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Potentials and challenges of floating wind in the Mediterranean Sea: A joint industrial and academic perspective

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HIGHLIGHTS

- Integrated policy, grid, and industry action are key for floating wind scale-up.
- Non-price criteria must balance system value with project bankability.
- System integration challenges shape offshore wind deployment outcomes.
- Early industrialisation enables learning, cost reduction, and resilience.
- Basin-aware planning accelerates deployment under diverse regional conditions.

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ABSTRACT

Accelerating decarbonisation while safeguarding energy security requires a rapid scale-up of renewables. Offshore wind energy is central, and floating wind can unlock deep-water resources where bottom-fixed foundations are not feasible. Yet progress is constrained not by costs alone but by permitting complexity, delays in government auctions, grid access, environmental safeguards, and the sequencing of logistics and industrial capacity. The Mediterranean combines major technical potential with persistent structural barriers. This review offers a basin-specific, industry-oriented assessment integrating techno-economic feasibility, regulation, and industrial readiness. It addresses three cross-cutting questions on technical feasibility, regulatory acceleration, and industrial coordination, covering siting, permitting, finance, grids, and supply chains. We find that cost competitiveness is necessary but insufficient. Floating projects require dedicated rules, infrastructure, and financing frameworks distinct from bottom-fixed, while overall progress depends on clear floating-fit auction schedules, targeted infrastructure and port upgrades, and synchronised grids. Early, place-based engagement and nature-inclusive design are essential to feasibility. Many challenges are shared across offshore wind but amplified for floating by deeper waters and more complex logistics. Aligning planning, grid integration, industrial capability and social licence is decisive to turning the Mediterranean's offshore potential, driven mainly by floating wind and enabled by basin-wide coordination, into bankable projects at pace.

1. Introduction

Offshore wind energy is increasingly recognised as a central pillar of the global energy transition [1]. Beyond its decarbonisation value, offshore wind also contributes to industrial competitiveness and energy security by diversifying supply sources and reducing exposure to imported fuels, a growing priority as global energy systems face volatility in commodity markets and supply chains. Recent system-level modelling indicates that renewables-based pathways can deliver the lowest total energy system costs while strengthening Europe's energy security, with wind and solar supplying over 80% of electricity by 2050 [2]. In the context of rising electricity demand and persistent dependence on imported primary energy sources, floating offshore wind offers a scalable and strategically resilient option. Recent experience has

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highlighted wind energy's systemic resilience: its decentralised and geographically dispersed nature limits the impact of localised disruptions and strengthens overall system robustness [3,4]. While onshore wind technologies remain more competitive in current markets [5], factors such as more favourable wind conditions [6–8] and fewer spatial and social constraints [6,9] are driving growing interest in offshore deployment. Historically, installations have been concentrated in the North Sea, owing to particularly advantageous geophysical conditions, including strong and consistent wind speeds combined with shallow water depths, that allow the use of bottom-fixed solutions. Accordingly, experience from the North Sea is used in this work as a reference for system-level mechanisms and development sequencing, while recognising that Mediterranean deployment requires context-specific adaptation rather than direct replication. Increasing attention is now being directed towards deep-water applications, where significant challenges must be addressed to unlock untapped potential: (i) *Techno-economic feasibility*, including complex technological solutions associated with high energy costs, grid access bottlenecks, and environmental impacts; (ii) *Socio-regulatory context*, in which fragmented regulatory frameworks, poorly designed auctions, conflicts with other marine uses, and the factors shaping public perception delay deployment; (iii) *Supply-chain readiness*, involving underdeveloped port infrastructure, lack of convergence of solutions, dependencies on external markets and a relative lack of experience and skilled labour among local suppliers. These three macro-areas are intentionally defined at a high level of aggregation. In particular, environmental and life-cycle considerations are treated within the techno-economic feasibility area, since they are addressed through the same quantitative, engineering-based assessment (such as life-cycle assessment and cumulative-impact modelling) and bear directly on project feasibility and cost. This deliberately broad classification is adopted to make legible the fragmentation that still characterises the existing literature and current developments.

These issues are interdependent. The inherently interdisciplinary nature of offshore wind deployment generates multiple cross-cutting interconnections. For instance, regulatory frameworks play a critical role in grid integration: supportive policies for cross-border offshore grid corridors can substantially enhance transmission capacity [10]. Addressing initial economic barriers is also fundamental and requires targeted policy support. In this context, stability, transparency, and clarity in the design of policy and market frameworks are decisive in determining whether industrial actors commit to long-term investments and supply-chain expansion. While the cost of floating wind remains high compared with established energy technologies, market integration of novel concepts is hindered by prototype costs, which can be substantially higher than those of industrial-scale developments. For instance, the Hywind Tampen project, the first large-scale floating wind farm, was supported by the Norwegian national government to overcome this initial barrier.

Despite global commitments to the adoption of clean energy systems, the current status of the offshore wind supply chain and the corresponding level of industrial readiness remain insufficient to support the massive expansion anticipated in the coming years.

It is worth noting that, although the market is moving towards convergence, no clear technological consensus has yet been achieved: several high-TRL designs are progressing in parallel, with optimisation and cost reduction still underway. In practice, effective convergence is likely to emerge only through a combination of test and demonstration activities and subsequent large-scale industrial deployment, where stakeholder coordination, serial production, and field learning can crystallise dominant designs. Meanwhile, environmental considerations are advancing via nature-inclusive design (NID) to mitigate impacts on marine flora and fauna, and existing infrastructures, local industries and ports, continue to exert a strong pull on design criteria [11].

Lastly, the development of a large-scale industry has significant implications for both the economy and social acceptance. Contrary to common assumptions, while wind turbine OEMs actively pursue local economic benefits as part of stakeholder engagement, localizing the supply chain does not automatically guarantee higher local acceptance. Although wind projects can generate employment, construction-phase jobs are by nature temporary but typically extend over multiple years, providing sustained activity and opportunities for skills development; nonetheless, local employment capture may remain limited unless targeted programmes are in place [12]. In parallel, the operational phase supports more stable, long-term and largely local jobs, reinforcing the potential for lasting socio-economic benefits. Public perception tends to improve most reliably through early engagement and fair benefit-sharing, for example via economic compensation schemes or job creation [13–15].

These interdependencies are examined in this study via three guiding research questions that connect technology, regulation, and industry, providing a unifying framework for the subsequent analysis. Indeed, when considering the literature, while these challenges are recognised as interlinked, only a limited number of studies analyse them in a holistic manner, resulting in a fragmented body of literature. Robertson et al. [9] highlight the strong link between technological innovation and industrial readiness in shaping the commercialisation of floating wind. The study provides a broad overview of floating wind solutions with respect to industrial aspects and infrastructure, addressing challenges related to major operations. However, although political and economic dimensions are discussed, the broad scope of the work limits its applicability to complex regional scenarios, such as the Mediterranean basin, where contextual specificities play a pivotal role.

McKenna et al. [6] offer the most comprehensive interdisciplinary study to date, examining wind energy impacts across multiple thematic areas (TAs), proposing potential solutions, and outlining research priorities with strong emphasis on political aspects. However, the floating wind context is only marginally addressed, being presented primarily as a potential means to reduce visual, social, and environmental impacts. As a result, the proposed framing is partly impractical when considering offshore applications, as it overlooks detailed considerations of a sector expected to constitute a major share of the electricity mix in the coming years.

With the aim of providing an exhaustive overview and perspective on floating wind energy development, this study examines: (i) the existing literature and industrial trends, providing insights from both academic and industrial perspectives; (ii) the technical, socio-regulatory, and supply-chain status; (iii) the mutual interactions among these factors examining buildability constraints, regulatory–market influences on deployment, and policy–grid–industry coordination for basin-scale integration.

The Mediterranean basin represents a distinctive case in which challenging geophysical conditions, the involvement of many coastal nations, and a strong common industrial base combine to create both barriers and opportunities for floating wind deployment.

Although several principles and regulatory processes are shared between bottom-fixed and floating offshore wind (FOW), key differences remain. Floating systems shift constraints from seabed foundations to floater fabrication, port and vessel capabilities, dynamic cables, and larger anchor footprints. These distinctions are acknowledged here, while a more detailed comparison is deferred to the technical sections.

This study serves as a resource for academic, industrial, and policy stakeholders, aiming to bridge gaps across disciplines and practices and to inform future research and decision-making. To ensure practical relevance, the manuscript benefited from structured feedback provided by several industrial stakeholders (mentioned in the acknowledgements), which helped align the analysis with current deployment and market realities.

To clarify the analytical logic of the paper, the remainder is structured as follows. Section 2 provides a dual review of the scientific literature and industrial practice, highlighting the mutual dependencies among technical, regulatory, and industrial aspects, and the fragmentation of existing contributions. Section 3 then applies this integrated lens to the Mediterranean basin as a representative environment, showing how technological design, environmental constraints, permitting frameworks, grid integration, and supply-chain capacity interact in practice. Section 4 distils cross-cutting messages and policy-relevant implications emerging from this combined analysis.

2. State of the art and industrial context for floating wind applications

To contextualise the complexities of the current offshore wind landscape, this section reviews both academic and industrial contributions on FOW. By mapping the literature across three interlinked domains,[1] namely techno-economic feasibility, socio-regulatory context, and industrial and supply-chain readiness, and comparing these with ongoing market developments, we highlight where research remains fragmented and where cross-cutting perspectives are missing.

We focus on factors that materially affect deployment at the project or system scale. Micro-level advances, such as detailed control-theory developments, are considered only when they influence feasibility, planning, or integration.

1. **Techno-economic feasibility:** technology options (such as floating, mooring, and turbine solutions), performance and costs (CAPEX, OPEX, learning), system integration including grid connection and offshore hubs, and environmental implications such as life-cycle assessment and cumulative impacts.
2. **Socio-regulatory aspects:** spatial planning and permitting, auction and support scheme design including non-price criteria, public acceptance and stakeholder engagement, and macroeconomic implications for host regions.
3. **Industrial and supply-chain aspects:** availability and scaling of key components and materials, port infrastructure and logistics such as quayside assembly and tow-to-site operations, installation vessels and workforce, and progress towards standardisation and serial production.

To provide a concise snapshot of the field, Table 1 catalogues representative studies on FOW (2020–2024) published in higher-impact outlets (SCImago Journal Rank, SJR $\geq$ 2), sorted in descending order of citations per year. While the overall analysis identified 178 studies, only those with broader applicability were considered. Technical papers focusing on specific aspects, such as detailed mooring system analyses, were excluded, resulting in a final set of 60 studies. Therefore, the table is illustrative rather than exhaustive: its purpose is to reveal publication patterns and recurrent gaps, not to enumerate all contributions. Here we trace how academic work has evolved and where it remains partial, while the remainder of the paper extends this evidence to derive implications and lessons that can be transferred to FOW from adjacent sectors.

Notably, almost half of the studies appear in 2024, signalling growing academic interest in the field. The three domains are sketched in Fig. 1, which also positions the floating offshore system within this broader landscape.

85% of the studies in Table 1 address the techno-economic domain, underscoring that social and industrial aspects of floating wind remain under-represented in academic research. A persistent limitation is the scarcity of genuinely holistic analyses of wind systems. Only a few recent contributions consider all three dimensions, namely techno-economic feasibility, socio-regulatory context, and industrial and supply-chain readiness, within a single integrated framework [6,9,76].[2]

Geographically, around 70% of the studies focus on a specific region or country, and interest is mainly concentrated towards European countries, covering 85% of the studies. Furthermore, coverage is skewed

Table 1
Literature review. Country codes follow the ISO 3166–1 alpha-2 standard. Regions shown in italic blue fall outside the ISO classification. Rows in bold indicate studies covering the Mediterranean region [16,17,19,20,23,25,26,29,30,32,34–38,40–46,48–54,56–63,65,66,68–73,75].

Reference	Year	TA	Region
[16]	2021	🟠	✗
[17]	2023	🟢	✗
[18]	2022	🟠	✗
[19]	2022	🟢	✗
[20]	2022	🟢	*NS*
[21]	2022	🔴	CN
[22]	2024	🟢	✗
[23]	2022	🟠	✗
[24]	2022	🟢	NO
[25]	2022	🟢	*NS*
[26]	2022	🟢	IE
[27]	**2021**	🟢	***MS***
[28]	2023	🟢	✗
[29]	2024	🟢	ES
[30]	2021	🟢	UK
[31]	**2023**	🟢	**IT**
[32]	2024	🟢	UK, DK, CN
[33]	**2021**	🟢	**GR**
[34]	2023	🟢	CN
[35]	2022	🟢	✗
[36]	2023	🟢	BE
[37]	2023	🟢	ES
[38]	2024	🟢	*EA*
[39]	**2023**	🟢	**IT**
[40]	2022	🟢	✗
[41]	2024	🟢	*NS*
[42]	2024	🟢	*EA*
[43]	2023	🟢	✗
[44]	2023	🟢	ES
[45]	2022	🟢	BR
[46]	2024	🟢	✗
[47]	2024	🟢	*MS*
[48]	2023	🟢	ES
[49]	2024	🟢	BR
[50]	2024	🟢	NO
[51]	2024	🟢🔴	*PO*
[52]	2024	🟢	IE
[53]	2024	🟢	CN
[54]	2023	🟢	UK
[55]	**2024**	🟢	***NS*, ES, PT**
[56]	2024	🟢	IE
[57]	2024	🟢	*NS*
[58]	2024	🟢	CN
[59]	2023	🟢	✗
[60]	2024	🟢	ES
[61]	2021	🟢	✗
[62]	**2024**	🟢	***NS*, ES, PT**
[63]	2024	🟢	ES
[64]	2024	🔴	NO
[65]	2021	🟢	✗
[66]	2021	🔴	ES
[67]	**2024**	🟢	**FR**
[68]	2023	🟢	ES, US
[69]	2024	🟢	✗
[70]	2024	🟢	NO
[71]	2024	🟢	NL
[72]	2024	🟢	✗
[73]	**2023**	🟢	**ES,PT**
[74]	2023	🔴	FR, NO, UK
[75]	2022	🟢	✗

🟢	Techno-economic feasibility
🔴	Socio-regulatory context
🟠	Supply chain readiness
NS	North Sea
MS	Mediterranean Sea
EA	European Atlantic
PO	Pacific Ocean
✗	General methodology

[1] While a detailed analysis would require a more complete and exhaustive representation of the domains of interest, some simplifications and integrations have been adopted to avoid overcomplicating the discussion.

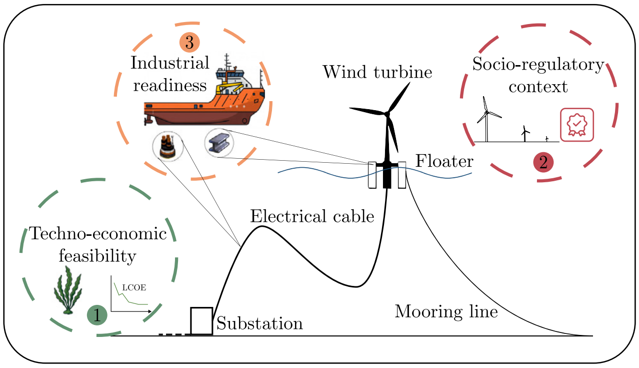

Fig. 1. Definition of the three interconnected domains: techno-economic feasibility, socio-regulatory context, and industrial readiness, highlighting cross-domain interactions.

towards Northern Europe, reflecting the historical concentration of offshore deployment in the North Sea over the past two to three decades. By contrast, Mediterranean contexts remain comparatively underexamined, representing 13% of the studies compared with 32% for the North Sea. Although several studies relate to Mediterranean countries, only a small subset focuses specifically on the southern basin's coasts and conditions [27,33,67].

While recent research argues for an integrated lens that spans techno-economic, socio-regulatory, and industrial dimensions, the literature also shows that FOW development draws heavily on lessons and practices from adjacent sectors, most notably Oil & Gas (O&G), and from onshore and fixed-bottom offshore wind. Accordingly, Table 1 focuses on floating-specific studies, but any meaningful appraisal of risks and opportunities requires a broader view of the development environment, including fixed-bottom precedents and onshore supply-chain experience. As sketched in Fig. 1, technology sits at the centre of this landscape, with other dimensions converging around it.

Advances in foundation design and installation techniques can unlock scale by reducing weight, simplifying assembly, and shortening critical-path operations [18]. Their impact, however, ultimately depends on an industry-oriented approach that aligns innovation with port capabilities and vessel availability, which are two persistent bottlenecks. Ports that enable quayside integration and tow-to-site strategies reduce reliance on scarce offshore construction vessels and compress weather-sensitive windows, lowering risk and overall project costs [11,77]. At the turbine level, the rapid increase in rotor size and rated capacity, although often beneficial for energy yield, risks outpacing the capacity of the installation fleet and reinforces the need for standardisation and coordinated investment in vessels and heavy-lift infrastructure [78]. This challenge is further accentuated for floating wind, where turbines originally designed for bottom-fixed applications operate under different load envelopes. In this regard, stabilising turbine growth within infrastructure limits has been proposed to improve market predictability [9]. While larger rotor sizes may enhance energy production, they may also impose adverse consequences on floating structures, increasing both costs and associated risks. At project level, these impacts can be partly offset by the reduced number of floating wind turbines and associated balance-of-plant components required for a given installed capacity. Nevertheless, the overall scaling effect remains positive, as energy yields increase faster than costs, resulting in a lower levelised cost of energy. In parallel, policy design should avoid support mechanisms that inadvertently dampen incentives for innovation and R&D, which could slow long-term industry development [21]. Likewise, auction criteria should refrain from favouring untested or commercially unavailable turbine ratings, such as awarding higher scores to projects proposing fewer, larger turbines, as this may distort technology choices and encourage prematurely upscaled designs.

Another strand of industrially oriented design targets critical materials. Recent trends favour advanced geared drivetrains and alternative generator configurations that reduce or eliminate rare-earth dependence, thereby limiting exposure to supply risks and price volatility while maintaining performance [28,79]. Such choices illustrate how technology roadmaps are inseparable from supply-chain resilience and geopolitics.

Environmental and ecological considerations add a further layer of interdependence. Despite growing evidence that cumulative and synergistic effects drive ecosystem responses, many studies still address impacts in isolation [80]. Robust application of Strategic Environmental Assessment and Environmental Impact Assessment (SEA and EIA) frameworks is therefore essential to mediate trade-offs and to identify pathways for co-benefits, including coexistence with other maritime activities such as fisheries and aquaculture.

On the socio-political side, beliefs and narratives can powerfully shape local responses to projects. Evidence suggests that conspiracy beliefs exert a stronger influence on opposition than demographic factors, underscoring the need for proactive, transparent information strategies [81]. Social acceptance is also context-sensitive: energy crises, for example, can either bolster or erode public support depending on policy design and communication [82]. In parallel, streamlining regulatory procedures and accelerating approvals can help alleviate development bottlenecks, while building trust through early stakeholder engagement and planned coexistence with other maritime sectors such as fisheries and aquaculture is increasingly recognised as a core element of effective deployment strategies [9].

These dynamics intersect directly with economics and policy. Curtailment (*i.e.*, a forced output reduction due to grid or system constraints) remains a critical challenge because it reduces revenues and weakens carbon outcomes; mitigation typically requires explicit regulatory measures [83]. Grid cost-allocation choices offer another nexus: shallow or super-shallow charging transfers connection costs from developers to transmission system operators (TSOs), generating savings but necessitating coordinated spatial planning to identify cost-effective zones for offshore build-out [84]. Such decisions link closely to auction design, since seabed and grid charges shape bidding strategies and risk profiles [85], *i.e.*, developers' exposure to cost uncertainty, curtailment risk, and grid-connection obligations. More broadly, auction visibility and design determine whether supply-chain actors commit to port upgrades and manufacturing capacity, reinforcing how industrial investment depends on stable policy frameworks and predictable volumes. Conversely, policy uncertainty amplifies energy-security risks, whereas stable and clear regulatory frameworks and prudent management of resource rents (*i.e.*, the surplus value generated from extracting natural resources) are essential to mobilise long-term capital [86]. Experience such as Norway's sovereign wealth fund illustrates how transparent, inclusive governance of resource revenues can underpin stability and facilitate the energy transition [86].

Although the literature remains fragmented, its message is clear: analysing offshore wind requires grappling with interdependent technical, social, environmental, and industrial factors that vary by context. In practice, multi-criteria decision methods, explicitly integrating technical, economic, environmental, and social dimensions, can guide site selection and programme design for floating wind, linking engineering feasibility with social acceptance and supply-chain logic [24]. Overall, public perception, regulation, cost trajectories, technological innovation, and ecological outcomes are tightly woven together, calling for coordinated strategies that cut across domains and time horizons.

[2] These three studies are not included in Table 1 as they do not meet the methodological selection criteria of the review, but they are nevertheless discussed in the analysis due to their relevance, being the only ones that jointly address all three identified domains.

Table 2
Online, under-construction, and permitted FOW projects of interest. Bold texts are referred to Mediterranean projects.

Project name	Country	Capacity [MW]	Turbine [MW]	Floater	Status	Depth [m]	Distance [km]
Hywind Tampen [89]	NO	95	8	Spar	IO	260–300	140★
Kincardine [90]	GB	48	9.6	Semisub	IO	60–80	15
Hywind Scotland [91]	GB	30	6	Spar	IO	95–120	25
WindFloat Atlantic [92]	PT	25	8.4	Semisub	IO	85–100	20
Provence Grand Large [93]	**FR**	**25**	**8.4**	**TLP**	**IO**	**100**	**17**
OceanX [94]	CN	16.6	2 × 8.3	Semisub	IO	40	80
CNOOC Guanlan [95]	CN	7.25	7.25	Semisub	IO	120	136
CSSC Fuyao [96]	CN	6.2	6.2	Semisub	IO	65	12
CTGNE Yangjiang Shapa Demo [97]	CN	5.5	5.5	Semisub	IO	28–32	30
Guoneng [98]	CN	4.0	4.0	Semisub	IO	35	*
TetraSpar Demo [99]	NO	3.6	3.6	Spar	IO	200	10
Kitakyushu [100]	JP	3.0	3.0	Barge	IO	50–55	15
Unitech Zephyros [101]	NO	2.3	2.3	Spar	IO	220	12
DemoSATH [102]	ES	2	2	Barge	IO	85	3
Floatgen [103]	FR	2	2	Barge	IO	33	22
Sakiyama [104]	JP	2.0	2.0	Spar	IO	106.5	5
EolMed [105]	**FR**	**30**	**10**	**Barge**	**UC**	**55**	**15**
EFGL [106]	**FR**	**30**	**10**	**Semisub**	**UC**	**65-80**	**16**
Goto Floating Wind Farm [107]	JP	16.8	2.1	Spar	UC	120–140	5
Eolink Demo [108]	FR	5	5	Semisub	UC	33	22
Gray Whale [109]	KR	1500	*	Semisub	CA	150	60–70
Haewoori [110]	KR	1500	*	Semisub	CA	120–130	75–95
KFWIND-A/B [94]	KR	750	*	Semisub	CA	175–275	80
Firefly [111]	KR	750	*	Semisub	CA	150–300	70
MunmuBaram [112]	KR	750	15	Semisub	CA	120–150	65
Green Volt [113]	GB	560	15	Semisub	CA	80–100	80
KFWIND-EBP [94]	KR	375	*	Semisub	CA	175–275	80
Pentland Floating Wind [114]	GB	100	15	Semisub	CA	75–101	7.5
White Cross [115]	GB	100	*	*	CA	69–78	52
Salamander [116]	GB	100	*	Semisub	CA	100	35
Project Erebus [117]	GB	96	*	Semisub	CA	70	44
Culzean Floating Wind [118]	GB	3	3	Semisub	CA	90	220
SeaTwirl S2x [119]	NO	1	1	Spar	CA	130	0.7

★ Not directly connected to shore. Connected to O&G platforms.
* Not clearly defined; IO In operation; UC Under construction; CA Consent authorised

2.1. Policy targets and industrial trends in floating wind domain

Building on the above, the role of institutions and policy-makers is pivotal in accelerating deployment. In Europe, offshore renewable energy targets were initially set at approximately 60 GW by 2030 and 300 GW by 2050 [87], and have since been revised upwards to 88 GW and 360 GW, respectively [88]. Yet these ambitions must be read against current market realities: in several regions, progress is still constrained by permitting, grid access, and supply-chain readiness.

Table 2 summarises the principal FOW projects that are in operation, under construction, or consent-authorised worldwide, together with key characteristics.

Although the first floating wind pilots and the majority of currently installed capacity are located in Europe, China is rapidly accelerating its efforts and now hosts one of the largest pipelines of pilot projects. South Korea, in parallel, has advanced its domestic agenda by designating and fast-tracking its first large-scale development areas. Project characteristics indicate a shift towards standardised semi-submersible concepts and tow-to-site strategies, reflecting priorities of buildability and logistics efficiency. Furthermore, turbine ratings continue to scale, tightening constraints on ports, vessels, and quayside integration. Together, these trends suggest that industrial capability, including port infrastructure, vessel availability, fabrication capacity, and workforce development, must co-evolve with technology choices and regulatory clarity if stated targets are to translate into timely build-out.

Concretely, Europe has about 233 MW of grid-connected FOW [120]. The Mediterranean contributes just 26 MW and, despite recently articulated targets, progress remains modest: the only operational project is Provence Grand Large (France), with EolMed and EFGL[3] in the final phases, ahead of commissioning expected later this year, also in French waters. Italy, despite considerable potential, has no operational FOW projects. The regional picture mirrors the literature bias towards the North Sea, although momentum is building in the south: the two largest Mediterranean projects under construction are in French waters, and the Gulf of Lion is widely recognised as one of the basin's most attractive areas for floating development [27].

Set against this snapshot, earlier national objectives were not met, revealing the gap between ambition and delivery. By 2020, none of the four main EU Mediterranean countries—Italy, France, Spain, and Greece—had achieved their initial offshore wind targets. Italy and France reported no operational offshore wind farms at that time [121, 122].[4] Spain had commissioned only about 5 MW [125], far below its 750 MW target [126], and Greece had installed no capacity despite a 300 MW goal [127,128]. Current plans now reflect higher ambition: Italy aims for 2.1 GW by 2030, 12 GW by 2040, and 20 GW by 2050 [129]; France targets 3.6 GW by 2030, 18 GW by 2035 [130], and 45 GW by 2050 [131]; Spain seeks 3 GW by 2030 and 17 GW by 2050 [132,133]; and Greece plans 1.9 GW by 2030 and 11.8 GW by 2050 [134]. Taken together, the missed 2020 targets and revised long-term goals highlight growing momentum but also the challenge of turning ambition into tangible Mediterranean deployment.

National and European ambitions can be met only if industry continues to shift towards standardisation. Platform choices are converging on concepts that prioritise buildability and operational simplicity [135]. Early developments drew heavily on O&G practice, most notably Tension Leg Platforms (TLPs) [22], but recent years have seen a decisive pivot. Semi-submersible (semisub) designs are now preferred

[3] Currently, EFGL turbines are installed but not yet connected to the grid.

[4] The first Italian and French offshore wind projects, Beleolico and Saint-Nazaire (both bottom-fixed), came online in 2022 [123,124].

owing to their moderate draft requirements (compared with spar-like structures), compatibility with quayside assembly, and tow-to-site installation, whereas alternative concepts such as TLPs, despite lower drafts, typically entail higher installation complexity [11,136]. Although spars still account for much of the installed European base, the near-term pipeline points to rebalancing: around 71% of forthcoming European projects are set to adopt semisubs, and globally about 98% of capacity announced in 2023 is semisub-based [137]. TLPs remain comparatively rare due to installation complexity and tighter site constraints [138].

While the potential drawbacks of standardisation have been noted, turbine scale-up has continued rapidly in both structural dimensions and rated power. In Europe, recent installations include GE Vernova's 13 MW Haliade-X in the UK, Siemens Gamesa's 14–15 MW direct-drive units in the North Sea, and Vestas's 15 MW class turbines, confirming a rapid upward shift in rated power. Stakeholder surveys in 2015 and 2020 projected average offshore ratings of about 11 MW by 2030 and 17 MW by 2035; however, present ratings (10.1 MW in 2024) anticipate future values to exceed this trajectory. Beyond Europe, further upscaling is being pursued by Asian manufacturers, with announced designs such as the Mingyang MySE 18.X–20 MW (260–292 metre rotor) [139], and a 22 MW concept reportedly planned with a 310 metre rotor [140]. Near-term European orders as of 2023 comprise approximately 192 units of Vestas's 15 MW model (236 metre rotor) and 167 units of Siemens Gamesa's 14.7 MW model (236 metre rotor) [141]. It is worth noting that Siemens Gamesa is currently testing a new 21.5 MW turbine in Denmark [142].

This scale-up has direct implications for floating concepts. Larger rotors and heavier nacelles increase global loads and dynamic response requirements on substructures and moorings. These factors further reinforce the shift towards semisubs, valued for compatibility with quayside integration and operational simplicity, while spars and tension-leg configurations (TLP-based systems) encounter stronger site- and installation-specific constraints. In practice, technology selection and infrastructure readiness increasingly co-determine viable deployment pathways. As a result, the near-term priority for the floating offshore wind industry may lie less in further turbine upscaling alone than in improving reliability, standardisation, and modularity within turbine classes that are already approaching commercial maturity, while allowing continued optimisation of turbine scale, in order to support predictable industrial scaling and reduce deployment risks.

Technology choices also carry clear economic implications. Early European demonstration projects, including Kincardine, Hywind Scotland, and WindFloat Atlantic, reported Levelised Cost Of Energy (LCOE) above 184 €/MWh as of 2022,[5] reflecting small project scale, system-level TRL 7–8 (covering floaters, turbines, mooring systems, and grid interfaces) [143], and immature supply chains [144]. These values reflect early demonstration economics; more recent assessments indicate higher floating wind LCOE under current inflation, cost-of-capital, and supply-chain conditions. Relative to bottom-fixed systems, floating concepts entail higher material and installation requirements, including greater steel tonnage, more complex substructures, and station keeping systems and dynamic cables, as well as higher operation and maintenance (O&M) costs [144].

Forward-looking assessments indicate significant room for cost reduction. The 2021 expert elicitation [5] presents pessimistic, median, and optimistic trajectories; median results suggest LCOE declines of about 17% by 2035 and 40% by 2050 relative to 2019 fixed-bottom baselines, driven by CAPEX/OPEX learning, higher capacity factors, and improved financing conditions. Europe-specific outlooks point to ∼18% reduction by 2035, with technology learning, supply-chain scaling, and extended service lifetimes[6] as key levers. Under optimistic

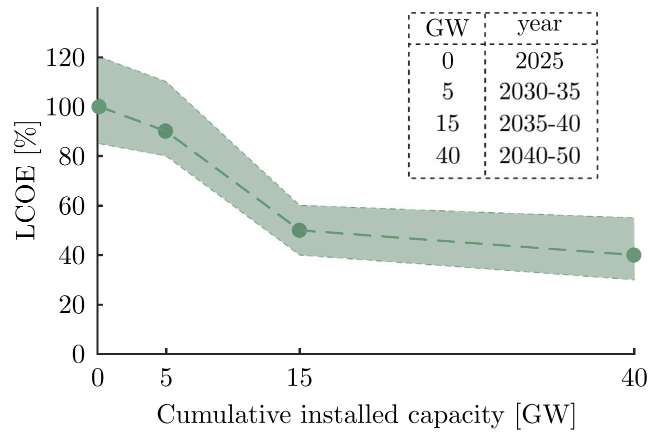

Fig. 2. Projected LCOE reduction for Mediterranean FOW vs added cumulative capacity, with optimistic, central, and conservative trajectories. Cumulative capacity refers to reference year bands.

trajectories, cumulative reductions could approach ∼56% by 2050 [5]. Despite higher CAPEX persisting into the 2030s, the cost gap with fixed-bottom would narrow materially, strengthening the case for deep-water regions such as the Mediterranean [5].

Uncertainty remains non-trivial. Limited commercial-scale experience and sensitivity to learning rates, financing terms, and logistics constraints produce wide forecast bands; conservative views foresee only modest reductions or near-stagnation [5]. Historical mispredictions, often conservative over-estimates of future costs [146], caution against both optimism and pessimism, and argue for policies robust to variance in outcomes. Indeed, persistent discrepancies between academic and industrial LCOE estimates reflect the metric's sensitivity to assumptions, deployment scale, and evolving market conditions. Exogenous shocks, such as supply-chain disruptions or geopolitical crises, can rapidly invalidate projections, underscoring the fragility of static cost metrics [147]. Traditional LCOE formulations, while widely used, overlook the temporal and systemic context of variable renewables [148]. Recent approaches extend LCOE to include contract structures [149], dynamic price trajectories [150], and temporal market value [151]. Metrics such as the Cost of Valued Energy capture the devaluation of generation during surplus periods. In this view, LCOE remains a useful benchmark but requires integration with time- and system-dependent indicators to ensure credible techno-economic assessments.

To contextualise recent cost trajectories, representative learning-curve scenarios were constructed by triangulating multiple independent sources, including the latest WindEurope market outlook [152], ETIPWind (2025) [153], DNV Energy Transition Outlook 2025 [154], and Fraunhofer ISE (2024) [155], complemented by direct industrial expertise feedback. These datasets are compatible and comparable, presenting similar underlying assumptions, value ranges, and trend slopes, often nearly identical, thus providing a coherent and robust reference framework. These are displayed in Fig. 2, where a single median trajectory with uncertainty bands is shown for clarity given the strong overlap among sources. The analysis adopts a reference baseline (100%) of 200 €/MWh, corresponding to today's early-industrial deployments, where costs still reflect limited series production, maturing supply chains, and non-optimised logistics. Updated financial and technical assumptions were applied, including a representative mid-term WACC of 6–7%, net capacity factor of 45–50%, and lifetime of 25 years. These values should be interpreted as reference assumptions for learning-curve

[5] Original values reported in USD/MWh were converted using 1 USD = 0.92 EUR for consistency across the manuscript.

[6] For example, the Danish Energy Agency extended the operational lifetimes of Middelgrunden and Nysted by 25 and 10 years, respectively, following technical assessments [145].

comparison rather than project-specific financing parameters; realised WACC and capacity factors may vary substantially across countries, sites, and market conditions, with higher early-stage financing costs captured within the conservative cost envelope. These are consistent with recent European tender data and OEM feedback.

Expressed as a function of cumulative installed capacity, the resulting trajectories describe the progressive industrialisation of FOW from early current stage (0 GW) to large-scale deployment (~40 GW by 2050). Uncertainties are also significant at the 2025 horizon, reflecting the early-industrial stage of the sector, with not well defined supply-chain configurations and port infrastructures, and optimised operations still evolving and not yet fully standardised. These values smooth over regional heterogeneity and assume continued learning without major supply-chain shocks. They remain indicative but consistent with the CAPEX levels (~5 M€/MW) used in this work, which should be interpreted as representative mid-range values rather than site-specific estimates, and with the cost ranges observed in recent European Contracts for Difference (CfD), including the GreenVolt floating wind project, awarded 400 MW at £139.93/MWh in the UK AR6 auction.

These learning-curve trajectories illustrate the path-dependence of cost reduction: progress requires active deployment to trigger learning, not the mere passage of time. Waiting for technologies to mature in isolation would risk a self-reinforcing stagnation. Instead, sustained buildout and timely auction rounds are prerequisites for moving down the cost curve. For this reason, the cost trajectories presented here explicitly assume the timely execution of planned auctions and the effective delivery of enabling measures. Absent such coordinated action, cost reductions may stall, not due to technological limits, but due to policy inaction.

It is worth noting that, although several insights and lessons learned from bottom-fixed offshore wind remain relevant, they cannot be transferred wholesale to floating systems. FOW operates under distinct industrial, logistical, and risk conditions, where progress depends on floating-specific enablers such as floater serialisation, port and tow-out capacity, dynamic cable design, and anchor handling requirements. For this reason, fixed-bottom benchmarks, whether in terms of LCOE, build rates, or supply-chain throughput, must be interpreted with caution when assessing floating trajectories.

Before delving further into the analysis, it is important to contextualise current trends within the broader offshore wind landscape. Recent global political developments have, in several cases, diverged from earlier wind-energy expansion trajectories, contributing to increased uncertainty in project pipelines [156]. In parallel, some offshore wind initiatives have been paused or commercially reassessed due to cost inflation, supply-chain bottlenecks, and higher financing costs, which have constrained project economics and slowed investment decisions [157]. Similar cost pressures have also affected floating-wind-based electrification plans for offshore oil and gas infrastructure, with some developers publicly reporting the reassessment or discontinuation of such initiatives due to elevated costs and financing constraints [158].[7] These developments highlight the importance of incorporating short-term market dynamics into forward-looking deployment trajectories.

2.2. Review section outlook

Taken together, the scientific and industrial evidence reviewed in this section reveals a recurring pattern: while techno-economic optimisation, regulatory design, and industrial capacity are frequently analysed in isolation, their interaction ultimately determines whether offshore wind projects reach financial close and physical delivery. These interdependencies become particularly visible in constrained regional settings, where spatial, ecological, grid, and supply-chain conditions cannot be abstracted away.

While the literature review clearly mapped a fragmented and non-exhaustive panorama, this gap becomes even more evident when specifically referring to the Mediterranean basin. Among the analysed studies (see Table 1), only a few explicitly address the Mediterranean Sea, and these are exclusively focused on the first thematic area. A similar situation emerges in relation to industrial projects, where only a limited number of French case studies concern Mediterranean deployments. Although the available studies predominantly relate to the first thematic area, several considerations can nevertheless be distilled from the Mediterranean-focused analyses:

(i) it is acknowledged that one of the most significant constraints on wind development in the Mediterranean relates to environmental and bathymetric conditions, where water depths prevent a gradual technological transition from bottom-fixed to floating solutions [27,47,55];
(ii) the limited number of industrial projects (as reflected in Table 2) in the Mediterranean basin has a direct impact on the associated cost of energy [27];
(iii) meaningful cost reductions may be achieved through tailored optimisation strategies [39], and the configuration of Mediterranean ports and vessel availability may provide advantages for O&M strategies compared to higher-wind Atlantic sites such as northern Spain [55];
(iv) from an environmental perspective, life-cycle assessments indicate that the substructure may carry a larger relative impact compared to bottom-fixed solutions; however, floating wind remains environmentally favourable when compared with alternative energy sources [31].

Although the existing literature does not yet provide a fully integrated treatment of these dimensions, it nevertheless highlights the inherently interdisciplinary nature of the topic, particularly in linking industrial readiness with technical design considerations [39,67]. The following section therefore applies a more structured lens to the Mediterranean context, building on the gaps identified here and connecting them to targeted pathways for deployment and improvement.

3. The Mediterranean sea: a basin-specific lens

In parallel to the academic and industrial evidence reviewed above, European collaborative programmes have recently reinforced this integration agenda, for instance through MARINEWIND [159] (market-uptake measures for floating offshore wind) and FLOATFARM [160] (environmentally-focused innovations for floating wind farms), while international coordination efforts such as IEA Wind TCP Task 49 [143] on Integrated Design of Floating Wind Arrays provide open-access reference work on array-level design and innovation prioritisation.

Generic EU-wide assessments blur the factors that actually determine whether offshore wind can be built in the Mediterranean. In this basin, deep-water morphology makes floating the default technological option rather than the exception, while bottom-fixed projects are limited to a few shallow coastal sites. Dense networks of marine protected areas and biodiversity corridors tighten environmental design requirements; electricity systems rely on fewer strong interconnectors and face curtailment and charging rules that diverge from North Sea precedents; industrial capabilities hinge on a handful of ports with specific draught and lay-down constraints; and a distinctive wind–solar profile increases the value of hybridisation and offshore hubs. Reading technology, regulation, and industry through this basin-specific lens is therefore essential to move from targets to delivery.

[7] While some examples refer to fixed-bottom projects, they illustrate broader market and financing pressures affecting offshore wind investment decisions.

Therefore, in this section we apply the same thematic areas through a basin-specific lens to illustrate how their interactions ultimately determine buildability. Rather than treating technology, permitting, grid integration, and supply chains as separate tracks, the following analysis shows how decisions in one domain (*e.g.*, floater and mooring concepts, port draught and lay-down capacity, grid-charging and curtailment rules, or nature-inclusive design requirements) propagate constraints and trade-offs across the others. The Mediterranean is used here as a stringent test case, where deep-water morphology, dense ecological constraints, fragmented jurisdictions, and limited interconnection capacity render these interdependencies both explicit and policy-relevant. This framing guides the reader through the subsections, progressively linking siting and design choices to environmental and social feasibility, then to permitting architectures, market instruments, grid coordination, and the industrial and materials base required to translate targets into deliverable projects, culminating in the integrated perspective schematically represented through the guiding-question framework.

We note that, given the limited literature specifically addressing the Mediterranean Sea, we adopt, where appropriate, a structured reinterpretation of bottom-fixed case studies through a floating-wind lens.[8] For instance, the discussion on industrial readiness begins with an assessment of the broader offshore wind supply chain (largely informed by bottom-fixed experience, *i.e.*, Section 3.7), and subsequently examines the adaptations and assumptions required to address the specific challenges and components associated with floating wind solutions (Sections 3.8, 3.9).

3.1. Siting, bathymetry, and climatic conditions

Offshore wind development in the North Sea has benefited from highly favourable conditions, including strong wind resources and shallow bathymetry. By contrast, the Mediterranean presents a more complex environmental setting, which helps to explain the significant lag of the industry in the basin despite its substantial untapped potential. With most suitable shallow-water areas in Northern Europe already utilised, a substantial share of the industry is likely to shift towards deeper basins, where floating structures become the necessary option.

Compared with the North Sea, the Mediterranean experiences milder wind and wave conditions, creating a different design and operational landscape. While global industry trends are moving towards ever larger turbines with heavier nacelles and generators, optimal strategies for the Mediterranean may lie in alternative scaling. For example, deploying larger rotors while maintaining constant generator rated power could reduce the LCOE by up to 13% [161]. Furthermore, the less severe metocean conditions may enable technological solutions that are more cost-efficient than those developed for harsher North Sea environments.

Industrial practice is also beginning to integrate innovative, cost-effective strategies. A notable example is the Hywind Tampen floating farm, the first project to adopt shared anchors. In this configuration, multiple mooring lines from different floaters are connected to the same anchor, reducing the number of anchors from 33 to 19. While such configurations introduce additional design complexity and risk concentration, mooring systems account for a non-negligible share of total CAPEX; reducing the corresponding equipment can therefore deliver material and installation cost savings, while also limiting environmental disturbance. Such approaches illustrate how basin-specific conditions can be leveraged to align technical innovation with both economic and ecological benefits.

Planning must also be climate-aware: projected changes in wind power density could shift optimal siting over time, with implications for long-lived infrastructure [162,163].

3.2. Environmental impact

Offshore wind farms (OWFs) deliver undisputed decarbonisation benefits; however, their rapid expansion raises ecological concerns, including potential habitat alteration, underwater noise, species collisions, invasive species, and cumulative ecosystem stress [164]. At the same time, emerging evidence suggests that OWFs may also generate local ecological benefits, highlighting the need for balanced, evidence-based assessments [165]. Significant knowledge gaps remain [80], contributing to a mismatch between perceived and actual impacts and, in turn, influencing public perception, policy choices, and the pace and cost of permitting [166].

These challenges are particularly acute in the Mediterranean, where dense networks of Marine Protected Areas (MPAs) intersect with prospective offshore wind zones. The Interreg PHAROS4MPAs initiative proposes an integrated framework to reconcile Blue Economy growth with MPA conservation [167]. Fig. 3 illustrates the extent of Mediterranean conservation sites, including the Pelagos Sanctuary [168] and the Cetacean Migration Corridor [169].

Lloret et al. [171] emphasise that, given current uncertainties, installing OWFs within or near MPAs and other biodiversity hotspots may entail ecological risks that outweigh the benefits; such locations should therefore be excluded from development. They further caution that planning, siting, and governance frameworks developed for the North Sea cannot be directly transposed to the Mediterranean without adaptation to its distinct ecological and socio-economic context, without implying limitations in existing wind turbine technologies or OEM experience across regions [171].

Current environmental assessments often underrepresent system-wide interactions and cumulative effects [80], an omission that is particularly relevant for multi-use platforms (MUPs) (*i.e.*, offshore installations engineered to integrate different maritime economic activities within the same space) [172]. McKenna et al. [6] identify system-level externalities as a critical research gap and call for integrated modelling frameworks that capture life-cycle emissions, material use, and biodiversity trade-offs, moving beyond purely local impacts to regional and global sustainability metrics. Site-specific risk varies with local biodiversity, migratory routes, and habitat sensitivity, factors still underrepresented in a literature dominated by North Sea case studies [80]. In semi-enclosed seas such as the Mediterranean, pre-existing stressors (*e.g.*, eutrophication) amplify vulnerability to cumulative pressures, including underwater noise impacts on marine mammals [171,173].

At the same time, OWFs can create ecological opportunities. Mooring and scour-protection structures may function as artificial reefs, and NID seeks to enhance biodiversity rather than merely mitigate impacts [174,175]. Knowledge gaps remain, notably concerning long-term effects (*e.g.*, from corrosion-protection systems) [176]. To manage uncertainty, robust plan-led tools such as SEAs and EIAs are essential [173,177,178].

Given the stakes in the Mediterranean, researchers are prioritising tailored designs to avoid, minimise, and, where feasible, generate positive ecological outcomes. NID in offshore infrastructures represents an emerging paradigm that integrates ecological function within engineering systems to support biodiversity protection and restoration alongside energy production [179]. Although most frameworks originate in North Sea contexts [180], recent European efforts, including the Horizon Europe project NiD4OCEAN, are beginning to define Mediterranean-specific objectives, indicators, and nature-based solutions [181]. Proposed NID strategies for bottom-fixed installations include textured bases to enhance benthic colonisation, modular reef units embedded in scour protection, and above-water features that support seabirds or mitigate light pollution [180].

In Mediterranean waters, where large-scale offshore wind remains at an early stage, pilot nature-enhancing structures already offer design insights. Artificial-reef initiatives such as ADRIREEF [182] and the Gibraltar Reef [183] demonstrate how engineered structures can be

[8] We would like to remark, that most of the applications can be easily mirrored, such as the social acceptance and the permitting frameworks.

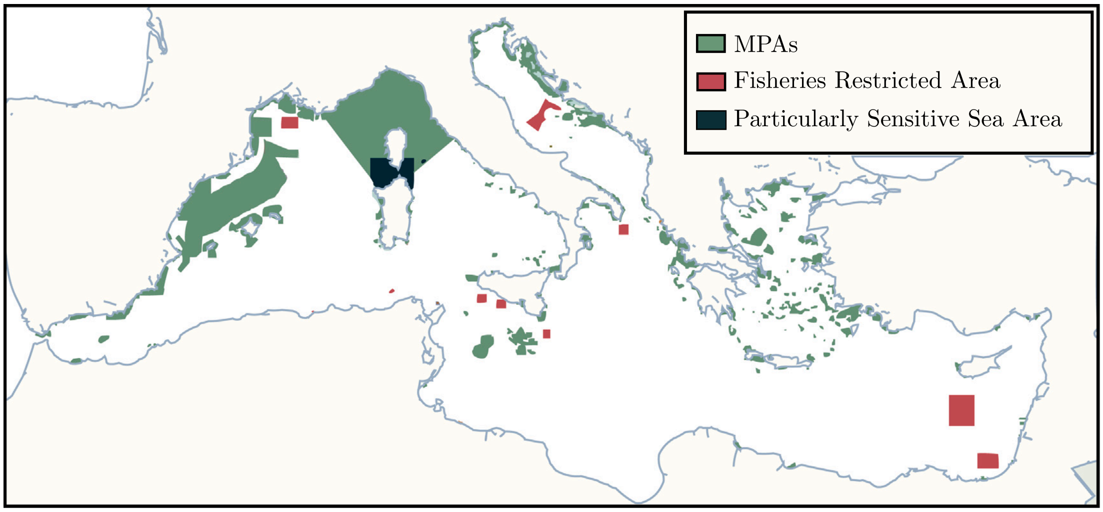

Fig. 3. Map of Mediterranean MPAs and additional sites of conservation interest [170].

configured to promote ecological functionality and local engagement. These cases provide transferable methodological precedents (identifying target species, aligning design parameters, and embedding monitoring protocols) for future offshore energy infrastructure.

Given the presence of sensitive habitats, notably Posidonia beds [184] and coralligenous assemblages [185], Mediterranean OWFs should be conceived from the outset as nature-inclusive infrastructures rather than retrofitted with mitigation measures post hoc. While a dedicated NID-focused assessment for floating offshore wind structures remains limited, a deep-water example is provided by the Hywind Scotland Pilot Park, where artificial substrates supported diverse benthic communities and clear ecological zonation patterns [186]. Finally, although floating wind may offer potential benefits for certain species, impacts on flora and fauna must be carefully assessed and designed for, given the limited number of documented applications currently available in the literature [187].

3.3. Social acceptance

Public acceptance is a critical yet often underestimated factor in offshore wind deployment. In offshore contexts, resistance is shaped less by a simple NIMBY (Not In My Backyard) effect, typically attenuated by greater distance from receptors, than by a more complex interplay of personal values, institutional trust, and perceived fairness [188,189]. Demographic variables (*e.g.*, age, gender, education), exposure to marine industries, and conspiracy beliefs all influence attitudes, sometimes more strongly than political orientation. Support tends to be higher in communities familiar with aquaculture or maritime transport, whereas associations with O&G can reinforce scepticism [64]. Evidence on age and gender effects is mixed: some studies report lower support among women and older individuals [64], while others find no significant differences [190], cautioning against broad generalisations. Conspiracy beliefs remain among the strongest predictors of opposition, underscoring the need for proactive, evidence-based communication well before project roll-out [81]. A notable example is Vattenfall's WIN@sea campaign with actor Samuel L. Jackson, which promoted offshore wind as a driver of both clean energy and marine ecosystem regeneration [191].

Tourism and fisheries are especially salient in the Mediterranean. Tourists' willingness to holiday near offshore wind farms varies by nationality and education [188], and acceptance tends to improve when projects are sited away from iconic coastlines and high-amenity areas [190]. Floating wind can help by enabling deeper-water siting farther offshore, albeit with grid and logistics trade-offs. Fisheries, by contrast, are highly organised stakeholders with legitimate concerns over spatial displacement; early, structured engagement and co-existence measures are therefore essential [192].

Case studies across Europe indicate that transparent, early-stage engagement improves acceptance even more when adapted to local contexts. In France, views are shaped by the country's nuclear legacy and industrial interests in turbine manufacturing [193]. In Norway, the European geopolitical tensions unexpectedly reduced, rather than increased, support for offshore wind, highlighting the importance of policy framing and timing [82].

Overall, socially viable deployment requires more than technical optimisation: it demands place-based, participatory approaches grounded in interdisciplinary understanding [194]. In practice, this entails distance-sensitive siting, early engagement with tourism and fisheries stakeholders, and the deployment of evidence-based visualisation tools (*e.g.*, photomontages, virtual reality) to communicate impacts transparently, recognising that the technically optimal configuration may not align with the socially acceptable one [190].

A complementary pathway is the development of MUPs within the blue economy framework. The EU Blue Economy, encompassing offshore energy, fisheries, aquaculture, maritime transport, tourism, and related sectors, accounted for 1.7% of EU-27 gross value added (GVA) and 4.82 million jobs in 2022, with marine renewables being the fastest-growing segment [195]. As spatial competition intensifies in the Mediterranean, maritime spatial planning (MSP) is essential to balance economic uses and conservation goals [196]. MUPs that combine offshore wind with low-trophic aquaculture (LTA) can co-produce renewable energy, sustainable seafood, and ecosystem services while improving spatial efficiency and stakeholder buy-in [197–199]. Other configurations, such as co-location with O&G infrastructure [199] or fisheries [200], remain at early stages and will require clear regulation, stakeholder alignment, and integrated risk governance [201].

3.4. Planning and permitting frameworks

Given the institutional heterogeneity of the more than twenty coastal states bordering the Mediterranean basin, this section does not attempt a jurisdiction-by-jurisdiction comparison; rather, it identifies recurrent regulatory archetypes and structural governance patterns that shape floating offshore wind deployment across the basin.

Permitting is often cited as a structural barrier to offshore wind in the Mediterranean, yet common narratives conflate administrative delays with deeper spatial, legal, and institutional misalignments [202]. Although several countries have adopted MSPs, these frequently remain declarative and unevenly operationalised [203]; in practice, tools for phasing, corridor differentiation, and cumulative-impact modelling are limited [204]. By definition, SEA is conducted ex ante on plans and programmes, but many key issues are deferred to project-level EIA rather than addressed upfront within pre-designated offshore development zones [205]. This prolongs timelines, increases litigation risk, and weakens cross-sectoral coordination, ultimately compounding the social and ecological frictions discussed in Sections 3.2 and 3.3.

More fundamentally, the absence of basin-level planning creates a spatial paradox: national competence is exercised over marine areas whose optimal use depends on atmospheric phenomena that cross borders [204,206]. Prevailing wind directions, *e.g.*, northerlies in the Adriatic or westerlies in the Alborán, determine which jurisdictions are upwind or downwind. Uncoordinated build-out by upstream States can therefore generate material wake interactions across Exclusive Economic Zone (EEZ) boundaries (see Section 3.6), depressing basin-wide capacity factors and heightening the potential for regulatory conflict. Current spatial frameworks only partially reflect this asymmetry [207]. Lessons from mature basins, *i.e.*, the North Sea and the Baltic Sea, highlight several priorities: early cross-border spatial planning, shared wake protocols and data rooms, corridor-aligned project phasing, and coordinated grid development. Together, these measures help limit cumulative wake effects, accelerate learning, and reduce lock-in risks for the Mediterranean.

Licensing regimes also remain rigid, issuing long-duration seabed concessions that lock in technology choices well before final investment decision [74]. Such static authorisation schemes are ill-suited to floating wind, where iterative design, hybrid configurations, and MUPs are intrinsic features [85,144]. Some European jurisdictions have introduced design-envelope approaches and non-price/performance-linked tender criteria to address this mismatch [74,208]; however, these instruments are not yet widely embedded in most Mediterranean frameworks [209].

A permitting architecture adapted to floating wind therefore requires not only administrative acceleration but also a shift in the sequencing of permits and the coordination between responsible authorities [210]. Priorities include moving from project-level to corridor-level[9] assessment (plan-led SEAs with nested project EIAs), aligning licensing with grid-development trajectories, and explicitly integrating transboundary effects, such as directional wake interference, into spatial design [206]. Without such alignment, permitting will remain a bottleneck regardless of procedural streamlining, and the basin's potential will continue to be constrained by fragmented jurisdictional logic [204].

A similar challenge is evident in Türkiye, where offshore wind governance is at an early stage. The Türkiye Offshore Wind Roadmap [211] identifies a fragmented landscape involving more than 30 permits across multiple authorities, compounded by unclear timelines and coordination mechanisms. The report highlights the need for streamlined procedures, predefined offshore development zones, and enhanced inter-agency collaboration—insights that are pertinent to several Mediterranean countries navigating early-stage offshore wind governance.

3.5. Economic regulatory framework

Support schemes for offshore wind in the Mediterranean remain fragmented, with persistent misalignment between auction design, technology maturity, and investment risk [212,213]. National tenders frequently retain price-only or technology-neutral formats [214]. Italy's FER2 decree (Ministerial Decree on Renewable Energy Sources) [215], for example, currently places fixed-bottom and floating in a single competitive category with a common reference tariff despite distinct cost curves and maturity levels, exposing early-stage floating projects to price pressure that sits uneasily with industrial scale-up and bankability.

In several markets, including mature Northern European jurisdictions, recent rounds have been undersubscribed or stalled, delaying build-out and weakening investor confidence; examples include the UK's Allocation Round (AR) 5 clearing no offshore, Denmark's 2024 no-bid tender [216], and Germany's 2025 no-bid round. While these outcomes reveal vulnerabilities to market shocks and design missteps, they occurred within generally well-established frameworks that have proved effective over the longer term.

The UK's CfD scheme, now through six completed allocation rounds, with AR7 currently underway and defining revised conditions for the next allocation [217], has provided long-term price stability and bankability; after the AR5 setback, AR6 secured major fixed-bottom capacity and a 400 MW floating award. France's floating-only Appel d'Offres 5 and 6 (AO5 and AO6) (South Brittany) coupled site pre-selection with state-backed grid connection via Réseau de Transport d'Électricité (RTE, the French TSO), materially reducing development risk [218]. Such approaches help de-risk pre-commercial deployments while local supply chains develop in parallel. Developers consistently cite clear, transparent, and stable frameworks, offering early visibility on decisions and their implementation, though not necessarily generous, as prerequisites for industrial mobilisation, particularly where floating foundations and hybrid or system-integration features are involved.

The Mediterranean context demands similar regulatory clarity [219]. Without forward visibility on remuneration, grid-charging rules, and project sequencing, governments risk missing offshore targets despite favourable fundamentals [213]. More fundamentally, regulatory frameworks must provide long-term stability to enable sustained investment decisions and supply-chain build-up, a prerequisite for both floating and bottom-fixed offshore wind. Coordinated action at EU and basin level should include Mediterranean-specific auction windows, differentiated CfDs for floating, and pre-qualification/award criteria that value system integration and multi-use capabilities. For floating offshore wind, non-price criteria should prioritise deliverability, responsible business conduct, and cybersecurity, while avoiding premature supply-chain constraints.

Deferring auctions until floating achieves further cost reductions may appear fiscally prudent, but it risks forfeiting strategic industrial and energy-security benefits. It would also forgo the opportunity to remain at the forefront of technological learning: without early industrialisation in Europe, other regions, such as China or South Korea, are likely to advance first, capturing the associated know-how, experience, and learning-by-building advantages that underpin future cost reductions and competitive positioning. Early rounds, even at higher strike prices, can catalyse domestic supply-chain development (ports, skills, vessels), enabling steeper cost declines in subsequent tenders. Conversely, postponement tends to shift delivery towards established foreign supply chains, limiting local value capture and slowing the emergence of a competitive regional industry. Delayed procurement also prolongs dependence on fossil-based generation for capacity that offshore wind could displace, with exposure to fuel price volatility and import dependence. Phased auction programmes in North Sea markets reflect these dynamics, using sequenced procurement to build both capability and competitiveness.

In sum, experience from the Netherlands, Germany, and Denmark indicates that well-designed non-price criteria can complement cost-based competition, ensuring that auctions deliver competitive prices while prioritising broader system value through socio-economic and environmental benefits. At the same time, recent Dutch auction outcomes show that extensive or overly rigid non-price commitments can become difficult to sustain under stressed market conditions, with some bid-stage obligations subsequently requiring revision to preserve project bankability. For the Mediterranean, aligning economic instruments with the planning and permitting reforms outlined in Section 3.4 is therefore essential to translate resource potential into bankable projects at pace.

[9] *i.e.*, evaluation of the entire offshore development and grid corridors rather than isolated projects.

3.6. Grid integration and cross-border spatial coordination

Grid access remains a critical barrier to large-scale offshore wind deployment [220], particularly in regions where transmission infrastructure, grid planning, and regulatory coordination lag behind deployment ambitions [221]. The April 2025 blackout affecting Spain and Portugal highlighted vulnerabilities not in renewable generation per se, but in system operation under stressed conditions, notably in voltage control and reactive power management within a network characterised by high shares of heterogeneous inverter-based resources [222–224]. Official assessments indicate that the event was driven by localised overvoltages and cascading disconnections across multiple asset types, underscoring the need for enhanced grid codes, coordinated voltage control, and system-level integration measures rather than limitations of wind or solar technologies. Complementary resource mixes, including wind and solar PV, can contribute to system robustness by smoothing temporal variability when supported by adequate grid infrastructure and operational frameworks [225]. In practice, four issues dominate wind integration: grid connection, grid charges, curtailment, and system hybridisation [221].

Connection processes are often slow due to grid saturation, fragmented permitting, and conservative planning. In 2022, Mediterranean EU countries faced a backlog of 245 GW of pending wind projects [221]. Physical constraints also matter: solar-heavy systems can limit wind uptake even where nameplate capacity suggests headroom. First-come, first-served queues delay viable projects, though emerging prioritisation, favouring hybrids or storage-backed schemes, can improve throughput. For floating, clear sequencing between port readiness, cable corridors and onshore reinforcements is crucial to avoid stranded capacity.

To accelerate integration and interconnection, cross-border radials and hybrid connections should be considered. As illustrated in Fig. 4, in cross-border radials, an OWF in the exporting state's EEZ connects directly to an importing state's onshore grid; hybrid connections link a project to two or more national grids, enabling multi-market exchange within the same sea basin [10]. Shifting to a sea-basin approach, already underway in the North Sea, would be beneficial in the Mediterranean, where cross-border corridors are advancing. Some examples include the 600 MW HVDC ELMED link (Sicily–Cap Bon) [226] and Interconnector 2 (Malta–Italy, ~225 MW, ~122 km) [227]. Coordinated planning can reduce costs, improve resilience, harmonise permits and grid codes, and enable shared offshore infrastructure; it also supports anticipatory investments and supply-chain planning when embedded in maritime spatial planning [10,228]. Recent industry discussions further stress regional alignment on voltage ride-through and reactive power standards appropriate to VSC–HVDC in offshore settings [229].

Offshore integration relies on timely expansion of transmission cables, substations, and HVDC assets, but also on inland reinforcements from landfall to demand centres [10]. Otherwise, curtailment emerges even when offshore infrastructure is in place. Modelling shows that dynamic line rating can deliver cost-effective congestion relief and reduce system costs by 3–5% under high-RES shares [231], while meshed offshore grids can partially compensate for constrained onshore expansion, enabling an ~8% increase in offshore capacity in North Sea scenarios [232]. These results highlight the need for synchronised onshore–offshore planning, with onshore grid readiness playing a fundamental role. Standardising technical requirements across countries would also create predictability for Original Equipment Manufacturers (OEMs) and lower costs [10]. McKenna et al. [6] emphasise that system-level impacts on stability and operational security remain under-represented, calling for more dynamic treatment of wind variability in grid studies and operations: issues that are acute in the Mediterranean, where inertia and interconnection capacity are limited. When focusing on the floating framework, voltage stability and reactive power control are even more critical given longer export distances and converter-dominated connections.

Grid-charge regimes differ widely. Most EU countries apply shallow costs with developers paying to the nearest connection point, whereas Italy applies a deep model, shifting the cost of reinforcement up to the onshore substation to the developer [233], raising fairness concerns [84] and potentially discouraging investment [234]. In some jurisdictions, super-shallow approaches also exist, whereby transmission system operators assume full responsibility for offshore connection assets, further reducing upfront developer exposure but increasing coordination requirements. *Curtailment* remains a key issue [83]. Compensation practices vary: only Italy and France reimburse curtailed energy; Spain, Greece, and Croatia do not, and dispatch-priority rules are heterogeneous [221]. Flexible connection agreements can help by allowing limited, pre-agreed curtailment in exchange for faster access.

Hybrid projects, in other words co-locating multiple renewable technologies, with or without storage, under a shared connection, can enhance stability, optimise marine space, and reduce infrastructure costs. Wind–solar hybrids smooth output and reduce seasonal swings [221,225]; studies in Austria and Spain report up to a 63% variability reduction while improving capacity density [225]. Wind–wave options are being assessed at selected Mediterranean sites, including: Tyrrhenian near Elba, north-western Sardinia, Aeolian Islands, southern Adriatic and Ionian [235]; while co-location may offer system-level benefits, fully integrated multi-technology concepts on a single floating platform remain technically complex and may face unfavourable cost–benefit trade-offs. Although technically more complex, they may add benefits such

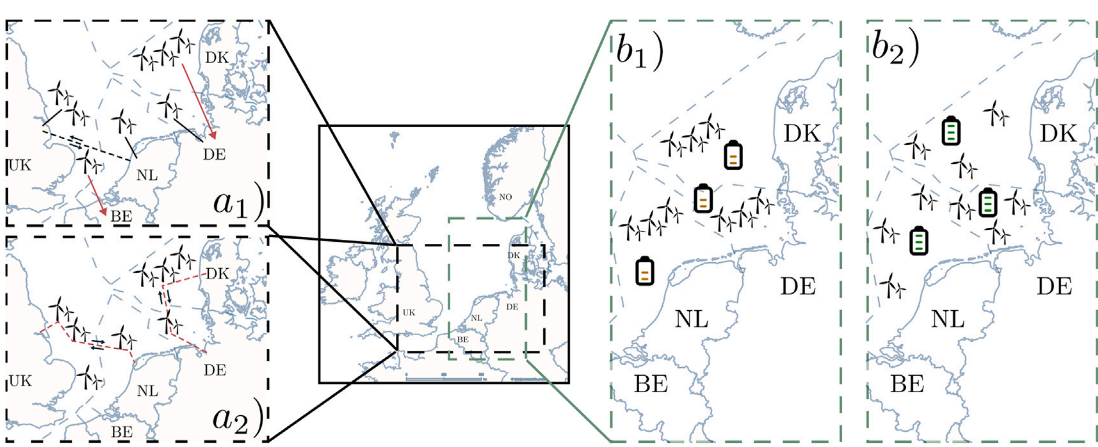

Fig. 4. Cross-border potential effects. On the left-hand side grid connection options for offshore wind farms: a_1) cross-border radials; a_2) offshore hybrids [10]. On the right-hand side, the potential effect of the wake in the German Bight: b_1) with no country coordination; b_2) with country coordination [230].

as coastal protection [236] and synergies with power-to-X, *e.g.*, green hydrogen [237,238]. Yet hybrids face regulatory gaps: Spain, Portugal, and Croatia permit installed hybrid capacity above grid-withdrawal limits, France caps at 17 MW, and Italy lacks a clear framework [221]. Higher CAPEX further disadvantages hybrids in undifferentiated auctions, pointing to the need for fit-for-purpose support, designed with sufficient lead times and regulatory clarity to allow permitting processes and project designs to adapt. For floating, hybridisation with solar, wave or storage systems offers an additional route to stabilise output and improve utilisation of expensive offshore infrastructure, provided permitting and market frameworks evolve accordingly.

Grid-enhancing technologies (GETs), for instance dynamic ratings, flow-control devices, and storage, offer near-term relief for congestion and renewables integration [239], but deployment is constrained by regulatory inertia, economics, and data-sharing reluctance. Anticipatory investments and structured dialogues among TSOs, developers, OEMs, and regulators can create stable investment conditions and foster innovation [229,234].

Large-scale deployment must also account for wake effects when planning arrays and corridors. While OEM-level design and control strategies can mitigate wake impacts at the turbine and array scale, wakes reduce wind speed and increase turbulence downstream and, critically, do not respect jurisdictional boundaries. In the German Bight, wake-related yield reductions can reach up to 30%, with nearly half attributable to cross-border interactions; optimised cross-country siting can reduce losses to 18%, recovering output equivalent to ~8 GW [230]. A graphical representation of both conditions is shown in Fig. 4. Treating wake mitigation as a priority in maritime spatial planning, via basin-level coordination, shared modelling, and joint zoning, can minimise cumulative losses and promote fairness across jurisdictions, aligning with the permitting principles in Section 3.4. In particular for floating, these actions may be significant for industrialisation and cost reduction, linking energy policy with supply-chain and maritime planning.

In sum, delivering Mediterranean offshore wind at scale requires aligned grid rules and standards, basin-level coordination for offshore corridors and interconnectors, synchronised onshore–offshore reinforcement, and regulatory frameworks that recognise hybrids and GETs. Without this integration, curtailment, connection delays, and cross-border externalities risk eroding the benefits highlighted in Sections 3.2 and 3.3.

3.7. Supply chain

According to WindEurope's latest analysis [240], more than €13 billion has been committed to wind-energy supply-chain investments in Europe since 2022, with offshore attracting the majority. Around €4.5 billion targets cables and foundations, with a further €1 billion for nacelles, towers, and blades. These commitments indicate the sector's ability to scale rapidly as projects approach procurement. For offshore wind, turbine manufacturing capacity is projected to reach 10–15 GW per year by 2028/29, broadly matching near-term demand. By contrast, the under-deployed port infrastructure remains a risk area, particularly with respect to aligning delivery timelines with project milestones. Despite these constraints, the European wind supply chain could support increased installations through at least 2029 [240]. Manufacturers consistently emphasise that policy clarity, visible, stable auction schedules and forward volumes are the keys to unlocking the next wave of investments [240].

In line with this, McKenna et al. [6] argue that infrastructure and supply-chain limitations are not merely logistical issues but strategic system bottlenecks that can delay deployment and raise costs. While the broader Mediterranean and Iberian regions host elements of onshore, bottom-fixed offshore wind and O&G supply chains, their direct applicability to floating wind cannot be assumed. Adapting existing manufacturing, ports, logistics, and workforce capabilities to floating-specific requirements will require targeted investment, regulatory alignment, and time. The challenge is therefore less the absence of industrial activity than the coordinated and timely transformation of existing assets into floating-ready capacity.

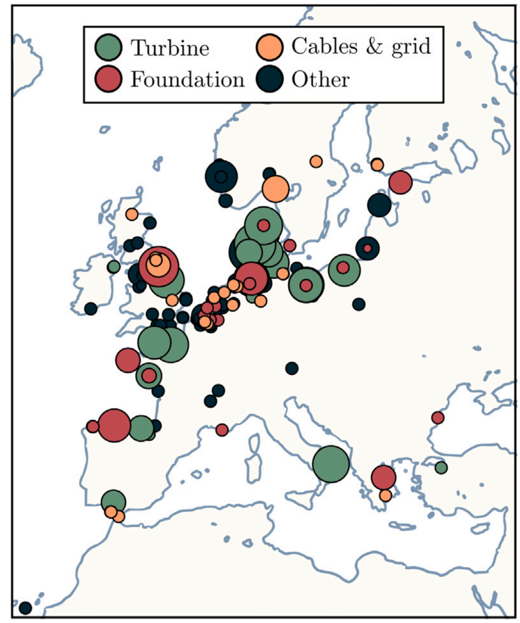

Fig. 5. Map of existing wind supply chain. "Other" includes: construction, assembly, logistics, O&M, R&D. Adapted from [242].

Against this backdrop, building a secure and resilient supply chain is a prerequisite for floating-wind deployment in Mediterranean countries. At present, there is no mass manufacturing for floating foundations in Europe; scaling will hinge on near-term FIDs and serial designs[241]. Today, the wind industry employs approximately 370,000 people. Fig. 5, published in [242], summarises the distribution of wind supply-chain capabilities across Europe in 2024, from component manufacturing and assembly to port services and O&M. While activity remains concentrated in Northern Europe, capabilities are relatively well distributed at European scale, providing a basis for regional build-out [242].

Fig. 6 illustrates recent investments across the European wind supply chain. The primary challenge is scaling existing capacity to meet offshore targets and reach the EU Net-Zero Industry Act (NZIA)'s 36 GW wind turbine manufacturing target rather than creating entirely new capabilities [241,243]. In the Mediterranean, port retrofitting and workforce retraining are critical enablers. Targeted upgrades at ports such as Augusta and Taranto in Italy [244], and at Filyos and Aliağa in Türkiye, can accommodate floating-turbine assembly and heavy-lift operations, while coordinated training programmes can equip local workers for installation, O&M, and, where relevant, green-hydrogen integration [211,244,245]. Current floating-fit port integration capacity in Europe is about 0.2 GW per year, with 1–1.5 GW per year possible by 2029–2030 given announced investments, and roughly 40 hectares per GW of typical land requirements [241,246]. This combination of port upgrades and workforce training strengthens regional resilience and supports faster scale-up.

Typical European offshore-wind development and commissioning spans roughly ten years, with wide national variation [242]. By comparison, the construction of new facilities or specialised vessels generally requires around 2–3 years, while port expansions and retrofitting are typically implemented through phased developments, with individual works deliverable within comparable timeframes once permitting and funding decisions are in place, as illustrated by recent offshore-wind-oriented port redevelopment projects [243,247]. This indicates that timely governmental action can still align supply-chain readiness with project pipelines.

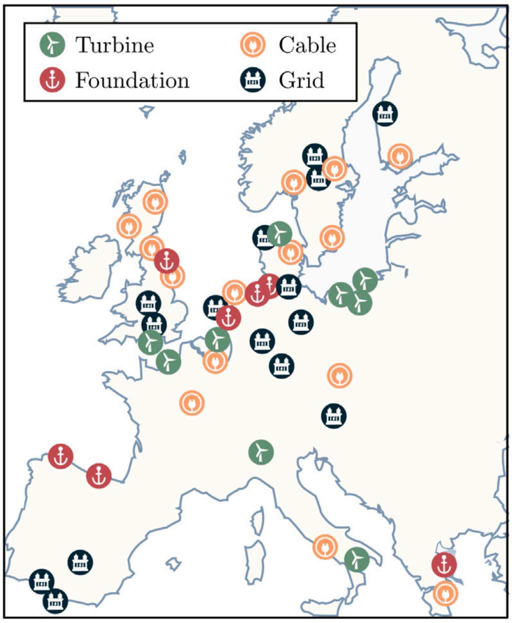

Fig. 6. Recent European wind supply chain investments. Adapted from [242].

Taken together, the evidence suggests that Europe can meet near-term capacity targets if stable auction pipelines, corridor-level planning and permitting, and supply-chain enablers such as ports, vessels, and workforce are sequenced coherently. For the Mediterranean, this alignment, developed alongside the grid-integration and spatial-coordination measures outlined above, is essential to convert resource potential into bankable projects at pace. Given today's underutilised capacity, the immediate bottleneck is project visibility and auction stability rather than manufacturing throughput [241].

3.8. Infrastructures

Ports are a critical enabler for offshore wind deployment, especially for floating turbines, which, unlike bottom-fixed, are predominantly assembled onshore. Floating foundations require heavy-duty cranes, deep-draught berths, dry docks, and extensive assembly areas [245,248], with specific needs varying by foundation type [11].

Between 60 and 70% of the existing supply chain for bottom-fixed offshore wind can be adapted to floating, facilitating industrial scaling. Port location has a material impact on installation costs [245]. Logistics-oriented siting studies offer useful screening frameworks [249], though political and social dimensions remain less explored. In 2025, Italy committed €78.3 million to upgrade Augusta and Taranto as floating-wind manufacturing and assembly hubs [244], signalling growing political momentum. Similar opportunities are emerging in the Eastern Mediterranean: the Türkiye Offshore Wind Roadmap identifies strategic ports, including Filyos and Aliağa, and highlights that local industries, *i.e.*, steel, cables, towers, could supply up to 60% of components under suitable investment and regulatory conditions [211]. These insights underline the potential for Mediterranean: wide port and supply-chain networks. Floating projects may in the future offer synergies with green hydrogen, where port-based electrolysers could absorb excess wind power and support local energy ecosystems while temporarily bypassing grid congestion [245].

Logistical planning should prioritise the number and type of turbines and foundations rather than headline megawatts [245]. Onshore assembly can reduce exposure to expensive offshore operations [77], whose costs are highly sensitive to weather windows [248]. Given the strategic importance and high upfront costs of port infrastructure, a coordinated European approach aligning port development with national offshore-wind pipelines is essential [241,246]. Investments in port infrastructure and skilled workforce development can generate long-term value beyond the offshore wind sector. Enhanced port capabilities, such as deep-water quays, heavy-lift equipment, and coordinated logistics, enable a broader range of industrial and maritime operations, including oversized cargo handling, naval maintenance, and other blue economy activities. Nevertheless, global demand for wind turbine installation vessels (WTIVs) is expected to rise five-fold by 2030 [250]. Only 25 WTIVs suitable for >10 MW turbines are projected to be available outside China by 2026, with just 23 accessible to Europe. This raises concerns about bottlenecks and competition from Asian markets [250], compounded by technical integration constraints and cybersecurity issues [251–253].

Cybersecurity is not just an IT issue, it is a cornerstone of Europe's energy independence. As offshore wind farms become critical infrastructure, protecting them from cyber threats is essential to safeguard electricity supply and industrial competitiveness. Reliance on imported components from global supply chains can introduce systemic vulnerabilities and extra integration costs due to differing technical standards, which, based on industrial feedback, can be significant. Building a resilient European supply chain and harmonised cybersecurity standards requires embedding secure-by-design principles in turbine technology, enforcing pre-qualification criteria in auctions, and aligning procurement with the NIS2 Directive and Cyber Resilience Act. Strengthening European manufacturing and digital security will reduce exposure to systemic cyber risks and support a sovereign, cyber-resilient energy system.

3.9. Floating wind components and materials

Meeting offshore-wind capacity targets will significantly increase global demand for materials.[10] Wind turbines rely primarily on iron and steel (71%), concrete (11%), and composites (10%) [243]. Offshore wind is highly mineral-intensive, using roughly twice as many mineral resources per MW as solar PV [254]. Rare-earth elements and specialty metals are particularly critical, for example for permanent-magnet generators, but their use can be reduced by adopting geared drive-train solutions. However, such designs exacerbate reliability concerns, as gearboxes account for a substantial proportion of turbine failures and, thereby increase maintenance costs [28]. For projections of future raw-material demand under various decarbonisation scenarios, see [255].

Europe remains heavily dependent on imported raw materials, exposing the wind supply chain to geopolitical risks. China accounts for a dominant share of global wind-manufacturing capacity in several upstream and component segments, exceeding half of global production in areas such as raw-material processing and selected components [256], while Russia is a major supplier of inputs such as nickel and aluminium [250]. At the same time, parts of the offshore wind value chain, such as turbine assembly and selected balance-of-plant components, retain significant European industrial presence, distinguishing wind from other clean-energy technologies such as solar PV. However, the war in Ukraine has underscored the vulnerability of concentrated external supply: raising turbine-manufacturing capacity alone is insufficient without reducing sourcing concentration [250]. The EU's Critical Raw Materials Act addresses these challenges by establishing targets for domestic extraction, processing, and recycling; by limiting reliance on any single supplier country; and by promoting new avenues for supply diversification through international partnerships [257]. Further analysis is nonetheless needed to identify cost-effective and geopolitically resilient sourcing strategies, as recently explored for solar PV [258].

Supply-chain diversification also requires strengthening local manufacturing. While turbine and nacelle production is dominated by a handful of global players [250], floating foundations offer greater

[10] For detailed information on primary raw-material demand and secondary-material supply in global offshore wind, see the dynamic material flow analysis by Li et al. [79] under three technology-development scenarios.

localisation potential and can be produced by domestic industries [77]. Yet no large-scale serial manufacturing for floating foundations exists in Europe today [241,246]. Opportunities for local content are significant in Southern Europe and Türkiye, where Small to Medium-sized Enterprises (SMEs) could supply key components, including steel structures, cables, auxiliary equipment, by leveraging existing industrial clusters and shipbuilding capacity. This can support manufacturing and assembly while reducing reliance on imports.

Europe retains a competitive position thanks to early North Sea deployments: four of the ten largest blade manufacturers are European [259], and EU firms hold a 21% global market share, rising to 71% when China is excluded [243]. Most blades (85%) used in the EU are domestically manufactured, as are all nacelles and towers [256]. However, demand is projected to outpace capacity from 2026, especially for blades, with 2030 needs expected to double current manufacturing levels [250]. Without timely investment, this gap could slow deployment and undermine the EU's wind leadership. Current European manufacturing capacity is underutilised, but new investments will materialise only with clear project pipelines and predictable auction schedules [241]. For detailed manufacturing and trade prospects under different growth scenarios, see [256].

Incorporating local-content strategies and workforce development into supply-chain planning can therefore bolster resilience against geopolitical and market risks. Domestic production of floaters and other key components by SMEs not only mitigates reliance on global suppliers but also reinforces regional industrial ecosystems, complementing the port upgrades and grid-integration measures discussed above, and contributes to a more diversified and secure offshore-wind supply chain across the Mediterranean basin.

3.10. Integrated deployment implications for the Mediterranean

Rather than introducing new analytical elements, this subsection consolidates the main implications emerging from the preceding sections. While the previous subsections structured the current Mediterranean panorama across three interconnected dimensions, this section aims to identify and address the key gaps that arise from their interaction. In the Mediterranean basin, deployment feasibility is shaped by the interplay of design choices, socio-environmental acceptance, and policy–market architecture. The three guiding questions below make these interdependencies explicit and operational.

Design-to-buildability under Mediterranean constraints: *Which combinations of rotor, floater, and mooring minimise system LCOE while meeting port and vessel buildability constraints in the Mediterranean?*

While the milder wind conditions that characterise the Mediterranean may favour low–specific-power turbines and thus lower LCOE [161], scaling rotors upward encounters non-trivial industrial constraints. Substantial departures from established turbine architectures undermine modularity and can introduce maintenance, logistics, and component-replacement challenges [78], which are further amplified in floating applications. Likewise, although blades tailored to Mediterranean wind regimes would offer aerodynamic gains, practicalities currently weigh against bespoke designs: global blade manufacturing is concentrated among a small number of suppliers, and rapidly growing demand is projected to outpace existing capacity [250], limiting near-term scope for dedicated product lines.

By contrast, on the substructure side, design choices are already converging on buildability and operational simplicity. As summarised in Table 2, semi-submersibles are expected to dominate upcoming projects owing to their lower draught requirements, compatibility with quayside assembly, and tow-to-site installation [11,136]. Mooring solutions similarly prioritise installation simplicity and reduced anchor counts where feasible, consistent with the broader emphasis on constructability and port and vessel constraints.

Social licence with ecological safeguards at pace: *What integrated siting and design protocol delivers measurable acceptance and biodiversity safeguards at pace, without degrading energy yield or delivery schedules under cumulative and transboundary wake constraints?*

The material in Sections 3.2 and 3.3 suggests a protocol with three layers: (i) *Plan-led siting:* adopt corridor-level MSP with *ex-ante SEA* and nested project EIAs that (a) budget for *transboundary wakes* and cumulative effects, and (b) apply distance-sensitive siting to iconic coastlines and high-amenity areas; this reduces late-stage conflict and preserves yield by addressing wake interactions early. (ii) *NID:* set project-level NID targets, including reef-forming scour protection and seabird-friendly features, with monitoring and adaptive-management commitments, shifting from mitigation to verifiable net-positive outcomes where feasible; this addresses gaps in cumulative-impact knowledge while enabling timely decisions [80]. (iii) *Participation and co-existence:* initiate early, evidence-based engagement, shown to reduce opposition even among sceptics [81], using transparent visualisation, including photomontages/VR, and codified coexistence measures, including fisheries corridors, seasonal and noise windows, where relevant multi-use with LTA. Taken together, *plan-led corridors, NID with monitoring, early, place-based engagement and coexistence* provide measurable acceptance and biodiversity safeguards without sacrificing delivery schedules or energy yield.

Policy measures that steer industrial development: *Which auction and grid-charging package most effectively de-risk projects and unlock anticipatory investment in ports, vessels and manufacturing, without undermining permitting timelines and bankability?*

Evidence from Sections 3.5 and 3.6 points to a *package* rather than a single lever. First, visibility of auction timelines and volumes is the key condition for mobilising the entire industrial chain, from developers to OEMs. Second, auctions should be *floating-fit*: differentiated CfDs for floating, and the progressive introduction of *non-price* criteria that could, in the future, reward factors such as port readiness, supply chain, or system-integration capabilities, *e.g.*, grid code compliance, hybrid eligibility, alongside *design-envelope* consenting to avoid premature technology lock-in. Third, grid-charging should shift towards *shallow or super-shallow* cost allocation where deep models prevail, to align risk-bearing with system benefits and mitigate fairness concerns [84]. Fourth, predictable curtailment rules (including compensation and flexible connection agreements), plus clear eligibility for hybrids and cross-border radials, reduce developer risk and crowd in anticipatory TSO and port investment (Sections 3.4, 3.6). Finally, synchronised pipelines that combine auction calendars, pre-designated zones, and jointly announced grid milestones provide OEMs and port authorities with the visibility needed to commit capital at pace without prolonging permitting timelines. In short, *floating-specific CfDs, appropriate indexation during construction and operation, non-price criteria, shallow charges, curtailment clarity, hybrid/cross-border eligibility, and synchronised pipelines* form a coherent package that de-risks delivery while preserving bankability and timelines.

4. Discussion and conclusions

The Mediterranean juxtaposes substantial technical potential for offshore wind with structural barriers that hinder delivery. Deep waters make floating the default rather than the exception, but this necessity can be reframed as a strategic opportunity, provided regulatory, infrastructural, and social constraints are addressed in an integrated manner. Read against the evidence in Section 2 and Section 3, four cross-cutting messages emerge.

First, cost competitiveness is necessary but not sufficient. Although forward trajectories point to narrowing gaps between floating and bottom-fixed, alongside other renewables, by mid-century, current Mediterranean deployment is paced more by regulatory framework, *i.e.*, auctions, permitting complexity, grid access, and supply-chain readiness than by LCOE alone. The downward revision of near-term European wind expectations to 344 GW *versus* a 425 GW target underscores the primacy of these systemic constraints [260]. Sequencing is decisive: plan-led corridors and pre-designated development zones (Section 3.4) must advance in lockstep with onshore–offshore grid reinforcements and port upgrades (Sections 3.6, 3.8); otherwise curtailment, connection delays, and logistics bottlenecks erode bankability.

Second, regulatory design must be basin-aware and technology-fit. Fragmented national frameworks and price-only, technology-neutral auctions (Section 3.5) sit uneasily with floating wind's risk profile, hybrids, and multi-use configurations. A Mediterranean sea-basin approach that embeds cross-border coordination from the outset through shared wake protocols and data rooms, corridor-aligned phasing, and coordinated grid planning, as discussed in Sections 3.4, Section 3.6 can reduce cumulative losses, compress learning, and strengthen investor confidence. Within countries, design-envelope consenting and non-price criteria such as system integration, port readiness, and ecological alignment align tenders with real buildability rather than nominal least cost, as discussed in Section 3.5. The regulatory framework should strike a careful balance, avoiding oversupport of particular technologies, while being sufficiently mature in its auction design to catalyse supply-chain development and, via visible economic spillovers (local employment and industrial participation), reinforce social acceptance.

Third, industrial capability must co-evolve with technology choices. The pipeline increasingly points to standardised semi-submersible concepts and tow-to-site strategies, which impose concrete requirements on quayside integration, draught, cranage, and lay-down areas. In this context, public funding and innovation programmes should prioritise technologies and projects that enable industrialisation and mass manufacturing, rather than dispersing resources across highly disruptive, low-TRL concepts (across key FOW subsystems) that cannot scale within the timelines required for deployment (Sections 3.7, 3.8). Ports and installation vessels remain potential bottlenecks despite under-utilised European manufacturing capacity in the near term (Section 3.7). New investments and reactivation of idle capacity will depend on transparent project pipelines and predictable auction volumes [241]. Timely, targeted upgrades at candidate Mediterranean hubs, together with workforce programmes, can convert existing industrial bases into floating-ready ecosystems; in parallel, local content in floaters and auxiliaries, particularly via SMEs, diversifies supply and mitigates geopolitical-risk exposure (Section 3.9). Without this alignment, turbine scale-up risks outpacing practical installability.

Fourth, environmental stewardship and social licence are integral to feasibility, not afterthoughts. Dense MPA networks and sensitive habitats require tailoring North Sea practices to Mediterranean ecologies (Section 3.2). Nature-inclusive design offers a route beyond mitigation towards net-positive outcomes, provided that monitoring and adaptive management are embedded in SEA/EIA and programme design. On acceptance (Section 3.3), evidence points beyond a simple NIMBY framing: perceptions of fairness, institutional trust, and sectoral coexistence (notably fisheries and tourism, which are particularly intensive along Mediterranean coasts) are decisive. Early, place-based engagement, distance-sensitive siting, and transparent visualisation tools can reduce conflict; where appropriate, multi-use options (*e.g.*, LTA) add co-benefits without diluting core delivery objectives.

Concluding findings on the floating wind pathway. FOW is a global endeavour, yet progress remains uneven and is often slowed by limited coordination among key actors. It is worth noting that recent global markets have exhibited significant volatility: cost inflation, supply-chain bottlenecks, and tightening financing conditions [156–158] introduce structural uncertainty into floating offshore wind deployment trajectories. These dynamics underscore the exposure of capital-intensive projects to regulatory instability, industrial fragilities, and macroeconomic pressures that can delay or suspend investment decisions even where technical potential remains strong.

Narrowing the considerations to basin-specific analyses, the Mediterranean is a distinctive case: deep waters, milder metocean conditions, heterogeneous institutions, and high biodiversity sensitivity mean it cannot replicate the North Sea model. Nonetheless, the region can leverage two decades of cumulative learning (technological, environmental, social, and industrial) if cross-border cooperation and a coherent sequencing of reforms and investments are achieved.

Basin-level planning, transparent and predictable auction schedules, stable economic instruments, and targeted infrastructure upgrades (ports, vessels, manufacturing, grid) are the practical levers to shift floating wind from promise to delivery. Aligning planning, grid integration, industrial capability, and social licence is the decisive condition for converting technical potential into bankable projects at pace in the Mediterranean, while maintaining high environmental standards and enabling blue-economy co-benefits. These findings reinforce the industrial position that FOW is ready to scale through industrialisation, technology-specific auctions, and coordinated investment in Europe's supply chain and port infrastructure. This review has identified gaps in policy design, grid readiness, and industrial coordination alongside clear opportunities for improvement. Although challenges remain, the direction of travel is positive: ongoing regulatory adaptations, strengthening supply-chain initiatives, and emerging project pipelines indicate that, over the coming decades, the Mediterranean can become a leading example of sustainable floating-wind deployment.

Future actions should prioritise: (i) basin-level regulatory coordination mechanisms; (ii) coordinated infrastructure investment; (iii) Mediterranean-focused pilot projects and data collection; (iv) structured stakeholder engagement frameworks; and (v) Mediterranean-adapted nature-inclusive design.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Riccardo Longo reports a relationship with WindEurope asbl vzw that includes employment. Alexandre Fremaux reports a relationship with WindEurope asbl vzw that includes employment. Lizet Ramirez reports a relationship with WindEurope asbl vzw that includes employment. Vasiliki Klonari reports a relationship with WindEurope asbl vzw that includes employment. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

No data were used for the research described in the article.

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