WATERBORNE

WATERBORNE TECHNOLOGY ROADMAP

Competitive, resilient and sustainable inland waterway transport (IWT)

September 2026

INLAND WATERWAY TRANSPORT TECHNOLOGY ROADMAP

01 THE SECTOR IN NUMBERS

EUR 7.5 bn

Turnover in IWT freight transport in the EU-27 plus Switzerland and Serbia was approximately EUR 7.5 billion in 2023, compared with EUR 7.8 billion in 2022 and EUR 6.1 billion in 2021. Rhine countries account for the largest share of turnover.

≈41,000 km of inland waterways, in 13 of the 25 Member States the network spans

≈150 bn tonne-kilometres of cargo carried by IWT every year

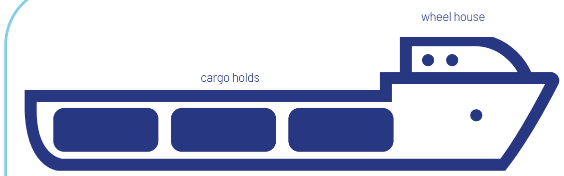
13,392 cargo vessels in operation, plus ≈3,000 day-trip passenger and ≈430 river cruise vessels

4.8% of the modal split of freight transport on land at EU-27 level in 2023

FLEET BY BASIN AND VESSEL TYPE, 2024

Rhine · dry cargo	**6,381**
Danube · dry cargo	**2,523**
Rhine · liquid cargo	**1,453**
Danube · liquid cargo	**120**

Rhine fleet 9,160 vessels; Danube fleet, including Germany's vessels, 3,324 ships. Danube figures represent minimum estimates due to incomplete reporting.



VESSEL ARCHETYPE
SELF - PROPELLED DRY CARGO VESSEL
"Solutions must be adaptable to the diversity of the fleet, including **self-propelled vessels, push boats, barges, and push-tow configurations.**"

"Propulsion and onboard power systems must accommodate **shallow draft navigation, frequent lock transits, bridge clearance and vessel dimension constraints.**"

RHINE AND DANUBE NETWORKS

Rhine countries   Danube countries   both

Main inland ports and network nodes, from Paris and Liège in the west to Constanța on the Black Sea. The Rhine–Danube and North Sea–Rhine–Mediterranean corridors connect major industrial regions and logistics hubs across Europe.

02 POLICY DRIVERS AND CONSTRAINTS

2.1 DRIVERS

EU Climate Law – sets a binding climate-neutrality objective for the Union by 2050; the amended framework adds a 2040 headline target of a 90% net GHG reduction relative to 1990.

TEN-T – a key instrument for planning a coherent, efficient, multimodal and high quality transport infrastructure across the EU, implemented amongst others by the Connecting Europe Facility.

Sustainable and Smart Mobility Strategy – targets a 25% increase in inland waterways and short sea shipping by 2030 and 50% by 2050, and market readiness of zero-emission vessels by 2030.

NAIADES III Action Plan (2021–2027) – the sectoral implementation layer for IWT: increasing modal share and steering the sector towards zero-emission operations, with digitalisation as a central enabler.

Sustainable Transport Investment Plan – identifies an investment need of around EUR 100 billion by 2035 and finds that existing support mechanisms have not delivered sufficient market impact.

2.2 CONSTRAINTS

Cost gap between sustainable alternative and fossil fuels – operators, in the mainly SME dominated sector, lack the ability to pass these costs onto customers, which reinforces a first-mover disadvantage.

Fuel availability and the chicken-and-egg dynamic – vessel investment depends on fuel infrastructure, while infrastructure deployment requires sufficient demand, slowing uptake on both sides of the market.

Financing and business-case constraints – high upfront costs, uncertain fuel-price differentials, uncertain residual values and vessel downtime during retrofit weaken the case for new vessels, retrofits or digital upgrades.

Hydrological variability and climate impact – reduced water levels limit vessel payload, decrease the energy efficiency, increase emissions to air, increase unit costs and disruptindustrial supply chains.

Digital governance fragmentation – digital governance remains incomplete in automation, interoperability standards with other modes, and cybersecurity frameworks, constraining the rollout of automation.

INLAND WATERWAY TRANSPORT TECHNOLOGY ROADMAP

03 TARGET CAPABILITIES

2035 • Early deployment phase

Partially decarbonised (reducing at least 55% GHG emissions in line with the EU Climate Law), digitally supported and interoperable component of European logistics chains.

- **Propulsion & energy** – mix of low- and zero-emission energy carriers, including drop-in fuels and hybrid propulsion; swapping points for batteries and tanktainers
- **Safety & resilience** – integrated cybersecurity platforms rolled out; initial resilience to climate variability through adaptive vessel deployment
- **Digital & automation** – digital twins and AI-enabled traffic coordination in initial deployment across terminal clusters
- **People & skills** – digital and sustainable alternative-fuel training programmes for crew and shore personnel are introduced
- **Regulation & corridors** – corridors operationally integrated with TEN-T maritime ports through interoperable digital traffic and cargo data systems

2040 • Scale-up phase

Fully integrated, zero-emission and digitally optimised operations across the waterborne ecosystem, supported by widely available and interoperable infrastructure.

- **Propulsion & energy** – vessels largely operate on zero-emission energy carriers, in line with the objective of eliminating harmful emissions
- **Safety & resilience** – operational safety reaches near-zero accident levels, supported by advanced monitoring, predictive management and cyber-secure operations
- **Digital & automation** – high levels of automation, remote control and continuous system optimisation; integrated digital corridormanagement platforms
- **People & skills** – human-machine teaming and decision-support systems integrated into highly automated operations
- **Regulation & corridors** – mutual recognition of testing, certification and approval evidence facilitates deployment across Member States and corridors

2050 • Full transformation

A fully zero-emission, automated, climate resilient and system integrated backbone of European transport and industrial ecosystems, including dual-use capacity

- **Propulsion & energy** – all harmful emissions are eliminated; ports function as integrated energy and logistics hubs ensuring circular resource use
- **Safety & resilience** – infrastructure, including inland ports, is climate-resilient, adapting to extreme climate conditions while maintaining continuous operations
- **Digital & automation** – operations are highly automated, with vessels navigating in coordination through fully digitalised infrastructure and decision-making systems
- **People & skills** – mature human-automation teaming supports routine highly automated vessel and corridor operations
- **Regulation & corridors** – the system operates as a "system of systems", integrating transport, energy, environmental monitoring and blue economy activities

SOURCES

Sector, drivers, constraints and target capabilities: Technology Roadmap – Competitive, resilient and sustainable inland waterway transport (IWT), Ch. 1-3.
Country categories on the map follow the Rhine and Danube commissions; Liège and Paris shown as network reference points.

All figures and wording taken from Technology Roadmap – Competitive, resilient and sustainable inland waterway transport (IWT), chapters 1-6, including the indicative expected impacts table.

GLOSSARY

IWT inland waterway transport
TRL technology readiness level
RIS River Information Services
ROC Remote Operations Centre
OPS onshore power supply
HVO hydrotreated vegetable oil
SAF sustainable alternative fuel
GHG greenhouse gas
TEN-T trans-European transport network
NRMM non-road mobile machinery
CESNI European Committee for drawing up Standards in the field of Inland Navigation
CCNR Central Commission for the Navigation of the Rhine
EWL Equivalent Water Level
LNWL Low Navigable Water Level
XR extended reality.

INLAND WATERWAY TRANSPORT TECHNOLOGY ROADMAP

04 TECHNOLOGY PATHWAYS

4.1 Future propulsion and energy systems enabling a zero-emission IWT fleet	Scalable, safe and cost-competitive systems adapted to the diversity of inland vessels, corridors and operating profiles — technology-neutral, prioritising energy efficiency, retrofitability and modularity.	TRL RANGE **6–9**
4.2 Intelligent safety, security and resilience as foundational enablers	Predictive safety and risk management, cyber-resilient vessel-shore interaction, enhanced sensing and incident response, and safe operation of sustainable alternative fuels, electrification and automated systems.	TRL RANGE **7–9**
4.3 Fully connected, automated and data-driven inland waterborne systems	Interoperable digital architectures, remote and autonomous vessel functions, digital twins and AI-supported coordination, with attention to vessel-infrastructure interaction at locks and movable bridges.	TRL RANGE **6–9**
4.4 Human-centred design and a future-ready inland workforce	Human-machine teaming, XR and simulation-based training, ergonomic interfaces and workload management — accessible, understandable and practical for SMEs and owner-operators.	TRL RANGE **6–9**
4.5 Forward looking regulation, standardization and system-level corridor integration	Goal-based rules, technical standards, certification approaches and regulatory sandboxes developed alongside technology, with common standards for system-level interoperability.	FRAMEWORKS **2035–50**

05 ENABLERS AND DEPLOYMENT

Corridor-based deployment
The Rhine, Danube and other TEN-T inland waterway corridors function as living deployment environments

Energy, refuelling, charging
Ports and terminals become the main energy nodes: OPS, high-capacity charging, battery exchange, renewable fuel bunkering

Retrofitting & shipyards
Modular, affordable and repeatable solutions; standardised, pre-certified retrofit packages rather than one-off pilot conversions

Digital infrastructure
RIS evolves towards interoperable corridorlevel systems with reliable, redundant connectivity and common data standards

Regulation & certification
Stable, goal-based and technology neutral EU framework; regulatory sandboxes and controlled corridor demonstrations

Finance & business models
Energy-as-a-service, battery-as-a-service, shared infrastructure and green corridor partnerships reduce upfront costs

Climate resilience & security
Harmonised safety procedures, cybersecurity requirements, resilience testing and fallback procedures accompany every phase

Skills & social acceptance
XR, simulators and digital training platforms support upskilling for complex or high-risk situations

DEPLOYMENT LOGIC

"The aim should be to move from individual pilots to replicable corridor packages that combine vessels, infrastructure, energy supply, digital services, operational procedures, regulatory approval and financing. Once validated on suitable corridors, these packages should be transferable to lower-volume, more complex or more climate-sensitive waterways."

INLAND WATERWAY TRANSPORT TECHNOLOGY ROADMAP

06 TOWARDS A COMPETITIVE, RESILIENT AND SUSTAINABLE SSS SECTOR — IMPACTS BY 2050

Indicative and scenario-based — monitoring should reward flexibility, modularity and interoperable infrastructure over convergence on a single fuel.

ENVIRONMENTAL

2035	15-20% average CO_2 intensity reduction versus 2020 IWT fleet; electric operation on 15% of short distance IWT vessels, SAF deployed on 15% of the fleet, zero-emission at berth on 25% of Inland ports
2040	45-50% CO_2 intensity reduction; electric operation on 30% of short distance IWT vessels, SAF deployed on 50% of the fleet, zero-emission at berth on 50% of Inland ports
2050	Zero-emission IWT fleet; 90%+ CO_2 reduction vs. 2020

ECONOMIC

2035	500 IWT vessels retrofits with hybrid/solar/battery systems, fuel cost savings of € 300–500M/year, shore-power available at 25% of major inland ports, 1.200 new jobs in IWT retrofit services
2040	1.000 additional IWT vessels retrofits with hybrid/solar/battery systems, fuel cost savings of € 600–950M/year, shore-power available at 50% of major inland ports, 2.500 new jobs in IWT retrofit services
2050	Zero-emission IWT fleet, fuel cost savings of € 2B/year, 5.000 new jobs in IWT retrofit services

TECHNOLOGICAL

2035	Aligned approval for systems/technologies by different regulatory bodies, energy management integrated and automated river information services on 500 vessels, 25 charging infrastructure demonstrations at locks on major European corridors
2040	Energy management integrated and automated river information services on 1,000 vessels, 50 charging infrastructure demonstrations at locks on major European corridors
2050	Full system of systems digital integration; remote/autonomous operations in place; 95%+ battery and component material recovery

SOCIAL

2035	4,000+ IWT crew members and port personnel trained in new technologies
2040	8,000+ trained; SME digital transformation complete for 80%+ of operators
2050	20,000+ trained

VISION FOR 2050

"By 2050, inland waterway transport operates as a fully zero-emission, automated, resilient, competitive and system-integrated backbone of European transport and industrial ecosystems, including dual-use capacity."

TABLE 2 · Indicative expected impacts by 2035, 2040 and 2050. Waterborne Technology Roadmap — Short Sea Shipping, Ch. 6, Table 2; figures are targeted outcomes, not measured results. [4]

CONTENT

LIST OF FIGURES

LIST OF TABLES

ROADMAP POSITIONING WITHIN THE WATERBORNE TECHNOLOGY LEADERSHIP FRAMEWORK

This roadmap operationalises the Technology Leadership[1] framework for the inland waterway transport sector. 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 inland waterway transport. 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 inland waterway transport 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 (Brussels: Waterborne Technology Platform, January 2026), 9, 11, 14.

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

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The EU Inland Waterway Transport (IWT) sector extends from the Atlantic Ocean to the Baltic Sea, the Black Sea and the Mediterranean. The European inland waterway network spans 25 Member States, 13 of which have about **41,000 kilometres** of navigable inland waterways. The Rhine-Danube and North Sea-Rhine-Mediterranean corridors, as part of the TEN-T corridors, connect major industrial regions and logistics hubs across Europe[3]. Every year, IWT carries around **126 billion tonne-kilometres of cargo, with approximately 13,392 cargo vessels** in operation, alongside around **3,000 day-trip passenger vessels and about 408 river cruise vessels**[4].

IWT is characterized by diverse operating conditions and market segments. The Rhine, the Danube, the Mozelle, the Sava, the Elbe, connected canal systems, **regional waterways and urban passenger networks differ in terms of vessel types, route length, cargo flows, waterway dimensions, bridge clearance, lock infrastructure and variability in water-levels and flow velocities.** The sector also includes a heterogeneous and ageing fleet, long asset lifetimes, **a high share of Small and Medium-sized Enterprises (SMEs) and owner-operators,** and strong dependence on corridor, port and fairway conditions.

These characteristics are considered in the technology roadmap, indicating that future solutions must be scalable and interoperable across the European network, while remaining flexible enough to reflect corridor-specific conditions, vessel size, propulsion needs, local energy availability and the need to coordinate vessel technologies with port, fairway, energy, and digital infrastructure.

1.1. STRUCTURE OF THE FLEET

The total commercially operated EU Inland Waterway Transport fleet accounts for **13,392 vessels**. Vessel types differ according to the goods transported and the region of operation. In 2024, the Rhine fleet accounted for **9,160 vessels**[5] of which **6,381 were dry cargo** and **1,453 were liquid cargo vessels.** Of the **6,381 dry cargo vessels, 3,228** are registered in the Netherlands, **1,374 in Germany, 879 in France and 873 in Belgium.** Their **loading capacity** is reported at approximately **10,000 million tonnes** in cumulative terms[6]. **The majority of liquid cargo vessels** in the Rhine countries are also registered mainly in the **Netherlands, accounting 715 vessels**, followed by **Germany with 448** and **Belgium with 143**, while **the rest registered in France, Switzerland and Luxembourg.** Their loading capacity tends to increase over the last 20 years, reaching **3.7 million tonnes in 2024.**[7]

The **Danube fleet**, including Germany's vessels, **accounted for 3,324 ships of which 2,523 were dry cargo vessels and 120 were liquid cargo vessels.** The Romanian cargo fleet is the largest in the Danube area with a share of 44% of all dry cargo vessels. According to the Statistical Yearbook of the Danube Commission, the fleet operating along the Danube includes several categories of vessels such as motorized cargo vessels, tugboats, pushers and tug-pushers. The available data indicates that the Danube fleet comprises at least **515 motorized dry cargo vessels and 48 motorized liquid cargo vessels**, alongside **118 tugboats, 681 tug-pushers and 389 pushers.** These figures though represent minimum estimates due to incomplete reporting from several Member States of the Danube Commission. This structure highlights the operational importance of **push-tow navigation systems**, which allow barges to be transported in convoys along long river corridors and remain a defining feature of Danube inland navigation logistics.[8]

3 European Commission, "Rhine-Danube Corridor," Trans-European Transport Network (TEN-T), accessed 16 March 2026, https://transport.ec.europa.eu/transport-themes/infrastructure-and-investment/trans-european-transport-network-ten-t/rhine-danube-corridor_en; see also "North Sea-Rhine-Mediterranean Corridor," https://transport.ec.europa.eu/transport-themes/infrastructure-and-investment/trans-european-transport-network-ten-t/north-sea-rhine-mediterranean-corridor_en.
4 Central Commission for the Navigation of the Rhine (CCNR), Market Observation: Inland Navigation in Europe — Annual Report 2025 (Strasbourg: CCNR, 2025), 10–11, https://www.ccr-zkr.org/files/documents/om/om25_II_en.pdf.
5 Ibid., 108–111.
6 Ibid
7 Ibid
8 Danube Commission, Statistical Yearbook of the Danube Commission 2022 (Budapest: Danube Commission, 2025), 19, https://www.danubecommission.org/uploads/doc/2025/Stat_2022/en_stat_2022.pdf.

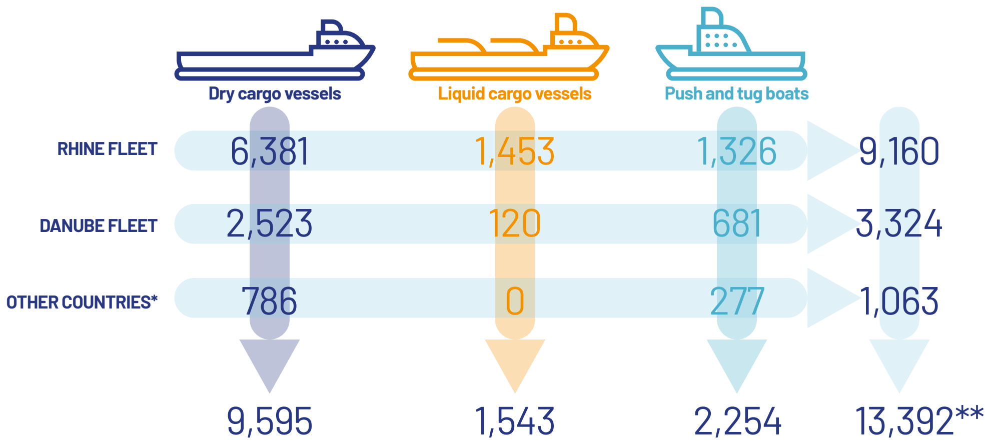


Figure 1: Number of Vessels per Macro-Region and Vessel Type in Europe[7]

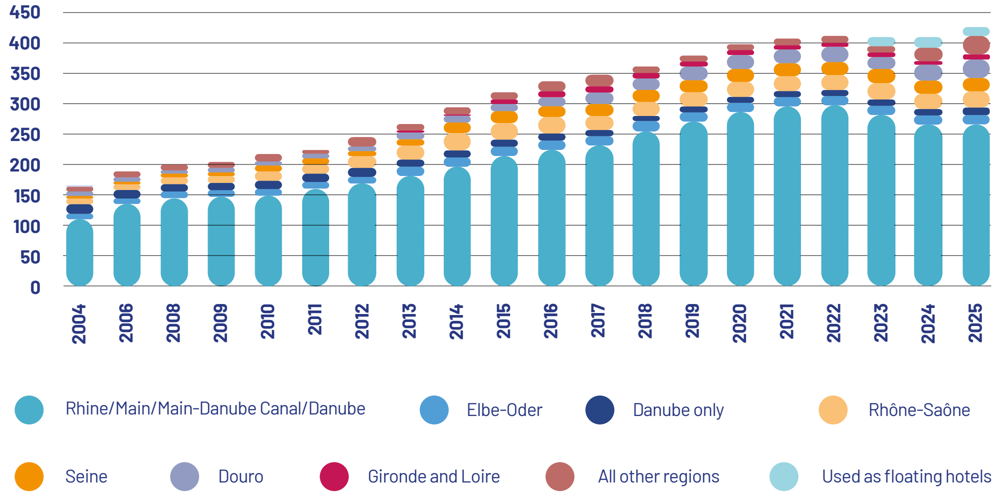


Figure 2: Number of River Cruise Vessels in EU by Region of Operations (2004-2025) [9]

For river cruises, capacity and economic activity have increased steadily since 2004. In 2025, the **Rhine Basin** accounted for **more than 250 vessels** and, when the other regions of operation are included, **the total number of river cruise vessels reached slightly more than 400.**

The estimated number of **new built dry cargo vessels** for the Rhine basin in 2024 was 13, compared with an average of 32 vessels per year in previous years.New tanker vessels entering the market by country of registration reached a peak of 58 in 2021. In 2024, **38 new vessels were built**, most of them registered under the Dutch flag.[10]

The European inland waterway transport fleet is characterized by a structurally ageing asset base, which fundamentally shapes its operational profile and transition capacity. A significant share of vessels currently in service will remain active well into the coming decades, as full fleet renewal is neither economically nor practically feasible by 2050[11]. This results in a heterogeneous fleet composed of vessels of varying age, size, and technological capability.

9 Ibid., 133.
10 Ibid., 116.
11 Inland Waterway Transport and Ports Sector, Statement on the Sustainable Transport Investment Plan (7 April 2025), 5.

Structural trends further indicate a gradual decline in smaller and older vessels, particularly small cargo units and push boats, while larger vessels are expected to increase in number due to efficiency gains and economies of scale. Consequently, the sector is marked by a dual dynamic of longevity of its assets and gradual transformation, where legacy vessels continue to dominate while incremental modernization occurs unevenly across segments.[12]

In terms of energy use, **the sector remains overwhelmingly dependent on fossil diesel, with nearly the entire fleet relying on conventional fuels for propulsion, due to a lack of availability of sustainable alternative fuels at economically feasible prices**.[13] This reflects both the long lifespan of vessels and their engines and the historical absence of viable large-scale alternatives. **Emerging fuel pathways illustrate a transition that is gradual and multi-layered**. On the one hand, drop-in fuels such as hydrotreated vegetable oil (HVO) and IWT-compatible FAME B100 (destined for bigger vessels) could offer an immediate compatibility with existing engines and infrastructure, allowing for short-term Greenhouse Gas (GHG) emissions reductions up to 90% without major technical adaptation. On the other hand, sustainable alternative energy carriers including hydrogen, battery-electric systems, and methanol require substantial modifications to energy storage and power systems of vessels and supporting infrastructure. These energy types and technologies are associated with significantly higher total costs of ownership compared to usage of fossil diesel and drop-in fuels. As a result, the sector's fuel landscape is best understood as transitional and diversified, with multiple technologies coexisting as the fleet gradually adapts to new regulatory, economic, and technological conditions.[14]

The sector is also characterized by a diverse structure of companies and employment across freight and passenger activities. In 2023, **5,462 inland waterway freight transport companies** were active in Europe (EU-27 plus Bosnia-Herzegovina, Serbia and Switzerland), of which **4,725** were in Rhine countries. **The Netherlands alone account for 3,203 companies. This is translated in a big number of micro companies (1 vessel per company), often chartered by companies of a bigger size.** By contrast, the Danube region hosts a relatively small number of **261 firms**. However, these firms accounted for around 21% of EU inland waterway freight transport performance, reflecting the generally larger size of companies in the region, many of which originate from former state-owned enterprises.[15]

Private employment in IWT freight transport reached **22,844 persons in 2022**, with **81% employed in Rhine countries, 13% in Danube countries and 6% elsewhere**, while the overall number of employees declined slightly by **6% between 2010 and 2022**. In passenger transport, **4,659 companies were active in 2023**, with **42% located in Rhine countries and 13% in Danube countries**, while southern European countries accounted for **29%** and Scandinavian countries **10%** of companies; total employment in passenger transport reached **23,945 persons**, with Germany, Italy and Switzerland accounting for around **61% of all employees** in the IWT passenger transport sector.[16]

12 Ibid., 4
13 Ibid., 3.
14 Ibid., 3-4.
15 Central Commission for the Navigation of the Rhine (CCNR), Market Observation: Inland Navigation in Europe – Annual Report 2025 (Strasbourg: CCNR, 2025), 144-145.
16 Ibid., 145-148.

Building on these structural characteristics, **automation constitutes a key driver of transformation in inland waterway transport to meet a growing shortage of qualified personnel in all segments of the sector.** The establishment of a common framework for levels of automation by the Central Commission for the Navigation of the Rhine (CCNR) provided a shared basis for assessing human-machine interaction in navigation. Automation develops along a continuum, from decision support functions to fully autonomous operations, and remains conditioned by sector-specific constraints, including confined waterways, lock infrastructure, and manoeuvrability requirements. While offering efficiency gains and reducing crew workload, automation also raises challenges related to safety, liability, and skills adaptation. This implies the need for parallel adjustments in regulatory frameworks, operational standards, and workforce capabilities.[17]

Inland ports constitute a core component of the European inland waterway transport system, forming a continuous network that links major river basins such as the Rhine and the Danube with maritime gateways and inland industrial regions. This network connects key nodes including Rotterdam, Antwerp, Duisburg, Frankfurt, Liège, Paris, Vienna, Budapest and Constanta, reflecting the role of inland waterways as an integrated transport corridor across Europe. Inland ports operate as multimodal interfaces between maritime transport and hinterland and continental distribution, supporting the movement of bulk cargo, containers and industrial goods across regions. Transport activity is particularly concentrated in areas where port infrastructure, industrial production and logistics networks coincide, notably in delta regions and along major corridors. In these areas, dense port systems and inter-port connections facilitate the circulation of goods between seaports and inland destinations, with the Scheldt-Rhine Delta identified as a key example due to its "dense delta network" and strong inter-port traffic between Rotterdam, Antwerp and Amsterdam.[18] Thereby, IWT is a critical part of port hinterland access, connecting TEN-T maritime ports with inland terminals, industrial areas and cross-border corridors.

Waterway administrations and fairway infrastructure managers are a distinct part of the IWT ecosystem. Safe, reliable and efficient navigation depends on continuous fairway management activities such as hydrographic surveying, dredging, aids to navigation, river engineering, water-level and bathymetric monitoring, River Information Services, Notices to Skippers and emergency response. These functions directly influence navigable depth, vessel loading capacity, voyage planning, safety, corridor reliability and cross-border interoperability.

17 Central Commission for the Navigation of the Rhine (CCNR), First International Definition of Levels of Automation in Inland Navigation, CC/CP (18) 20 (Strasbourg: CCNR, 18 December 2018), https://www.ccr-zkr.org/files/documents/AutomatisationNav/NoteAutomatisation_en.pdf. This 2018 instrument predates the 2019–2025 reference window and is retained as the foundational international definition of automation levels, not restated in later CCNR instruments.

18 Central Commission for the Navigation of the Rhine (CCNR), Market Observation: Inland Navigation in Europe — Annual Report 2025 (Strasbourg: CCNR, 2025), 35.

1.2. MARKET PERFORMANCE, MODAL SHARE AND ECONOMIC TRENDS IN IWT

IWT represents a limited share of total EU freight volumes, but it plays a specific role in corridors with waterway capacity, industrial activity and port-hinterland flows. **It is particularly relevant for bulk commodities, construction materials, chemicals, agricultural products, containers on selected corridors and, increasingly, renewable energy carriers and circular economy flows.** Its market performance is therefore closely linked to industrial production, seaborne trade, energy markets, hydrological conditions and the quality of multimodal connections.

At EU-27 level, **inland waterways accounted for 4.8% of the modal split of freight transport on land in 2023**. The share differs substantially across Member States: the Netherlands, Romania, Bulgaria and Belgium have significantly higher IWT shares because of favourable waterway geography, port systems and industrial-logistics structures. These differences indicate that IWT potential is corridor-specific rather than uniform across Europe[19].

The sector's economic performance has fluctuated in recent years. **Turnover in IWT freight transport in the EU-27 plus Switzerland and Serbia was approximately EUR 7.5 billion in 2023, compared with EUR 7.8 billion in 2022 and EUR 6.1 billion in 2021**. Rhine countries account for the largest share of turnover, with the Netherlands and Germany representing the main markets[20]. In the Danube region, Romania, Hungary and Serbia contribute important activity, although the company structure and fleet profile differ from the Rhine basin[21].

River cruising and day trip tourism play a vital role in shaping a more sustainable, inclusive and resilient European tourism model. With growing demand for eco-conscious tourism, inland passenger vessels present a low-emission, high-impact opportunity for regional development.

Recent trends underline both the opportunities and the vulnerability of the sector. Inland container transport often follows developments in global seaborne trade and port activities, while bulk cargo flows are affected by the changing European energy, industrial and agricultural landscape. The gradual decline of coal and shifts in traditional bulk commodities may reduce some historical cargo flows, while new flows related to sustainable alternative fuels, circular materials, **military mobility** and industrial transformation may create new opportunities. At the same time, climate-related water level events constrain loading capacity and weaken service reliability. It is expected that the global warming will aggravate these low and high-water events. These dynamics suggest that IWT's future role depends on the combined evolution of industrial demand and land-use planning, waterway reliability and resilience, fleet modernisation, digital integration and fair competition with other modes.

19 Eurostat, Freight transport statistics – modal split, 2023 data (Luxembourg: Eurostat, 2025), https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Freight_transport_statistics_-_modal_split.

20 Central Commission for the Navigation of the Rhine (CCNR), Market Observation: Inland Navigation in Europe – Annual Report 2025 (Strasbourg: CCNR, 2025), 149.

21 Ibid., 149-150.

1.3 WATERWAY OPERATIONAL CHALLENGES

Water level conditions are a central operational parameter for inland navigation and mainly concern free-flowing European waterways. In Europe, inland waterways are classified under the CEMT system according to their capacity to accommodate vessels, with classes determined by vessel dimensions and infrastructure constraints such as locks and bridge clearance[22]. For the Rhine, low-water severity is assessed through the **Equivalent Water Level (EWL)**, while the Danube uses the Low **Navigable Water Level (LNWL)**, defined as the water level exceeded during 94% of days a year.[23]

The number of days below critical thresholds varies significantly by year and corridor. The years 2018, 2022 and 2026 stand out as particularly difficult low-water years for both Rhine and Danube navigation, whereas 2024 recorded favourable conditions at Rhine gauge stations. These variations illustrate that IWT performance is sensitive not only to market demand but also to hydrological conditions. Climate change is expected to increase the frequency and severity of droughts and extreme events, making climate resilience a structural technology and infrastructure issue rather than a temporary operational concern.

Every waterway comes with different operational conditions. As regards the Lower Danube and river-sea sections, hydrological variability, low-water events, sediment dynamics, environmental constraints and the need for coordinated cross-border fairway management are part of these operating conditions, directly influencing the sector's transition.

These operating conditions have direct implications for vessel and energy system design. The overall IWT vessel design and propulsion and onboard power systems must accommodate shallow draft navigation, low-speed and variable-load duty cycles, frequent lock transits, bridge clearance and vessel dimension constraints, and uneven access to charging and sustainable alternative fuel infrastructure along inland corridors. Solutions must be adaptable to the diversity of the fleet, including self-propelled vessels, push boats, barges, and push-tow configurations, as well as newbuild vessels. River cruise vessels present additional requirements arising from their substantial hotel loads, passenger-safety and comfort needs, and specific berthing and port-call patterns.

The sector's technology transition should therefore address vessels, ports, energy supply, fairways and digital systems together. Zero-emission propulsion alone will not be sufficient if corridors cannot provide reliable navigation conditions, alternative energy supply, digital connectivity, safety management and multimodal interfaces.

22 United Nations Economic Commission for Europe (UNECE), Standardization of Inland Waterways: Proposal for the Revision of the Classification Adopted by the European Conference of Ministers of Transport in 1992 (Resolution No. 30), ECE/TRANS/SC.3/WP.3/2022/4 (Geneva: UNECE, 2022), https://unece.org/sites/default/files/2022-02/ECE-TRANS-SC.3-WP.3-2022-04e.pdf.

23 Central Commission for the Navigation of the Rhine (CCNR), Market Observation: Inland Navigation in Europe — Annual Report 2025 (Strasbourg: CCNR, 2025), 62.

2. POLICY DRIVERS AND CONSTRAINTS

2. POLICY DRIVERS AND CONSTRAINTS

2.1. POLICY AND MARKET DRIVERS

The transformation of inland waterway transport is driven by the interaction of various areas of involvement, such as, climate regulation, and policy drivers that translate climate, energy, security and resilience objectives into concrete investments needs, complemented by multimodal transport policy, sectoral programming, investment instruments, environmental constraints on the water cycle, defence and dual-use requirements, and industrial competitiveness policy. The most important drivers are set out below.

- **EU Climate Law Regulation:** (EU) 2021/1119 sets a binding climate-neutrality objective for the Union by 2050,[26] in pursuit of the Paris Agreement long-term temperature goal.[24] It establishes a binding 2030 net domestic GHG-reduction target and the Union aim of negative emissions thereafter[25]. The December 2025 political agreement on the amendment of the Climate Law adds a 2040 headline target of a 90% net GHG reduction relative to 1990, with a contribution of up to 5% from high-quality international credits[26], formally adopted by the Council on 5 March 2026. The amended framework provides a stable trajectory to 2050 and a predictable investment signal for fleet renewal, fuel supply and waterway infrastructure.[27]
- **TEN-T:** The EU's Trans-European Transport Network policy, the TEN-T policy, is a key instrument for planning and developing a coherent, efficient, multimodal, and high-quality transport infrastructure across the EU[28]. The network comprises railways, inland waterways, short sea shipping routes and roads linking urban nodes, maritime and inland ports, airports and terminals. It fosters efficient transportation for people and goods, ensures access to jobs and services, and enables trade and economic growth. It strengthens the EU's economic, social and territorial cohesion and creates seamless transport systems across borders, without gaps, bottlenecks or missing links. In particular since its revision in 2024, it also aims to reduce the environmental and climate impact of transport and to increase the safety and the resilience of the network. TEN-T is, amongst others, implemented by means of the Connecting Europe Facility.
- **Sustainable and Smart Mobility Strategy:** The Strategy operationalises the Climate Law for transport along three pillars: making all modes more sustainable, making sustainable alternatives widely available within a multimodal system, and putting the right incentives in place.[29] It targets a 25% increase in inland waterways and short sea shipping by 2030 and 50% by 2050, the market readiness of zero-emission vessels by 2030, and a multimodal TEN-T equipped for sustainable and smart transport by 2050.[30] It links these objectives to alternative-fuel supply, port electrification and the transformation of ports into zero-emission multimodal and clean-energy hubs, operationalised for inland waterways through NAIADES III.33

24 "This Agreement, in enhancing the implementation of the Convention, including its objective, aims to strengthen the global response to the threat of climate change, in the context of sustainable development and efforts to eradicate poverty, including by: (a) Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change". United Nations Framework Convention on Climate Change (UNFCCC), Paris Agreement (2015), 3, https://unfccc.int/files/essential_background/convention/application/pdf/english_paris_agreement.pdf. This 2015 treaty predates the 2019–2025 window and is retained as the foundational legal source of the temperature-goal definition.

25 Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 Establishing the Framework for Achieving Climate Neutrality and Amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ('European Climate Law'), OJ L 243, 9.7.2021, art. 2(1), 8; art. 4(1), 9

26 European Commission, "EU Agrees on a 2040 Climate Target That Sets a Clear Path towards a Decarbonised and Competitive Economy," press release, 10 December 2025, https://ec.europa.eu/commission/presscorner/api/files/document/print/en/ip_25_2967/IP_25_2967_EN.pdf.

27 Council of the European Union, "2040 Climate Target: Council Gives Final Green Light," press release, 5 March 2026, https://www.consilium.europa.eu/en/press/press-releases/2026/03/05/2040-climate-target-council-gives-final-green-light/.

28 European Commission, "Trans-European Transport Network (TEN-T)," Mobility and Transport, accessed 2026, https://transport.ec.europa.eu/transport-themes/infrastructure-and-investment/trans-european-transport-network-ten-t_en.

29 European Commission, Sustainable and Smart Mobility Strategy — Putting European Transport on Track for the Future, COM(2020) 789 final (Brussels: European Commission, 9 December 2020), 3, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0789.

30 Ibid., 3, 7, 11.

- **NAIADES III Action Plan (2021–2027):** NAIADES III is the sectoral implementation layer for IWT, structured around two objectives: increasing modal share and steering the sector towards zero-emission operations.[31] It mobilises Horizon Europe, the Connecting Europe Facility and the revision of the TEN-T Regulation, advances zero-emission vessels and alternative-fuel infrastructure, and positions digitalisation as a central enabler through the revision of the River Information Services Directive and a single access point for corridor information.[32] The mid-term evaluation indicates limited modal-shift impact under baseline conditions and a stronger response only where improved fairway conditions, higher fleet utilisation and stable financial incentives, including the internalisation of CO_2 costs, are combined.[33]
- **Sustainable Transport Investment Plan:** STIP shifts the EU policy focus from target-setting to investment mobilisation for renewable and low-carbon fuels in aviation and waterborne transport.[34] It identifies an investment need of around EUR 100 billion by 2035 and finds that existing support mechanisms have not delivered sufficient market impact, with many projects remaining at demonstration stage. It promotes coordinated use of the Innovation Fund, InvestEU, EIB financing and Horizon Europe, together with market-based instruments such as double-sided auctions to provide long-term price certainty and bridge the producer–off-taker gap.[35]
- **Water Resilience Strategy:** The Strategy places the restoration of the natural water cycle at the centre of EU policy action, identifying climate change, pollution and overexploitation as structural pressures that have reduced both the quantity and the quality of water.[36] It introduces water availability and quality as structural parameters for inland navigation, since fairway depth and reliability depend on stable hydrological conditions, while climate change, droughts and over-abstraction alter water levels and operational predictability.[37] It applies the "water efficiency first" principle, strengthens monitoring of water abstraction and deploys smart water-management systems, positioning water as a limiting factor in infrastructure planning, corridor management and operational decision-making.[38] It also signals competition with water-intensive uses such as hydrogen production, energy systems and industrial processes, reinforcing trade-offs between transport, energy and industrial water demand.[39]
- **EU Biodiversity Strategy[40] and Water Framework Directive[41]:** IWT competes with ecological priorities on waterways. Biologically sensitive corridors increasingly impose speed limits, emission restrictions, and noise requirements affecting vessel design beyond GHG targets.

31 European Commission, NAIADES III: Boosting Future-Proof European Inland Waterway Transport, COM(2021) 324 final (Brussels: European Commission, 24 June 2021), https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52021DC0324, 17.
32 Ibid., 17.
33 European Commission, Directorate-General for Mobility and Transport (DG MOVE), EU IWT Policy beyond 2027 Workshop: Final Draft Technical Summary (Brussels: European Commission, DG MOVE, 19 January 2026), organised by DG MOVE Unit D3, Inland Navigation Europe (INE) and PLATINA4Action, held at the Conference Centre Albert Borschette, 3–4.
34 European Commission, Sustainable Transport Investment Plan, COM(2025) 664 final (Brussels: European Commission, 5 November 2025), 3, 7–8, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2025:664:FIN.
35 Ibid., 8–12.
36 European Commission, European Water Resilience Strategy, COM(2025) 280 final (Brussels: European Commission, 4 June 2025), 3, https://environment.ec.europa.eu/publications/water-resilience-strategy_en.
37 Ibid., 3.
38 Ibid., 7–8.
39 Ibid., 8.
40 European Commission, EU Biodiversity Strategy for 2030: Bringing Nature Back into Our Lives, COM(2020) 380 final (Brussels: European Commission, 2020), https://environment.ec.europa.eu/strategy/biodiversity-strategy-2030_en.
41 Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 Establishing a Framework for Community Action in the Field of Water Policy (Water Framework Directive), OJ L 327, 22.12.2000, 1, https://environment.ec.europa.eu/topics/water/water-framework-directive_en.

- **Military Mobility framework:** The proposal for a Regulation on military mobility embeds defence requirements into the design, operation and governance of the Union's transport system through harmonised cross-border procedures and uninterrupted, secure movements.[42] It requires inland waterway transport, alongside other modes, to be adapted to dual-use functions capable of supporting both civilian logistics and military operations, with redundancy to road and rail networks and a contribution to crisis-response logistics.[43] It reinforces resilience against physical and hybrid threats and provides for coordination and pooling of transport capabilities across Member States and with NATO allies using EU-based infrastructure.[44]

42 European Commission, Proposal for a Regulation of the European Parliament and of the Council on Establishing a Framework of Measures to Facilitate the Transport of Military Equipment, Goods and Personnel across the Union, COM(2025) 847 final (Brussels: European Commission, 19 November 2025). https://transport.ec.europa.eu/document/download/4557a31a-0444-4489-a26f-2ef156f10d9f_en?filename=COM_2025_847.pdf.
43 Ibid., 27.
44 Ibid., 27.
45 European Commission, EU Industrial Maritime Strategy, COM(2026) 111 final (Brussels: European Commission, 4 March 2026), 12, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52026DC0111.
46 Ibid., 12, 16.
47 Ibid., 20.
48 European Commission, EU Ports Strategy, COM(2026) 112 final (Brussels: European Commission, 4 March 2026), 5-6, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52026DC0112.

- **Strategic supply-chain resilience and resilient port–hinterland logistics:** IWT provides a high-capacity, low-congestion transport option for essential bulk cargo, agricultural products, construction materials, energy-transition equipment, critical raw materials, circular-economy flows and emergency logistics. As an example, there is a need for resilient east-west logistics corridors linking the Black Sea, the Danube basin and Central Europe. IWT is increasingly relevant for continuity of supply chains, strategic autonomy, food security, reconstruction-related flows and dual-use mobility. This is particularly relevant where maritime routes face geopolitical disruption or capacity pressure. In parallel, industrial policy instruments such as the Net-Zero Industry Act, the Critical Raw Materials Act and the Clean Industrial Deal reinforce the need to strengthen European manufacturing capacity, supply-chain resilience and strategic autonomy.

  This driver stimulates investment in vessels as well as in fairway reliability, hydrographic and navigational information services, maintenance capacity, port interfaces and digital corridor coordination.

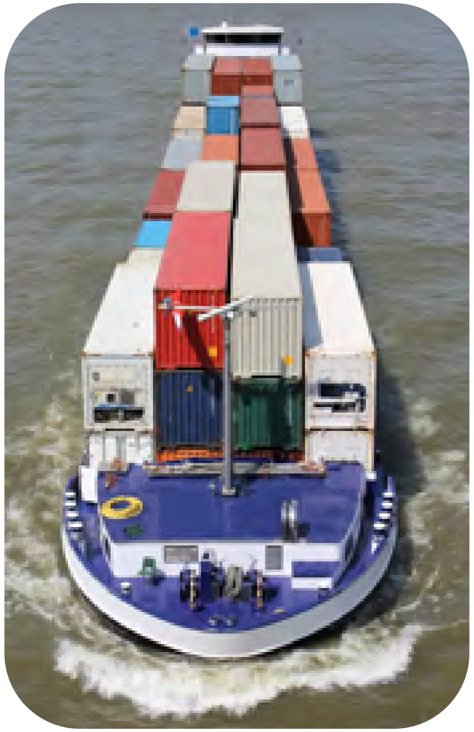
- **NIS2 and CER Directives**. NIS2 strengthens cybersecurity risk management, incident reporting and supervisory requirements for essential and important entities, while CER establishes a complementary all-hazards framework addressing the physical and operational resilience of critical entities. Their coordinated national implementation is important to avoid fragmented requirements and to ensure that cyber risks, physical threats, supply chain dependencies and cross-sector infrastructure interdependencies are addressed consistently. Together, the two directives drive investment in secure and resilient vessels, ports, waterway infrastructure, digital services and corridor management systems capable of maintaining and restoring essential transport services during disruptions.
- **EU Industrial Maritime Strategy:** The Strategy positions inland waterway transport within Europe's maritime industrial ecosystem, identifying IWT as an underutilised capacity constrained by ageing fleets, fragmented infrastructure and slow technological uptake.[45] It supports a follow-up to NAIADES III oriented towards port modernisation, infrastructure resilience and the deployment of zero- and low-emission vessels alongside digital and automated solutions, linked to Horizon Europe research ecosystems and the Zero Emission Waterborne Transport Partnership.[46] The announced Land and Multimodal and Transport Block Exemption designed to support fleet renewal and address cost differentials with road transport have been adopted by the European Commission.[47]
- **The EU Ports Strategy:** adopted on 4 March 2026, integrates inland waterway transport (IWT) as priority to absorb freight from larger vessels, shifting cargo away from stressed road networks.[48] It furthermore proposes an Action Plan on Inland Waterway Transport (IWT) for the period 2028-2034 and tackles the resilience of the inland waterways.
- **Digitalisation, automation and data-driven logistics:** Performance increasingly depends on interoperable digital systems, port community platforms, terminal operating systems, digital twins, AI-enabled planning, zero-emission and automated equipment and trusted data exchange with vessels, authorities and hinterland networks. Digitalisation is therefore a competitiveness driver, but also a condition for resilience, safety, energy optimisation and multimodal integration.

2.2. CONSTRAINTS

Inland waterway transport contributes to European decarbonisation through modal shift and energy efficiency, but its transition is structurally constrained by cost asymmetries, lack of alternative fuel availability, hydrological variability, impacts of climate change on waterways, awareness and digital gaps, and governance fragmentation.[49] The main constraints are set out below:

- **Cost gap between sustainable alternative and fossil fuels.** A persistent price differential between sustainable alternative and fossil fuels distorts market conditions. The resulting cost gap makes the transition to low and zero-emission inland waterway transport impossible.[50] Operators, in the mainly SME dominated sector, lack the ability to pass these costs onto customers, which reinforces a first-mover disadvantage and discourages early adoption. Fragmented policy frameworks have produced only marginal improvements in modal share, with measurable progress expected to occur primarily where strong financial incentives and the internalisation of CO_2 costs are combined.
- **Fuel availability and the chicken-and-egg dynamic.** Drop-in fuels such as Hydrotreated Vegetable Oil (HVO) are technically deployable across the existing fleet without engine modification and by making use of the existing infrastructure.[51] Supply remains constrained, costs remain substantially higher than fossil equivalents, and the business case for SME operators is weak. Investment in zero- and low-emission vessels depends on the availability of fuel infrastructure, while infrastructure deployment requires sufficient demand, producing a structural mutual dependency that slows uptake on both sides of the market. Creating the demand is the first priority and binding legal interventions on EU level are being evaluated to achieve this.
- **Financing and business-case constraints.** Many IWT operators have limited capacity to finance new vessels, retrofits or digital upgrades. The business case is often weakened by high upfront costs, uncertain fuel and energy-price differentials, charter arrangements, limited ability to pass costs to customers, uncertain residual values, vessel downtime during retrofit, and fragmented demand for green transport services. Without de-risking instruments, predictable demand and European long-term financial tools, first movers may face disproportionate costs. This may be further hampered by potential shortages in critical components and industrial capacity to renew or retrofit the current fleet. Retrofitting depends on shipyard capacity, vessels downtime, technical compatibility and financing.
- **Hydrological variability and climate impact.** Climate change increases the frequency of droughts and floods, alters water quality and degrades the ecological condition of inland waterways, with direct effects on both transport performance and ecosystem services.[52] Reduced water levels limit vessel payload, decrease the energy efficiency, increase emissions to air, increase unit costs and disrupt industrial supply chains that rely on waterborne transport, including for water supply to citizens, energy production, agriculture and industrial clusters.[53]

49 Inland Waterway Transport and Ports Sector, Statement on the Sustainable Transport Investment Plan (7 April 2025), 1–2.
50 Ibid.
51 Ibid., 1–2.
52 Inland Navigation Europe (INE), "INE Contribution to the Upcoming European Climate Resilience Framework" (Brussels: Inland Navigation Europe, 11 March 2026), 2.
53 Ibid., 2.



- **Insufficient and uneven capacity for fairway maintenance, hydrographic monitoring and rapid operational response along climate-vulnerable inland waterways.** Reliable navigation depends on continuous bathymetric surveys, dredging, aids to navigation, real-time water-level information, Notices to Skippers, maintenance vessels and qualified personnel. Where these capacities are limited or funded only through short-term projects, navigation reliability, vessel loading capacity and corridor competitiveness are directly affected. Fairway-management capacity and long-term operational funding are a key deployment bottleneck.
- **Port Infrastructure and fleet-investment mismatch.** A key bottleneck is the insufficient capacity and integration of port-side infrastructure needed to absorb higher inland waterway transport flows, such as quay availability, rail-road-water interface capacity, digital traffic management, storage capacity, customs/border processes, low-emission energy infrastructure and last-mile connections. Electricity grid capacity constraints (grid congestion) at port nodes delay projects that are already technically mature. Competition for use of port land and public domain between logistics, energy infrastructure and urban development limits the space available for new energy infrastructure at existing quays.
- **Multifunctionality of inland waterways.** Inland waterways function simultaneously as transport corridors and as ecological corridors supporting biodiversity, water regulation and nature-based solutions, which makes sustainability inherently systemic rather than sectoral.[54] This multifunctionality generates trade-offs between transport, environmental and industrial water uses that cannot be resolved through transport policy alone.
- **Infrastructure-vessel interaction.** The deployment of automated inland vessels depends on their ability to safely interact with waterway infrastructure, particularly locks, movable bridges and port facilities, as well as to cope with the water flows and other users of the waterway. Charging infrastructure at locks and on corridor infrastructure is technically feasible but requires coordination with waterway authorities, lock operators, and national road/rail agencies sharing corridor infrastructure.
- **Low-power density operation and energy storage space constraints.** Battery systems, hydrogen tanks, and fuel-cell modules compete for payload space and add weight reducing cargo capacity.
- **Hydrological variability and draft-dependent energy performance.** Low water levels force reduced payloads and increase specific energy consumption per tonne-km. Energy storage systems must be sized for worst-case hydrological conditions.
- **Awareness, information and capacity gaps.** Effective planning is limited by insufficient monitoring, modelling and forecasting capacities, and by a partial understanding of the multifunctional role of inland waterways within broader environmental and economic systems.[55] These gaps weaken the evidence base for effective EU policy making, corridor-level decisions and reduce the quality of cost-benefit assessments underpinning investment.
- **Policy silos and sectoral fragmentation.** Transport, energy, agriculture and environmental objectives are pursued independently, leading to conflicting or suboptimal outcomes for inland waterway transport. Policy effectiveness depends on combining measures into a coherent and integrated framework rather than on isolated interventions.

54 Ibid., 1.
55 Ibid., 2.

- **Digital governance fragmentation.** Real-time corridor management and data-sharing protocols advance with EuRIS and the new RIS Directive, but digital governance remains incomplete—notably in automation, interoperability standards with other modes, and cybersecurity frameworks. This fragmentation limits system efficiency and resilience and constrains the rollout of automation, predictive maintenance, and condition-based logistics.
- **Security and cyber-physical exposure.** Increasing automation and connectivity enlarge the cyber-attack surface of inland waterway transport. Critical infrastructure is exposed to sabotage and hybrid threats. Resilience must be designed into system architecture rather than added afterwards.
- **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. Automation, remote technical support and digital decision-support tools can improve safety, reduce workload and make inland waterway transport operations more attractive for future generations of waterborne 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-centred design will be necessary to ensure that digital and automated systems support rather than overburden crews and shore-based operators.
- **Governance and administrative burden.** Despite CESNI's uniform standards for vessels, crew and information technology, regulatory fragmentation, slow procedures, inconsistent interpretation and uneven enforcement across Member States create legal uncertainty that inhibits innovation.[56] Coordination of funding and infrastructure planning across Member States remains limited.[57] Excessive administrative burden and overlapping reporting requirements divert resources from implementation and innovation. Funding structures remain insufficient for long-term planning, and effective implementation requires clearer policy direction, measurable targets and stronger coordination between the EU and national levels.

To ensure a successful transformation of the European inland waterway transport sector, at European level, European institutions play a central role in setting strategic priorities, funding programmes and coordinating cross-border initiatives and creating the supporting regulatory framework. National governments translate these priorities into actionable strategies, supporting infrastructure development and fostering innovation ecosystems. Industry stakeholders, including shipowners, operators, shipyards, and equipment manufacturers, are critical drivers of change. Their investment decisions, operational needs and willingness to adopt new solutions will largely determine the pace of transformation. In parallel, research organisations and universities contribute by developing new technologies, testing concepts and supporting knowledge transfer. Port authorities and inland waterway operators also play a key role, as they provide the operational environment where innovations are implemented and scaled. Their involvement is essential for ensuring practical feasibility and integration into existing systems. Finally, workforce organisations, training institutions and social partners must be included to address skills development and workforce adaptation. Their engagement ensures that the human dimension is aligned with technological progress, enabling a sustainable and inclusive transition.

56 Ibid., 4–5.
57 Ibid., 2.

3. TARGET CAPABILITIES

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3.1. CURRENT STATE-OF-PLAY AND ACHIEVED DEVELOPMENTS

Inland waterway transport enters the transition with an ageing, heterogeneous and predominantly diesel-powered fleet, making retrofitting and compatibility with existing vessels central to technological deployment. While fleet renewal and uptake remain slow, several low- and zero-emission solutions have progressed beyond the conceptual stage.

Sustainable drop-in fuels can already be used in much of the existing fleet, while battery-electric propulsion, hybrid systems, exchangeable battery containers, hydrogen, methanol and fuel-cell applications are in early operation or demonstration on selected vessels and corridors. Technical standards are evolving to address batteries, electric propulsion and sustainable alternative fuels, but infrastructure availability, cost, safety approval and vessel-specific integration continue to limit broader uptake.

Digitalisation is more advanced. River Information Services, Inland AIS, electronic charts, electronic reporting, water-level information and voyage-planning services are already established on major waterways. Decision-support, remote monitoring and automated-navigation functions are operational, although higher levels of remote and autonomous operation remain at pilot or demonstration stage.

Overall, the sector has established the technical, regulatory and digital foundations for transition, but deployment remains limited in scale and uneven across vessels, corridors and Member States.

3.2. 2035: EARLY DEPLOYMENT PHASE

By 2035, inland waterway transport operates as a partially decarbonised (reducing at least 55% GHG emissions in line with the EU Climate Law), digitally supported and interoperable component of European logistics chains. Vessels run on a mix of low- and zero-emission energy carriers, including drop-in fuels and hybrid propulsion, while maintaining operational reliability and competitiveness. The widespread adoption of HVO supports the near-term transition to zero GHG emissions in IWT, which can be distributed via the use of the existing infrastructure. The system ensures availability of basic sustainable alternative fuel and energy infrastructure, ensuring sufficient onshore power supply for both passenger and freight carriers along the entire network of waterways, including swapping points for batteries and tanktainers, and superchargers for fixed batteries on board for both passenger and freight carriers along the network of waterways, enabling continuous operations.

By 2035, the wider deployment of electrification is supported by smart port energy management, interoperable charging systems and, where technically and commercially viable, bidirectional charging and flexibility services. European and national financing and incentive frameworks support investment in vessels and charging infrastructure, while common requirements and assessment methods address battery performance, safety, durability, lifecycle impacts and end-of-life management.

The transition relies on the deployment of sustainable alternative energy carriers and cross-sectoral integration across logistics and energy grid and energy value chains.[58] Ports developed into 'energy hubs' which gives opportunities for inland waterway transport to serve as transport lanes for supply and distribution of sustainable alternative fuels (e.g. ammonia, hydrogen, methanol, HVO) to various industries.

Vessels, ports and infrastructure are digitally connected, with in-advance data exchange and early-stage automation for routing, traffic management and energy use.[59] The system integrates into multimodal logistics chains, with synchronised operations between inland waterways, ports and hinterland transport in the entire logistics chain. Digital twins and AI-enabled traffic coordination are in initial deployment across terminal clusters. Automated vessel-traffic coordination is integrated with port digital platforms, integrated cybersecurity platforms are rolled out, and adaptive and nature-based port and waterway infrastructure demonstrated. Waterway administrations provide interoperable real-time and forecast-based navigation services, combining water-level data, hydrographic surveys, bathymetric information, dynamic draught advice, Notices to Skippers, traffic information and maintenance planning. A minimum capability for climate-adapted, low-emission public-service vessels is established. Inland waterway transport corridors are operationally integrated with TEN-T (maritime) ports through interoperable digital traffic and cargo data systems, improved port-call planning, and better water-rail-road coordination.

Digital and sustainable alternative-fuel training programmes for inland waterway transport crew and shore personnel are introduced. Education and training programmes have been updated, and crew members and onshore personnel upskilled.

Retrofitting capacity enables fleet transition, and operations demonstrate initial resilience to climate variability through adaptive vessel deployment and basic waterway management. These capabilities require coordinated deployment of innovation and system integration across stakeholders.[60]

3.3. 2040: SCALE-UP AND SYSTEM INTEGRATION PHASE

By 2040, the system delivers fully integrated, near zero-emission and digitally optimised operations across the waterborne ecosystem. Vessels largely operate on zero-emission energy carriers (including HVO) supported by widely available and interoperable alternative fuels infrastructure, in line with the objective of eliminating harmful emissions.[61] Operations rely on advanced digital systems, supporting high levels of automation, remote control and continuous system optimisation. Smart vessels, smart ports and smart administration and infrastructure operate through real-time data exchange and advanced automation.[62]

58 Waterborne Technology Platform, Strategic Research Agenda for the European Waterborne Sector, v5.0 (Brussels: Waterborne Technology Platform, June 2025), 9, https://www.waterborne.eu/images/250708_Strategic_Research_Agenda_Final.pdf.

59 Ibid., 9.

60 Waterborne Technology Platform, Waterborne Technology Leadership, 8; Waterborne Technology Platform, Strategic Research Agenda, 6.

61 Waterborne Technology Platform, Waterborne Technology Leadership, 18; Waterborne Technology Platform, Strategic Research Agenda, 9.

62 Waterborne Technology Platform, Waterborne Technology Leadership, 19; Waterborne Technology Platform, Strategic Research Agenda, 11.

Infrastructure functions adaptively and resiliently, with dynamic traffic management, integrated energy systems and climate-adapted design capable of handling extreme weather conditions and progressive climate change.[63] Inland waterway corridors operate through integrated digital corridor-management platforms. Operational safety reaches near-zero accident levels, supported by advanced monitoring systems, predictive management and cyber-secure operations.[64] The system is capable of large-scale retrofitting and affordable production, ensuring rapid deployment of new technologies across the fleet.[65]

3.4. 2050: FULL TRANSFORMATION PHASE

By 2050, inland waterway transport operates as a fully zero-emission, automated, climate resilient and system-integrated backbone of European transport and industrial ecosystems, including dual-use capacity. All harmful emissions are eliminated, and digitalisation fully unlocks data-driven operations, enabling highly efficient, reliable and sustainable transport systems.[66]

Operations are highly automated, with vessels navigating in coordination through fully digitalised infrastructure and decision-making systems.[67] Ports function as integrated energy and logistics hubs, managing energy flows, cargo and multimodal connectivity while ensuring zero-emission operations and circular resource use.[68]

Infrastructure, including inland ports, is climate-resilient, adapting to extreme climate conditions while maintaining continuous operations.[69] Inland waterways are managed as climate-resilient, digitally integrated transport systems maintaining agreed navigation-service levels under changing hydrological conditions. The system operates as a “system of systems”, integrating transport, energy, environmental monitoring, military mobility and blue economy activities, underwater operations and logistics coordination, positioning inland waterway transport as a key enabler of the broader blue economy and European resilience.[70]

3.5. CROSS-CUTTING CAPABILITY IMPLICATIONS

The target capabilities require coordinated progress across vessels, ports, waterways, energy systems, digital infrastructure, regulation, finance and skills. Technology choices must reflect vessel type, operating profile, fairway and infrastructure constraints, hydrological conditions and access to charging or renewable-energy supply; no single solution will suit all inland waterway operations.

Fleet transformation must combine newbuilds with affordable, modular and interoperable retrofit solutions for existing vessels, particularly for SMEs and owner-operators. Digitalisation, automation and the energy transition must develop within harmonised safety, cybersecurity, data and certification frameworks, supported by reliable vessel-shore-waterway connectivity.

Climate resilience and human-centred deployment are also essential. Vessel design, fairway management, port infrastructure, training and operating procedures must support safe and reliable operations under changing water levels, extreme weather and evolving onboard and shore-based roles.

63 Waterborne Technology Platform, Waterborne Technology Leadership, 21; Waterborne Technology Platform, Strategic Research Agenda, 14.
64 Waterborne Technology Platform, Waterborne Technology Leadership, 20; Waterborne Technology Platform, Strategic Research Agenda, 10.
65 Waterborne Technology Platform, Strategic Research Agenda, 12.
66 Waterborne Technology Platform, Waterborne Technology Leadership, 18, 20; Waterborne Technology Platform, Strategic Research Agenda, 9.
67 Waterborne Technology Platform, Waterborne Technology Leadership, 20; Waterborne Technology Platform, Strategic Research Agenda, 9.
68 Waterborne Technology Platform, Waterborne Technology Leadership, 23; Waterborne Technology Platform, Strategic Research Agenda, 16–17.
69 Waterborne Technology Platform, Waterborne Technology Leadership, 21–22; Waterborne Technology Platform, Strategic Research Agenda, 14.
70 Waterborne Technology Platform, Waterborne Technology Leadership, 24; Waterborne Technology Platform, Strategic Research Agenda, 14.

4. TECHNOLOGY PATHWAYS

4. TECHNOLOGY PATHWAYS

The Waterborne Technology Leadership priorities are translated into five technology pathways for inland waterway transport. The pathways reflect the specific characteristics of IWT, including its heterogeneous and ageing fleet, shallow-draft and low-speed operations, corridor dependence, hydrological variability, lock and bridge constraints, high share of SMEs and owner-operators, and close interaction between vessels, waterways, ports and inland logistics systems. They define the research, development and innovation needed to achieve the target capabilities set out in Chapter 3.

4.1. FUTURE PROPULSION AND ENERGY SYSTEMS ENABLING A ZERO-EMISSION INLAND WATERWAY TRANSPORT FLEET

The transition of inland waterway transport requires scalable, safe and cost-competitive propulsion and energy systems adapted to the diversity of inland vessels, corridors and operating profiles. Technology development should remain technology-neutral while prioritising energy efficiency, retrofitability, modularity, operational reliability and integration with charging, refuelling and port-energy infrastructure.

Particular attention is required to the existing fleet and the high share of SMEs and owner-operators. Solutions should therefore be affordable, modular and suitable for retrofit, while accommodating shallow-draft conditions and the diverse operating profiles of inland vessels. Relevant pathways include battery-electric and hybrid propulsion, sustainable drop-in fuels, hydrogen, methanol and other renewable energy carriers, fuel cells and renewable-assisted systems.

4.1.1 Operational objective

Enable cost-efficient, zero-emission inland navigation through propulsion and energy systems adapted to different vessel types, corridor operations and shallow-draft conditions, with strong potential for both retrofit and newbuild applications.

4.1.2 Target capabilities for 2035, 2040 and 2050

By 2035

- Scalable and affordable battery-electric solutions demonstrated and entering operation on suitable dedicated corridors, including container transport, urban and regional services (TRL 8-9), supported by:
  - Quayside charging during downtime,
  - Intermediate fast recharging,
  - Charging during regular operational stops (locks, stopovers),
  - Battery transfer or swapping where appropriate
- Fuel-flexible and upgradeable energy concepts validated for the use of sustainable alternative fuels suited to corridor and vessel requirements (TRL 6-8)
- Hybrid-electric and solar assisted retrofit concepts validated for legacy barges (TRL 6-7)
- Hydrogen, methanol and fuel-cell propulsion concepts demonstrated on selected core TEN-T inland waterway corridors (TRL 7-9)
- Integrated energy-management systems demonstrated for battery, hybrid and multi-energy vessel configurations (TRL 6-8)

By 2040

- Standardized zero- and near zero-emission propulsion solutions commercially deployable across the main inland vessel segments (TRL 7-9)
- Battery-electric, hybrid and sustainable alternative fuel solutions deployed across suitable corridors and operating profiles (TRL 8-9)
- Containerised and modular energy systems available for different barge and vessel configurations (TRL 8-9)
- Fuel flexible propulsion and energy systems enable adaptation to different sustainable energy carriers and corridor conditions (TRL 8-9)

By 2050

- Zero-emission propulsion and energy solutions deployed across the inland waterway fleet (TRL 9)
- Standardised modular propulsion architectures widely available for both retrofit and newbuild vessels (TRL 9)
- Zero-emission propulsion technologies deployed at scale across European inland waterways. (TRL 9)

4.1.3 Key research gaps

- Scalable and cost-competitive zero- and near-zero-emission propulsion solutions for different inland vessel types and operating profiles
- High energy density, lightweight and durable batteries compatible with shallow draft operations
- Fast charging and battery swapping solutions suited for corridor operations and vessel schedules
- Modular zero-emission propulsion and energy system solutions for cost effective retrofit of existing vessels
- Integrated power- and energy-management systems for variable load profiles and multi-energy vessel configurations
- Cost efficient, fuel flexible energy conversion systems capable of accommodating different sustainable energy carriers
- Performance, degradation and lifecycle optimisation of batteries and other energy-storage systems under IWT operating conditions
- Validation of hydrogen, methanol, fuel-cell and renewable-assisted propulsion solutions under representative inland waterway conditions

4.2. INTELLIGENT SAFETY, SECURITY AND RESILIENCE AS FOUNDATIONAL ENABLERS

As vessels and operations become more digital, interconnected and dependent on new energy technologies, safety, security and resilience become essential conditions for deployment. Research should support predictive safety and risk management systems, cyber-resilient vessel-shore interaction, enhanced sensing and incident response, and safe operation of sustainable alternative fuels, electrification and automated systems.

Resilience should address the ability to plan and prepare for, absorb, respond to and recover from and adapt to disruptions, including extreme weather, changing water levels, infrastructure failures, cyber incidents and loss of connectivity. This pathway provides the safety, security and resilience foundations for the connected, remote and automated capabilities developed under Section 4.3.

4.2.1 Operational objective

Enable safe, resilient and interconnected inland waterway operations through predictive risk management, cyber-resilient vessel-shore systems, reliable incident detection and response, and validated safety concepts for new energy technologies and increasingly automated operations.

4.2.2 Target capabilities for 2035, 2040 and 2050

By 2035

- Collision avoidance concepts utilising automatic vessel to vessel, shore to vessels and shore to shore communication demonstrated, including interaction with non-RIS users (e.g. boating) (TRL 7-8)
- Automatic safety incident communication between vessels, ports and waterway operators demonstrated (TRL 7)
- Risk-based automatic re-routing guidance demonstrated using traffic, incident and weather information (TRL 7)
- Cyber-resilient and redundant data and communication systems demonstrated (TRL 8)
- Enhanced forecasting supports safe navigation under changing water level and weather conditions (TRL 8)
- Climate-resilient concepts integrating vessel, infrastructure, information and logistics systems demonstrated (TRL 8)

By 2040

- Automatic safety incident communication deployed across connected inland waterway operations (TRL 8-9)
- Dynamic risk-based re-routing and predictive safety systems deployed in corridor operations (TRL 8-9)
- Cyber-resilient and redundant vessel-shore systems widely deployed (TRL 9)
- Safety and resilience cases validated for remote and highly automated inland waterway navigation deployed in corridors (TRL 8-9)
- Integrated safety management supports operations under extreme weather, infrastructure disruption and degraded connectivity

By 2050

- Continuously assured safety and cyber resilience support highly automated inland waterway operations.
- Predictive and adaptive safety systems respond dynamically to operational, environmental and cyber risks.
- Integrated vessel-shore-infrastructure safety systems support rapid response, recovery and continuity of operations.

4.2.3 Key research gaps

- Predictive safety and dynamic risk assessment under changing traffic, weather and waterway conditions.
- Safety and resilience of operations under degraded or lost connectivity.
- Incident-response and fallback concepts for remote and automated operations.
- Validation of safety, security and resilience cases under real traffic and mixed-operation conditions.
- Cybersecurity and cyber-physical resilience of connected vessel, shore and waterway systems.
- Safety of batteries, sustainable alternative fuels and high-voltage systems, including detection, emergency response and coordinated vessel-shore procedures.
- Resilience of vessels and operations to extreme weather, low and high-water levels and critical infrastructure disruption.
- Integrated sensing, early warning and decision-support systems for collision, fire, fuel leakage, cyber incidents and other operational hazards.

4.3 FULLY CONNECTED, AUTOMATED AND DATA-DRIVEN INLAND WATERBORNE SYSTEMS

The future waterborne system will function as a continuously connected network where vessels, ports, waterways and logistics nodes share data and optimize operations in real time and in advance. Priorities include interoperable digital architectures, remote and autonomous vessel functions, advanced sensing and communication systems, digital twins, and AI-supported traffic and logistics coordination. These developments can improve efficiency, reliability and safety, reduce emissions and support new business models based on service provision and lifecycle optimization. Automation should progress from decision and remote assistance towards higher levels of automated operation, while maintaining appropriate human oversight and safe fallback. Particular attention is required to vessel-infrastructure interaction, as automated inland navigation depends on reliable coordination with locks, movable bridges, River Information Services and waterway traffic management systems.

4.3.1 Operational objective

Enable connected, data-driven and increasingly automated inland waterway operations through secure connectivity, interoperable digital systems, remote operations and coordinated vessel-infrastructure interaction.

Develop automated and remotely supported navigation through locks, movable bridges, narrow passages and traffic-managed areas, supported by real-time exchange of infrastructure status, passage permissions, operating instructions and vessel route, timing and manoeuvring information.

Demonstrations of remote and automated operations should also provide the operational evidence needed to define responsibilities, liability and insurance arrangements associated with autonomous operations.

4.3.2 Target capability 2035, 2040 and 2050

By 2035

- Reliable and continuous high-bandwidth connectivity along inland waterways, including cross-border corridors (TRL 7-9)
- Redundant communication architectures (e.g. 4G/5G/satellite hybrid solutions) to ensure safe remote/automated operations (TRL 6-8)
- Common data standards supporting interoperability between vessel, shore and waterway systems
- Corridor Management Services and Remote Operations Centres (ROC) supervising multiple vessels under defined safety and security frameworks (TRL7-8)
- Autonomous vessel-traffic coordination demonstrated in mixed traffic with automated and conventionally operated vessels (TRL 7–8).
- Augmented-reality navigation and decision-support solutions demonstrated for challenging operating conditions (TRL 7).
- Automated lock- and bridge-passage functions demonstrated under real operating conditions, including approach planning, slot allocation, vessel positioning, infrastructure-status exchange and safe fallback procedures. (TRL 6-8)
- Standardised vessel-infrastructure communication interfaces demonstrated between automated or remotely operated vessels, locks, bridges, River Information Services and waterway traffic-management systems. (TRL 6-8)

By 2040:

- Highly automated inland navigation deployed on suitable corridors under validated safety and operational frameworks (TRL 8–9).
- Mature automation and robotics deployed in inspection, maintenance and other suitable operational functions (TRL 8–9).
- Digital twins evolve into predictive and prescriptive tools, enabling proactive capacity management and disruption mitigation. Port digital twins are widely integrated and used by operators and port authorities (TRL 7–9).
- Interoperable automated lock transit, bridge passage and traffic-management interaction deployed along selected inland waterway corridors, including cross-border operations and mixed traffic with conventionally operated vessels. (TRL 8-9)
- Remote Operations Centres support increasingly advanced multi-vessel supervision and corridor-scale operations (TRL 8–9).

By 2050

- Highly automated inland waterway operations are deployed at scale, while human operators supervise and intervene where required. (TRL 9)
- Vessels, waterway infrastructure, ports and traffic-management systems operate as an integrated digital corridor system. (TRL 8-9)
- AI-supported systems continuously optimise navigation, traffic coordination, infrastructure use and logistics operations. (TRL 8-9)
- Automated vessel-infrastructure interaction is standard across suitable locks, bridges and traffic-managed sections of the European inland waterway network. (TRL 9)

4.3.3 Key research gaps.

- Multi-vessel supervision and Remote Operations Centre concepts.
- Data latency, reliability and availability requirements for remote and automated navigation
- Cybersecurity frameworks for remote vessel, shore systems and Remote Operations Centres
- Performance and resilience of communication networks in critical areas (e.g. locks, bridges, border regions)

- Fail-safe operational concepts and fallback modes under degraded or lost connectivity
- Integration of multi-channel communication technologies (cellular, satellite, radio)
- Automated approach, entry, positioning, transit and exit at locks.
- Automated interaction with movable bridges and restricted-clearance passages.
- Cooperative vessel-infrastructure decision-making and passage sequencing.
- Safe operation in mixed traffic involving automated, remotely operated and conventionally operated vessels.
- Validation of vessel-infrastructure interoperability under degraded communications, inaccurate positioning and infrastructure failure.
- Common digital communication standards and machine-readable operational messages for vessels and waterway operators.

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

The transition of inland waterway transport depends on people as much as on technology. In the IWT and Ports sector, people are at the centre, without neglecting the impact of digital transformation on the individual. Electrification, sustainable alternative fuels, digitalisation, remote support and automation will change tasks, responsibilities and competence requirements both on board and ashore. Human-centred design, intuitive decision-support systems, ergonomic interfaces and appropriate workload management should therefore be integrated into technology development.

R&I should also support human-machine teaming, XR and simulation-based training, safe working conditions and effective human oversight of increasingly automated systems. Particular attention is required to the needs of SMEs and owner-operators, for whom digital and automated systems must remain accessible, understandable and practical to operate.

4.4.1 Operational objective

Development of adaptive, real-time decision support systems tailored to human operators onboard and ashore, and advance human-centred simulation and optimization methods that improve voyage planning, execution and interaction with increasingly digital and automated systems. Human centred design is supposed to attract people to the sector.

4.4.2 Target capabilities for 2035, 2040 and 2050

By 2035

- XR assisted decision support concepts demonstrated for congested, narrow, shallow water operations and other challenging conditions (TRL 6-7)
- Human-centred interfaces and decision-support systems demonstrated for onboard and shore-based operators (TRL 6-8).
- XR and simulation-based training demonstrated for new energy technologies, automated systems and emergency situations (TRL 6-8).
- Remote diagnostics and shore-based operational support increasingly integrated into vessel operations (TRL 7-8).

By 2040

- Human-machine teaming and decision-support systems integrated into highly automated inland waterway operations (TRL 8-9).
- Human-AI interaction and fallback procedures validated for onboard and Remote Operations Centre operators (TRL 8-9).
- XR-based training and simulation routinely support maintenance, emergency response and automated operations (TRL 8-9).
- Human-centred interfaces support effective supervision of multiple vessels and increasingly complex shore-based operations (TRL 8-9).

By 2050

- Mature human-automation teaming supports routine highly automated vessel and corridor operations (TRL 9).
- Adaptive and explainable decision-support systems provide context-specific assistance to onboard and shore-based operators (TRL 9).
- Continuous XR, simulation and competence-support tools are integrated into vessel and shore-based operations (TRL 9).

4.4.3 Key research gaps

- Human factors in remote and automated operations, including fatigue, situational awareness, workload
- Human-machine teaming in mixed-autonomy operations, including allocation of responsibilities, intervention thresholds and safe fallback.
- Explainable and trustworthy AI-supported decision-making for onboard and shore-based operators.
- Human factors and trust in AI-supported maintenance and autonomous functions.
- Design and validation of intuitive, low-complexity digital interfaces suitable for SMEs and owner-operators.
- Human-centred design of Remote Operations Centres, including multi-vessel supervision, alarm management and operator workload.
- Effectiveness of XR and simulation-based training for routine and rare-but-critical operating situations.
- Competence requirements and human-performance implications of new fuels, electrification, remote operations and increasing automation.

4.5 FORWARD LOOKING REGULATION, STANDARDIZATION AND SYSTEM-LEVEL CORRIDOR INTEGRATION

Regulation, standardisation and certification will shape the speed and scale of technological deployment in inland waterway transport. Sustainable alternative fuels, electrification, remote and automated operations, data governance and cyber resilience require harmonised frameworks that provide safety, investment certainty, a level playing field and cross border acceptance. RD&I should support the development and validation of goal-based rules, technical standards, certification approaches and regulatory sandboxes alongside technological development.

Common standards are also essential for system-level integration, ensuring interoperability between vessels, ports, waterways, energy infrastructure and digital systems. This includes standardized interfaces, data exchange and consistent methods for assessing and comparing environmental performance.

4.5.1 Operational objective

Support the transition towards zero-emission, digital and increasingly automated inland waterway transport through forward-looking, technology-neutral and harmonised regulatory, standardisation and certification frameworks. Develop common standards and assessment methods that enable system interoperability, cross-border deployment and transparent comparison of environmental performance.

4.5.2 Target capabilities for 2035, 2040 and 2050

By 2035

- Harmonised, goal-based European frameworks support the approval and cross-border operation of emerging IWT technologies.
- Adaptive regulatory mechanisms enable timely incorporation of new fuels, propulsion systems and other technologies, including more flexible updating of requirements under the NRMM framework.
- Harmonised methods and common interpretation practices support comparable calculation and reporting of transport emissions, building on standards such as ISO 14083.

- Common interoperability and communication requirements are established for vessel, shore and waterway systems.
- Responsibilities, liability and insurance arrangements for remote and autonomous operations are progressively defined.
- A proper regulatory framework providing a clear business-economic feasibility for the broad use of renewable energy in IWT

By 2040

- Mature certification and approval pathways support sustainable alternative fuels, electrification, automation, digital systems and cybersecurity.
- Mutual recognition of testing, certification and approval evidence facilitates deployment across Member States and inland waterway corridors.
- Standardised interfaces and data-exchange requirements support interoperable vessel, shore and waterway systems.

By 2050

- Harmonised regulation, standards and certification support zero-emission, highly automated and digitally integrated inland waterway operations across Europe.
- Regulatory and technical frameworks can accommodate continuous technological development without requiring lengthy revision cycles.

4.5.3 Key research gaps.

- Harmonised methodologies and interpretation of standards to enable fair comparison of environmental performance across vessel types, technologies and operating profiles.
- Regulatory approaches and updated mechanisms that allow timely incorporation of emerging technologies without requiring lengthy revision cycles.
- Safety-case, risk-assessment and alternative-design methodologies for innovative propulsion, energy, digital and automated systems.
- Certification and assurance approaches for AI-supported and continuously updated software systems.
- Cybersecurity standards and assurance requirements for connected vessel, shore and waterway systems.
- Common technical standards, interfaces and data models supporting interoperability between vessels, ports, locks, bridges, River Information Services and other waterway systems.
- Mutual recognition and transferability of testing, certification and approval evidence across Member States and relevant authorities.
- Approaches for maintaining and updating approvals as software, energy systems and operational concepts evolve during the vessel lifecycle.
- Adaptation of existing private-law and liability frameworks to remote and autonomous operations, including allocation of responsibilities and associated insurance requirements.

5. ENABLERS AND DEPLOYMENT

5. ENABLERS AND DEPLOYMENT

The technology pathways identified in Chapter 4 require coordinated enabling conditions to move from research, demonstrations and first-of-a-kind applications towards wider deployment across inland waterway corridors, fleets, ports and logistics systems. Deployment must therefore address vessels, waterways, ports, energy infrastructure, digital systems, regulation, finance and skills together. Particular attention is required to the heterogeneous and ageing IWT fleet, the large share of SMEs and owner-operators, cross-border operations and the strong dependence of inland navigation on fairway, lock, bridge and port infrastructure.

5.1. CORRIDOR-BASED DEPLOYMENT AND SYSTEM INTEGRATION

Deployment should be organised around strategic inland waterway corridors and inland ports. The Rhine, Danube and other TEN-T inland waterway corridors should function as living deployment environments where vessels, ports, energy suppliers, infrastructure managers, shipyards, equipment manufacturers, classification societies, authorities and logistics users jointly develop scalable solutions. This approach reflects current practice in EU-funded and sector-led initiatives, where clean energy infrastructure, digital services, renewable energy corridors, green energy container systems and remote-operation concepts are increasingly tested in real operating environments.

A corridor-based approach is necessary because the feasibility of each technology depends on the full operating system: vessel type, route length, cargo profile, fairway depth, water-level and flow velocity variability, port infrastructure, energy availability, grid capacity, terminal operations, lock and bridge constraints, safety procedures and commercial demand.

Initial deployment should therefore prioritise routes with high traffic density, predictable operations and strong potential for early uptake.

Initial deployment corridors should validate renewable energy supply, bunkering and charging, green energy container exchange, digital traffic management, lock and bridge coordination, predictive water-level and voyage planning information, emission reporting, remote-operation procedures, safety cases and business models. Particular attention should be given to automated vessel infrastructure interaction at locks, movable bridges and traffic-managed sections.

The aim should be to move from individual pilots to replicable corridor packages that combine vessels, infrastructure, energy supply, digital services, operational procedures, regulatory approval and financing. Once validated on suitable corridors, these packages should be transferable to lower-volume, more complex or more climate-sensitive waterways.

5.2. RENEWABLE ENERGY SUPPLY, REFUELLING AND CHARGING INFRASTRUCTURE

Energy availability is a key condition for the transition of inland navigation to a zero-emission mode of transport. Different vessel types and operating profiles will require different combinations of sustainable drop-in fuels, battery-electric propulsion and hydrogen, methanol and other renewable energy carriers. Infrastructure development should therefore remain technology-neutral and avoid premature dependence on a single energy pathway. Battery-electric solutions and exchangeable battery containers are already entering early operational use on suitable routes, while other renewable energy technologies and related infrastructure are being demonstrated. These developments show that different energy pathways will be suitable for different operating profiles. Battery-electric solutions are most relevant in the near term for predictable routes with regular terminal calls, such as container shuttles, ferries, passenger vessels, urban logistics and short-distance push operations. Hydrogen, methanol and other renewable fuels will require dedicated bunkering infrastructure, safety procedures, storage solutions and integration with renewable energy production and distribution systems.

Ports and terminals should become the main energy nodes of the inland waterway system. They should provide onshore power supply, high-capacity charging, battery exchange, renewable-fuel bunkering and links to local energy systems. OPS should gradually evolve from hotel-load supply at berth towards charging infrastructure for propulsion batteries, including intermediate fast charging, overnight charging, sequenced charging during regular downtime and heating and cooling of goods for both passenger and freight vessels. Clean-energy infrastructure should be planned at corridor level, linking vessel demand, port capacity, grid readiness, fuel availability, safety requirements and logistics flows.

5.3. FLEET RETROFITTING, SHIPYARD CAPACITY AND INDUSTRIAL READINESS

Because much of the inland fleet will remain in operation for decades, retrofitting must be a central deployment pathway. Wider uptake will require modular, affordable and repeatable solutions adapted to different vessel categories, routes and operating profiles, including legacy barges and push-tow configurations.

Standardised propulsion modules, battery and charging systems, fuel storage arrangements, electrical drivetrains, energy-management systems, after-treatment systems, control systems and safety packages can reduce costs, shorten vessel downtime, and simplify certification. Retrofit planning should begin well before the vessel enters the shipyard, with equipment preparation, prefabrication, interface definition, cabling and system integration undertaken in advance wherever possible. This can substantially reduce installation time, off-hire periods and the overall cost of retrofit.

Shipyards, equipment manufacturers, classification bodies, and technology suppliers should prepare for larger-scale retrofit programmes through modular designs, common technical specifications, interoperable interfaces, adequate yard capacity and skilled personnel. Standardised and, where possible, pre-certified retrofit packages should enable repeated application rather than one-off pilot conversions.

Demonstration and deployment projects should increasingly move towards efficient retrofit processes, including pre-engineering, prefabrication, installation sequencing, commissioning and coordination between vessel operators, shipyards and equipment suppliers.

Deployment models should increasingly combine technology provision with maintenance, energy supply, digital services and financing. Such integrated service models are particularly important for SMEs and owner-operators that may lack the financial and technical capacity to manage complex conversions independently.

5.4 DIGITAL INFRASTRUCTURE, DATA GOVERNANCE AND SMART CORRIDOR MANAGEMENT

Digital infrastructure is a prerequisite for efficient, safe and resilient and increasingly automated inland waterway operations. River Information Services (RIS) and the European RIS environment provide an important foundation through services such as water-level information, lock and bridge operating information, route planning and notices to skippers. These services should progressively evolve towards interoperable corridor-level systems that combine vessel, waterway, port, traffic, energy and logistics information.

Reliable and redundant connectivity should be available along key inland waterway corridors, including cross-border sections and critical areas such as locks, bridges, port approaches, urban waterways and congested traffic zones. Minimum requirements for bandwidth, latency, availability and failover performance are particularly important for remote and automated operations. Different communication channels, including cellular, satellite and radio systems, should be integrated where necessary to provide operational resilience.

Common data standards and interoperable communication protocols are required between vessels, RIS, ports and terminals, locks, bridges, traffic-management systems and Remote Operations Centres. Standardised vessel–shore and vessel–infrastructure interfaces should support the exchange of operational information, including waterway conditions, infrastructure status, passage availability and permissions, vessel route and timing information, and emergency or safety messages.

The modernisation of RIS should support a wider digital corridor architecture capable of providing predictive and proactive services rather than information only on request. This should include advanced voyage and traffic planning, predictive water-level information, lock and berth coordination, multimodal logistics integration, automated emission reporting, energy planning and remote-operation support. Digital twins and AI-supported corridor-management tools can progressively support capacity management, disruption mitigation and more efficient use of waterway infrastructure.

Data governance should ensure adequate data quality, timeliness, accessibility and interoperability while protecting commercially and privacy sensitive information and supporting appropriate data-sharing between public and private actors. Cybersecurity, secure data exchange and clearly defined responsibilities for data provision, access and use should be embedded in digital corridor services from the outset.

Remote and automated operations will also require formal integration of Remote Operations Centres into the wider digital ecosystem, including interoperable communication with vessel systems, RIS and waterway infrastructure. Cross-border interoperability, telecom roaming performance and common operational interfaces are therefore essential for scaling these services beyond individual pilots and national systems.

5.5. REGULATION, STANDARDS AND CERTIFICATION

A stable, goal-based and technology-neutral EU regulatory framework is essential for investment certainty. At the same time, regulatory frameworks need to be sufficiently flexible and adaptive to accommodate emerging technologies without lengthy delays between technological development and regulatory acceptance. Approval mechanisms should enable timely introduction of new technologies while maintaining equivalent safety and environmental performance.

EU Regulatory sandboxes and controlled corridor demonstrations should be used to test new concepts under representative operating conditions and generate evidence for permanent regulatory and certification pathways. This is particularly relevant for sustainable alternative fuels and renewable energy carriers, exchangeable energy containers, high-voltage battery systems, remote operations, reduced crew concepts, automated navigation and vessel infrastructure interaction.

Existing technical frameworks should evolve towards timely, goal-based requirements that can accommodate new technologies, including updates to the NRMM framework and harmonised fuel-safety provisions under ES-TRIN and ADN.

Harmonised frameworks for remote and automated operations should cover ROC recognition, human roles and competencies, fallback and reduced-crew concepts, certification, cross-border acceptance, liability and insurance responsibilities.

Common standards, communication interfaces and data requirements should ensure interoperability between vessels, RIS, ports, locks, bridges, traffic-management systems and Remote Operations Centres.

Certification should support mutual recognition and transferability of approval evidence across Member States and accommodate technologies that evolve after initial approval, including software, AI-supported systems and modular energy solutions.

Common interpretation of environmental accounting standards, including ISO 14083 where applicable, should enable transparent and comparable emission assessment and set clear benchmarks.

5.6. FINANCE, BUSINESS MODELS AND MARKET UPTAKE

The main deployment barrier is often not technological readiness but the absence of a positive business case. Sustainable alternative fuels and energy carriers and zero-emission technologies remain more expensive than conventional diesel, while many operators cannot easily pass higher costs to cargo owners or passengers. This creates first-mover disadvantages and delays investment, especially among SMEs and owner-operators.

EU, national and regional funding should support retrofitting, newbuilds, charging and refuelling infrastructure, sustainable fuel cost gaps and first movers. Financial instruments may include grants, guarantees, low interest loans, de-risking instruments, contracts for difference or similar mechanisms, and revenue recycling from market-based instruments where applicable. Funding and financing mechanisms should be accessible to SMEs and owner-operators and reflect the scale and characteristics of inland navigation investments.

New business models such as energy-as-a-service, battery-as-a-service, shared infrastructure and green corridor partnerships can reduce upfront costs and distribute risks across the value chain. Public procurement, green transport contracts, stable cargo-owner commitments, cooperative fuel purchasing and shared infrastructure models should also be used to create demand and reduce market risk.

Financiers and insurers should be involved early in innovative deployment projects so that technology and operational risks can be assessed and progressively reduced, supporting the transition from demonstration to commercially viable deployment.

5.7 CLIMATE RESILIENCE, SAFETY AND SECURITY

Technology deployment must be combined with climate-resilient infrastructure and operations. Water level information, hydrological forecasting, traffic management and digital navigation support are already used to manage operational risks. These efforts should be strengthened through vessel design, fairway management, port planning and corridor operations that address low- and high-water conditions, shallow-draft optimisation, dynamic loading, predictive water-level services, resilient port and waterway infrastructure and emergency response.

Safety and security must remain central to deployment. Sustainable alternative fuels, batteries and high-voltage electrical systems introduce new operational risks, while digitalisation, remote operations and automation increase cyber and connectivity related exposure. Harmonised safety procedures, emergency-response plans, cybersecurity requirements, incident reporting, resilience testing and fallback procedures should accompany every deployment phase.

For remote and automated operations, particular attention should be given to degraded or lost connectivity, positioning failures, human responsibility, mixed traffic and interaction with locks, bridges and traffic management systems. Reliable and redundant communication infrastructure, standardised fallback procedures and coordinated vessel-shore emergency arrangements are essential for safe operation under degraded conditions.

Ports, terminals and congested or infrastructure-critical areas should establish appropriate safety zones and coordinated procedures for incidents and emergencies. Cross-border acceptance of safety, security and resilience arrangements will also be necessary for scaling remote and automated operations beyond individual corridors and national systems.

5.8 SKILLS, WORKFORCE TRANSITION AND SOCIAL ACCEPTANCE

The green and digital transition will change the skills required in inland navigation. Training and certification should evolve alongside sustainable alternative fuels, electrical and high-voltage systems, digital navigation, cybersecurity, automation, remote operations, emergency response and emission reporting.

Remote and automated operations require particular attention to human factors, workload, situational awareness, fatigue, responsibility allocation and fallback roles. Harmonised minimum competency requirements and training and certification standards should be developed for onboard personnel and Remote Operations Centre operators, together with appropriate approaches for reduced crew concepts.

XR, simulators and digital training platforms can support upskilling and continuous professional development, especially for complex or high-risk situations such as alternative fuel handling, battery incidents, low-water navigation, congested port approaches, cyber incidents, degraded connectivity and remote-operation procedures.

Social dialogue, targeted training funding and flexible pathways into the profession will be necessary to address labour shortages and support a socially sustainable transition. Human-centred technology development, safe working conditions and attractive career opportunities should remain central to deployment.

5.9. DEPLOYMENT MILESTONES

By 2035, selected zero-emission and digital corridors are operational. Sustainable drop-in fuels are available under stable and cost competitive conditions; OPS is deployed at key nodes; first high-capacity charging and battery-swapping solutions are in commercial use on suitable routes; hydrogen, methanol and other renewable energy solutions operate under validated safety frameworks; and digital corridor services support advanced voyage planning, predictive water-level information, emission reporting and first remote and automated operations.

By 2040, deployment moves from pilots to wider scale. Zero-emission propulsion solutions are commercially available for the main vessel segments and supported by interoperable charging and refuelling infrastructure along core corridors. Digital corridor management, predictive fairway management, remote-operation support, and cyber-secure data exchange are widely deployed. Standardised retrofit packages, mature shipyard processes and harmonised certification pathways support large-scale fleet conversion.

By 2050, inland waterway transport operates as a zero-emission, digitally integrated and climate-resilient system. Vessels, ports, waterways, energy systems and logistics platforms function as an interoperable network supporting highly automated operations, reliable multimodal supply chains, circular economy flows, and resilient European transport corridors.

6. EXPECTED IMPACTS

6. EXPECTED IMPACTS

The implementation of this roadmap is expected to support the transformation of inland waterway transport into a zero-emission, resilient, digitally connected and commercially competitive component of the European transport system. The impacts will depend on sufficient availability of sustainable alternative fuels at an economically feasible price, the coordinated deployment of clean-energy infrastructure, fleet retrofitting, digital corridor services, regulatory certainty, finance and funding, climate resilience and skills development. Table 1 provides indicative expected impacts, which will be further refined at implementation.

ENVIRONMENTAL	ECONOMIC
2035: 15-20% average CO_2 intensity reduction versus 2020 IWT fleet; electric operation on 15% of short distance IWT vessels, SAF deployed on 15% of the fleet, zero-emission at berth on 25% of Inland ports **2040:** 45-50% CO_2 intensity reduction; electric operation on 30 % of short distance IWT vessels, sustainable alternative fuels deployed on 50% of the fleet, zero-emission at berth on 50% of Inland ports **2050:** Zero-emission IWT fleet; 90%+ CO_2 reduction vs. 2020;	**2035:** 500 IWT vessels retrofits with hybrid/solar/battery systems, fuel cost savings of € 300 – 500M/year, shore-power available at 25% of major inland ports, 1.200 new jobs in IWT retrofit services **2040:** 1.000 additional IWT vessels retrofits with hybrid/solar/battery systems, fuel cost savings of € 600 – 950M/year, shore-power available at 50% of major inland ports, 2.500 new jobs in IWT retrofit services **2050:** Zero-emission IWT fleet, fuel cost savings of € 2B/year, 5.000 new jobs in IWT retrofit services
TECHNOLOGICAL	**SOCIAL**
2035: aligned approval for systems/technologies by different regulatory bodies, energy management integrated and remote control and automation on 500 vessels, 25 charging infrastructure demonstrations at locks on major European corridors **2040:** Energy management integrated and remote control and automation on 1,000 vessels, 50 charging infrastructure demonstrations at locks on major European corridors **2050:** Full system of systems digital integration; remote/autonomous operations in place; 95%+ battery and component material recovery	**2035:** 4,000+ IWT crew members and port personnel trained in new technologies **2040:** 8,000+ trained; SME digital transformation complete for 80%+ of operators **2050:** 20,000+ trained

Table 1: Indicative Expected Impacts

6.1. ENVIRONMENTAL AND CLIMATE IMPACTS

The roadmap facilitates the elimination of greenhouse gas emissions from inland waterway transport through the use of certified sustainable drop-in fuels, cleaner engines, energy-efficiency measures and operational optimisation in the short term, and through battery-electric propulsion, hydrogen, methanol and other renewable energy carriers in the medium and long term. It also eliminates air pollutant emissions, particularly in ports, urban waterways and densely populated river corridors, through shoreside electricity, cleaner propulsion systems and improved voyage planning.

6.2. MODAL SHIFT AND LOGISTICS-CHAIN IMPACTS

Zero-emission, reliable and better-connected IWT services strengthen the entire multimodal logistics chains via a stronger role of inland navigation.

Improved corridor management, water-level information, future proof and resilient waterways, berth and lock coordination, emission reporting and multimodal data exchange make IWT a more predictable and transparent option for shippers, ports and logistics integrators. This supports modal shift, especially in new markets and for bulk cargo, containers, construction materials, industrial inputs, sustainable alternative fuels, circular-economy flows and regular port-hinterland connections as well as sustainable tourism on inland waterways.

The roadmap also strengthens the dual-use role of inland waterways by improving their capacity to support both civilian logistics and, where required, military mobility and crisis-response operations. Greater use of IWT can provide additional transport capacity and redundancy to road and rail networks, while supporting strategic supply chains, emergency logistics and European transport resilience.

6.3. COMPETITIVENESS AND INDUSTRIAL IMPACTS

The roadmap strengthens the competitiveness of the European IWT sector and the wider waterborne technology ecosystem. Retrofitting, zero-emission propulsion, digital systems, battery-container solutions, hydrogen applications, shore-side power and remote-operation services create demand for European shipyards, equipment manufacturers, ports, energy suppliers and technology providers. Repeatable retrofit packages, standardised components and service-based business models support more innovation from individual pilots to scalable market applications.

6.4. PORT AND ENERGY-SYSTEM IMPACTS

Inland ports and terminals become key energy and logistics nodes. Their role will expand from cargo handling towards shore-side electricity, high-capacity charging, green energy container exchange, renewable-fuel bunkering, energy management and digital corridor services. Coordinated planning of vessel demand, grid capacity, renewable energy supply and terminal operations reduces deployment risks and improve infrastructure use.

6.5. SAFETY, SECURITY AND CLIMATE-RESILIENCE IMPACTS

The roadmap improves safety and resilience through digital navigation support, water-level forecasting, predictive maintenance and management, traffic coordination and incident communication. It also supports safer deployment of sustainable alternative fuels, high-voltage systems, automation and remote operations through harmonised safety procedures, cybersecurity requirements, emergency-response planning, fallback procedures and crew training. Climate-resilient vessel design, adaptive fairway management and resilient port infrastructure improve service continuity under changing hydrological conditions.

6.6. DIGITALISATION AND OPERATIONAL-EFFICIENCY IMPACTS

The roadmap accelerates the development of a digitally connected IWT system. Modernised RIS, interoperable corridor services, real-time fairway information, voyage optimisation, automated reporting, emission monitoring and multimodal data exchange improve competitiveness, efficiency, reliability and infrastructure use. In the longer term, these systems support remote operations, automated navigation functions and higher levels of vessel automation where appropriate.

6.7. WORKFORCE AND SOCIAL IMPACTS

The roadmap changes the skills profile of inland waterway transport, ports and terminals as well as related areas. Crews, port workers, terminal operators, shipyard personnel, equipment manufacturers, inspectors, traffic managers and public authorities will need new competences in sustainable alternative fuels, electrical systems, digital navigation, cybersecurity, automation, remote operations, emergency response and emission reporting. Digital training tools, simulators, XR applications and updated certification schemes support upskilling, while human-centred design and social dialogue are needed to ensure that the transition is safe and socially sustainable, creating an economic sound business case for automation.

6.8. GOVERNANCE, REGULATION AND MARKET-TRANSFORMATION IMPACTS

The roadmap supports a more coherent and adaptive deployment framework through harmonised standards, quickly adaptable certification procedures, regulatory sandboxes, cross-border acceptance and technology-neutral rules. This reduces regulatory delays and supports faster uptake of emerging technologies while maintaining appropriate safety and environmental performance.

It also shifts the sector from demonstration to deployment by linking technology development with finance, infrastructure, public procurement, green corridor agreements and market demand.

6.9 IMPACT MILESTONES AND MONITORING

By 2035, the roadmap delivers visible early impacts in selected zero-emission and digital corridors, including increased use of sustainable drop-in fuels, OPS at key nodes, commercial battery-electric and battery-swapping applications in dedicated corridors, hydrogen and methanol demonstrations, early remote operation applications and interoperable digital services.

By 2040, zero-emission propulsion solutions are commercially available for the main vessel segments, retrofit packages and certification pathways mature, charging and refuelling infrastructure available along core corridors, and digital corridor management, predictive fairway services and emission reporting a standard practice.

By 2050, inland waterway transport operates as a zero-emission, digitally integrated and climate resilient mode, supporting zero-emission transport, reliable multimodal supply chains, circular economy flows, crisis resilience and European industrial competitiveness.

Progress will be monitored through a limited set of indicators, including greenhouse gas emissions, air pollutant emissions, share of vessels using renewable or zero-emission energy solutions, number of retrofitted vessels, availability of OPS and charging or bunkering infrastructure, corridor reliability, modal share, accident and incident rates, digital reporting coverage, trained workers and demonstration solutions reaching commercial deployment.

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