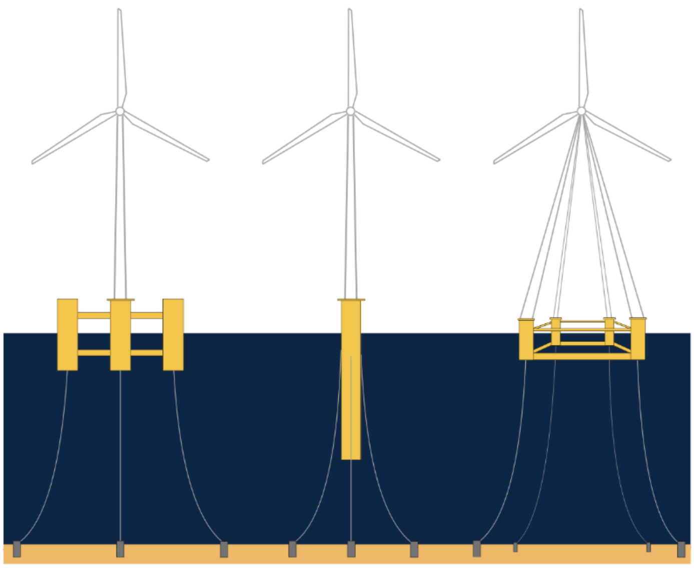
Source: authors' compilation as of May 2025; data from 4C Offshore (2025), EMODnet (n.d.) and Global Energy Monitor (2025).

Notes: Floating offshore wind project sites in pre-construction stages and those that have been announced are also plotted.

In 2017, Hywind Scotland (UK) became the world's first floating wind farm to enter operation with a capacity of 30 MW. Commissioned in 2022, Hywind Tampen (Norway) took over as the operating floating wind farm with the greatest capacity (88 MW) – designed to power offshore oil and gas operations. In Portugal, WindFloat Atlantic, commissioned in 2020, became the first 25 MW semi-submersible floating wind farm. In China, the deep-sea floating wind demonstration project in Wenchang features the 7.25 MW Haiyou Guanlan floating platform, which was installed in 2022 to supply power to the Wenchang oilfields in the western part of the South China Sea.

The floating offshore wind sector is actively testing various platform and mooring systems to identify the most efficient, cost-effective, and low-maintenance solutions for construction and installation. The sector has not yet converged on standardised platform designs as seen in the bottom-fixed wind industry (Diaz et al., 2022). From startups to established turbine manufacturers, the wind industry has seen hats of all types thrown in the ring trying out unique design concepts for floating installations (Figure 6).

Figure 6. Designs for floating offshore wind platforms



Source: authors' elaboration.

Most manufacturers are leaning towards semi-submersible platforms (Musial et al., 2021). These use partially submerged multi-column platforms, which offer flexibility in deployment and are adaptable to various water depths and seabed conditions. Semi-submersible structures are beginning to scale and demonstrate commercial viability. By contrast, other manufacturers are exploring spar-buoy platforms, which rely on a single, deep cylinder to maintain stability by using a low centre of gravity. They are particularly suitable for deep waters. Beyond this, startups and new projects are being launched to test novel and unique systems, such as the experimental floating pyramid design. An interesting trend is that some developers are now increasingly designing their own platforms – even if they may not always be the most disruptive.

Despite the ongoing experimentation and development of these diverse floating designs, the industry has yet to reach a consensus on floating platform geometry, mooring and anchor systems, or even the type of turbines best suited to these installations. This lack of convergence, to a certain extent, is impeding mass industrialisation.

The floating offshore wind industry is also striving to reduce OPEX, which is currently higher than that for bottom-fixed solutions[15]. The elevated OPEX for floating wind systems stems mainly from the complexities involved in their operation and maintenance in deeper waters, including logistics, repairs and harsh offshore conditions. Technological innovations and operational efficiencies aimed at lowering costs include developing more durable materials, refining installation techniques, optimising maintenance schedules, and improving remote monitoring and autonomous repair technologies.

The problems of achieving commercial availability for floating systems in Class II/III areas are even more pronounced when compared with Class I regions. The presence of abundant Class I areas in Europe has, to some extent, diverted attention and resources away from advancing floating technologies for lower wind speed regions. Although some floating offshore wind technologies have been demonstrated for Class II/III areas, operational prototypes (beyond TRL 5) are still under development. Floating offshore wind technologies for Class II/III regions remain a niche area.

Optimistic projections suggest that these advanced systems might be tested in operational environments by 2030. The path forward will require overcoming substantial technical and economic obstacles to adapt floating wind solutions for the lower wind speeds.

The scalability of these projects in the EU hinges on resolving a classic chicken-and-egg dilemma: limited market demand dampens the incentives to advance and commercialise these technologies and vice versa. Prototype developers also face particularly acute difficulties, including higher costs and congested supply chains. Recent spikes in equipment costs have especially hindered these smaller-scale niche projects: the high cost of components increases project costs, limiting financial feasibility and deterring investors. This cycle, where immature technology stifles investment and limited

[15] Most publications estimate the OPEX of floating offshore wind to be higher than that of bottom-fixed offshore wind. However, NREL (2024) places the floating offshore wind OPEX only slightly higher than bottom-fixed offshore wind.

investment slows technological advancement, creates a valley of death for floating wind development in lower wind regions.

All these issues compound the challenges of progressing Class II/III floating solutions from TRL 5 to TRL 7-8 (Table 3). Overcoming them will likely require targeted policy interventions by the EU and its Member States to encourage innovation and prototype deployment. Without substantial support, expectations for widely available and tested solutions in the EU by 2030 may be overly optimistic.

Table 3. Technology readiness level of bottom-fixed and floating offshore systems across wind classes

	Bottom-fixed offshore wind systems	Floating offshore wind systems
Wind Class I	**Commercially available (TRL 9)** Monopiles, gravity, and jacket foundations all have achieved widespread use depending on the seabed conditions Expertise and preparations for operating in offshore conditions allow for 25-year lifespans Work is ongoing to improve reliability in order to reduce OPEX	**Successful demonstrators and first small wind parks (TRL 7-8)** Many demonstrators exist with functional connection to land power grids, and the first (small) wind parks with up to a dozen turbines. There is not yet full commercial scale but progress is ongoing Various platforms continue to be tested, though some market convergence towards semi-submersible is observed Turbines and hubs are essentially the same as bottom-fixed, hence fully commercially available
Wind Class II/III	**Commercially available (TRL 9)** Pitch regulated, 100 m+ rotors are already on the market Some developments are underway for improving pitch regulation and gearboxes for lower wind speed conditions	**Technology demonstrated (TRL 5/6)** There are a few projects demonstrating advances (TRL 5), with operational prototypes under construction (TRL 6-7) to enable technologies developed in Class I to be adjusted and scalable for Class II/III Work continues on testing unique mooring systems There is a reliance on large turbines to expand in commercial availability and reduce in cost

Source: authors' compilation.

4. OFFSHORE WIND DEPLOYMENT ACROSS WIND CLASSES – A GLOBAL OVERVIEW

This section provides a global overview of offshore wind farms across various wind classes and countries. Relying on the dataset analysis presented in the Annex. Methodology, it draws *general* conclusions about market trends in offshore wind.

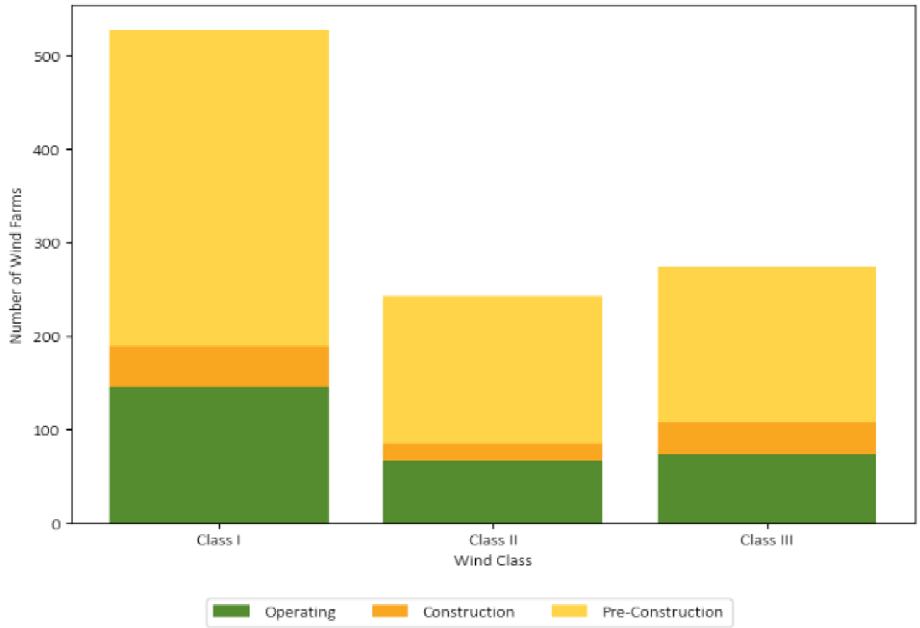
As most offshore wind farms currently use bottom-fixed technologies, and floating wind projects remain limited to a few small-scale operational projects, this analysis primarily pertains to the market for bottom-fixed offshore wind. This overview shows that Europe has mainly focused on high-wind bottom-fixed developments. In contrast, China has made significant progress in adapting bottom-fixed technologies to lower wind speeds. It has taken advantage of its extensive coastlines with conditions similar to those in southern Europe and captured a considerable share of the low-wind market. Furthermore, the pipeline of announced and planned projects indicates that China is steadily entering the high wind speed segment of offshore wind.

4.1 TRENDS IN OFFSHORE WIND DEPLOYMENT ACROSS WIND CLASSES

The majority of operating offshore wind farms are concentrated in Class I areas, and there is a notable trend of increasing their capacity. It is commonly expected that, as long as offshore farms in high-wind areas keep producing substantial electricity volumes more efficiently than in lower-wind areas, the global market will mostly continue planning and constructing farms in the former until their resource potential is thoroughly exhausted.

While Class I farms are considered exemplary in offshore wind technologies, Class II/III installations are rapidly catching up in terms of development and adoption (Figure 7).

Figure 7. Global number of offshore wind farms by wind class (operating, under construction and planned)



Source: authors' elaboration.

A growing number of wind farms are located in Class II and III areas, with a clear uptick in siting projects in regions with average winds above 6 m/s (Figure 8). A trend can also been seen in the gradual increase of capacity, with a clear tendency to double or triple capacity for pre-construction projects. There is also marked interest in further exploring extremes of speeds, beyond 10 m/s and below 6 m/s.

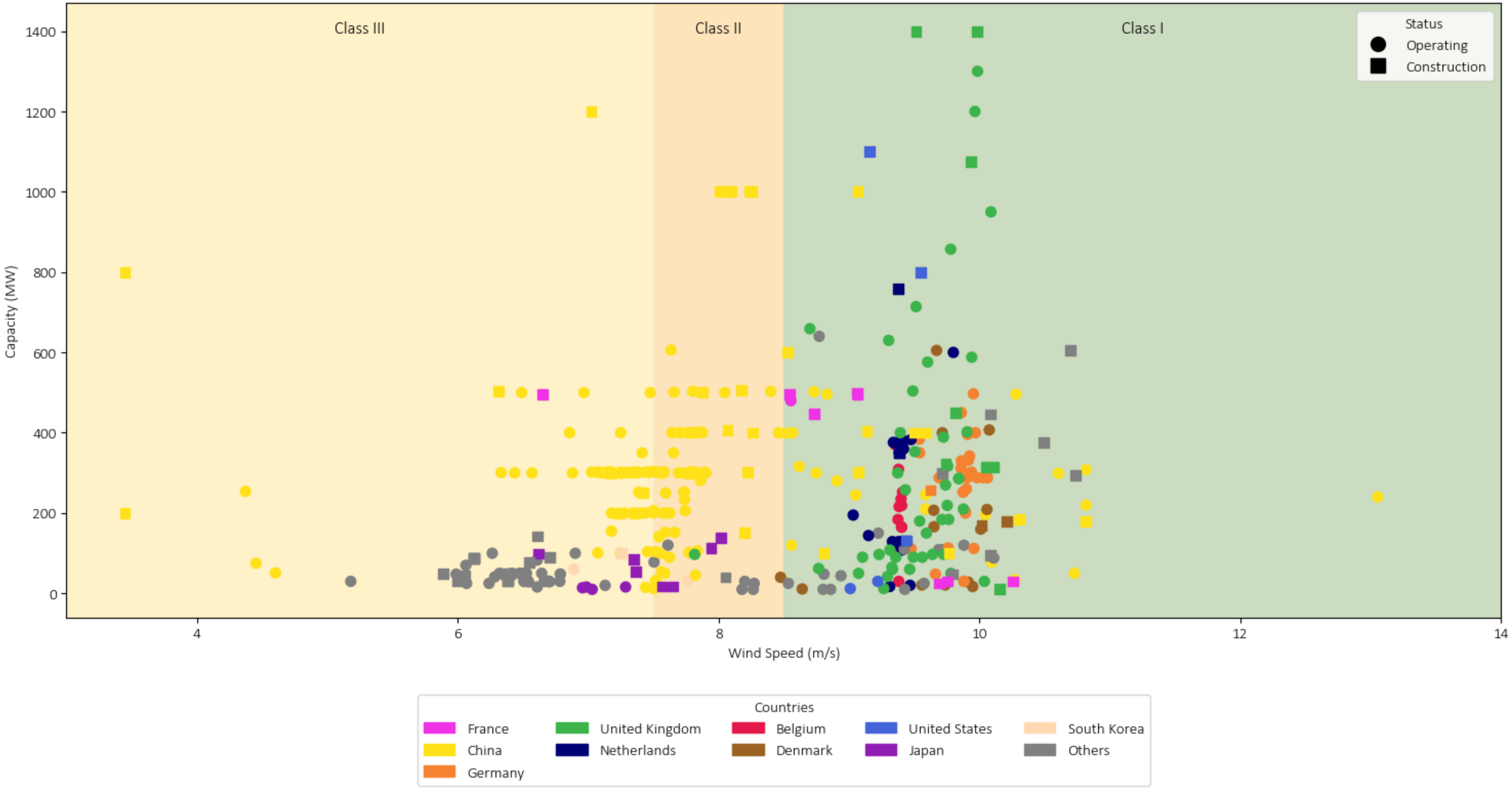
The country distribution (Figure 9) shows that China dominates not only in the number of operating and under-construction wind farms in medium wind areas but is also increasingly expanding operations in higher-wind areas.

Figure 8. Offshore wind farms (operating, under construction, and in pre-construction stages) by nominal capacities (MW) across their associated wind classes

Source: authors' elaboration.

Note: Despite efforts being made to ensure all the projects plotted are offshore, projects not categorised specifically as offshore/onshore in the databases may have led to the plotting of additional, non-offshore anomalous entries as offshore.

Figure 9. Offshore wind farms (operating and under construction) across countries by wind class and associated nominal capacities (MW)

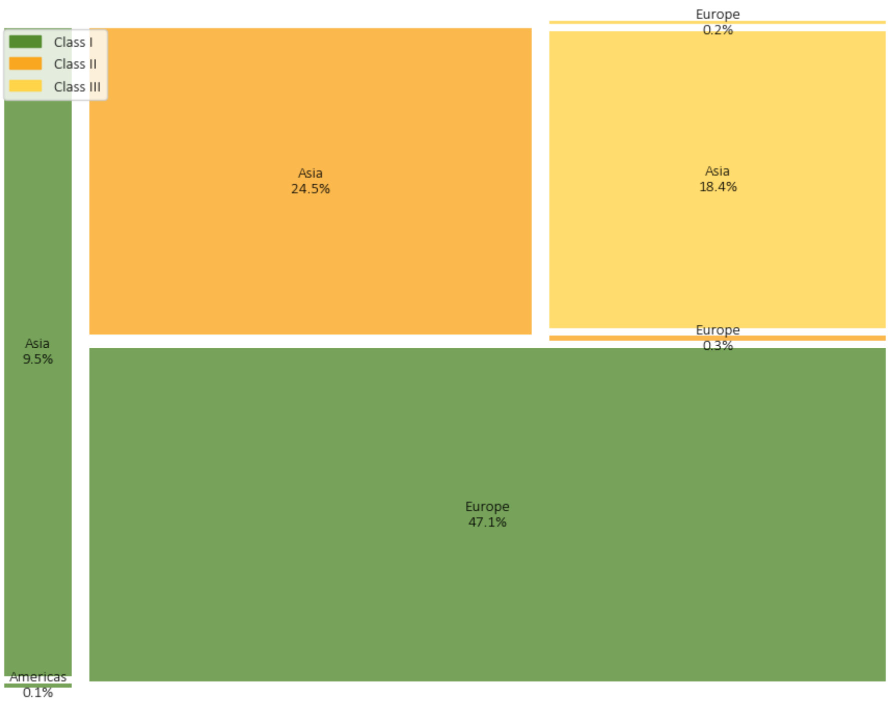


Source: authors' elaboration.

Note: Despite efforts being made to ensure all the projects plotted are offshore, projects not categorised specifically as offshore/onshore in the databases may have led to the plotting of additional, non-offshore anomalous entries as offshore.

However, many countries find themselves with limited (or no) access to Class I wind resources. This constraint exerts inherent pressure on these nations to deploy offshore wind farms under low and medium wind speed conditions. Consequently, approximately 25 % of the world's operating, offshore wind-energy capacity is located within Class II, and another 19 % within Class III regions. China leads the market for offshore Class II and III installations in the Sea of Japan, Yellow Sea, and the South and East China Seas. This results in a global offshore wind market roughly split in half between operating wind farms in Class I and Class II/III areas (Figure 10).

Figure 10. Regional distribution of operating wind farms across wind classes



Source: authors' elaboration.

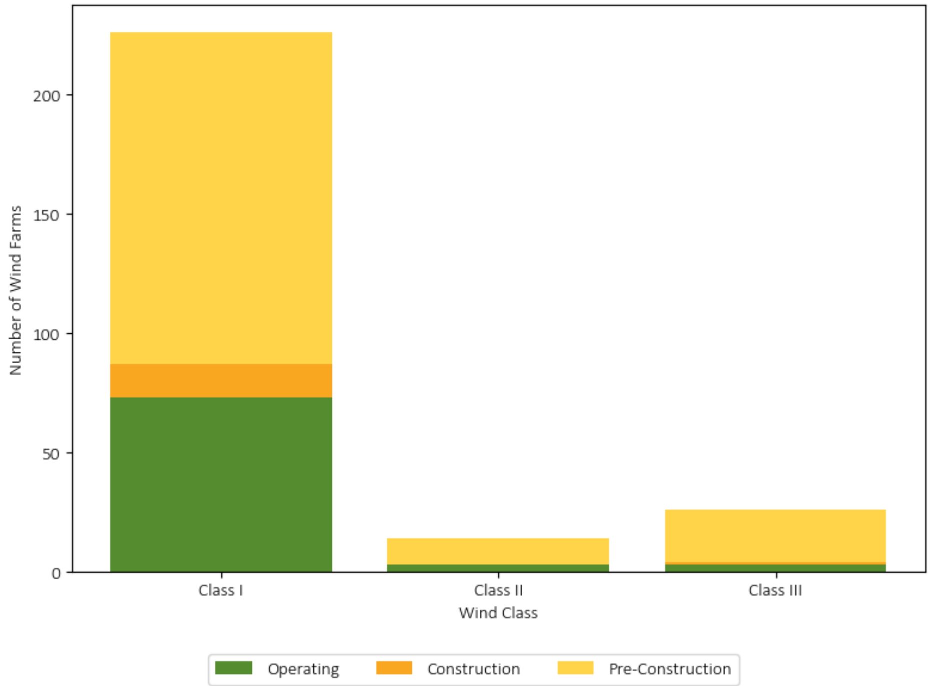
4.2 CLASS I OFFSHORE WIND DEPLOYMENT: KEY MARKETS AND TRENDS

Europe's historical leadership in offshore wind technology has driven its rapid deployment of offshore wind farms, supported by the favourable economics present in northern Europe. Consequently, most operational offshore wind farms have been strategically located in these high wind speed areas with higher associated power outputs.

The combined capacity of the UK and EU accounts for over 80 % of the global operating capacity in Class I regions. The UK leads in high-speed offshore wind farms in terms of both capacity and the number of operating farms. Their planned growth reflects the UK's intention of maintaining its leadership, with more capacity under construction and announced in Class I regions than any other country. The EU on its own holds more than

40 % of the global share, with its offshore wind farms principally located in Class I areas (i.e. North, Irish, and Baltic Seas) – see Figure 11.

Figure 11. Number of offshore wind farms (operating, under construction, and in pre-construction) in Europe by associated wind class



Source: authors' elaboration.

The leading position of Europe in Class I wind farms is supported by major European wind turbine manufacturers, such as Siemens Gamesa and Vestas. These companies offer high nominal capacity turbines designed for high wind speed conditions.

However, with the rising costs, Europe's current dominance in Class I wind farms may diminish. While the UK and EU countries are likely to retain their leadership in Class I regions in the short term, the substantial proportion of capacity under construction in other regions, and China in particular, suggests that the share of global Class I capacity installed in the UK and EU is likely to fall.

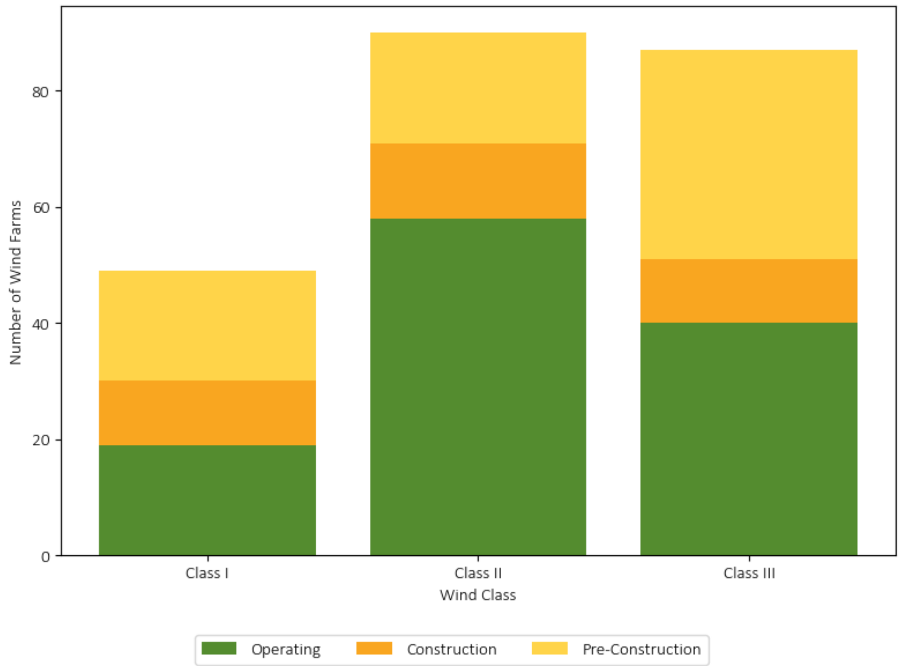
The mapping of Class I area development worldwide implies tougher competition for European manufacturers and developers globally, with Chinese proposals gaining ever more traction. The playing field is becoming more uneven, as Chinese companies can offer project developers de-risking terms that European companies simply cannot match with respect to costs, especially amid a period of tightening macroeconomic conditions. This also raises questions about the potential risks associated with the steadily growing dependency of European industry on China for Class I technologies and supply components.

4.3 CLASS II/III OFFSHORE WIND DEPLOYMENT: KEY MARKETS AND TRENDS

Operational offshore wind farms in Class II/III regions today account for roughly half of the global capacity. China's pre-eminence in lower and medium wind speed regions cannot be overstated, with a well-developed market for low and medium (bottom-fixed) wind speed turbines and associated technologies. Not only are the majority of Class II/III farms and capacities located in Chinese waters, but also most of the projects under construction in both Class II and Class III regions are within Chinese territory (Figure 12 and Figure 13).

A comparison with China in Figure 12 shows that China holds a significant share of Class II/III wind farms, although its portfolio of Class I wind farms is growing.

Figure 12. Number of Chinese offshore wind farms (operating, under construction, and in pre-construction stages) by associated wind class

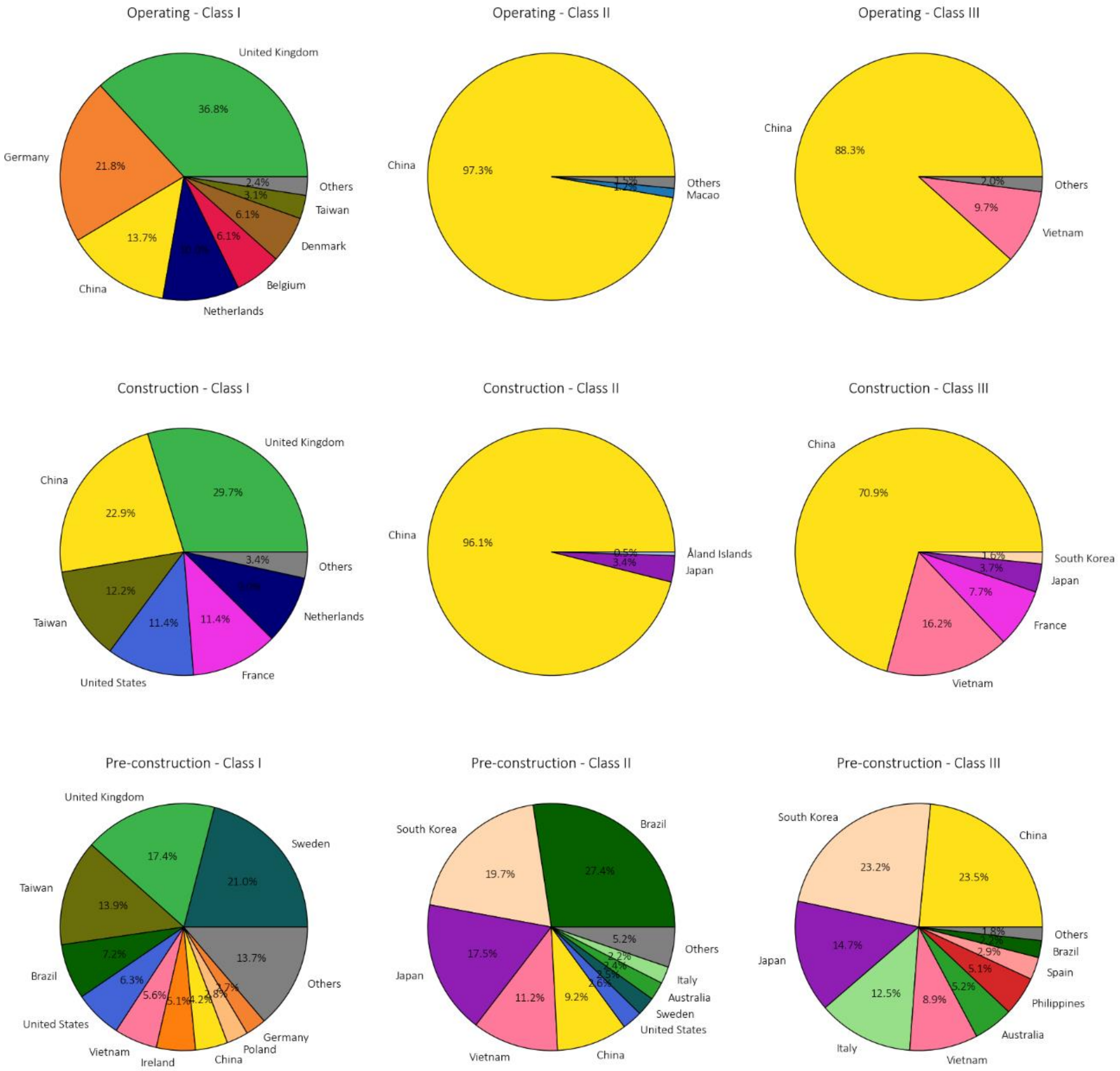


Source: authors' elaboration.

Chinese manufacturers, including Envision and Goldwind, have extensive portfolios featuring dedicated low-speed and medium-speed turbines with lower nominal capacities. These are specifically designed for the Class II/III conditions found in the Yellow Sea, East China Sea, and South China Sea.

South Korea, Japan, and Vietnam are emerging players with a substantial fleet of offshore projects in the pre-construction stages for low and medium wind speed regions (Figure 13). If these countries successfully execute their planned projects, they will contribute to diversifying the low wind speed market, although China will likely remain the largest player in the development of Asia's offshore wind sector.

Figure 13. Proportion of offshore wind farms (operating, under construction, and pre-construction stages) by wind class and country



Source: authors' elaboration.

In Class II/III regions, Europe has a very limited presence, with only a few pilot projects across the continent. It is highly questionable whether European manufacturers can ever compete with Asian developers. In the future, project developers may face having to rely on Chinese technologies. For example, the wind turbines for Beleolico, an Italian wind farm close to the Taranto port, were MingYang MySE3.0-135 turbines.

While technologies are key to unlocking the potential of offshore wind in low and medium wind speed regions, the supply chain is equally pivotal. Innovative solutions tailored for Class II/III often require components (such as larger and uniquely suited turbines) not readily available on the market. The component market also tends to be over-stretched, with suppliers primarily focusing on larger clients. This further adds to the risks of relying on Chinese solutions for Class II/III technologies.

4.4 FLOATING OFFSHORE WIND MANUFACTURERS

Europe's top position as a deployer of floating offshore wind farms is reflected across the manufacturing sector, in which European turbine manufacturers, e.g. Siemens Gamesa and Vestas, dominate the global market. Almost all floating offshore wind turbines deployed in Europe are manufactured by either of these two corporations. In 2018, 77% of the world's floating offshore wind market was made up of turbines of European origin (Diaz et al., 2022).

However, as emerging markets expand in the coming years (Figure 4), the global share of 'made in the EU' turbines will likely shrink. New floating offshore wind farms in Europe may continue to use European turbines, but Asian markets could opt mostly for homegrown ones.

MingYang Smart Energy is the main player in China, with MySE7.25-185 and MySE5.5-155 being the principal turbines installed in China's floating offshore wind farms. The Chinese manufacturer Goldwind, which accounts for the largest share of wind turbines globally, has not yet entered the floating offshore wind market, but is expected to do so in the coming years. Likewise, Shanghai Electric and Dongfeng Electric are also expected to account for increasing shares of the floating offshore wind market in China, and perhaps overseas.

Similarly, Japanese-manufactured Hitachi and Mitsubishi wind turbines have been installed in Japanese floating offshore wind farms. South Korea, however, is deploying Vestas V236-15.0 MW turbines in its first GW-scale, floating offshore project: Gray Whale Floating Wind Farm.

5. CONCLUSIONS: ACTION POINTS FOR THE 2024-2029 POLITICAL CYCLE

In response to the various challenges facing the European wind industry, the European Commission's 2023 European Wind Power Action Plan outlines strategic action to keep offshore wind deployment on track with the EU's 2030 targets. The European Wind Charter, endorsed by Member States, builds on this plan to support the wind sector.

The 2024-2029 political cycle, under the broader political umbrella of the Clean Industrial Deal, places strong emphasis on 'made in the EU' cleantech manufacturing and accelerated deployment of renewables. In this context, the Draghi report highlights the importance and leadership positions of the wind industry. But it warns against 'a massive gap' that has emerged with China in some wind components.

However, the future trajectory of offshore wind in Class II/III regions remains insufficiently discussed at the current stage of the policy debate. There is a critical need to thoroughly calibrate expectations for offshore wind deployment in Europe's lower wind speed regions.

A notable success story within EU cleantech, the (offshore) wind industry faces significant difficulties, including rising costs sector-wide and obstacles in advancing new projects, even in high wind regions. The complex context in which the EU's offshore wind industry operates is exacerbated by the broader, tight macroeconomic environment across the EU.

This backdrop makes it even more necessary to have a thorough and open discussion of strategies to bolster the business case for offshore wind in less favourable wind conditions within the EU. With European investment concentrated in Class I areas, there is a pressing need for political clarity. The strategic objectives of the EU and Member States for offshore wind must sufficiently address measures for developing Class II/III zones and their implementation during the 2024-2029 political cycle.

Sustaining offshore wind deployment in EU Class II/III regions

The weaker economics of projects due to less favourable technical potential compared with those in Class I areas needs to be acknowledged. They should be factored into the design and implementation of regulatory measures and financial incentives to stimulate offshore wind energy development in lower wind conditions.

In the absence of targeted measures and a common vision to address their poorer economics, investors are likely to continue prioritising Class I sites, both within Europe and globally. This trend could further impede the progress of offshore wind development in Class II/III regions within the EU. Class II/III projects may simply be outcompeted by Class I, especially under current tightening economic conditions, leaving regions with only Class II/III areas disproportionately disadvantaged. A lack of action will jeopardise the future of offshore wind in these areas.

Recommendation #1. It is essential to have a thorough and open discussion of strategies to bolster the business case for offshore wind in the less favourable wind conditions of Class II/III regions. The weaker economics of these projects compared with those in Class I areas need to be acknowledged and factored into regulatory measures and financial incentives. An EU vision for these areas and a joint vision for cross-border areas are critical. Unless action is taken, investors are likely to continue prioritising Class I sites, both within Europe and globally.

Preserving EU offshore wind leadership in floating solutions for Class II/III

In the coming years, a primary concern for the European offshore wind industry will be maintaining its positions in high wind markets. This will grow particularly pressing as Chinese companies intensify competition by offering favourable supply contract terms to project developers and gradually penetrate the European market for wind equipment. In Class II/III, Chinese manufacturers have made especially notable advancements. They have established dominance in the bottom-fixed market, likely leading to an increasing displacement of European firms.

Europe retains opportunities to advance its innovation in floating wind technologies. By maintaining a leading position in the development of floating wind farms in Class I areas, European firms can further apply their expertise to floating solutions in lower wind conditions, even as Chinese companies start actively pursuing this field.

Floating offshore wind technologies for Class II/III conditions today represent a niche but promising industry, both within Europe and globally. Prototypes for floating offshore wind technologies in Class II/III are under development in the EU. The key now is to effectively support their progression from the current TRL 5 to full commercialisation and market deployment. This calls for resolving the chicken-and-egg dilemma confronting these emerging technologies. To do that, it is important to focus on better targeted policy support and to enhance the coherence of funding and support mechanisms, at the EU, regional and national levels.

Recommendation #2. The expertise in floating structures for Class I areas, where European firms continue to hold a leading position alongside intensifying Chinese competition, must be leveraged for applications in Class II/III lower wind conditions. This will require resolving the chicken-and-egg dilemma confronting these emerging technologies. Among other things, it is important to provide better targeted policy support and coherent funding and support mechanisms, at the EU, regional and national levels.

This current window of opportunities should also be used for enhancing global cooperation in (floating) offshore wind technologies for Class II/III areas. The EU retains substantial expertise and technological capabilities in offshore wind, which is of notable interest to nations with considerable or dominant Class II/III areas. It is advisable to further explore collaboration with countries that have shown interest in (floating) wind technology for lower wind conditions. This can be done through both new and existing cooperation channels, thus facilitating knowledge exchange and joint development efforts.

Recommendation #3. The EU's extensive expertise and technological capabilities in floating offshore wind holds significant interest for nations with substantial or dominant Class II/III areas. It should leverage this to explore and enhance collaboration with countries that have shown such interest. In this vein, new and existing cooperation channels can be used to facilitate knowledge exchange and joint development efforts.

ANNEX. METHODOLOGY

To assess the global offshore wind market across wind classes, data were combined from the Global Wind Atlas and the Wind Power Tracker from the Global Energy Monitor to connect recognised offshore wind projects with their respective IEC wind classifications (Classes I, II, and III).

This analysis was conducted using an open-source Python script. The 100 m mean wind speed data for the entire globe were downloaded as a tif-file from the Global Wind Atlas, and the Global Wind Power Tracker data were obtained as a geojson-file (downloaded in July 2023).

The data were then organised into a single dataframe by sourcing the mean wind speed at each wind farm's location (based on its latitude and longitude) and labelling each project with the IEC wind classification corresponding to that mean wind speed. Distinctions between onshore and offshore wind farms were made by detecting the word 'offshore' in the farm's installation type field. Although this method has limitations, with some onshore farms labelled 'offshore mount unknown' being classified as offshore, it provided a general mapping of offshore wind projects (including operating, planned, announced, pre-construction, under construction, decommissioned, and cancelled) with their wind classes.

After creating this dataset, analyses were performed to evaluate the overall installed and planned capacities of individual countries and regions across wind classes and to map trends in the pipeline of planned and under-construction offshore wind farms within each class.

To obtain the spatial distribution visualisations of Europe's (i) offshore wind resource, (ii) operating bottom-fixed offshore wind farms, and (iii) floating offshore wind farms, the average annual wind speed (m/s) raster tif-files at 100 m were downloaded from Global Wind Atlas for each European country/territory of interest (coastal). These were uploaded onto the basemap on the GIS software with corresponding coordinates – WGS 84.

The locations of bottom-fixed and floating offshore wind projects (and their associated capacities) were obtained from the Global Wind Power Tracker, 4C Offshore, and EMODnet. Project locations were digitised onto the basemap as point vector layers. The associated wind resource for each project's location was extracted from the attribute table. Operating bottom-fixed and floating offshore wind projects, as well as floating offshore wind projects under construction, were plotted onto the basemap in terms of their nominal capacity. Floating offshore wind projects that have been announced and are in pre-construction stages were not. The datasets used were downloaded in May 2025.

While the reliability of information in the analysed datasets may benefit from further scrutiny, the resulting dataset allows for general conclusions about market trends and the global status of offshore wind projects by wind class.

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