WATERBORNE

WATERBORNE TECHNOLOGY ROADMAP

Competitive, resilient and sustainable offshore vessels

September 2026

OFFSHORE VESSELS TECHNOLOGY ROADMAP

01 THE SECTOR IN NUMBERS

For this roadmap, offshore vessels are defined by function. Offshore vessels are a wide category of vessels that facilitate offshore installations, operations and maintenance. Many of the offshore vessels are complex work vessels, such as installation vessels, dredgers, tugs and cable-laying vessels, which are capable of executing very accurate work. These types of vessels typically have high power needs, and a high energy consumption at peak moments. As the offshore vessels are predominantly built in Europe, they are a suitable category for demonstration purposes.

1,567 offshore vessels in the European-controlled fleet as of January 2026, totalling 16.7 million gross tonnes[1]

25% world offshore vessel capacity by gross tonnage is held by Europe[1]

37% of world dredger capacity is held by Europe[1]

37 GW offshore wind capacity in Europe at the end of 2024, of which the EU-27 accounted for 21 GW[2]

549 DREDGERS 2.0 m GT1

The European-controlled fleet is substantial and specialised. The dredging industry estimates a working fleet of around 750 units once support vessels are included, and installs high technology equipment even on older hulls.[3] Ownership is fragmented: 90% of the more than 4,000 shipping companies in the EU-27 and Norway control fewer than ten vessels. The fleet ages slowly and renews through retrofit and the second-hand market as much as through newbuilding. European vessels leaving the fleet are frequently sold for continued operation on other continents, and tug building, once European-led, is now strongly contested by Turkish and other non-EU builders, while Europe retains clear leadership in dredgers and in the most complex cable and construction vessels.[4]

OPERATIONAL PROFILE

The operating profile of offshore vessels is defined by station-keeping, harsh-weather exposure, mission equipment and proximity to offshore energy, port and subsea critical infrastructure. Unlike cargo and passenger ships, whose design is usually governed by range, payload and voyage speed, offshore vessels are designed to perform specialised work at sea. Dynamic positioning, heave compensation, towing, high bollard pull, heavy lift, cable tensioning, trenching and dredge-pump operation create high installed-power requirements, rapid load transients and stringent redundancy needs.[5] Across the segment, the common design challenge is therefore not average fuel consumption alone, but the ability to deliver safe, redundant and efficient power across highly variable duty cycles.

SIX VESSEL FAMILIES IN SCOPE

Offshore wind service vessels — field endurance; transfer safety; gangway workability; DP capability; battery and charging compatibility; hotel load; motion comfort · **Platform supply vessels** — clear deck area; segregated bulk/liquid tanks; DP capability; transit/work-mode split; peak shaving; safe approach to installations · **Anchor-handling, towage and pilotage vessels** — bollard pull; rapid load transients; manoeuvrability; availability; redundancy; firefighting and safety notations; battery or hybrid peak power capacity · **Subsea construction and installation vessels** — crane capacity; DP class up to DP3; motion compensation; jack-up leg length where applicable; high peak power; station-keeping reliability· **Cable-laying, pipe laying and cable-repair vessels** — carousel/turntable capacity; controlled tension; burial depth; shallow/intertidal capability; repair mobilisation time; critical-infrastructure protection · **Dredging and reclamation vessels** — hopper capacity; cutter and dredge-pump

STRATEGIC ROLE IN THE EUROPEAN WATERBORNE ECOSYSTEM

Offshore vessels are a strategic enabler of European offshore renewable energy and offshore energy hubs. New offshore projects require installation, cabling, service and maintenance vessels at every stage of the asset lifecycle.[2] Europe leads globally in submarine cable vessels, offshore wind support vessels, floating and converter platforms, dredgers and icebreakers, but has lost wind turbine installation vessel building to competitors, principally China.[8] Leadership is concentrated in the most complex, highest-value vessel types and is not secure across the full fleet.

25 yrs average age of harbour tugs in wider Europe

≈35/yr tug renewal rate, about €311 million of annual investment[4]

€10–11 m a standard tug, against about €13 million for an LNG or hybrid tug[4]

80–90% of the cargo passing through Europe's major ports is assisted by harbour towage[4]

11,150 jobs and about €1.2 billion in annual turnover in wider Europe[4]

€1.45 bn in total gross value added contributed by harbour towage[4]

€11.1 bn invested in new equipment by the European dredging industry between 2008 and 2017[3]

FUEL & TECHNOLOGY BASELINE

The fuel and power baseline remains diesel electric. Most vessels burn low-sulphur marine diesel oil and switch to marine gas oil in sulphur emission control areas, hydrotreated vegetable oil is used as a drop-in substitute, and hybrid battery systems are deployed cost-effectively. The most advanced announced design pairs 2 MW of hydrogen-fuelled PEM fuel cells with 5.5 MW of diesel engines for a zero-emission operating range of up to two weeks.

02 POLICY DRIVERS AND CONSTRAINTS

2.1. DRIVERS

Regulatory drivers — from 1 January 2025 offshore ships of 400 GT and above are required to monitor, report and verify their greenhouse gas emissions under the revised MRV Regulation; from 1 January 2027 offshore ships above 5,000 GT enter the EU Emissions Trading System; and FuelEU Maritime strengthens the wider market signal for renewable and low-carbon marine fuels.[6]

Offshore-energy demand — offshore wind is the dominant demand driver and sets the workload for installation, cabling, service and maintenance vessels. Larger wind farms, deeper sites, floating offshore wind, longer export-cable routes and more distant interconnectors increase transit distance, time on station, installation complexity and maintenance intensity.[2]

Offshore renewable energy integration requirements — vessel-to-infrastructure energy exchange, charging infrastructure at remote installations, and energy optimisation across offshore ecosystems become deployment conditions.

Coastal resilience and counter-cyclical demand — dredging demand is structurally resilient and weakly correlated with economic cycles, because it is linked to port maintenance, navigation-channel depth, land reclamation, coastal protection and adaptation to sea-level rise and flooding.[3]

Critical-infrastructure protection and dual use — offshore vessels have become instruments of strategic autonomy. Subsea communication cables, electricity interconnectors, offshore energy assets and pipelines require dedicated installation, inspection, maintenance, repair and protection capability.[7]

Industrial competitiveness and sovereignty — the Industrial Maritime Strategy focuses on strengthening Europe's "Build, Equip and Repair" capability, and the Ports Strategy recognises that offshore wind and floating installations require larger and reinforced port facilities for assembly, storage and deployment.[8]

Systemic weight and safety-criticality of towage — towage is a systemically important and safety-critical service whose decarbonisation cannot reduce operational availability, emergency response capability or port safety.[4]

2.2. CONSTRAINTS AND BOTTLENECKS

Peak and transient power — the binding technical constraint is peak and transient power, not average consumption. Energy storage must be sized for these peaks rather than for mean load.

Worksite fuel and energy availability and bunkering — bunkering hydrogen, ammonia or methanol at far from shore worksites and offshore charging are undeveloped, and port electrification, grid capacity, shorepower connections and charging systems remain unevenly deployed across European ports.[5]

Offshore energy infrastructure interface standardisation — vessels approaching floating platforms or offshore substations for charging require plug-and-play connection standards, yet no such standards exist. Each offshore project design custom interfaces, creating integration costs and deployment delays.

Remote operation and situational awareness infrastructure gaps — satellite communication provides global coverage but insufficient bandwidth and latency (0.5-2 seconds delays) for precision docking, dynamic positioning under waves, or emergency response.

Battery thermal management in harsh environments — battery durability, state-of-health estimation, and thermal safety in harsh environments remain open technical challenges.

Fleet age, heterogeneity and retrofit economics — the fleet is heterogeneous, long-lived and renews slowly, which makes retrofit as important as newbuilding. Retrofitability, modularity and lifecycle-cost reduction are therefore decisive.[4]

Industrial build-share erosion and the cost gap — Europe has lost wind turbine installation vessel building to China, and consultation evidence puts the premium for an alternative-fuel vessel at one-third to one-half over a conventional diesel equivalent.[8]

Regulatory design mismatch — the EU climate instruments are voyage- and port-call-based, whereas offshore vessels consume most of their energy on station rather than between ports, and the 400 GT, 500 GT and 5,000 GT thresholds split the towage market.[9]

2.3 DEPLOYMENT LOGIC
The Work-Mode / Transit-Mode Split

Zero-emission operation at the field, in port, or during defined safety-critical work modes can be achieved earlier than full zero-emission operation across all transit and endurance requirements. This makes offshore vessels a practical market for staged deployment: energy-efficiency measures, digital energy management and hybridisation in the near term; zero-emission work modes and port-based and offshore charging or bunkering in the 2030s; scalable sustainable alternative fuels and fuel-cell systems for far-field operations through the 2040s; and integrated offshore vessel, energy and infrastructure systems by 2050.

03 TARGET CAPABILITIES

3.1 CURRENT STATE-OF-PLAY AND ACHIEVED DEVELOPMENTS

Hybrid-battery systems, digital energy management, dynamic-positioning optimisation, predictive maintenance and drop-in renewable fuels are already deployable in selected applications. Methanol capable engines, fuel-cell hybrids, shore and offshore charging concepts, remote support systems and digital twins are moving from demonstration to early commercial deployment. Full zero-emission far-field operation, offshore bunkering of new fuels, high-power charging during mission operations, autonomous dynamic-positioning functions and harmonised certification of alternative-fuel offshore vessels still require targeted RD&I, demonstration and regulatory development.

2035 • Early deployment phase

Propulsion and energy: Zero-emission work mode will be standard on service vessels; battery-electric systems will serve low-energy duties such as service and crew transfer, while offshore wind farms, offshore charging and sustainable alternative fuel systems serve energy-intensive duties such as anchor-handling and heavy construction.[11]

Safety, security and resilience: Advanced situational awareness will integrate environmental, vessel and offshore-installation data; predictive maintenance will reduce operational risk and downtime; and cyber-secure systems will protect mission-critical offshore operations.[12]

Connected, automated and data-driven operations: Connected, partly remote-operated fleets will exchange real-time data with offshore installations and shore control centres; low-complexity functions such as inspection and light construction will operate autonomously; and digital twins will support mission planning.[13]

Human-centred operations and workforce: Decision-support systems will assist crews during complex operations, simulation and extended-reality environments support mission preparation, and remote-operation-centre concepts will support selected offshore missions.[10]

Regulation and system-level integration: Regulatory pathways will enable certification of alternative-fuel offshore vessels, and regulatory sandboxes support pilot projects for autonomous offshore operations.[8]

2040 • Scale-up phase

Propulsion and energy: Fuel-cell and sustainable alternative fuel propulsion will be in commercial, scaled deployment across segments. Vessels will integrate with offshore and onshore energy systems through charging, bunkering and energy exchange, and technology-neutral pathways will be adapted to mission and power demand.[14]

Safety, security and resilience. Safety systems will predict operational risk during complex missions, autonomous incident-response systems will assist crews in high-risk scenarios, and cyber-resilient operational architectures will support autonomous functions and secure communication.

Connected, automated and data-driven operations. Offshore missions will be monitored and supported from shore-based control centres, autonomous functions will cover repetitive logistics, inspection and monitoring, and digital twins will support predictive maintenance across vessels and infrastructure.

Human-centred operations and workforce. Advanced human-machine teaming will support planning, safety monitoring and maintenance, shore-based specialist support will be integrated into operations, and standardised human-centred design applies across vessel systems.

Regulation and system-level integration. International standards will govern zero-emission offshore vessel operations and energy systems, and integrated planning frameworks coordinate offshore energy infrastructure and maritime logistics.

2050 • Full transformation

Propulsion and energy: The fleet will be fully zero-emission. Zero-emission propulsion will be standardised, modular and scalable across vessel categories, and vessels interact dynamically with offshore renewable infrastructure for energy supply and optimisation. High-capacity charging solutions will be available both in ports and at sea in offshore power zones.

Safety, security and resilience. Fully integrated predictive safety ecosystems will link vessels, offshore infrastructure and shore control centres, enabling near-zero-incident operations, and reliable European-controlled communication, satellite and positioning infrastructure underpins secure operation throughout.[15]

Connected, automated and data-driven operations. Fully connected offshore energy-logistics systems will coordinate vessels, installations and energy infrastructure, autonomous logistics will operate for selected mission types, and highly automated vessels will operate with minimal intervention in defined areas.

Human-centred operations and workforce. Highly automated operations will run under human oversight supported by advanced decision support, integrated digital workforce ecosystems will combine training, operations and lifecycle support, and mature social-acceptance and ethics frameworks are in place.

Regulation and system-level integration. A fully harmonised regulatory ecosystem will support climate-neutral fleets and integrated offshore energy systems, and European frameworks and standards will be adopted globally.

04 TECHNOLOGY PATHWAYS

4.1 Future propulsion and energy systems enabling a zero-emission offshore fleet

Enable scalable, safe and efficient zero-emission propulsion and energy systems for offshore vessels. This includes complementary technology pathways such as batteries, fuel cells and sustainable alternative fuels, including hydrogen, ammonia and methanol, to decarbonize offshore vessel operations across work, transit, standby and port modes and to support integration with offshore energy systems.

4.2 Intelligent safety, security and resilience as foundational enablers

Enable predictive safety systems and resilient offshore vessel operations capable of managing increasingly complex design architectures, complex missions, sustainable alternative fuel systems and increasingly digitalised operations under demanding environmental conditions.

4.3 Fully connected, automated and data-driven offshore systems

Enable fully integrated offshore mission systems where vessels, offshore installations and onshore control centres exchange operational data in real time to optimise logistics, maintenance, safety and energy use.

4.4 Human-centred design and a future-ready offshore workforce

Enable safe and effective human-machine collaboration in offshore operations through advanced decision support, training systems and ergonomic vessel design. Solutions must support social acceptance, ethical use of AI, remote-operation centres and competence development for increasingly automated offshore operations.

4.5 Forward-looking regulation, standardization and system-level integration

Enable harmonised regulatory frameworks that support large-scale deployment of zero-emission and digitally integrated offshore vessel operations. The objective is to move from case-by-case approval towards predictable certification, standardised interfaces, regulatory sandboxes and system-level planning.

KEY RESEARCH GAPS

- Integrating scalable zero-emission propulsion systems, including batteries, fuel cells and sustainable alternative fuels, across all offshore operational modes.
- Operation, durability and reliability of fuel cells under representative offshore environmental and duty-cycle conditions.
- Goal-based safety frameworks for autonomous and remotely operated offshore systems, supporting certification beyond prescriptive approaches.
- Vessel integrated deployment, recovery and coordination of autonomous and remotely operated assets, including interoperable mission-system interfaces.
- Regulatory models for autonomous offshore vessel operations, addressing current regulatory uncertainty.
- Energy-storage technologies and power systems capable of handling variable and high-demand offshore operational profiles.
- High-power charging and energy exchange in port and offshore environments, including high voltage safety, interoperability and connection systems.
- Maritime-domain-awareness systems supporting monitoring and protection of offshore energy infrastructure and other critical offshore assets.
- Human-machine interaction design for high-risk offshore operations, addressing safety, trust and usability.
- Certification frameworks for modular propulsion and energy systems, addressing the current lack of standardised approaches.
- Storage, handling, onboard conversion, operations, monitoring and risk mitigation for fuels such as hydrogen, ammonia and methanol in offshore environments.
- AI-based decision-support systems for offshore operational safety, moving beyond current advisory systems.
- Autonomous navigation and operational systems adapted to complex offshore environments.
- Remote-operation centres, including human oversight, decision authority, data needs and control-room design.

OFFSHORE VESSELS TECHNOLOGY ROADMAP

3.5 CROSS-CUTTING CAPABILITY IMPLICATIONS

The pathway is differentiated by duty cycle and distance, not by a single trajectory: near-shore service vessels follow an electrification pathway, while far-field construction and cable vessels follow a high-density-fuel and fuel-cell pathway. Dynamic positioning and station-keeping, not range, are the defining design constraints across every domain. The critical-infrastructure and dual-use dimension runs across all domains and horizons, because cable, construction and survey vessels are simultaneously commercial and strategic assets.[16]

05 ENABLERS AND DEPLOYMENT AT SCALE

Performance can be limited by one port without adequate shore power, one weak-grid island, one destination with access restrictions, one supply chain vulnerability or one unresolved safety approval.

5.1 Energy, bunkering and charging infrastructure

Deployment will depend on port-based electrification, high-capacity charging, offshore charging concepts and bunkering infrastructure for hydrogen, ammonia, methanol and other sustainable alternative fuels. Standards for energy exchange between vessels, ports, offshore installations and energy infrastructure will be needed.

5.2 Vessel design, modularity and retrofit

Future vessel concepts should be modular, retrofit-ready and adaptable to different missions, vessel sizes and energy pathways, with standardised interfaces where appropriate for propulsion, mission equipment and autonomous or remotely operated systems.

5.3 Safety, certification and regulatory readiness

Standardised certification procedures are needed for sustainable alternative fuels, modular energy systems, autonomous functions, AI-enabled decision support and remote operations. Regulatory sandboxes and shared validation environments should generate evidence under realistic conditions.

5.4 Digital, communication and autonomy infrastructure

The priority is to move towards interoperable digital architectures linking vessels, autonomous and remotely operated assets, offshore installations, ports, shore control centres, logistics providers, energy infrastructure and wider offshore digital platforms.

5.5 Industrial coordination, finance and procurement

Several deployment barriers are commercial rather than technical. Long-term contracts and charter commitments, green procurement, fleet renewal instruments, retrofit support, infrastructure co-investment and targeted funding for large-scale demonstrations can reduce these risks.

5.6 Human capital, training and acceptance

The roadmap will only be deployable if technological innovation is matched by skills, acceptance and safe human-centred implementation. Competence frameworks should cover onboard personnel, shore-based specialists, technicians, port personnel and emergency responders.

SOURCES

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2 WindEurope, Wind Energy in Europe: 2024 Statistics (2025); IEA, Energy Technology Perspectives 2026 (2026), 145.
3 European Dredging Association, consultation (2026); EuDA Annual Report 2024 (2024), 6–7.
4 Ecorys, Economic Impact of the European Towage Sector (2019), 11, 18–20; European Tugowners Association, consultation (2026).
5 Waterborne Technology Platform, SRIA (2021), 32.
6 Regulation (EU) 2015/757 as amended by Regulation (EU) 2023/957 (MRV); Directive (EU) 2023/959 (EU ETS); Regulation (EU) 2023/1805 (FuelEU Maritime); Regulation (EU) 2023/1804 (AFIR).
7 European Commission, European Preparedness Union Strategy, JOIN(2025) 130 (2025), 12-14.
8 European Commission, EU Industrial Maritime Strategy (2026), 3, 10; EU Ports Strategy (2026).
9 European Commission, COM(2026) 616 final, 17 July 2026.
Chapters 1 and 2 of the Offshore Vessels Technology Roadmap; vessel families per Table 1.
10 Waterborne Technology Platform, Waterborne Technology Leadership (2026), section 3.4.
11 Waterborne Technology Leadership (2026), section 3.4; SRIA (2021), 32.
12 Waterborne Technology Leadership (2026), section 3.4; European Preparedness Union Strategy (2025).
13 Waterborne Technology Leadership (2026), section 3.4.4; EMSA, Safety Analysis 2025 (2025).
14 Waterborne Technology Leadership (2026), sections 3.4.4–3.4.5.
15 European Commission, EU Industrial Maritime Strategy (2026), 13.
16 Waterborne Technology Platform, SRIA (2021), 26, 32.
Chapters 3 and 4.

GLOSSARY

AHTS anchor-handling tug supply
AUV autonomous underwater vehicle
CSOV commissioning service operation vessel
CTV crew transfer vessel
DP dynamic positioning
GT gross tonnes
MRV monitoring,reporting and verification
PEM proton-exchange membrane
PSV platform supply vesse
ROV remotely operated vehicle
SOV service operation vessel
TSHD trailing suction hopper dredger
USV uncrewed surface vessel
WTIV wind turbine installation vessel.

PROVENANCE

Chapters 5 and 6 of the Offshore Vessels Technology Roadmap; impact figures per Table 7.
Table 7 impact figures are indicative sector-level ambitions and should be refined as fleet, market and technology baselines evolve.

OFFSHORE VESSELS TECHNOLOGY ROADMAP

06 EXPECTED IMPACTS

CLIMATE & ENVIRONMENT

2035 **20-25% CO_2 intensity** • Zero-emission work modes on 30-40% of the fleet

2040 **45-50% CO_2 intensity** • Zero-emission work modes on 60-70% of the fleet

2050 **90-95% CO_2 emissions** • >80% of fleet operating zero-emission where feasible

ECONOMIC & INDUSTRIAL

2035 **40-60 vessels retrofitted** • 10-15 European retrofit centres

2040 **100-150 vessels retrofitted** • €1.2 bn/year retrofit & upgrade activity

2050 **€20-30 bn cumulative economic value** • European capability maintained in strategic technologies

TECHNOLOGY & OPERATIONS

2035 **Alternative fuels validated** • 100+ vessels with advanced energy management • autonomous/remote pilots

2040 **Modular 5-20 MW fuel cells** • 70-80% of relevant vessels connected to digital twins

2050 **Full vessel-energy-infrastructure integration** • highly automated operations in defined domains

SAFETY & RESILIENCE

2035 **Predictive safety and situational awareness increasingly deployed** • shared validation for new technologies

2040 **Cyber-resilient systems and autonomous incident response** • faster recovery from disruption

2050 **Integrated predictive safety ecosystems** • near-zero-incident operation pursued

SKILLS & WORKFORCE

2035 **3,000-5,000 personnel trained** • 5-8 specialised training facilities

2040 **8,000-12,000 trained** • remote operations on 25-30% of fleet for selected tasks

2050 **Continuous learning embedded** • 10-15 specialised training & research centres

VISION 2050

"By 2050, offshore vessels will increasingly operate as part of zero-emission, connected, resilient, competitive and sustainable offshore energy and logistics ecosystems."

CONTENT

LIST OF TABLES

ROADMAP POSITIONING WITHIN THE WATERBORNE TECHNOLOGY LEADERSHIP FRAMEWORK

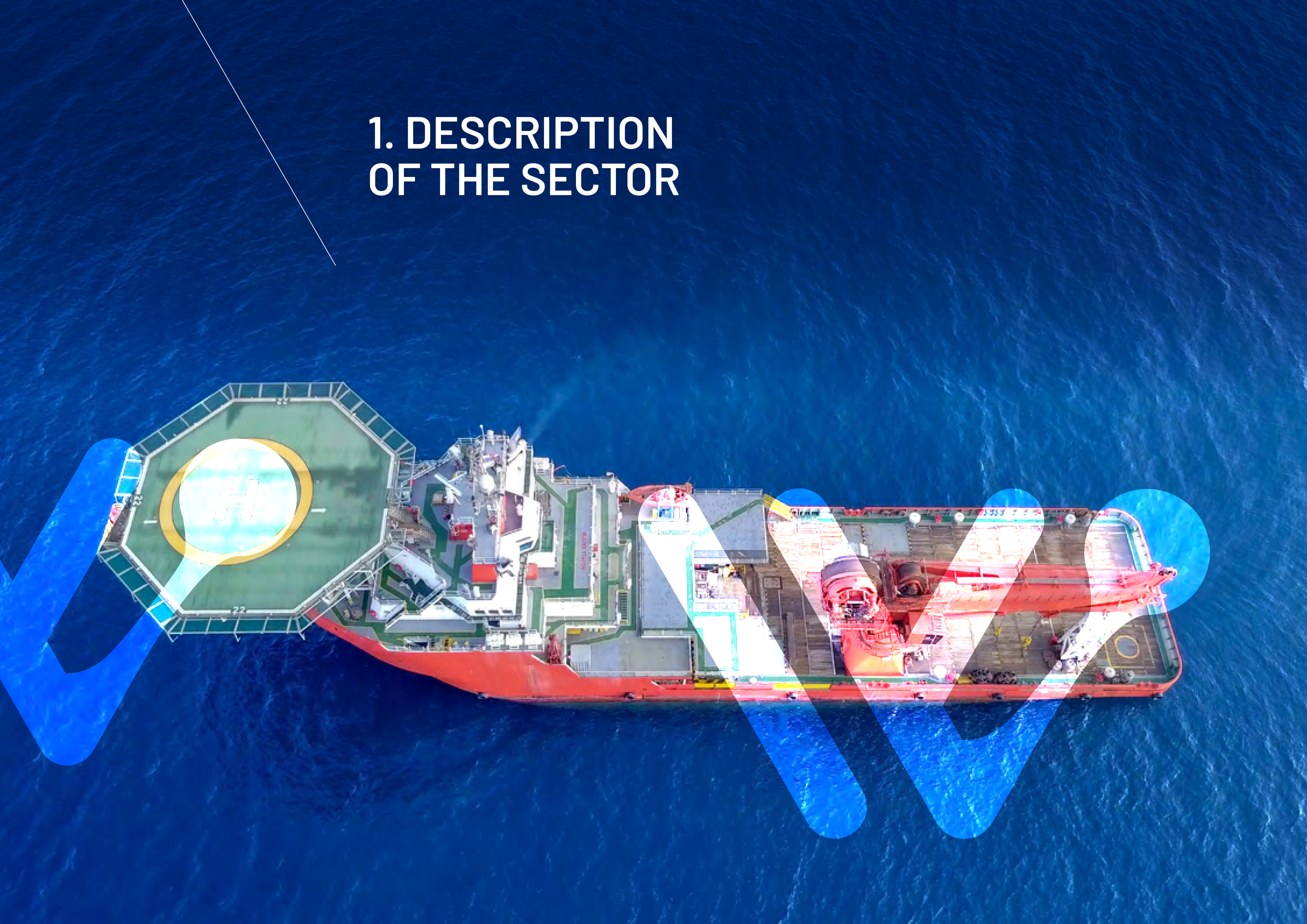
This roadmap operationalises the Technology Leadership[1] framework for offshore vessels. It translates the overarching objectives, including competitiveness, resilience, sustainability, zero-emission operations[2], digitalisation, safety and security, human-centred innovation, standards, skills and deployment at scale, into the specific conditions of offshore vessels. It reflects the Technology Leadership document's ecosystem approach, linking shipowners, shipyards, equipment manufacturers, ports, energy, infrastructure and service providers, classification societies, financial institutions, authorities, research organisations and logistics users into a coordinated deployment pathway.

The roadmap on offshore vessels is closely interlinked with the following dedicated Technology Roadmaps: maritime technology sector, port ecosystems and blue economy.

1 Waterborne Technology Platform, Waterborne Technology Leadership: Towards a Competitive, Resilient and Sustainable Waterborne Sector - A Co-programmed Partnership under Framework Programme 10, January 2026

2 Throughout this roadmap, references to zero-emission may, depending on the context, encompass broader environmental performance objectives, including the elimination of local pollutant emissions. Net-zero emission refers specifically to greenhouse gas emissions from a lifecycle perspective and may include carbon neutral fuels, carbon capture pathways and other net-zero solutions

1. DESCRIPTION OF THE SECTOR



1. DESCRIPTION OF THE SECTOR

1.1 DEFINITION AND SCOPE

For this roadmap, offshore vessels are defined by function. Offshore vessels are a wide category of vessels that facilitate offshore installations, operations and maintenance. Historically, this segment focussed on oil and gas installations. But with the onset of offshore renewable energies and other blue economy activities, this fleet has transformed into an enabler of sustainable growth. Many of the offshore vessels are complex work vessels, such as installation vessels, dredgers, tugs and cable-laying vessels, which are capable of executing very accurate work. These types of vessels typically have high power needs, and a high energy consumption at peak moments. The technologies used for power generation are the same as those listed for transport vessels. **As the offshore vessels are predominantly built in Europe, they are a suitable category for demonstration purposes.**

The variety of operating profiles, as well as the size of ships, make offshore vessels ideal candidates for innovative solutions. Their close shore activities allow for more frequent fuelling, and thus low-density energy carriers can be applied.

Operating close to shore also means that it is necessary to reduce SOx and PM emissions to the maximum extent possible. Offshore vessels often have high peak power demand, significant energy consumption, and long periods of low-speed operation or idling within confined areas such as offshore wind farms and oil & gas installations. These operating profiles make many vessels well suited for battery-electric propulsion where offshore power is available, particularly from offshore wind farms[3]. Electrification supports Europe's broader energy transition by reducing fossil fuel imports, exposure to fuel price volatility and emission costs, while lowering emissions. Designs from full electric to hydrogen powered fuel cell hybrid solutions will make sense in this context. Today, hybrid battery systems are already being cost effectively deployed and some of the newest vessels can perform their operations at sea with zero- emission technologies, while transit is still covered with conventional diesel-electric systems using low- sulphur marine diesel oil. The latest announcements on new ship designs for offshore vessels show an extended zero emission target range of up to two weeks operation time based on a hybrid concept with 2MW hydrogen powered PEM fuel cells combined with 5,5MW diesel ICE.

The roadmap covers **six vessel families** and the vessel side systems that determine their performance: propulsion and energy systems, power management, dynamic positioning, station-keeping, deck and mission equipment, digital, automation and communication systems, onboard safety and security systems, human-machine interfaces, and interfaces with port, energy and offshore infrastructure.

- **Offshore wind service vessels.** These vessels carry technicians, parts and equipment to and from offshore wind farms for commissioning, operations and maintenance. The family runs from crew transfer vessels for nearshore day transfers to service operation vessels and commissioning service operation vessels for far-from-shore fields, the latter equipped with motion-compensated walk-to-work gangways, dynamic positioning and accommodation for technicians on multi-week campaigns.[4] Their defining parameters are dynamic-positioning station-keeping, gangway workability in significant wave height, and field endurance. As wind farms move further offshore and into deeper water, day-return crew transfer gives way to

3 Port of Rønne, Baltic Energy Island, and Stillstrom by Maersk, Bornholm Energy Island: Powering Maritime Electrification (whitepaper, June 2026), 5.
4 Waterborne Technology Platform, SRIA (2021), 32; WindEurope, Wind Energy in Europe: 2024 Statistics and the Outlook for 2025–2030 (Brussels: WindEurope, 2025).

resident service operation, which is the central trend reshaping the family. The duty cycle (long time on station at moderate load, with frequent return to port or to charge in ports or at sea in/close to an offshore wind farm) makes this the family most amenable to battery-electric and methanol or fuel-cell hybrid solutions. The deployment of floating offshore wind is expected to drive the emergence of a specialised sub-segment within this vessel family. Service vessels supporting floating offshore assets will require enhanced endurance, dynamic-positioning capability, motion-compensated access systems and greater operational flexibility to support deep-water installations, floating structures, mooring systems and dynamic cable infrastructure

- **Platform supply vessels.** These vessels carry deck cargo and below-deck bulk (drilling fluids, brine, cement, fuel and water) to offshore installations and wind farms and form the logistics backbone of offshore operations. They are characterised by a large clear aft deck, segregated cargo and liquid-mud tanks, and dynamic positioning for safe approach to installations. Their profile combines extended transit with prolonged dynamic-positioning standby alongside the asset. This split makes dual-fuel arrangements for transit and hybrid-battery systems for peak-shaving and station-keeping the natural decarbonisation route. Offshore vessels operating predictable routes are suitable for battery-electric propulsion and offshore charging.

- **Anchor-handling and towage vessels.** This family consists of tows, anchor-handlers, escorts and assists. Anchor-handling tug supply vessels move and set anchors for rigs and floating units and tow large structures; harbour tugs berth and unberth ships and are the dominant population, numbering some 1,595 port tugs across wider Europe in 2019, excluding offshore, supply and inland units; escort tugs deliver steering and braking force in confined waters; and pilotage vessels transfer pilots in port approaches, the coastline and offshore.[5] The defining parameters are high bollard pull with rapid power transients (averaging around 50 tonnes across the fleet and rising toward 80–90 tonnes for the largest vessels and occasional naval work, fire-fighting and safety-system notation on offshore units, and dynamic positioning on anchor-handlers.[6]) The work is intermittent but safety-critical and continuous in availability, operating around the clock. The duty cycle is the segment's hardest decarbonisation case: short, very high-power peaks during assistance and anchor work, separated by long low-load standby, against which battery-only operation remains endurance-limited (a battery tug delivers roughly one-eighth of the work of a diesel tug before recharging) so methanol, hydrogen and hybrid architectures are the routes under examination.[7] Vessels with long low-load standby are suited for higher use of battery-electric operations in hybrid set-ups and charging can happen in ports and offshore where available.

5 Ecorys, Economic Impact of the European Towage Sector (Rotterdam: Ecorys, for the European Tugowners Association, 29 October 2019), 9–10 (1,595 port tugs, wider Europe, harbour towage, 2019, excluding offshore, supply and inland tugs); European Tugowners Association, stakeholder consultation for the Offshore Vessels Technology Roadmap (2026).
6 Ecorys, Economic Impact of the European Towage Sector (2019), 20, 28; dynamic-positioning classes per International Maritime Organization, Guidelines for Vessels and Units with Dynamic Positioning Systems, MSC.1/Circ.1580 (London: IMO, 2017).
7 European Tugowners Association, consultation (2026).

- **Subsea construction and installation vessels.** These vessels install and maintain subsea and offshore structures (turbine foundations and turbines, jackets, manifolds and subsea production systems) and deploy, recover, maintain, recharge and coordinate fleets of AUVs, ROVs, USVs and aerial drones in harsh offshore conditions. The family includes offshore construction vessels with heavy-lift cranes and high-redundancy station-keeping; wind turbine installation vessels, which are self-elevating jack-up units that raise the hull clear of the water on legs to form a stable lifting platform; diving support vessels; and survey and remotely-operated-vehicle support vessels.[8] This is the build/ installation fleet for offshore energy, and the wind turbine installation vessel is the specific type Europe has been losing to Chinese builders. Defining parameters are heavy-lift crane capacity, dynamic-positioning class up to DP3, jack-up leg length, which sets the installable water depth, motion compensation launch and recovery systems and during lifts, reconfigurable mission decks, onboard maintenance and charging facilities and integrated mission-control architectures linking surface, underwater, aerial and shore-based assets.[9] Peak power during heavy lifts and dynamic positioning is very high and the operations are increasingly far from shore, which points the family toward high-density fuels and high-power fuel-cell integration rather than batteries alone.

- **Cable-laying, pipe laying and cable-repair vessels.** These vessels install, bury, protect and repair power and communication cables, interconnectors and umbilicals. The family is depth-stratified: cable-lay vessels with carousels and tensioners serve deep and ultra-deep water; trenching-support vessels deploying seabed trenchers, ploughs and jetting tools serve medium and deeper water; shallow-draught support vessels serve shallow water; and the ultra-shallow and intertidal landfall zone, where export cables come ashore, remains under-served by conventional barges, anchor spreads and land excavators. Defining parameters are cable storage capacity on carousels or turntables, controlled lay tension, burial depth of up to about seven metres, and rock placement or stone-dumping for cable and pipeline protection.[10] The driver is twofold: the export cables and interconnectors that offshore wind requires, and the protection of critical subsea infrastructure, which makes this the family most directly tied to the strategic-autonomy agenda.[11]

- **Dredging and reclamation vessels.** These vessels excavate, transport and place seabed material for navigation channels, port maintenance, coastal protection, land reclamation and offshore foundation preparation. The principal types are trailing suction hopper dredgers, self-propelled vessels that load a hopper while under way and discharge by bottom-dumping, pipeline or rainbowing; cutter suction dredgers, which cut hard material and pump it ashore or to barges; grab dredgers, used in confined or contaminated sites but not in deep water; and rock-placement and stone-dumping vessels.[12] Defining parameters are hopper capacity, which currently ranges from roughly 4,000 to 30,000 cubic metres at working loads near 80%, cutter and dredge-pump installed power, and dredging depth.[13] Demand is structurally resilient and weakly correlated with economic cycles, reflecting the sector's role in coastal and climate resilience. Installed power is very high and sustained during dredging, so LNG and dual fuel are already adopted at the large end of the fleet, with battery systems applied to peaks.

8 International Maritime Organization, MSC.1/Circ.1580 (2017); European Dredging Association, stakeholder consultation for the Offshore Vessels Technology Roadmap (2026).
9 European Commission, EU Industrial Maritime Strategy (Brussels: European Commission, 4 March 2026), 3.
10 European Dredging Association, consultation (2026).
11 European Commission, EU Industrial Maritime Strategy (2026), 10; European Commission, European Preparedness Union Strategy, JOIN(2025) 130 (Brussels, 26 March 2025).
12 European Dredging Association, consultation (2026); European Dredging Association, EuDA Annual Report 2024 (Brussels: EuDA, 2024).
13 European Dredging Association, consultation (2026).

A summary of the main missions and defining technical parameters by vessel family is shown in the table below.

Vessel family	Main missions	Defining technical parameters
Offshore wind service vessels	Crew transfer, service operation, commissioning support, wind-farm maintenance, technician accommodation and walk-to-work operations.	Field endurance; transfer safety; gangway workability; DP capability; battery and charging compatibility; hotel load; motion comfort.
Platform supply vessels	Deck cargo and below-deck bulk logistics for offshore installations, wind farms and subsea operations.	Clear deck area; segregated bulk/liquid tanks; DP capability; transit/work-mode split; peak shaving; safe approach to installations.
Anchor-handling, towage and pilotage vessels	Anchor handling, towage, escort, berthing, emergency assistance, pilot transfer and safety-critical port/offshore support.	Bollard pull; rapid load transients; manoeuvrability; availability; redundancy; firefighting and safety notations; battery or hybrid peak-power capacity.
Subsea construction and installation vessels	Heavy lift, subsea construction, wind-turbine and foundation installation, diving support, ROV/survey support, offshore decommissioning.	Crane capacity; DP class up to DP3; motion compensation; jack-up leg length where applicable; high peak power; station-keeping reliability, reconfigurable mission decks, onboard maintenance and charging facilities and integrated mission-control architectures
Cable-laying, pipe laying and cable-repair vessels	Power cable, telecom cable, interconnector and umbilical laying, burial, protection, survey and repair.	Carousel/turntable capacity; controlled tension; burial depth; shallow/intertidal capability; repair mobilisation time; critical-infrastructure protection.
Dredging and reclamation vessels	Port and channel maintenance, capital dredging, coastal protection, land reclamation, seabed preparation, rock placement.	Hopper capacity; cutter and dredge-pump power; dredging depth; discharge mode; high sustained power; emissions per cubic metre dredged.

Table 1: Vessel families of the Offshore Sector

Harbour towage, pilotage and dredging overlap with the Port Ecosystems and Blue Economy roadmaps. They are retained here where the technology issue is the vessel, not the port service or the wider activity. Conversely, generic waterborne engines, fuels and equipment industrialization are treated in the Maritime Technology roadmap, and subsea or floating systems deployed by offshore vessels are treated in the Blue Economy roadmap[14].

Offshore vessel electrical and automation systems integrate propulsion, dynamic positioning, mission equipment, power distribution, energy storage, redundancy management, and communication systems to support mission-critical operations under harsh environmental conditions and extended endurance requirements. This scope encompasses integrated power management systems (IMPs) coordinating main engines, generators, batteries, fuel-cell systems, dynamic load management, station-keeping precision, and offshore infrastructure interfaces. Electrical systems must support multiple power profiles (peak power for lifting/towing, sustained power for dredging, variable standby power for dynamic positioning) and maintain operational redundancy while transitioning to zero-emission and hybrid architectures.

1.2 STRATEGIC ROLE IN THE EUROPEAN WATERBORNE ECOSYSTEM

Offshore vessels are a strategic enabler of European offshore renewable energy and offshore energy hubs. Europe had 37 GW of offshore wind capacity at the end of 2024, of which the EU-27 accounted for 21 GW. New offshore projects require installation, cabling, service and maintenance vessels at every stage of the asset lifecycle.[15] The sector is also part of Europe's industrial and security base. The 2026 EU Industrial Maritime Strategy[16] identifies advanced shipbuilding, offshore wind support vessels, underwater drones and high-tech maritime equipment as priorities for competitiveness, innovation and industrial sovereignty. The EU Ports Strategy[17] highlights the need for larger and reinforced port facilities for offshore wind assembly, storage and deployment. In addition, ports need additional power supply to service both port operations and vessels with abilities to go use shore power at berth and charge battery-electric vessels, incl. offshore vessels. Offshore power zones at sea will supplement power supply in ports and reduce bottlenecks in ports- space at berth and power supply.

Europe leads globally in submarine cable vessels, offshore wind support vessels, floating and converter platforms, dredgers and icebreakers, but has lost wind turbine installation vessel building to competitors, principally China.[18] Leadership is concentrated in the most complex, highest-value vessel types and is not secure across the full fleet. Subsea cables and pipelines require dedicated laying, repair and protection capability, an imperative sharpened by shadow-fleet activity and incidents in the Baltic and reflected in the European Preparedness Union Strategy and the EU Industrial Maritime Strategy.[19]

Towage and dredging add scale and continuity to this role. Harbour towage is a safety-critical service that assists roughly 80 to 90% of the cargo passing through Europe's major ports, supports around 11,150 jobs and about €1.2 billion in annual turnover in wider Europe, and contributes some €1.45 billion in total gross value added.[20] Dredging delivers coastal and climate resilience and land reclamation, and the European dredging industry invested over €11.1 billion in new equipment between 2008 and 2017 while steadily reducing emissions per cubic metre dredged.[21]

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14 Offshore vessel families per the Chapter 4 scope note; European Shipowners (ES|ECSA), The Economic Value of European Shipping (Brussels: ES|ECSA, 2026), 6–7.

> Offshore vessel families per the Chapter 4 scope note.

15 WindEurope, Wind Energy in Europe: 2024 Statistics (2025), 42-47; International Energy Agency, Energy Technology Perspectives 2026 (Paris: IEA, 2026), 145.(European Commission, 2024).

16 European Commission, European Preparedness Union Strategy (2025); European Commission, EU Industrial Maritime Strategy (2026), 10.

17 European Commission. EU Ports Strategy. Brussels, 4 March 2026.

18 European Commission, EU Industrial Maritime Strategy (2026), 3.

19 European Commission, European Preparedness Union Strategy (2025); European Commission, EU Industrial Maritime Strategy (2026), 10.

20 Ecorys, Economic Impact of the European Towage Sector (2019), 12–17, 27 (wider-Europe harbour towage: 80–90% of cargo tug-assisted; ~11,150 jobs; ~€1.2 billion turnover; ~€1.45 billion total GVA, 2019).

21 European Dredging Association, EuDA Annual Report 2024 (2024), 6–7.

1.3 OPERATIONAL PROFILE

The operating profile of offshore vessels is defined by station-keeping, harsh-weather exposure, mission equipment and proximity to offshore energy, port and subsea critical infrastructure. Unlike cargo and passenger ships, whose design is usually governed by range, payload and voyage speed, offshore vessels are designed to perform specialised work at sea. Dynamic positioning, heave compensation, towing, high bollard pull, heavy lift, cable tensioning, trenching and dredge-pump operation create high installed-power requirements, rapid load transients and stringent redundancy needs.[22]

Power demand varies significantly across vessel families. Service and supply vessels combine transit with moderate-load dynamic-positioning standby. Tugs combine short, very high bollard-pull peaks with long periods of low-load standby. Construction and installation vessels require high peak power during lifting, jacking, positioning and subsea operations. Cable-laying and cable-repair vessels combine precise low-speed work with significant auxiliary loads for tensioning, storage, burial and protection systems. Dredgers require high sustained power during excavation, pumping, sailing and discharge. Across the segment, the common design challenge is therefore not average fuel consumption alone, but the ability to deliver safe, redundant and efficient power across highly variable duty cycles.

Two characteristics cut across all vessel families. First, harsh-weather exposure sets demanding requirements for reliability, structural response, motion compensation, crew safety and operational availability. Second, proximity to critical infrastructure raises the requirements for safety, cyber-physical protection, situational awareness and operational resilience. These requirements are becoming more demanding as offshore wind, floating energy systems, subsea interconnectors and other offshore assets move further from shore and into deeper and harsher environments. The historic assumption that offshore vessels can rely on frequent port calls, short transit distances and low-density energy carriers no longer applies across the fleet.

The energy transition for offshore vessels must therefore be duty-cycle- and distance-dependent rather than uniform. Nearshore service vessels, harbour tugs and selected port-based offshore support duties can move earlier towards battery-electric and hybrid-electric operation because they can return frequently to charging or bunkering points. Service operation vessels, platform supply vessels and anchor-handling units require hybrid and dual-fuel architectures that combine energy-efficiency, redundancy and operational flexibility. Cable, construction, dredging and far-field offshore vessels require higher-density fuels, fuel-cell or combustion-based sustainable-fuel systems, and resilient onboard energy architectures capable of supporting long endurance and mission-critical power demand.

The transition will consequently proceed through a work-mode/transit-mode split. Zero-emission operation at the field, in port, or during defined safety-critical work modes can be achieved earlier than full zero-emission operation across all transit and endurance requirements. This makes offshore vessels a practical market for staged deployment: energy-efficiency measures, digital energy management and hybridisation in the near term; zero-emission work modes and port-based and offshore charging or bunkering in the 2030s; scalable sustainable alternative fuels and fuel-cell systems for far-field operations through the 2040s; and integrated offshore vessel, energy and infrastructure systems by 2050.

1.4 SECTOR BASELINE AND MARKET CHARACTERISTICS

The European-controlled fleet is substantial and specialised. As of January 2026 it comprised 1,567 offshore vessels totalling 16.7 million gross tonnes,[23] alongside 549 dredgers totalling 2.0 million gross tonnes. Europe holds 24% of world offshore vessel capacity by gross tonnage and 37% of world dredger capacity.[24] The dredging industry estimates a working fleet of around 750 units once support vessels are included, and installs high-technology equipment even on older hulls.[25] Ownership is fragmented: 90% of the more than 4,000 shipping companies in the EU-27 and Norway control fewer than ten vessels.[26]

22 Waterborne Technology Platform, SRIA (2021), 32.
23 European Shipowners (ES|ECSA), The Economic Value of European Shipping (Brussels: ES|ECSA, 2026), 12 (data: Clarksons Research, status January 2026).
24 Ibid..
25 European Dredging Association, consultation (2026).
26 ES|ECSA, The Economic Value of European Shipping (2026), 4.

The fuel and power baseline remains diesel electric. Most vessels burn low-sulphur marine diesel oil and switch to marine gas oil in sulphur emission control areas, hydrotreated vegetable oil is used as a drop-in substitute, and hybrid battery systems are deployed cost-effectively. The most advanced announced design pairs 2 MW of hydrogen-fuelled PEM fuel cells with 5.5 MW of diesel engines for a zero-emission operating range of up to two weeks.[27]

The fleet ages slowly and renews through retrofit and the second-hand market as much as through newbuilding. Harbour tugs in wider Europe show an average age of around 25 years and a renewal rate of roughly 35 vessels a year, equivalent to about €311 million of annual investment, with building concentrated in Turkey, the Netherlands, the United Kingdom, Italy, Germany and Spain; a standard tug costs roughly €10–11 million against about €13 million for an LNG or hybrid tug.[28] European vessels leaving the fleet are frequently sold for continued operation on other continents, and tug building, once European-led, is now strongly contested by Turkish and other non-EU builders, while Europe retains clear leadership in dredgers and in the most complex cable and construction vessels.[29]

1.5 OFFSHORE AS A EUROPEAN TECHNOLOGY-LEADERSHIP OPPORTUNITY

Offshore vessels offer one of Europe's strongest demonstration arenas for zero-emission, digitally enabled and mission-critical waterborne technologies. The segment combines European industrial capability, high technical complexity and operational diversity. Many offshore vessels are still designed, built, equipped or upgraded within European maritime value chains, and their duty cycles range from nearshore, port-connected operations to far-field, high-endurance missions. This makes the sector well suited for first-of-a-kind deployment of fuel-cell, battery-electric, alternative fuel hybrid and digitally optimized energy systems, before these technologies are transferred to larger-volume maritime segments.[30]

The segment also matches the type of high-value, low-volume specialised market prioritised by the EU Industrial Maritime Strategy for concentrated European industrial effort. Its most complex vessel types, including cable-laying, offshore construction, dredging and offshore towage vessels, are not only commercial assets. They are also part of the industrial and operational base needed for offshore renewable energy, subsea infrastructure protection, coastal resilience, emergency response and dual-use preparedness. In this sense, offshore vessels are directly linked to European strategic autonomy.

Sustaining this leadership requires deliberate RD&I, demonstration, procurement and fleet-renewal investment. European strength in specialized offshore vessels cannot be assumed to continue automatically. The loss of wind turbine installation vessel building to non-European competitors shows that leadership in complex maritime technologies can erode when industrial investment, market demand, certification pathways and deployment support are not aligned.[31]

27 Waterborne Technology Platform, SRIA (2021), 32.
28 Ecorys, Economic Impact of the European Towage Sector (2019), 11, 18–20 (average fleet age 25 years; ~35 newbuilds and ~€311 million investment per year; standard tug €10–11 million, LNG or hybrid tug ~€13 million).
29 European Tugowners Association, consultation (2026); ES|ECSA, The Economic Value of European Shipping (2026), 12.
30 Waterborne Technology Platform, SRIA (2021), 32.
31 European Commission, EU Industrial Maritime Strategy (2026), 3.

2. DRIVERS AND CONSTRAINTS

2. DRIVERS AND CONSTRAINTS

2.1 DRIVERS

- **Regulatory drivers.** The EU climate framework is now reaching offshore vessels and is becoming a strong near-term driver of monitoring, reporting, fleet renewal and technology deployment. From 1 January 2025 offshore ships of 400 GT and above are required to monitor, report and verify their greenhouse gas emissions under the revised MRV Regulation; from 1 January 2027 offshore ships above 5,000 GT enter the EU Emissions Trading System; and FuelEU Maritime, which applies from 1 January 2025 to ships above 5,000 GT within its defined scope, strengthens the wider market signal for renewable and low-carbon marine fuels, while the Alternative Fuels Infrastructure Regulation (AFIR) mandates shore-side electricity for container and passenger ships but not specifically for offshore vessels.[32] These instruments do not affect all offshore vessel families equally: the largest construction, cable-laying, supply and service vessels are more directly exposed, while parts of the towage and smaller offshore support fleet remain below pricing thresholds.[33] A proposal of the European Commission to revise the EU ETS Directive would extend obligations to offshore worksites directly and reserve dedicated allowances for smaller vessels transitioning to zero-emission propulsion, though this remains subject to co-decision.[34] The result is a differentiated but increasingly clear demand signal for propulsion, energy-efficiency, monitoring, certification and compliance solutions. Furthermore, (inter)national regulatory drivers will influence the offshore sector, like UK ETS, which will start on 1 January 2027 for offshore ships, and the upcoming IMO Net-Zero Framework.[35][36]
- **Offshore-energy demand.** Offshore wind is the dominant demand driver and sets the workload for installation, cabling, service and maintenance vessels. EU-27 offshore wind capacity reached 21 GW at the end of 2024, within a European total of 37 GW, with 2.6 GW of new offshore capacity connected during 2024.[37] Demand is also moving into more complex operating environments. Larger wind farms, deeper sites, floating offshore wind, longer export-cable routes and more distant interconnectors increase transit distance, time on station, installation complexity and maintenance intensity. From the 2030s, export cable and interconnector projects will also require more capable landfall, burial, repair and protection solutions in shallow, ultra-shallow and intertidal zones where conventional barges, anchor spreads and land-based equipment are often constraint. The commercial deployment of floating offshore wind is expected to become an additional source of demand for specialised offshore vessels. Unlike fixed-bottom projects, floating wind farms require activities such as mooring installation, anchor handling, towing operations and dynamic cable deployment, increasing the need for offshore construction vessels, anchor-handling vessels, cable-laying vessels and specialised support units. As floating projects expand into deeper waters and more remote locations, they are expected to further reinforce demand for advanced offshore capabilities and services. This demand drives innovation in propulsion, dynamic positioning, mission equipment, automation, cable handling, digital planning and offshore logistics integration.

32 Regulation (EU) 2015/757, as amended by Regulation (EU) 2023/957 (MRV), offshore ships of 400 GT and above from 1 January 2025; Directive (EU) 2023/959 (EU ETS), offshore ships above 5,000 GT from 1 January 2027; Regulation (EU) 2023/1805 (FuelEU Maritime), ships above 5,000 GT from 1 January 2025; Regulation (EU) 2023/1804 (AFIR).

33 European Tugowners Association, consultation (2026).

34 European Commission, proposal for a Directive amending Directive 2003/87/EC and Decision (EU) 2015/1814 as regards driving competitiveness and cost-effective decarbonisation, COM(2026) 616 final, 17 July 2026, Article 1(2)(e), Article 1(4), Article 1(5).

35 UK Emissions Trading Scheme (Maritime) Order 2026; International Maritime Organization, MEPC 83 (April 2025) and extraordinary session (October 2025), adoption postponed to October 2026.

36 The Greenhouse Gas Emissions Trading Scheme (Amendment) (Extension to Maritime Activities) Order 2026, SI 2026/392, https://www.legislation.gov.uk/ukdsi/2026/9780348278279; International Maritime Organization, "Marine Environment Protection Committee, 83rd Session (MEPC 83)," 7–11 April 2025, https://www.imo.org/en/mediacentre/meetingsummaries/pages/mepc-83rd-session.aspx; International Maritime Organization, "IMO Net-Zero Shipping Talks to Resume in 2026," 17 October 2025, https://www.imo.org/en/mediacentre/pressbriefings/pages/imo-net-zero-shipping-talks-to-resume-in-2026.aspx.

37 WindEurope, Wind Energy in Europe: 2024 Statistics (2025),32-37; International Energy Agency, Energy Technology Perspectives 2026 (2026), 145.

- **Offshore renewable energy integration requirements**. The European Grean Deal targets and the EU strategy on offshore renewable energy[38] requires offshore vessels to integrate with offshore energy systems. Vessel-to-infrastructure energy exchange, charging infrastructure at remote installations, and energy optimisation across offshore ecosystems become deployment conditions.
- **Coastal resilience and counter-cyclical demand.** Dredging demand is structurally resilient and weakly correlated with economic cycles, because it is linked to port maintenance, navigation-channel depth, land reclamation, coastal protection and adaptation to sea-level rise and flooding.[39] Climate adaptation, port expansion, offshore foundation preparation and beach nourishment create continuing demand for specialised dredging and reclamation vessels. Decommissioning of ageing oil and gas infrastructure adds a further counter-cyclical workload for construction, lifting, subsea support and specialised offshore service vessels.
- **Climate change resilience and extreme weather adaptation.** The EU Adaptation Strategy[40] brings emerging requirements for resilience to extreme weather and changing ocean conditions. As a result, offshore operations move into deeper waters, harsher environments, and polar regions, where vessel systems must maintain functionality under extreme conditions (high waves, ice, temperature extremes).
- **Critical-infrastructure protection and dual use.** Offshore vessels have become instruments of strategic autonomy. Subsea communication cables, electricity interconnectors, offshore energy assets and pipelines require dedicated installation, inspection, maintenance, repair and protection capability. This is reflected in the EU Action Plan on Cable Security, the European Preparedness Union Strategy and the EU Industrial Maritime Strategy measures on maritime domain awareness, subsea infrastructure and cable security.[41] Cable-laying, cable-repair, survey, construction, dredging, towage and offshore support vessels have a strategic function beyond their commercial role. Large dredgers and specialized offshore vessels also have a dual-use relevance for emergency response, coastal resilience, military mobility, seabed intervention and critical infrastructure protection, reinforcing the case for retaining European capability.[42]
- **Emerging integrated surface-underwater operational ecosystem.** The maturation of autonomous underwater systems to inspect, monitor, maintain and protect subsea infrastructure is gradually shifting from episodic vessel-based intervention towards persistent underwater operations. This creates demand for offshore vessels capable of deploying and coordinating AUVs, ROVs, USVs, aerial drones, seabed sensor networks and underwater docking or charging systems.

38 European Commission, "Offshore Renewable Energy," Directorate-General for Energy (Brussels: European Commission). https://energy.ec.europa.eu/topics/renewable-energy/offshore-renewable-energy_en

39 European Dredging Association, EuDA Annual Report 2024 (2024), 6–7; European Dredging Association, consultation (2026).

40 European Commission, "EU Strategy on Adaptation to Climate Change" (Brussels: European Commission). https://climate.ec.europa.eu/areas-action/adaptation-and-resilience-climate-change/eu-adaptation-strategy_en

41 European Commission, European Preparedness Union Strategy (2025), 12–14; European Commission, EU Industrial Maritime Strategy (2026), 10, 13–14.

42 European Commission, EU Industrial Maritime Strategy (2026), 10.

- **Industrial competitiveness and sovereignty.** The EU Industrial Maritime Strategy and the EU Ports Strategy, both adopted in March 2026, create a supply-side driver for the offshore vessel segment. The Industrial Maritime Strategy focuses on strengthening Europe's "Build, Equip and Repair" capability, reinforcing maritime manufacturing and technological leadership, and examining an EU framework for the mutual recognition of offshore service and industrial vessels. The Ports Strategy recognises that offshore wind and floating installations require larger and reinforced port facilities for assembly, storage and deployment.[43] Together, these strategies connect offshore vessel innovation to European shipbuilding, maritime equipment, ports, offshore energy deployment and strategic autonomy. They also underline the need to prevent further erosion of European leadership in specialised vessel types.
- **Systemic weight and safety-criticality of towage.** Towage is a systemically important and safety-critical service whose decarbonisation cannot reduce operational availability, emergency response capability or port safety. Harbour towage assists a large share of cargo movements through Europe's major ports, operates around the clock and supports port continuity, navigational safety and resilience during abnormal or emergency conditions. This makes towage a specific driver for high-power hybridisation, alternative fuel readiness, batter peak-shaving, shore charging, operational optimisation and robust safety standards.
- **Operational availability, charter requirements and resilience of critical offshore energy infrastructure.** Offshore vessel downtime can interrupt construction, maintenance, energy production, cable repair and emergency support. Verified safety, redundancy and recoverability can improve charterability, insurability and access to projects, particularly for vessels supporting offshore wind and critical subsea infrastructure. Expansion of remote operation, dynamic positioning, batteries and sustainable alternative fuels creates additional demand for validated safety and cyber-physical resilience.
- **Supply chain and energy sovereignty.** The offshore sector plays a key role in ensuring supply chain and energy sovereignty, more specifically in the area of renewable energies.
- **Strategic autonomy and dual-use preparedness.** The EU preparedness union strategy[44] and industrial policies emphasize the importance of critical infrastructure protection and dual-use vessel capabilities. Offshore vessels support subsea cable protection, emergency response, and rapid offshore deployment capability.

2.2 CONSTRAINTS AND BOTTLENECKS

- **Peak and transient power.** The binding technical constraint is peak and transient power, not average consumption. Dynamic positioning, bollard pull, heavy compensation and cutter or dredge-pump operation demand high installed power and rapid load transients, and energy storage must be sized for these peaks rather than for mean load.

43 European Commission, EU Industrial Maritime Strategy (2026), 3, 10; European Commission, EU Ports Strategy (Brussels, 4 March 2026).

44 https://commission.europa.eu/topics/preparedness_en

- **Rapid load transients.** Rapid load transients present unique electrical system challenges. Bollard-pull transients in tugs, dynamic positioning load shifts during station-keeping near installations, and offshore lift transients create voltage transients, harmonic distortion, and frequency instability in hybrid and electrified systems. Energy storage systems must respond in milliseconds to transients, yet current battery management systems and power electronics cannot reliably handle repeated extreme transients in harsh offshore environments over 20 – 30-year vessel lifespans. This creates technical and economic barriers to hybridization.
- **Worksite fuel and energy availability and bunkering.** Fuel logistics constrain deployment as much as vessel technology. Bunkering hydrogen, ammonia or methanol at far-from-shore worksites and offshore charging are undeveloped, so nearshore duties that allow frequent refuelling favour battery-electric solutions while far-field duties depend on onboard generation, high-density carriers or dedicated supply vessels.[45] Port electrification, grid capacity, shore-power connections and charging systems remain unevenly deployed across European ports.
- **Offshore energy infrastructure interface standardisation.** Offshore wind farms, floating energy systems, and subsea infrastructure currently lack standardised vessel-to-infrastructure electrical interfaces. Vessels approaching floating platforms or offshore substations for charging require plug-and-play connection standards (voltage, frequency, power factor, protection coordination), yet no such standards exist. Each offshore project design custom interfaces, creating integration costs and deployment delays. Without standardised interfaces, offshore energy integration remains project-specific and prevents scalable deployment of vessel charging.
- **Remote operation and situational awareness infrastructure gaps.** Remote operation of offshore vessels requires real-time communication, global positioning, environmental data, and vessel situational awareness at bandwidth and latency specifications not currently available offshore. Satellite communication provides global coverage but insufficient bandwidth and latency (0.5-2 seconds delays) for precision docking, dynamic positioning under waves, or emergency response. Terrestrial systems (5G, LTE) provide better latency, but coverage is limited to nearshore. Until communication infrastructure is upgraded, remote operation remains limited to low-speed, non-time-critical operations.
- **Battery thermal management in harsh environments.** Lithium-ion and other battery chemistries exhibit degraded performance at temperature extremes (Arctic operations (<-20°C), tropical operations (>40°C) and salt-spray environments). Thermal management systems (heating, cooling, environmental protection) add significant weight, cost and complexity. Current systems have not been validated for 20 – 30-year continuous operation offshore with acceptable maintenance requirements. Battery durability, state-of-health estimation, and thermal safety in harsh environments remain open technical challenges.
- **Quay load-bearing capacity and ashore storage area at marshalling ports.** Currently the quay load-bearing capacity and ashore storage area at marshalling ports is insufficient at many European ports for next-generation turbine components (turbines above 15 MW).

45 Waterborne Technology Platform, SRIA (2021), 32.

- **Fleet age, heterogeneity and retrofit economics.** The fleet is heterogeneous, long-lived and renews slowly, which makes retrofit as important as newbuilding. Harbour tugs in wider Europe show an average age of around 25 years and a renewal rate of roughly 35 vessels a year, and offshore and dredging vessels are frequently bespoke with thin secondary markets.[46] Retrofitability, modularity and lifecycle-cost reduction are therefore decisive.
- **Vessel-to-underwater-system integration.** The future readiness of offshore vessels increasingly depends on mission-system interfaces including motion-compensated launch and recovery systems, reconfigurable mission decks, onboard AUV/ROV maintenance and charging facilities, underwater communication systems, multi-domain mission-control architectures and software platforms coordinating underwater, surface, aerial and shore-based assets.
- **Standardised modular mission interfaces.** Many offshore vessels continue to be bespoke and mission-specific, which limits serialisation, slows reconfiguration, increases engineering costs and complicates certification. Standardised interfaces would support the transition towards configurable platform families and more scalable deployment models.
- **Modular propulsion system certification and logistics.** Modular propulsion systems (swappable fuel-cell modules, detachable battery packs, dual-fuel engine modules) offer operation flexibility but require certification for each modular combination and configuration. Classification societies have no established procedures for type approving modular systems that can be reconfigured across vessel types and power architectures. Permitting flexible reconfiguration of certified modular systems requires regulatory innovation beyond current prescriptive rules, creating uncertainty for equipment manufacturers and delaying deployment of modular solutions.
- **Industrial build-share erosion and the cost gap.** European leadership is concentrated in the most complex vessel types and is not secure. Europe has lost wind turbine installation vessel building to China and faces strong competition in tug building from Turkish and other non-EU yards, and a green newbuild carries a clear cost penalty: a standard tug costs roughly €10–11 million against about €13 million for an LNG or hybrid tug, and consultation evidence puts the premium for an alternative-fuel vessel at one-third to one-half over a conventional diesel equivalent.[47]
- **Thin margins, fragmented ownership and the financing gap.** The segment combines margins with fragmented ownership and capital-intensive assets. Harbour towage operates at an average profit margin of about 8%, and 90% of the more than 4,000 shipping companies in the EU-27 and Norway control fewer than ten vessels, while there are no financial instruments specific to the segment.[48]
- **Safety and regulatory readiness.** Safety frameworks lag technology. Offshore handling of hydrogen, ammonia and methanol near structures, battery fire risk, high-power charging during dynamic positioning, and autonomous operation all require updated safety cases and certification, and national approval regimes remain fragmented; the European Commission will examine mutual recognition of offshore service and industrial vessels, while concerns persist over the market-access provisions of the Port Services Regulation.[49]

46 Ecorys, Economic Impact of the European Towage Sector (2019), 11; European Tugowners Association, consultation (2026).

47 European Commission, EU Industrial Maritime Strategy (2026), 3; Ecorys, Economic Impact of the European Towage Sector (2019), 20; European Tugowners Association, consultation (2026).

48 Ecorys, Economic Impact of the European Towage Sector (2019), 15; ES|ECSA, The Economic Value of European Shipping (2026), 4.

49 European Commission, EU Industrial Maritime Strategy (2026), 10; European Maritime Safety Agency, Safety Analysis 2025 (Lisbon: EMSA, 2025); Regulation (EU) 2017/352 (Port Services Regulation).

- **Regulatory design mismatch.** The EU climate instruments are designed for transport shipping and map imperfectly onto offshore duty cycles. They are voyage- and port-call-based, whereas offshore vessels consume most of their energy on station rather than between ports, and the 400 GT, 500 GT and 5,000 GT thresholds split the towage market and leave many smaller offshore vessels inside monitoring but outside pricing.[50] A proposal of the European Commission to revise the EU ETS Directive would address this directly by treating the offshore worksite itself as a qualifying port of call and by reserving allowances to bridge vessels between 400 and 5,000 GT into zero-emission propulsion, though the mismatch persists under current law and the proposal remains subject to co-decision.[51]
- **Critical-infrastructure vulnerability and export controls.** Cable, construction and survey vessels are strategic assets exposed to cyber and physical risk, with limited redundancy and surveillance capability relative to the value of the infrastructure they protect, and the dual-use status of large dredgers is mirrored by export controls that complicate fleet supply.[52]
- **Digital fragmentation and interoperability.** Interoperability across vessels, asset-owner and operator systems is limited, which holds back the connected operations that efficiency and automation require. Data exchange between vessels, offshore installations and shore control centres remains largely project specific.[53]
- **Limited representative validation under offshore operating conditions.** Motion, weather, remote access and delayed external response affect safety performance. Vessel, offshore installation and remote-centre risks are often assessed separately. Loss of power, position or communications can combine with fire or hazardous release. Full-scale testing across these interfaces is costly and not widely available.
- **Skills availability and workforce shortages are cross-cutting constraints.** The safe deployment of new fuels, electrification, digital systems, automation and remote operations depends on the availability of suitably trained crews, shore operators, port personnel, emergency responders, inspectors and maintenance teams[54]. Automation, remote technical support and digital decision-support tools can improve safety, reduce workload and make offshore operations more attractive for future generations of maritime professionals. Skills gaps may slow deployment or increase operational risk. Training systems, competence standards and certification requirements will need to evolve in parallel with fleet and infrastructure renewal, while human-centered design will be necessary to ensure that digital and automated systems support rather than overburden crews and shore-based operators.

50 Directive (EU) 2023/959; Regulation (EU) 2023/1805, Article 2 (scope); European Tug owners Association, consultation (2026).

51 European Commission, COM(2026) 616 final, Article 1(2)(e) (amending Article 3, point (z)) and Article 1(4) (amending Article 3ga).

52 European Commission, European Preparedness Union Strategy (2025); European Dredging Association, consultation (2026).

53 Waterborne Technology Platform, Waterborne Technology Leadership (2026), section 3.3; European Tug owners Association, consultation (2026).

54 European Tug owners Association, consultation (2026); European Maritime Safety Agency, Safety Analysis 2025 (2025).

3. TARGET CAPABILITIES

3. TARGET CAPABILITIES

The capabilities are stated across three horizons. Five domains recur within each, carrying the objectives they serve: **propulsion and energy; safety, security and resilience; connected, automated and data-driven operations; human-centred operations and workforce; and regulation and system-level integration.**[55] The horizons build on a current baseline of cost-effective hybrid-battery systems, zero-emission at-field operation with conventional transit, and maturing digital twins and predictive maintenance, with European leadership concentrated in the most complex vessel types.[56]

3.1 CURRENT STATE-OF-PLAY AND ACHIEVED DEVELOPMENTS

Technology readiness varies significantly across the offshore vessel segment and is therefore a central consideration for roadmap sequencing. Hybrid-battery systems, digital energy management, dynamic-positioning optimisation, predictive maintenance and drop-in renewable fuels are already deployable in selected applications. Methanol-capable engines, fuel-cell hybrids, shore and offshore charging concepts, remote support systems and digital twins are moving from demonstration to early commercial deployment. Full zero-emission far-field operation, offshore bunkering of new fuels, high-power charging during mission operations, autonomous dynamic-positioning functions and harmonised certification of alternative-fuel offshore vessels still require targeted RD&I, demonstration and regulatory development. The roadmap therefore distinguishes between solutions that can be deployed immediately, solutions that must be scaled through the 2030s, and solutions that require coordinated research, infrastructure and regulatory action before full commercial deployment.

3.2 BY 2035 — EARLY DEPLOYMENT

Propulsion and energy: Hybrid and zero-emission propulsion will be scaled across offshore segments. Zero-emission work mode will be standard on service vessels; battery-electric systems will serve low-energy duties such as service and crew transfer, while offshore wind farms, offshore charging and sustainable alternative fuel systems serve energy-intensive duties such as anchor-handling and heavy construction. Hybridization will be retained for dynamic-positioning redundancy, dual-fuel systems provide flexibility under fuel-supply constraints, and integrated DC grids, advanced energy management and hydrodynamic energy-saving devices reduce demand.[57] Integrated load management systems coordinating propulsion, dynamic positioning, mission equipment and hotel loads to minimize peak instantaneous power demands. Peak power optimization reducing peak demand through load shifting, sequencing, and demand scheduling, while maintaining mission-critical power availability and operational safety. Redundant electrical architectures with automated fault isolation and graceful degradation maintaining mission-critical power during single-point electrical failures. Standardized electrical interfaces (voltage, frequency, protection protocols) for vessel-to offshore-infrastructure connections, enabling plug-and-play charging at offshore wind farms and subsea installations. Common connector standards and power-quality specifications across European offshore operations.

55 Waterborne Technology Platform, Waterborne Technology Leadership (Brussels, 2026), section 3.4; capability domains aligned with Chapter 4 (Technology Pathways); vessel-only boundary per Chapter 1.1.
56 Waterborne Technology Platform, SRIA (2021), 32; European Commission, EU Industrial Maritime Strategy (2026), 3.
57 Waterborne Technology Platform, Waterborne Technology Leadership (2026), section 3.4; Waterborne Technology Platform, SRIA (2021), 32.

Safety, security and resilience: Advanced situational awareness will integrate environmental, vessel and offshore-installation data; predictive maintenance will reduce operational risk and downtime; and cyber-secure systems will protect mission-critical offshore operations.[58] Fire, gas and battery detection are validated under motion and harsh conditions. A safe fallback for loss of power, position and communications in place. Certified cybersecurity frameworks for mission-critical offshore vessel systems, meeting NIS2 Directive requirements and IMO cyber-security guidelines. End-to-end encryption, zero trust architecture, and continuous threat monitoring across vessel, communication, and offshore infrastructure interfaces.

Connected, automated and data-driven operations: Connected, partly remote-operated fleets will exchange real-time data with offshore installations and shore control centres; operational optimisation will reduce energy consumption; low-complexity functions such as inspection and light construction will operate autonomously; and digital twins will support mission planning.[59] Selected offshore vessels will be capable of deploying, recovering and supporting AUVs, ROVs and autonomous surface assets for inspection, monitoring and survey missions, including onboard maintenance, charging and mission-control functions.

Human-centred operations and workforce. Decision-support systems will assist crews during complex operations, simulation and extended-reality environments support mission preparation, and remote-operation-centre concepts will support selected offshore missions.[60]

Regulation and system-level integration. Regulatory pathways will enable certification of alternative-fuel offshore vessels, and regulatory sandboxes support pilot projects for autonomous offshore operations.[61]

3.3 BY 2040 — SCALE-UP

Propulsion and energy. Fuel-cell and sustainable alternative fuel propulsion will be in commercial, scaled deployment across segments. Vessels will integrate with offshore and onshore energy systems through charging, bunkering and energy exchange, and technology-neutral pathways will be adapted to mission and power demand.[62] Predictive load scheduling integrating 24-hours weather forecasts, mission profiles, energy availability, and offshore infrastructure status to pre-optimize power distribution and energy storage state across entire mission sequence. Coordinated multi-vessel scheduling reducing fleet-level power demand peaks. Self-healing electrical systems capable of isolating faulted sections, re-routing power, and maintaining critical functions during cascade failures or cyber incidents. Microgrids onboard supporting energy storage, fuel-cell integration, and emergency modes. Interoperable energy-management protocols enabling coordinated energy scheduling between multiple vessels, offshore infrastructure, and onshore grids. Standardized digital interfaces for energy data exchange and predictive energy balancing."

58 Waterborne Technology Platform, Waterborne Technology Leadership (2026), section 3.4; European Commission, EU Industrial Maritime Strategy (2026), 10; European Commission, European Preparedness Union Strategy (2025).
59 Waterborne Technology Platform, Waterborne Technology Leadership (2026), section 3.4.4; European Maritime Safety Agency, Safety Analysis 2025 (Lisbon: EMSA, 2025).
60 Waterborne Technology Platform, Waterborne Technology Leadership (2026), section 3.4.
61 European Commission, EU Industrial Maritime Strategy (2026), 10; Chapter 4, section 4.5.
62 Waterborne Technology Platform, Waterborne Technology Leadership (2026), sections 3.4.4–3.4.5.

Safety, security and resilience. Safety systems will predict operational risk during complex missions, autonomous incident-response systems will assist crews in high-risk scenarios, and cyber-resilient operational architectures will support autonomous functions and secure communication. Integrated suppression and remote coordinated emergency response and digital safety twins for vessel-installation operations in place. Predictive models for compound weather, cyber and technical failures in place. Autonomous threat detection and response systems capable of identifying and isolating cyber incidents without human intervention while maintaining operational continuity. Resilient communication architecture surviving partial network disruption or communication jamming.

Connected, automated and data-driven operations. Offshore missions will be monitored and supported from shore-based control centres, autonomous functions will cover repetitive logistics, inspection and monitoring, digital twins will support predictive maintenance across vessels and infrastructure, and automated launch-and-recovery and integrated logistics platforms will be in use. Offshore vessels will be capable of coordinating heterogeneous mission assets including AUVs, ROVs, USVs, aerial drones, seabed sensors and shore-control centres.

Human-centred operations and workforce. Advanced human-machine teaming will support planning, safety monitoring and maintenance, shore-based specialist support will be integrated into operations, and standardised human-centred design applies across vessel systems.

Regulation and system-level integration. International standards will govern zero-emission offshore vessel operations and energy systems, and integrated planning frameworks coordinate offshore energy infrastructure and maritime logistics.

3.4 BY 2050 — FULL TRANSFORMATION

Propulsion and energy. The fleet will be fully zero-emission. Zero-emission propulsion will be standardised, modular and scalable across vessel categories, and vessels interact dynamically with offshore renewable infrastructure for energy supply and optimisation. High-capacity charging solutions will be available both in ports and at sea in offshore power zones. Fully integrated offshore energy ecosystem with vessels operating as active grid participants providing demand response, peak shaving, and frequency support to offshore renewable installations. Autonomous energy orchestration across multiple vessels and infrastructure reducing lifecycle energy demand. Fully resilient electrical architectures with heterogeneous energy sources, distributed control, and autonomous recovery from extreme incidents. Fully integrated offshore energy networks with standardized protocols for energy commodity trading, demand response, and energy optimization across vessels, infrastructure, and renewable sources.

Safety, security and resilience. Fully integrated predictive safety ecosystems will link vessels, offshore infrastructure and shore control centres, enabling near-zero-incident operations, and reliable European-controlled communication, satellite and positioning infrastructure underpins secure operation throughout.[63] Quantum-resistant cryptography and AI-enabled anomaly detection providing continuous cybersecurity assurance across entire offshore vessel fleet and critical infrastructure.

63 European Commission, EU Industrial Maritime Strategy (2026), 13.

Connected, automated and data-driven operations. Fully connected offshore energy-logistics systems will coordinate vessels, installations and energy infrastructure, autonomous logistics will operate for selected mission types, and highly automated vessels will operate with minimal intervention in defined areas. Offshore vessels will operate as components of surface-underwater operational ecosystems. Continuous assurance and adaptive recovery with human oversight established.

Human-centred operations and workforce. Highly automated operations will run under human oversight supported by advanced decision support, integrated digital workforce ecosystems will combine training, operations and lifecycle support, and mature social-acceptance and ethics frameworks are in place.

Regulation and system-level integration. A fully harmonised regulatory ecosystem will support climate-neutral fleets and integrated offshore energy systems, and European frameworks and standards will be adopted globally.

3.5 CROSS-CUTTING CAPABILITY IMPLICATIONS

The pathway is differentiated by duty cycle and distance, not by a single trajectory: nearshore service vessels follow an electrification pathway, while far-field construction and cable vessels follow a high-density-fuel and fuel-cell pathway. Dynamic positioning and station-keeping, not range, are the defining design constraints across every domain. The vessel is treated throughout as a platform; the subsea systems, energy systems and floating infrastructure it deploys are specified in the Blue Economy roadmap, and the boundary is held so that the two roadmaps integrate without duplicating. The critical-infrastructure and dual-use dimension runs across all domains and horizons, because cable, construction and survey vessels are simultaneously commercial and strategic assets.[64]

64 Waterborne Technology Platform, SRIA (2021), 26, 32.

4. TECHNOLOGY PATHWAYS

4. TECHNOLOGY PATHWAYS

The technology pathways translate the target capabilities into research, development, innovation, upscaling and deployment priorities for offshore and specialised maritime work vessels.

4.1 FUTURE PROPULSION AND ENERGY SYSTEMS ENABLING A ZERO-EMISSION OFFSHORE FLEET

Objective: Enable scalable, safe and efficient zero-emission propulsion and energy systems for offshore vessels. This includes complementary technology pathways such as batteries, fuel cells and sustainable alternative fuels, including hydrogen, ammonia and methanol, to decarbonize offshore vessel operations across work, transit, standby and port modes and to support integration with offshore energy systems. Solutions must reflect the diversity of offshore vessel segments, power profiles, endurance needs and mission requirements.

Target capability:

Horizon	Target capability	Expected readiness
2035	Scaled deployment of hybrid and zero-emission propulsion systems across offshore vessel segments, building on current hybrid solutions and expanding zero-emission capabilities across operational profiles.	TRL 8-9
	Hybridisation and resilient electrical architectures maintained in relevant vessel segments to ensure operational redundancy, safety and continuity during mission-critical offshore operations and dynamic positioning.	TRL 8-9
	Sustainable alternative fuel propulsion systems for energy-intensive operations such as anchor-handling and heavy construction, and battery-electric propulsion systems for less energy-intensive operations such as service and crew-transfer duties, enabling technology differentiation based on power demand and mission profile.	TRL 8-9
	Commercial dual-fuel systems enabling use of sustainable alternative fuels when available, providing flexibility under fuel availability constraints.	TRL 8-9

Table 2: Target capabilities "future propulsion and energy systems enabling a zero-emission offshore fleet"

Horizon	Target capability	Expected readiness
2035	Widespread use of battery systems and hybrid architectures for battery-prioritised propulsion, redundant manoeuvring, peak shaving and energy optimisation, expanding beyond current partial electrification.	TRL 9
	Initial deployment of fuel-cell and sustainable alternative fuel solutions in offshore vessel segments, moving beyond pilot projects and early demonstrations.	TRL 6-8
	Retrofit solutions enabling dual-fuel and zero- or low-emission capabilities for existing vessels, addressing current barriers related to cost and technical integration.	TRL 7-8
	Increased use of unmanned and remotely operated vessels for subsea operations, reducing energy demand and reducing reliance on large, energy-intensive vessels.	TRL 7-8
	Deployment of integrated DC-grid and hybrid-energy systems enabling flexible combination of power sources and storage, building on current system-integration approaches.	TRL 8-9
	Advanced energy-management systems with high energy efficiency, optimising power dispatch across multiple energy sources and storage systems under dynamic load profiles and improving efficiency compared with current operational practices.	TRL 8-9
	Offshore vessel designs optimised for energy efficiency and reduced environmental impact, including reduced emissions to sea and lower overall energy demand compared with current operational baselines.	TRL 8-9
	Reduced energy demand for offshore vessel travel through development, validation and improvement of hydrodynamic energy-saving devices. No single energy-saving technology will significantly reduce travel energy consumption on its own, but combined energy-saving device packages can offer shipowners meaningful reductions in energy demand.	TRL 8-9

Table 2: Target capabilities "future propulsion and energy systems enabling a zero-emission offshore fleet"

Horizon	Target capability	Expected readiness
2040	Commercial and scaled deployment of fuel-cell and sustainable alternative fuel propulsion systems, including hydrogen, ammonia and methanol, across offshore vessel segments, moving from early adoption to widespread commercial use.	TRL 8-9
	Integration with offshore and onshore energy systems, including commercial charging, bunkering and energy exchange, enabling coordinated energy use across offshore energy infrastructure.	TRL 7-8
	Increased deployment of hybrid and low-emission unmanned vessels, reducing overall fleet energy demand and shifting towards more efficient fleet structures.	TRL 7-8
	Technology-neutral propulsion pathways deployed across offshore vessel categories, enabling adaptation to different missions, energy demands and operational environments.	TRL 8-9
2050	Fully zero-emission offshore fleet across European offshore energy operations.	TRL 9
	Standardised, modular and scalable zero-emission propulsion systems deployable across offshore vessel categories, enabling industrialised deployment and global competitiveness.	TRL 9
	Fully integrated offshore energy ecosystems where vessels interact dynamically with renewable-energy infrastructure for energy supply and optimisation, moving beyond isolated vessel operations to system-level integration.	TRL 9

Table 2: Target capabilities "future propulsion and energy systems enabling a zero-emission offshore fleet"

Key research gaps:

- Research on integrating scalable zero-emission propulsion systems, including batteries, fuel cells and sustainable alternative fuels, across all offshore operational modes, addressing current limitations in full-mission zero-emissions. (TRL 5-7 -> 7-9)
- Research on energy-storage technologies and power systems capable of handling variable and high-demand offshore operational profiles, improving performance under dynamic-load conditions. (TRL 5-7 -> 7-9)
- Research on storage, handling, onboard conversion where relevant, operations, monitoring and risk mitigation for fuels such as hydrogen, ammonia and methanol in offshore environments, where current solutions rely on limited operational experience. (TRL 5-7 -> 7-9)
- Research on operation, durability and reliability of fuel cells under representative offshore environmental and duty-cycle conditions, including vessel motion, vibration, air quality, marine exposure and extended operational cycles. (TRL 5-7 -> 7-9)
- Research on propulsion systems enabling multi-mission capability and adaptability across vessel types and operations, moving beyond vessel-specific designs. (TRL 5-7 -> 7-9)
- Research evaluating performance, safety, cost and operational suitability of different fuel and energy pathways, including testing and validation prior to large-scale deployment, supporting technology-neutral decision-making. (TRL 4-6 -> 7-8)
- Research on ship-design methods and tools that support optimisation for complex operational profiles and multiple design criteria, beyond current single-objective design approaches. (TRL 5-7 -> 7-9)
- Research on advanced energy-saving technologies, including drag reduction, efficient propulsion, energy harvesting and voyage optimisation, to reduce overall energy demand across offshore operations. (TRL 5-7 -> 7-9)
- Research on hydrodynamic hull-form optimisation and propulsor integration for offshore vessels operating under highly variable duty cycles, reducing baseline energy demand across vessel categories and operational profiles. (TRL 4-6 -> 7-9)
- Research on probabilistic extreme-load modelling, structural monitoring and vessel-response systems, supporting safe and efficient offshore operations under changing environmental conditions and future climate scenarios. (TRL 4-6 -> 7-9)
- Research, demonstration and standardisation of high-power charging and energy exchange in port and offshore environments, including high voltage safety, interoperability, connection systems and operation under marine conditions. (TRL 4-6 -> 7-9)

4.2 INTELLIGENT SAFETY, SECURITY AND RESILIENCE AS FOUNDATIONAL ENABLERS

Objective: Enable predictive safety systems and resilient offshore vessel operations capable of managing increasingly complex design architectures, complex missions, sustainable alternative fuel systems and increasingly digitalised operations under demanding environmental conditions. Solutions must support safe autonomous and remotely operated offshore functions, clear human responsibility and cyber-secure operations.

Target capability:

Horizon	Target capability	Expected readiness
2035	Advanced situational-awareness systems integrating environmental sensing, vessel systems and offshore-installation data, expanding beyond isolated monitoring systems.	TRL 7-8
	Advanced predictive-maintenance systems reducing operational risk and downtime, moving beyond scheduled and reactive maintenance approaches.	TRL 7-8
	Cyber-secure vessel systems protecting mission-critical offshore operations, addressing increasing digitalisation and cyber-risk exposure.	TRL 7-8
2040	Safety systems capable of predicting operational risks during complex offshore missions, building on current early-stage predictive tools.	TRL 7-8
	Independent autonomous incident-response systems assisting crews during high-risk operational scenarios, expanding beyond manual emergency-response procedures.	TRL 7-8
	Integrated cyber-resilient offshore operational architectures supporting autonomous functions, secure communication and resilient offshore operations.	TRL 7-8
2050	Fully integrated predictive safety ecosystems linking vessels, offshore infrastructure and shore control centres, enabling system-level safety management.	TRL 9
	Zero-incident offshore operations enabled through intelligent monitoring and automated risk mitigation, representing a shift from reactive to fully predictive safety systems.	TRL 9

Table 3: Target capabilities "Intelligent safety, security and resilience"

Key research gaps:

- AI-based decision-support systems for offshore operational safety, moving beyond current advisory systems towards predictive and autonomous support. (TRL 5-7 -> 7-9)
- Integration of environmental monitoring data into real-time vessel safety systems, addressing current fragmentation between data sources and operational systems. (TRL 5-7 -> 7-9)
- Safe handling, monitoring and emergency-response systems for sustainable alternative fuels in offshore environments, as current solutions rely on limited operational experience and case-specific assessments. (TRL 5-7 -> 7-9)
- Research on cybersecurity priorities for autonomous and remotely operated offshore vessels, addressing continuously evolving cyber threats. (TRL 5-7 -> 7-9)
- Research on responsibility, decision-making and liability in autonomous offshore operations, clarifying human, operator and system roles. (TRL 4-6 -> 7-8)
- Research on dual-use preparedness and resilience for offshore vessels operating near critical infrastructure. (TRL 4-6 -> 7-8)
- Research on goal-based safety frameworks for autonomous and remotely operated offshore systems, supporting certification beyond current prescriptive regulatory approaches. (TRL 4-6 -> 7-9)
- Research on Operational Design Domain definition and functional-equivalence methodologies for offshore autonomous functions operating under varying environmental and mission conditions. (TRL 4-6 -> 7-9)
- Research on maritime-domain-awareness systems supporting monitoring and protection of offshore energy infrastructure and other critical offshore assets. (TRL 5-7 -> 8-9)
- Research on resilient operational architectures combining vessel, infrastructure and logistics data to maintain operational continuity during cyber incidents, environmental disruptions and infrastructure failures. (TRL 5-7 -> 7-9)
- Representative scale validation of integrated detection, mitigation, safe fallback and emergency response systems under realistic offshore operating conditions, including compound failures and degraded communication, to generate robust safety and certification evidence. (TRL 4-6 -> 7-9)

4.3 FULLY CONNECTED, AUTOMATED AND DATA-DRIVEN OFFSHORE SYSTEMS

Objective: Enable fully integrated offshore mission systems where vessels, offshore installations and onshore control centres exchange operational data in real time to optimise logistics, maintenance, safety and energy use.

Target capability:

Horizon	Target capability	Expected readiness
2035	Connected and partly remote-operated offshore vessel fleets exchanging real-time operational data with offshore installations and shore control centres demonstrated in commercial context, moving beyond current pilot and project-based deployments.	TRL 7-8
	Operational-optimisation systems improving fleet coordination and reducing energy consumption demonstrated in commercial context, expanding beyond isolated optimisation tools.	TRL 7-8
	Autonomous operation of vessel systems with limited complexity, such as inspection, maintenance and light construction, demonstrated in commercial context, while more complex operations are piloted.	TRL 7-8
	Digital twins used as operational enablers for selected offshore vessels and mission planning.	TRL 7-8
2040	Remote operational capabilities enabling offshore missions to be monitored and supported from shore-based control centres, enabling more efficient and centralised operations.	TRL 7-8
	Autonomous vessel functions supporting repetitive offshore logistics, inspection and monitoring tasks, scaling beyond current demonstration projects.	TRL 7-8
	Digital twins supporting predictive maintenance and operational planning for vessels and offshore installations, integrating vessel and infrastructure data beyond current isolated applications.	TRL 7-8

Table 4: Target capabilities "Fully connected, automated and data-driven offshore systems"

Horizon	Target capability	Expected readiness
2040	Automated launch-and-recovery and system-interaction capabilities demonstrated for selected offshore missions.	TRL 7-8
	Autonomous maintenance and below-deck system monitoring supporting reduced manual intervention onboard.	TRL 7-8
	Integrated offshore logistics and operational-planning platforms enabling real-time coordination of vessels, offshore installations, maintenance activities and energy systems across offshore operations.	TRL 7-8
2050	Fully connected offshore energy-logistics systems coordinating vessels, installations and energy infrastructure.	TRL 9
	Autonomous offshore logistics operations deployed for selected mission types such as inspection, monitoring and cargo transfer.	TRL 8-9
	Highly automated offshore vessels capable of operating with minimal manual intervention in defined missions and operational areas.	TRL 8-9

Table 4: Target capabilities "Fully connected, automated and data-driven offshore systems"

Key research gaps:

- AI-supported fleet and mission optimisation for offshore logistics, moving beyond current rule-based and fragmented optimisation approaches. (TRL 5-7 -> 7-9)
- Autonomous navigation and operational systems adapted to complex offshore environments, addressing challenges related to safety, reliability and environmental conditions. (TRL 5-7 -> 7-9)
- Integrated digital systems enabling more complete and automated offshore maritime operations, overcoming current system fragmentation and enabling system-level optimisation. (TRL 5-7 -> 7-9)
- Research on vessel integrated deployment, recovery and coordination of autonomous and remotely operated assets, including interoperable mission-system interfaces, launch-and-recover systems, communication and positioning, onboard support functions and multi-asset mission management (TRL 5-7 -> 7-9)
- Research on what autonomous offshore systems can and cannot safely perform across navigation, maintenance, logistics and mission operations. (TRL 4-6 -> 7-8)
- Research on reliability, redundancy and fail-safe behaviour of autonomous and remotely operated offshore systems. (TRL 5-7 -> 7-9)
- Research on virtual testing, algorithm training and virtual prototyping for autonomous offshore operations. (TRL 4-6 -> 7-9)
- Research on automated maintenance and below-deck energy-system monitoring in vessels with reduced or no manual onboard operation. (TRL 5-7 -> 7-9)

4.4 HUMAN-CENTRED DESIGN AND A FUTURE-READY OFFSHORE WORKFORCE

Objective: Enable safe and effective human-machine collaboration in offshore operations through advanced decision support, training systems and ergonomic vessel design. Solutions must support social acceptance, ethical use of AI, remote-operation centres and competence development for increasingly automated offshore operations.

Target capability:

Horizon	Target capability	Expected readiness
2035	Decision-support systems assisting crew during complex offshore operations, moving beyond current manual and experience-based decision-making.	TRL 7-8
	Digital training environments using simulation and extended reality for offshore mission preparation, addressing current limitations in training for complex and high-risk operations.	TRL 7-8
	Remote-operation-centre concepts supporting selected offshore missions and shore-based operational support.	TRL 6-8
2040	Advanced human-machine teaming where AI systems support operational planning, safety monitoring and maintenance, enabling more efficient and safer offshore operations.	TRL 7-8
	Remote support from shore-based specialists integrated into offshore operations, expanding beyond current limited remote-support capabilities.	TRL 7-8
	Standardised human-centred design approaches supporting safer and more consistent interaction across offshore vessel systems.	TRL 7-8

Table 5: Target capabilities "Human-centred design and a future-ready offshore workforce"

Horizon	Target capability	Expected readiness
2050	Highly automated offshore vessel operations with human oversight supported by advanced decision-support systems.	TRL 9
	Integrated digital workforce ecosystems combining training, operations and lifecycle support.	TRL 9
	Mature social-acceptance and ethics frameworks for remote and autonomous offshore operations.	TRL 8-9

Table 5: Target capabilities "Human-centred design and a future-ready offshore workforce"

Key research gaps:

- Human-machine interaction design for high-risk offshore operations, addressing challenges related to safety, trust and usability. (TRL 5-7 -> 7-9)
- Training systems for complex hybrid and autonomous vessel systems, moving beyond current training methods towards immersive and continuous learning. (TRL 4-6 -> 7-9)
- Workload optimisation in increasingly automated offshore operations, addressing cognitive load, fatigue and human-performance limitations. (TRL 5-7 -> 7-9)
- Research on social acceptance, ethical implications and trust in remote and autonomous offshore operations. (TRL 4-6 -> 7-8)
- Research on remote-operation centres, including human oversight, decision authority, data needs and control-room design. (TRL 5-7 -> 7-9)
- Research on common human-centred design principles across offshore vessel systems and control interfaces. (TRL 5-7 -> 7-9)
- Research on crew comfort, motion exposure and seasickness in increasingly automated and remotely supported offshore operations. (TRL 4-6 -> 7-8)

4.5 FORWARD-LOOKING REGULATION, STANDARDISATION AND SYSTEM-LEVEL INTEGRATION

Objective: Enable harmonised regulatory frameworks that support large-scale deployment of zero-emission and digitally integrated offshore vessel operations. The objective is to move from case-by-case approval towards predictable certification, standardised interfaces, regulatory sandboxes and system-level planning that align vessels, ports, offshore energy infrastructure and digital systems.

Target capability:

Horizon	Target capability	Expected readiness
2035	Regulatory pathways enabling certification of sustainable alternative fuel offshore vessels, reducing reliance on case-by-case approvals and enabling more predictable deployment.	TRL 7-8
	Regulatory sandboxes supporting pilot projects for offshore autonomous operations, building on current limited testing environments.	TRL 6-8
2040	International standards for offshore zero-emission vessel operations and energy systems, replacing fragmented national and project-specific frameworks.	TRL 7-8
	Integrated planning frameworks for offshore energy infrastructure and maritime logistics, addressing current lack of coordination between vessel deployment and energy systems.	TRL 7-8
2050	Fully harmonised regulatory ecosystem supporting zero-emission offshore fleets and integrated offshore energy systems, enabling efficient and scalable deployment.	TRL 9
	Global adoption of European regulatory frameworks and standards for offshore vessel technologies, positioning Europe as a leader in offshore maritime innovation.	TRL 9

Table 6: Target capabilities "Forward-looking regulation, standardisation and system-level integration"

Key research gaps:

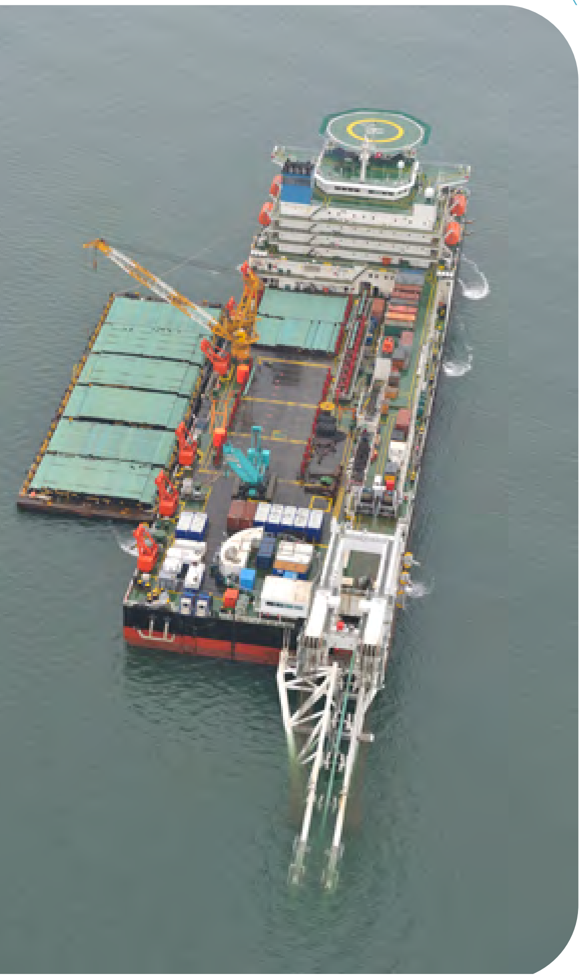
- Regulatory models for autonomous offshore vessel operations, addressing current regulatory uncertainty and enabling safe deployment. (TRL 4-6 -> 7-9)
- Standards for offshore energy exchange between vessels and infrastructure, supporting integration of offshore energy systems. (TRL 4-6 -> 7-8)
- Certification frameworks for modular propulsion and energy systems, addressing the current lack of standardised approaches and enabling scalable deployment. (TRL 5-7 -> 7-9)
- Standards and interoperability frameworks for vessel digital and mission system interfaces, supporting integration with autonomous and remotely operated assets, shore control centres and offshore infrastructure (TRL 4-6 -> 7-8)

Key research gaps:

- AI-based decision-support systems for offshore operational safety, moving beyond current advisory systems towards predictive and autonomous support. (TRL 5-7 -> 7-9)
- Integration of environmental monitoring data into real-time vessel safety systems, addressing current fragmentation between data sources and operational systems. (TRL 5-7 -> 7-9)
- Safe handling, monitoring and emergency-response systems for sustainable alternative fuels in offshore environments, as current solutions rely on limited operational experience and case-specific assessments. (TRL 5-7 -> 7-9)
- Research on cybersecurity priorities for autonomous and remotely operated offshore vessels, addressing continuously evolving cyber threats. (TRL 5-7 -> 7-9)
- Research on responsibility, decision-making and liability in autonomous offshore operations, clarifying human, operator and system roles. (TRL 4-6 -> 7-8)
- Research on dual-use preparedness and resilience for offshore vessels operating near critical infrastructure. (TRL 4-6 -> 7-8)
- Research on goal-based safety frameworks for autonomous and remotely operated offshore systems, supporting certification beyond current prescriptive regulatory approaches. (TRL 4-6 -> 7-9)
- Research on Operational Design Domain definition and functional-equivalence methodologies for offshore autonomous functions operating under varying environmental and mission conditions. (TRL 4-6 -> 7-9)
- Research on maritime-domain-awareness systems supporting monitoring and protection of offshore energy infrastructure and other critical offshore assets. (TRL 5-7 -> 8-9)
- Research on resilient operational architectures combining vessel, infrastructure and logistics data to maintain operational continuity during cyber incidents, environmental disruptions and infrastructure failures. (TRL 5-7 -> 7-9)
- Representative scale validation of integrated detection, mitigation, safe fallback and emergency response systems under realistic offshore operating conditions, including compound failures and degraded communication, to generate robust safety and certification evidence. (TRL 4-6 -> 7-9)

5. ENABLERS AND DEPLOYMENT

5. ENABLERS AND DEPLOYMENT



Deployment of the offshore vessel roadmap depends on coordinated action across energy infrastructure, vessel design, regulation, finance, digital systems, skills and procurement. Many relevant technologies and practices are already emerging through hybrid propulsion projects, battery systems, digital twins, predictive maintenance, shore-charging pilots, sustainable alternative fuel demonstrations, autonomous and remote-operation trials, and offshore wind logistics innovation.

5.1 ENERGY, BUNKERING AND CHARGING INFRASTRUCTURE

Zero-emission and low-emission offshore vessels require reliable access to electricity and sustainable alternative fuels where their missions take place. Deployment will depend on port-based electrification, high-capacity charging, offshore charging concepts and bunkering infrastructure for hydrogen, ammonia, methanol and other sustainable alternative fuels. These systems must be developed as part of a full energy value chain, from renewable energy production and storage to safe onboard use. Existing shore power and charging experience, port energy hub concepts and offshore power zones, hydrogen, ammonia and methanol demonstrations, and offshore renewable energy developments provide a basis for deployment. However, offshore vessels need infrastructure adapted to variable duty cycles, high power demand, long endurance and remote worksites. Standards for energy exchange between vessels, ports, offshore installations and energy infrastructure will be needed to support interoperable charging, bunkering, energy optimisation and future integration with offshore renewable assets. Common technical and safety standards will also be required for high-power electrical interfaces, connection systems and power quality where vessels exchange energy with port and offshore infrastructure.

5.2 VESSEL DESIGN, MODULARITY AND RETROFIT

Offshore vessels are heterogeneous, long-lived and mission specific. Deployment must therefore combine newbuild design with retrofit pathways. Hybrid propulsion, battery systems, energy management, dynamic positioning optimisation and energy saving devices are already available or demonstrated in several applications, but they must be integrated more systematically into offshore vessel design. Future vessel concepts should be modular, retrofit-ready and adaptable to different missions, vessel sizes and energy pathways, with standardised interfaces where appropriate for propulsion, mission equipment and autonomous or remotely operated systems. This will allow staged upgrades as fuels, safety cases, certification rules and infrastructure mature. Offshore vessel design must also combine energy efficiency, hydrodynamic performance, operational redundancy, climate resilience and mission equipment integration. Full-scale validation and cost-benefit evidence will be important to support investment decisions, especially for energy saving devices, next generation propulsion units and complex retrofit packages. Lifecycle design should also consider component reuse, refurbishment, recycling and end-of-life recovery, particularly for batteries, electrical systems and other material intensive technologies.

5.3 SAFETY, CERTIFICATION AND REGULATORY READINESS

Safety and certification are decisive deployment conditions. Offshore vessels operate near crews, ports, offshore energy assets and subsea critical infrastructure. Sustainable alternative fuels, large battery systems, high power charging, autonomous functions and remote operation require safety frameworks that move beyond case-by-case approval. Work already undertaken by class societies, technology providers, regulators and demonstration projects provides a starting point for fuel specific safety cases, battery safety, autonomous system assurance and digital certification. The next step is harmonisation. Standardised certification procedures are needed for sustainable alternative fuels, modular energy systems, autonomous functions, AI-enabled decision support and remote operations. Regulatory sandboxes, shared validation environments and representative offshore missions should be used to generate safety and performance evidence under realistic operating conditions, supporting certification and reducing reliance on project specific approval processes. Joint resilience exercises involving vessel operators, offshore asset operators, authorities and emergency response actors should also be used to test operational continuity and coordinated response under compound operational, environmental and cyber disruptions. International cooperation will also be necessary to reduce fragmentation across flag states, coastal states, classification societies and operating regions.

5.4 DIGITAL, COMMUNICATION AND AUTONOMY INFRASTRUCTURE

Digitalisation, automation, remote support and increasingly autonomous offshore operations require secure, reliable and interoperable communication and digital infrastructure. Offshore vessels need robust sensing, communication, positioning and cybersecurity systems that can function in harsh environments and support mission-critical operations. Existing work on digital twins, predictive maintenance, vessel optimisation, remote monitoring and autonomous trials provides an important foundation, but deployment remains fragmented across projects, operators and platforms. The priority is to move towards interoperable digital architectures linking vessels, autonomous and remotely operated assets, offshore installations, ports, shore control centres, logistics providers, energy infrastructure and wider offshore digital platforms. High-reliability communications, trusted positioning, cyber-secure data exchange, redundancy requirements and virtual testing environments will be essential. These systems must support not only efficiency and maintenance, but also safety, resilience, maritime domain awareness and critical-infrastructure protection.

5.5. INDUSTRIAL COORDINATION, FINANCE AND PROCUREMENT

Technology deployment will depend on coordinated investment across the offshore value chain. Vessel operators, shipyards, equipment manufacturers, offshore energy developers, ports, energy suppliers, classification societies, regulators and financiers must align vessel design, infrastructure planning, certification, procurement and operating requirements. Stable and predictable long-term policy and regulatory frameworks will be important to provide investment certainty and support coordinated fleet renewal, infrastructure development and technology deployment. Where relevant, port authorities and other infrastructure stakeholders should be involved in coordinated spatial and infrastructure planning and co-investment in grid reinforcement, charging and bunkering infrastructure needed to support offshore vessel deployment. Cross sector demonstration initiatives and coordinated public-private investment can support deployment of integrated vessel, energy and infrastructure solutions at scale. Several deployment barriers are commercial rather than technical. Sustainable alternative fuels remain costly and unevenly available; zero-emission and sustainable alternative fuel vessels carry higher capital costs; and many offshore vessel operators face uncertain utilisation, fragmented ownership and limited access to dedicated finance. Long-term contracts and charter commitments, green procurement, fleet renewal instruments, retrofit support, infrastructure co-investment and targeted funding for large-scale demonstrations and operational living labs can reduce these risks. End user involvement is essential so that new technologies are operationally relevant and accepted by crews, operators and charterers. Technology transfer from aviation, automotive and defence can also accelerate progress in autonomy, safety assurance, simulation, cyber resilience and human-machine interaction. Resilient European supply chains for mission-critical components, digital systems and energy technologies will also be important to support deployment at scale and reduce strategic dependencies.

5.6. HUMAN CAPITAL, TRAINING AND ACCEPTANCE

The offshore vessel transition requires a workforce capable of operating and supervising sustainable alternative fuels, hybrid power systems, high voltage equipment, batteries, fuel cells, digital twins, autonomous functions and AI-supported decision tools. Training must therefore evolve alongside technology deployment. Simulation, extended reality, augmented reality support and remote operation centre training can build on existing maritime and offshore training practices, but need to be adapted to new fuel, automation and digital operating environments. Human-machine interface standards should ensure that systems remain usable, safe and consistent under demanding offshore conditions. Competence frameworks should cover onboard personnel, shore-based specialists, technicians, port personnel and emergency responders.

Social acceptance and wellbeing are also deployment conditions. Remote operation, AI-supported monitoring, reduced crewing and autonomous functions must be introduced with clear rules on responsibility, ethics, oversight and trust. Crew comfort, fatigue, motion exposure, seasickness and workload must remain central design and operational considerations. The roadmap will only be deployable if technological innovation is matched by skills, acceptance and safe human-centred implementation.

6. EXPECTED IMPACTS

6. EXPECTED IMPACTS

Implementation of this roadmap will support the transformation of offshore vessels into a zero-emission, safe, resilient, digitally integrated and globally competitive segment of the European waterborne sector. Impacts will be realised progressively, as technologies move from vessel-specific pilots and early commercial deployment to fleet scale uptake, infrastructure integration and system level operation. This requires to ensure that offshore vessels are a priority in the European RD&I domain, whereby mission-oriented demonstrators; harmonisation of standards and certification; retrofit and fleet renewal are executed in a public/private cooperation, whilst simultaneously safeguarding European capabilities in strategic vessels families.

Because offshore vessels differ significantly by mission, duty cycle, power profile and operating distance, impacts should be assessed by vessel family and operational mode. Progress should therefore combine environmental and energy performance with indicators of industrial deployment, technological readiness, operational efficiency, safety, resilience and workforce capability. The following indicative impacts provide reference points for assessing progress towards 2035, 2040, and 2050. They represent sector-level ambitions and should be refined as fleet, market and technology baselines evolve.

Impact area	2035 early deployment	2040: Scale-up and integration	2050 full transformation
Climate and Environmental	20–25% reduction in average CO_2 intensity compared with a 2020 baseline. Zero-emission-at-field operation deployed on 30-40% of the active offshore fleet. Hybridisation of 50–60% of service vessels and tugs. Methanol dual-fuel systems demonstrated on 5–10 commercial offshore vessels. Battery-electric tugs and service vessels operating at 15–20 major ports. Around 25–30% average reduction in NOx, SOx and particulate-matter emissions.	45–50% reduction in average CO_2 intensity compared with 2020. Zero-emission work modes deployed on 60–70% of the active fleet. Fuel-cell systems supporting 20–30% of high-power offshore operations. Ammonia- and methanol-capable systems commercially deployed on 30–50 vessels. Substantial elimination of black carbon emissions at major ports and offshore installation sites. Around 40–50% of vessel energy in relevant applications supplied through integration with renewable energy systems.	90–95% reduction in offshore vessel CO_2 emissions compared with 2020, aligned with the sector's net-zero trajectory. Full mission zero-emission operation for more than 80% of the active fleet, where technically and operationally feasible. Near elimination of local air pollutants from offshore operations, high levels of renewable energy integration and more than 95% material recovery for batteries and other key components.

Table 7: Expected Impacts

Table 1: Indicative Expected Impacts

Impact area	2035 early deployment	2040: Scale-up and integration	2050 full transformation
Economic and industrial	40–60 existing vessels retrofitted with hybrid propulsion, battery systems or advanced power management. Development of 10–15 retrofit and upgrade centres across European ports. Fuel and energy-cost reductions of around 20–25% in suitable hybrid operational modes. Creation of approximately 1,500–2,000 jobs in offshore electrical systems, renewable-energy integration and digital services. European capability maintained in high value specialised offshore vessel markets.	100–150 vessels retrofitted with advanced propulsion, power management and digital systems. European market position maintained or strengthened in specialised offshore vessels and equipment. Offshore vessel equipment and digital services markets approaching €800 million annually, with retrofit and upgrade activity reaching approximately €1.2 billion annually EU-wide.	Renewal or retrofit of the active offshore fleet with advanced propulsion, energy and digital systems. Cumulative economic value from new vessels, retrofits, equipment, digital services and training in the order of €20–30 billion over the roadmap period. Offshore vessel related European maritime exports reaching €5–8 billion annually. European manufacturing capacity maintained or strengthened to account for 60%+ of strategic offshore vessel technologies and systems, reinforcing industrial resilience and strategic autonomy.
Technological and operational	Certification and commercial validation of methanol, ammonia and fuel cell systems for offshore vessel applications. Advanced energy management systems deployed on 100+ offshore vessels. Standardised electrical interfaces and digital specifications developed for offshore energy exchange. Establishment of 3–5 EU-based marine battery manufacturing, refurbishment or repurposing centres. Autonomous inspection and remote operation capabilities demonstrated in multiple offshore pilots.	Commercial deployment of modular 5–20 MW fuel-cell systems across relevant vessel types. Predictive maintenance systems achieve high levels of component failure prediction accuracy. 70–80% of relevant offshore vessels connected to digital-twin or equivalent operational platforms. Harmonised cybersecurity frameworks and standardised offshore energy exchange protocols support increasingly integrated vessel infrastructure operation.	Full system level integration of vessels, energy infrastructure and offshore renewable systems. Highly reliable autonomous offshore operations in defined missions and operational domains. Modular and reconfigurable propulsion and energy architectures support adaptation to future technologies. Circular lifecycle management is embedded across vessel systems, supported by strong European manufacturing capability in batteries, fuel cells, power electronics, digital platforms and other strategic technologies.

Table 7: Expected Impacts

Impact area	2035 early deployment	2040: Scale-up and integration	2050 full transformation
Safety, security and resilience	Predictive safety, situational awareness and condition monitoring systems increasingly deployed in mission-critical offshore operations. Representative scale validation environments and shared safety evidence support sustainable alternative fuel, autonomous and remote operation certification. Improved cyber resilience and reduced exposure of personnel to hazardous inspection and intervention tasks.	Integrated predictive safety systems, cyber resilient architectures and autonomous incident response functions increasingly deployed. Improved system availability reduced unplanned downtime and faster recovery from operational, environmental and cyber disruptions. Joint vessel infrastructure situational awareness strengthens protection of critical offshore and subsea assets.	Fully integrated predictive safety ecosystems connect vessels, offshore infrastructure and shore control centres. Near-zero-incident operation is pursued through intelligent monitoring, automation and risk mitigation, while secure European-controlled communication, positioning and digital infrastructure support resilient offshore operations and critical infrastructure protection.
Social, skills and workforce	3,000–5,000 offshore personnel trained in hybrid systems, batteries, fuel cells and digital platforms. Development of 5–8 specialised training and simulation facilities. Improved worker safety through reduced manual exposure, advanced situational awareness and enhanced mission preparation. Greater crew support through human-centred design and remote assistance	8,000–12,000 personnel trained in autonomous systems, digital twins and cybersecurity. Widespread use of simulation and extended reality training. Remote operation functions deployed across approximately 25–30% of the fleet for selected tasks and operating modes. New career pathways combine maritime operations, digital systems and offshore energy expertise.	Continuous learning and skills development embedded across the offshore workforce. Mature professional profiles combine maritime operations, digital technologies, renewable energy systems and offshore logistics. Around 10–15 specialised offshore training and research centres support European competence development, while improved working conditions, safety, career opportunities, diversity and inclusion strengthen the attractiveness of the sector.

Table 7: Expected Impacts

The environmental impact pathway will differ substantially across vessel families. Nearshore service vessels, harbour tugs and port-based support operations benefit earlier from battery-electric operation and direct electrification, while construction, cable laying, dredging and other high power or far field operations will require sustainable alternative fuels, fuel cells and advanced hybrid architectures. Near-term improvements reduce fuel and energy consumption across standby, port operations, dynamic positioning, towing, lifting, dredging, cable work and other high or variable load operating modes. Where direct electrification is technically and operationally feasible, it improves overall energy efficiency, reduces dependence on fuel supply chains and associated emissions costs, and strengthens integration with renewable electricity systems. By 2040 and 2050, vessel level improvements are increasingly complemented by integrated offshore energy and logistics systems, reducing lifecycle emissions and improving energy efficiency across offshore renewable deployment, subsea infrastructure, dredging, towage and support services.

Safety and resilience impacts should similarly be assessed at both vessel and system level. Predictive safety systems, advanced sensing, cyber-secure architectures, digital twins and improved situational awareness reduces operational risk during dynamic positioning, heavy lift, towing, cable laying, trenching, dredging subsea intervention and harsh-weather operations. Greater integration of vessels with autonomous and remotely operated assets supports more coordinated offshore missions, reduces reliance on large vessel deployment for selected tasks and improves the efficiency, safety and flexibility of inspection, monitoring and intervention activities. Improved maritime domain awareness, secure communications, autonomous inspection and resilient operational architectures also strengthen prevention, detection, response and recovery capabilities for critical offshore and subsea infrastructure. Progress is reflected in increasingly robust and transferable safety cases, improved system availability, reduced unplanned downtime and faster recovery from operational, environmental and cyber disruptions.

Operational efficiency impacts extend beyond energy performance. Digital energy management, mission optimisation, predictive maintenance, integrated logistics platforms and digital twins reduce waiting time, unnecessary vessel movements, fuel use and unplanned downtime. Better coordination between vessels, offshore installations, ports, energy infrastructure and shore control centres improve planning and asset utilisation across installation, maintenance, repair, decommissioning, dredging and towage. Automation and remote support are deployed where they improve safety, reduce exposure to hazardous conditions and support efficient mission execution, with early applications in inspection, monitoring, light intervention, repetitive logistics, below-deck monitoring and selected support operations. By 2050, offshore vessels increasingly operate as part of connected offshore energy and logistics ecosystems rather than as isolated assets.

Industrial impacts extend beyond vessel construction. Successful implementation reinforces European capability in specialised vessel design, retrofit, equipment integration, power electronics, energy systems, digital technologies, classification and lifecycle services. This is particularly important for cable-laying vessels, offshore support vessels, dredgers, construction vessels and specialised towage, where European capability is strategically significant but cannot be assumed to remain secure. The roadmap therefore contributes both to competitiveness and to strategic autonomy by supporting the vessels and technologies required for offshore renewable energy, subsea infrastructure protection, coastal resilience, emergency response and dual-use preparedness.

Workforce and social impacts should be assessed alongside technological deployment. New competence requirements span sustainable alternative fuels, high-voltage systems, batteries, fuel cells, automation, remote operation, digital twins, cybersecurity, AI-supported decision tools and human-machine interaction. Beyond the quantitative training targets in Table 7, progress should include safer work, better mission preparation, improved emergency response and stronger crew support during complex operations. Automation and remote operation must be introduced with clear rules on safety, accountability, working conditions and trust. Crew wellbeing, fatigue, motion exposure, seasickness, workload and ergonomics should remain central considerations in vessel design, training and operational practice.

Impact monitoring should combine lifecycle and operational indicators and establish transparent baselines for the relevant vessel families and deployment pathways. By 2035, monitoring should focus on GHG- and energy intensity improvement, zero emission work mode deployment, numbers and types of completed retrofits, commercial sustainable alternative fuel and battery applications, advanced energy management systems, autonomous and remote operation demonstrations, validated safety cases, trained personnel and European industrial capacity. By 2040, monitoring should additionally assess scaled fuel-cell and sustainable fuel deployment, renewable energy integration, digital twin uptake, predictive maintenance performance, cyber resilience, operational availability and recovery performance, retrofit and equipment markets, remote operation uptake and workforce competence. By 2050, assessment should focus on progress towards fleet-wide net-zero operation, system level offshore energy and logistics integration, highly automated operations in defined domains, circular lifecycle performance, European manufacturing capacity, strategic autonomy and long-term workforce capability.

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